

KIRTLAND AIR FORCE BASE ALBUQUERQUE, NEW MEXICO

Quarterly Pre-Remedy Monitoring and Site Investigation Report for January – March 2012

Bulk Fuels Facility Spill Solid Waste Management Units ST-106 and SS-111

June 2012



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**KIRTLAND AIR FORCE BASE
ALBUQUERQUE, NEW MEXICO**

**QUARTERLY PRE-REMEDY MONITORING AND
SITE INVESTIGATION REPORT
JANUARY – MARCH 2012**

**BULK FUELS FACILITY SPILL
SOLID WASTE MANAGEMENT UNITS ST-106 AND SS-111**

June 2012

Prepared for

U.S. Army Corps of Engineers
Albuquerque District
Albuquerque, New Mexico 87109

USACE Contract No. W912DY-10-D-0014
Delivery Order 0002

Prepared by

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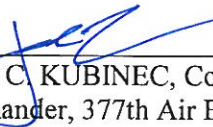
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PREFACE

This Quarterly Pre-Remedy Monitoring and Site Investigation Report for January – March 2012 has been prepared by Shaw Environmental & Infrastructure, Inc. (Shaw) for the U.S. Army Corps of Engineers (USACE), under Contract W912DY-10-D-0014, Delivery Order 0002. It pertains to the Kirtland Air Force Base (AFB) Bulk Fuels Facility (BFF) Spill, Solid Waste Management Units ST-106 and SS-111, located in Albuquerque, New Mexico. This report was prepared in accordance with all applicable federal, state, and local laws and regulations, including the New Mexico Hazardous Waste Act, New Mexico Statutes Annotated 1978, New Mexico Hazardous Waste Management Regulations, Resource Conservation and Recovery Act, and regulatory correspondence between the New Mexico Environment Department Hazardous Waste Bureau and the U.S. Air Force, dated April 2, June 4, August 6, and December 10, 2010.

This work was performed under the authority of USACE Contract No. W912DY-10-D-0014, Delivery Order 0002. All work was conducted from January through March 2012. Mr. Walter Migdal is the USACE Albuquerque District Project Manager; Mr. Wayne Bitner, Jr. is the Kirtland AFB Restoration Section Chief; and Mr. Thomas Cooper is the Shaw Project Manager. This report was prepared by Diane Agnew, Gary Hecox, and Melissa Halick.



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CONTENTS

Section	Page
ACRONYMS AND ABBREVIATIONS	xvi
EXECUTIVE SUMMARY	ES-1
1. INTRODUCTION.....	1-1
2. SVE REMEDIATION SYSTEM PERFORMANCE	2-1
2.1 SVE Remediation System Description, Monitoring, and Calculations.....	2-1
2.1.1 Description of System	2-1
2.1.2 Vapor Monitoring and Sampling.....	2-3
2.1.3 Calculation of Destruction Removal Efficiency	2-3
2.1.4 Calculation of Hydrocarbon Remediation Attributable to Natural Attenuation by Bioventing	2-3
2.2 ST-106 FFOR SVE System (Unit 249).....	2-4
2.2.1 System Operation	2-4
2.2.2 Hydrocarbon Recovery and Degradation	2-4
2.3 SS-111 SVE System (Units 335, 344, and 345).....	2-4
2.3.1 System Operation	2-5
2.3.2 Hydrocarbon Recovery and Degradation	2-5
2.4 Waste Generation	2-5
2.5 SVE and Treatment System Operational Summary	2-6
3. SITE INVESTIGATION.....	3-1
3.1 Site Investigation Objectives.....	3-1
3.2 Site Investigation Activities	3-1
3.2.1 Geophysical Logging	3-2
3.2.2 Well Installation	3-6
3.2.3 Surveying	3-17
3.2.4 FFOR Investigation	3-18
3.2.5 Slug Testing	3-21
3.2.6 Quarterly Groundwater Sampling Field Activities.....	3-23
3.2.7 Quarterly Soil-Vapor Sampling Field Activities.....	3-24
3.2.8 SVE Radius of Influence Testing.....	3-25
4. VADOSE ZONE SAMPLING AND MONITORING	4-1
4.1 Soil Sampling Results	4-1
4.2 Vadose Zone Vapor Monitoring Results.....	4-4
4.3 Soil-Vapor Data Evaluation	4-6
4.4 Selection of Vadose Zone Constituents of Concern.....	4-8
4.5 Vapor Concentrations Over Time	4-9
5. GROUNDWATER MONITORING	5-1
5.1 Quarterly Pre-Remedy Groundwater Monitoring	5-1

CONTENTS (concluded)

Section	Page
5.2	Liquid Level Data5-3
5.2.1	Groundwater Levels5-3
5.2.2	NAPL Thicknesses.....5-6
5.3	Groundwater Quality Data5-6
5.3.1	Organic Compound Results5-6
5.3.2	Microbial Degradation Indicators5-10
5.3.3	Piper and Stiff Diagram Inorganic Chemistry Evaluation5-13
5.3.4	Selection of Groundwater Constituents of Concern.....5-14
5.4	Production Well Data.....5-15
5.5	NAPL and Soil Hydraulic Property Laboratory Test Results5-16
5.5.1	Soil Test Results.....5-16
5.5.2	NAPL Test Results.....5-17
5.6	Time-Series Data Analysis.....5-18
5.6.1	Groundwater Levels5-18
5.6.2	NAPL Thickness5-19
5.6.3	Groundwater Concentrations.....5-20
5.7	Groundwater Plume Migration Analysis.....5-20
6.	INVESTIGATION-DERIVED WASTE6-1
6.1	Well Installation Investigation-Derived Waste6-1
6.1.1	Drill Cuttings.....6-1
6.1.2	Decontamination and Development Water6-2
6.2	Groundwater Sampling Investigation-Derived Waste6-2
6.3	SVE Internal Combustion Engine Investigation-Derived Waste6-3
7.	CONCEPTUAL SITE MODEL.....7-1
7.1	Regional Geology.....7-1
7.2	Site-Specific Geology7-2
7.3	Hydrology7-3
7.4	Contaminant Fate and Transport Conceptual Model Contaminant.....7-4
7.4.1	Vadose Zone.....7-4
7.4.2	Groundwater.....7-6
7.5	Data Gaps.....7-8
8.	PROJECTED ACTIVITIES AND RECOMMENDATIONS.....8-1
8.1	Quarterly Monitoring Activities.....8-1
8.2	Drilling Program8-2
8.3	FFOR Investigation.....8-2
8.4	SVE Systems.....8-2

REFERENCES

APPENDICES

- A Summary of SVE System Operation, Maintenance, Repair, and Hydrocarbon Recovery Calculations
 - A-1. SVE and Treatment System Maintenance and Repair Summary
 - A-2. SVE and Treatment System Hydrocarbon Recovery Calculations
- B Data Quality Evaluation Reports and Data Packages
 - B-1. Data Quality Evaluation Report – Groundwater
 - B-2. Data Quality Evaluation Reports – Soil, Second and Third Quarter 2011
 - B-3. Data Quality Evaluation Report – Soil-Vapor
 - B-4. Groundwater, Soil, and Soil Vapor Data Packages
- C Waste Disposal Documentation
 - C-1. IDW Soil Disposal
 - C-2. Offsite Waste Disposal Manifest
 - C-3. Waste Disposal Analytical Data
- D Well Installation Forms
 - D-1. Well Borehole Logs, Completion Diagrams, and Development Records
 - D-2. Shallow Soil Boring Logs
 - D-3. FFOR Shallow Soil Boring Logs
- E Historical Data Summaries
 - E-1. Groundwater, Soil, and Soil-Vapor Historical Data
 - E-2. Groundwater and NAPL Depths and Elevations Historical Data
 - E-3. Report Tables in Excel Format
- F Time-Series Plots
 - F-1. Water-Level Hydrographs
 - F-2. NAPL Thickness Time-Series Graphs
 - F-3. Groundwater Time-Series Graphs
 - F-4. Soil-Vapor Time-Series Graphs
- G Field Sampling Data and Records
 - G-1. Groundwater Purge Logs
 - G-2. Groundwater Sample Collection Logs
 - G-3. Soil-Vapor Purge Logs
 - G-4. Soil-Vapor Sample Collection Logs
 - G-5. Survey Plates
 - G-6. Water Level Measurement Field Forms
- H Slug Test Results
 - H-1. Slug Testing
 - H-2. Field Verification of Test Procedures
 - H-3. Individual Slug Test Analyses Sheets
- I Correspondence
 - I-1. Field Work Variances
 - I-2. Letter Addenda
 - I-3. Response to Comments Tables
 - I-4. NMED Correspondence Letters

APPENDICES (concluded)

- J Additional Cross-Sections
 - J-1. NMED Transects – Third and Fourth Quarters 2011
 - J-2. Soil Cross-Sections – Third Quarter 2011
- K NAPL and Soil Hydraulic Property Laboratory Reports
 - K-1. PTS Laboratory Soil and NAPL Test Results
 - K-2. Core Laboratories NAPL Test Results
- L Radius of Influence Test Report
- M Geophysical Records
 - M-1. Geophysical Calibration Data
 - M-2. Geophysical Logging QC Forms

FIGURES

Figure

- 1-1 Site Location Map
- 2-1 Location of Soil Vapor Monitoring and Extraction Wells, Bulk Fuels Facility
- 2-2 SVE Cumulative Mass Recovery Over Time
- 3-1 Groundwater Monitoring Well and Soil Boring Locations
- 3-2 Soil Vapor Monitoring Locations
- 3-3 FFOR Borehole Locations
- 3-4 Radius of Influence Test Wells
- 3-5 Test Wellhead Setup for Use with RSI SVE Unit 249
- 3-6 Wellhead Setup Connected to Wells SVEW-01 through SVEW-09
- 3-7 Vacuum Pressure in Monitoring Wells for Test 5DTKAFB106121-450
- 3-8 Barometric Efficiency of 450 ft Wells
- 3-9 Distribution of Data for ROI Test 5DTKAFB10649-484
- 3-10 Distribution of Data for ROI Test 5DTKAFB10649-484, Excluding KAFB 106117-450
- 3-11 Distribution of Data for ROI Test 5DTKAFB106121-450
- 4-1 SVE and SVM Well Locations
- 4-2 VOC Vapor Sample Locations
- 4-3 Total VOC Vapor Plume Footprints by Elevation, March 2012
- 4-4 Benzene Vapor Plume Footprints by Elevation, March 2012
- 4-5 Lithology and Total VOC Vapor Cross-Sections F-F'
- 4-6 Lithology and Total VOC Vapor Cross-Sections G-G'
- 4-7 Lithology and Total VOC Vapor Cross-Sections H-H'
- 4-8 Lithology and Total VOC Vapor Cross-Sections I-I'
- 4-9 Lithology and Total VOC Vapor Cross-Sections J-J'
- 4-10 Lithology and Total VOC Vapor Cross-Sections K-K'

FIGURES (continued)

Figure

- 4-11 Lithology and Benzene Vapor Cross-Sections F-F'
- 4-12 Lithology and Benzene Vapor Cross-Sections G-G'
- 4-13 Lithology and Benzene Vapor Cross-Sections H-H'
- 4-14 Lithology and Benzene Vapor Cross-Sections I-I'
- 4-15 Lithology and Benzene Vapor Cross-Sections J-J'
- 4-16 Lithology and Benzene Vapor Cross-Sections K-K'
- 5-1 Monitoring Well Locations
- 5-2 Shallow Groundwater Contours, Corrected for NAPL Thickness, January 2012
- 5-3 Intermediate Groundwater Contours, Corrected for NAPL Thickness, January 2012
- 5-4 Deep Groundwater Contours, Corrected for NAPL Thickness, January 2012
- 5-5 Comprehensive Posting of January 2012 Water Level Elevations
- 5-6 NAPL Thickness, Shallow Groundwater, January 2012
- 5-7 Gasoline Range Organics Concentrations in Shallow Groundwater
- 5-8 Gasoline Range Organics Concentrations in Intermediate Groundwater
- 5-9 Gasoline Range Organics Concentrations in Deep Groundwater
- 5-10 Diesel Range Organic Concentrations in Shallow Groundwater
- 5-11 Diesel Range Organic Concentrations in Intermediate Groundwater
- 5-12 Diesel Range Organic Concentrations in Deep Groundwater
- 5-13 1,2-Dibromoethane Concentrations in Shallow Groundwater
- 5-14 1,2-Dibromoethane Concentrations in Intermediate Groundwater
- 5-15 1,2-Dibromoethane Concentrations in Deep Groundwater
- 5-16 Benzene Concentrations in Shallow Groundwater
- 5-17 Benzene Concentrations in Intermediate Groundwater
- 5-18 Benzene Concentrations in Deep Groundwater

FIGURES (continued)**Figure**

- 5-19 Toluene Concentrations in Shallow Groundwater
- 5-20 Toluene Concentrations in Intermediate Groundwater
- 5-21 Toluene Concentrations in Deep Groundwater
- 5-22 Total Xylenes Concentrations in Shallow Groundwater
- 5-23 Total Xylenes Concentrations in Intermediate Groundwater
- 5-24 Total Xylenes Concentrations in Deep Groundwater
- 5-25 1,2,4-Trimethylbenzene Concentrations in Shallow Groundwater
- 5-26 1,2,4-Trimethylbenzene Concentrations in Intermediate Groundwater
- 5-27 1,2,4-Trimethylbenzene Concentrations in Deep Groundwater
- 5-28 Naphthalene Concentrations in Shallow Groundwater
- 5-29 Naphthalene Concentrations in Intermediate Groundwater
- 5-30 Naphthalene Concentrations in Deep Groundwater
- 5-31 Dissolved Oxygen Concentrations in Shallow Groundwater
- 5-32 Dissolved Oxygen Concentrations in Intermediate Groundwater
- 5-33 Dissolved Oxygen Concentrations in Deep Groundwater
- 5-34 Oxidation-Reduction Potential in Shallow Groundwater
- 5-35 Oxidation-Reduction Potential in Intermediate Groundwater
- 5-36 Oxidation-Reduction Potential in Deep Groundwater
- 5-37 Alkalinity, Bicarbonate (as CaCO₃), Concentrations in Shallow Groundwater
- 5-38 Alkalinity, Bicarbonate (as CaCO₃), Concentrations in Intermediate Groundwater
- 5-39 Alkalinity, Bicarbonate (as CaCO₃), Concentrations in Deep Groundwater
- 5-40 Iron Concentrations in Shallow Groundwater
- 5-41 Iron Concentrations in Intermediate Groundwater
- 5-42 Iron Concentrations in Deep Groundwater

FIGURES (continued)

Figure

- 5-43 Manganese Concentrations in Shallow Groundwater
- 5-44 Manganese Concentrations in Intermediate Groundwater
- 5-45 Manganese Concentrations in Deep Groundwater
- 5-46 Nitrogen (Nitrate-Nitrite) Concentrations in Shallow Groundwater
- 5-47 Nitrogen (Nitrate-Nitrite) Concentrations in Intermediate Groundwater
- 5-48 Nitrogen (Nitrate-Nitrite) Concentrations in Deep Groundwater
- 5-49 Sulfate Concentrations in Shallow Groundwater
- 5-50 Sulfate Concentrations in Intermediate Groundwater
- 5-51 Sulfate Concentrations in Deep Groundwater
- 5-52 Piper Diagram NAPL Area
- 5-53 Piper Diagram Near and Far Downgradient
- 5-54 Piper Diagram Nondetect
- 5-55 Piper Diagram Upgradient, Regional
- 5-56 Stiff Diagrams NAPL Area Part 1
- 5-57 Stiff Diagrams NAPL Area Part 2
- 5-58 Stiff Diagrams Near and Far Downgradient Part 1
- 5-59 Stiff Diagrams Near and Far Downgradient Part 2
- 5-60 Stiff Diagrams Near and Far Downgradient Part 3
- 5-61 Stiff Diagrams Nondetect
- 5-62 Stiff Diagrams Upgradient, Regional Part 1
- 5-63 Stiff Diagrams Upgradient, Regional Part 2
- 7-1 NMED Cross Section Transects
- 7-2 Geologic Cross Section A-A'
- 7-3 Geologic Cross Section B-B'

FIGURES (concluded)

Figure

- 7-4 Geologic Cross Section C-C'
- 7-5 Geologic Cross Section D-D'
- 7-6 Geologic Cross Section E-E'
- 7-7 EDB Groundwater Concentrations for Cross Section A-A' – First Quarter 2012
- 7-8 EDB Groundwater Concentrations for Cross Section B-B' – First Quarter 2012
- 7-9 EDB Groundwater Concentrations for Cross Section C-C' – First Quarter 2012
- 7-10 EDB Groundwater Concentrations for Cross Section D-D' – First Quarter 2012
- 7-11 EDB Groundwater Concentrations for Cross Section E-E' – First Quarter 2012

TABLES

Table

- 2-1 FFOR SVE System – Active Extraction Wells, October 2011 – March 2012
- 2-2 Summary of Vapor Operating Data Collected from SVE Unit 249, January 2011 – March 2012
- 2-3 Summary of Vapor Operating Data Collected from SVE Unit 335, January 2011 – March 2012
- 2-4 Summary of Vapor Operating Data Collected from SVE Unit 345, January 2011 – March 2012
- 2-5 Summary of Vapor Operating Data Collected from SVE Unit 344, January 2011 – March 2012
- 3-1 Geophysical Well Logging Details, December 2010 – September 2011
- 3-2 Groundwater Well Construction Details, January – September 2011
- 3-3 Continuous Core Samples Collected for Mobility Testing, Unified Soil Classification System
- 3-4 SVM Well Construction Details, January – September 2011
- 3-5 Pneulog, LNAPL Containment, and SVE Well Construction Details
- 3-6 Well Installation Survey Data, January 2011 – March 2012
- 3-7 FFOR Sample Collection Summary
- 3-8 Installation of Bennett Pump Sampling Systems, January 2011 – March 2012
- 3-9 Summary of SVE ROI Tests Completed
- 3-10 Monitoring Wells Used in the Analysis of Each Five-Day ROI Test
- 3-11 Summary of Data for ROI Test 5DTKAFB106149-484
- 3-12 Summary of Data for ROI Test 5DTKAFB106121-450
- 3-13 Summary of Data for ROI Test 5DTSVEW-05
- 4-1 Field Measurements for Soil-Vapor Monitoring Wells, January – March 2012
- 4-2 Soil Vapor Analytical Results, January – March 2012
- 4-3 Vapor Constituent of Concern Screening Analysis
- 4-4 Vapor Constituent of Concern Summary
- 5-1 Groundwater Analytical Results, January – March 2012

TABLES (concluded)

Table

- 5-2 Shallow Zone Groundwater COC Screening Analysis, January 2009 – March 2012
- 5-3 Shallow Zone Groundwater COC Summary, January 2009 – March 2012
- 5-4 Intermediate Zone Groundwater COC Screening Analysis, January 2009 – March 2012
- 5-5 Intermediate Zone Groundwater COC Summary, January 2009 – March 2012
- 5-6 Deep Zone Groundwater COC Summary, January 2009 – March 2012
- 5-7 Deep Zone Groundwater COC Summary, January 2009 – March 2012
- 5-8 Groundwater and NAPL Depths and Elevations, January 2012
- 5-9 Degradation Indicators
- 5-10 Summary of Aquifer Characteristics Determined by Slug Testing
- 6-1 IDW Roll-Off Bin Sampling and Disposal, January – March 2012
- 6-2 Wastewater Sampling and Disposal, January – March 2012
- 6-3 IDW Groundwater Sampling Storage and Disposal, January – March 2012

ACRONYMS AND ABBREVIATIONS

°F	degrees Fahrenheit
°K	degrees Kelvin
µg/L	microgram per liter
µg/m ³	microgram per cubic meter
3D	three-dimensional
AFB	Air Force Base
APH	air-phase petroleum hydrocarbons
API	American Petroleum Institute
ARCH	air rotary casing hammer
ASDE	after survey depth error
ASTM	ASTM International
BFF	Bulk Fuels Facility
bgs	below ground surface
BTOC	below top of casing
C&D	Construction and Demolition
CAS	Chemical Abstracts Service
cm/sec	centimeters per second
CO	carbon monoxide
COC	constituent of concern
CO ₂	carbon dioxide
CSS	Colorado silica sand
DAF	dilution attenuation factor
DO	dissolved oxygen
DoD	U.S. Department of Energy
DOT	U.S. Department of Transportation
DPT	direct-push technology
DRE	destruction removal efficiency
DRO	diesel range organics
EDB	1,2-dibromoethane/ethylene dibromide
EDC	1,2-dichloroethane
ELAP	Environmental Laboratory Accreditation Program
EPA	U.S. Environmental Protection Agency
ERP	Environmental Restoration Program
FFOR	Former Fuel Offloading Rack
FOD	frequency of detection
ft	foot/feet
g/cm ³	grams per cubic centimeter
g/mol	grams per molecule
GIS	Geographic Information System
GPS	global positioning system
GRO	gasoline range organics

ACRONYMS AND ABBREVIATIONS (continued)

GWM	groundwater monitoring
GWQB	Ground Water Quality Bureau (NMED)
HWB	Hazardous Waste Bureau (NMED)
ICE	internal combustion engine
ID	identification
IDW	investigation-derived waste
inWC	inches water column
Jet West	Jet West Geophysical Services
KAFB	Kirtland AFB
LAS	Log ASCII Standard
LNAPL	light non-aqueous phase liquid
MA DEP	Massachusetts Department of Environmental Protection
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
msl	mean sea level
MW	molecular weight
NAPL	non-aqueous phase liquid
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
O ₂	oxygen
O.D.	outside diameter
ORP	oxidation-reduction potential
oz	ounce
PDF	portable document format
PG	Professional Geologist
PIANO	paraffins, isoparaffins, aromatics, naphthalenes, and olefins
PLC	programmable logic controller
PMP	Project Management Professional
ppbv	parts per billion by volume
ppmv	parts per million by volume
PSH	phase-separated hydrocarbon
PVC	polyvinyl chloride

ACRONYMS AND ABBREVIATIONS (concluded)

QA	quality assurance
QAPjP	Quality Assurance Project Plan
QC	quality control
RCRA	Resource Conservation and Recovery Act
ROI	radius of influence
RSI	Remediation Service International
Shaw	Shaw Environmental & Infrastructure, Inc.
SM	Standard Method
SSL	soil screening level
SVE	soil-vapor extraction
SVEW	soil-vapor extraction well
SVM	soil-vapor monitoring
SVMW	soil-vapor monitoring well
SVOC	semivolatile organic compound
TMB	trimethylbenzene
TOC	total organic carbon
TPH	total petroleum hydrocarbons
USACE	U.S. Army Corps of Engineers
USAF	U.S. Air Force
USCS	Unified Soil Classification System
VA	Veterans Affairs
VOA	volatile organic analysis
VOC	volatile organic compound
yr	year

EXECUTIVE SUMMARY

This report has been prepared in response to correspondence dated June 4, 2010, from the New Mexico Environment Department (NMED) Hazardous Waste Bureau (HWB) (NMED, 2010a) to Kirtland Air Force Base (AFB) outlining the reporting, sampling, and analysis requirements related to the characterization and remediation of contaminated groundwater at Solid Waste Management Units ST-106 and SS-111, Bulk Fuels Facility (BFF) Spill, Kirtland AFB, New Mexico. Quarterly reporting incorporates information and data collected in support of ongoing remediation and site characterization activities related to the Stage 2 abatement action for the Former Fuel Offloading Rack (FFOR), designated as ST-106, and the phase-separated, hydrocarbon-impacted groundwater, designated as SS-111. As specified by the NMED-HWB, quarterly reporting for the ST-106 and SS-111 sites has been integrated due to the interrelated nature of the sites and the applicability of different data sets to characterization and remediation activities at the BFF Spill site.

Quarterly remediation and site investigation reporting presents field and analytical data and information associated with the operation, maintenance, and performance of the interim remedial measures soil-vapor extraction (SVE) and treatment systems; characterization and remediation activities associated with the groundwater and vadose zone and FFOR investigations; and pre-remedy quarterly monitoring for groundwater and soil vapor at the BFF Spill site.

The major site characterization findings from the quarterly reports are cumulative and summarized as follows:

Vadose Zone

- Based on the three-dimensional (3D) distribution of vadose zone soil and vapor concentrations for wells installed and sampled to date, it appears that the majority of the vadose zone contaminant mass is located within 100 feet (ft) above the water table at depths of approximately 400 to 500 ft below ground surface (bgs).

- Based on the data collected to date and the soil concentration footprints at various depths, the soil concentrations indicate that the non-aqueous phase liquid (NAPL) migrated in a predominantly vertical direction along relatively narrow pathways until it reached the capillary fringe above the water table where it spread out in horizontal directions. The Pneulog testing planned for Second Quarter 2012 will further delineate these pathways.
- Soil concentrations define the soil residual NAPL saturations, which overall are less than 0.01 cubic centimeters (cm³)-NAPL/cm³-soil. This is a low value but is consistent with the medium- to coarse-grained nature of the sandy soil at the site.
- 3D volumetric analysis shows that the current extent of soil contamination, as defined by soil concentrations of total petroleum hydrocarbons (TPH) greater than 10 milligrams per kilogram (mg/kg), is approximately 29 million cubic yards with 12.4 million cubic yards (43%) at or below an elevation of 5,000 ft above mean sea level (approximately 350 ft bgs).
- Based on a screening process that accounts for frequency of detection, the following compounds are determined to be vapor constituents of concern (COCs): 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; 2-butanone; acetone; benzene; C5-C8 aliphatic hydrocarbons; C9-C10 aromatic hydrocarbons; C9-C12 aliphatic hydrocarbons; cyclohexane; ethylbenzene; heptane; isopropanol; m,p,o-xylenes; methylene chloride; n-hexane; propene; propylene; toluene; and total xylenes (in lieu of quantifying individual m,p,o-xylene isomers). Currently, there are no maximum contaminant level (MCL) standards for remediation of these vapor compounds. However, vapor will continue to be monitored to adequately characterize the vadose zone contaminant mass.
- The time-series analysis of the vapor concentration data since 2007 shows only marginal vapor concentration declines over time, even in the SVE wells. It is concluded that while substantial contaminant mass has been removed from the vadose zone (approximately 400,000 gallons of NAPL-equivalent mass vapor), the overall effect of the current SVE efforts is difficult to determine from the vapor concentration data.
- During Second Quarter 2012, the SVE systems will resume operation. The SVE systems will be moved to more optimum positions and monitored to ensure each system is functioning at its maximum capacity.
- Radius of influence (ROI) testing for SVE wells conducted in November and December 2011 shows that the ROI within the BFF is most likely between 220 and 300 horizontal feet using the current SVE system. A vertical ROI has not yet been determined.

Groundwater and NAPL

- Historical water level data from well KAFB-3 show that the groundwater table has declined approximately 140 ft since 1949 with the majority (about 100 ft) of this decline occurring since the mid-1970s.
- As the water table declined as a result of regional groundwater extraction, the NAPL from the initial and subsequent releases followed the falling water table downward. Over time, this has had the effect of creating a residual NAPL “smear zone” from nominal depths of 400 to 500 ft bgs.
- Based on an analysis of historic and present groundwater levels at the site, the water table has risen between approximately 4 and 6 ft since 2009. This can be attributed to the water conservation

practices implemented by the City of Albuquerque to reduce groundwater withdrawals, starting in 2008 and 2009.

- Rising groundwater levels continue to result in decreases in NAPL thickness and observations in monitoring wells. During the last three quarters, NAPL has been consistently observed in only a few monitoring wells. The majority of the NAPL mass observed in 2009, the year of lowest water levels, is now trapped below the water table.
- NAPL chemical analytical results show that the trapped NAPL will be an ongoing source of dissolved groundwater contamination indefinitely.
- Current groundwater flow directions are toward the KAFB-3 and Ridgecrest water supply wells with average groundwater velocity of 95 ft/year (yr) and a range of 18 to greater than 300 ft/yr to the northeast at a direction of North 25° to 35° East.
- A number of hydraulic properties were measured at the site using field slug tests and laboratory tests. The results are incorporated into the following groundwater migration analysis:

Parameter	Units	Average Value ^a	Standard Deviation	Minimum Value ^b	Maximum Value ^b
Hydraulic conductivity	ft/day	70	NM	40	129
Effective Porosity	Fraction	0.274	±0.049	0.22	0.32
Gradient	Fraction	0.001	±0.0006	0.0004	0.0016
Fraction Organic Carbon	mg/kg	230	±78	<100	380
Groundwater Velocity	ft/day	0.26	NM	0.05	0.94
Groundwater Velocity	ft/yr	95	NM	18	340
50-Year Downgradient Migration Distance	ft	4,750	NM	900	17,000

^aGeometric mean used for hydraulic conductivity.

^bMean ±1 standard deviation used for minimum and maximum for gradient and porosity values.

Minimum porosity value was used to calculate maximum velocity and maximum porosity was used to calculate minimum velocity.
NM - not meaningful.

- Groundwater analytical data for new monitoring wells indicate that organic compounds are present in 11 of the Intermediate and 2 of the Deep Zone wells. These wells are generally within the historic NAPL area, however, some wells are downgradient of the source area, including deep wells KAFB-106058 and KAFB-106057.
- Based on the analysis of the degradation indicator compounds and the spatial extent of the organic compounds, it appears that microbial degradation is limiting the extent of a majority of the organic compounds including benzene; ethylbenzene; toluene; xylene; 1,2,4-trimethylbenzene; and naphthalene. Additional evaluations are required to quantify the degradation rates and impact on future plume migration.
- 1,2-Dibromoethane/ethylene dibromide (EDB) has migrated the full length of the monitoring network and was detected above the U.S. Environmental Protection Agency (EPA) maximum contaminant level (0.05 micrograms per liter [µg/L]) in samples from 30 of 51 shallow wells, 11 of 27 of intermediate wells, and 2 of 28 deep wells during the First Quarter 2012 event. EDB is the one compound that was detected in the shallow, intermediate, and deep zones in the farthest downgradient well clusters (GWM 10; KAFB-106055, KAFB-106057, and KAFB-106058; and GWM 3; KAFB-106035, KAFB-106036; KAFB-106037) for the last three quarters.

- The extent of EDB groundwater contamination at the northeastern extent of the plume is not defined at this time. Assuming no degradation and adsorption factors, a simple migration calculation shows that EDB has a low retardation factor of $R = 1.03$. Therefore, it is possible that EDB will migrate at an estimated velocity of 0.97 times the groundwater flow velocity if there is limited EDB degradation. Assuming a 50-year NAPL on water table and an average groundwater velocity of 95 ft/yr, the calculated EDB plume downgradient of the NAPL area is approximately 4,500 ft long if no EDB degradation is assumed. The observed EDB plume length downgradient of the NAPL area is 2,500 ft, which is substantially less than the calculated estimate; however, the northeastern extent of the plume is still undefined at this time and will require additional monitoring wells to delineate the downgradient extent of the EDB plume.
- The effect of microbial degradation on EDB migration rates and extent is less clear, and the current extent of EDB is a strong indication that any EDB degradation rates are quite slow. Additional compound-specific microbial and isotope data are required to determine whether microbial degradation is having any effect on EDB migration. Activities to acquire these additional data are planned for 2012.
- Based on a screening process that accounts for frequency of detection (5%) and comparison between maximum detected concentrations and NMED and EPA regulatory screening levels, the following analytes are determined to be groundwater COCs:
 - Shallow Zone: EDB; 1,2-dichloroethane (EDC); benzene; bis (2-ethylhexyl) phthalate; dibenzo(a,h)anthracene; ethylbenzene; iron; manganese; methylene chloride; naphthalene; nitrogen (nitrate as N); phenol; sulfate (SO_4); tetrachloroethene; toluene; trichloroethene; and xylenes (total).
 - Intermediate Zone: EDB; benzene; ethylbenzene; iron; manganese; and naphthalene.
 - Deep Zone: EDB; bis (2-ethylhexyl) phthalate; and manganese.
- Additional screening will be conducted over the next year to determine, which, if any, of the inorganic analytes in this COC list are related to background concentrations. Those constituents determined to be related to background will be deleted from the COC list. It is also noted that during recent monitoring events, EDC has been detected above the EPA MCL of 5.0 $\mu\text{g/L}$ in samples from only a few wells. As such, EDC may not remain on the groundwater COC list in future quarters.

1. INTRODUCTION

The Bulk Fuels Facility (BFF) Spill site is located within the western portion of Kirtland Air Force Base (AFB), New Mexico (Figure 1-1) and is comprised of two solid waste management units, designated as ST-106 and SS-111. The component of the BFF Spill project related to investigation and remediation of the vadose zone near the Former Fuel Offloading Rack (FFOR) is designated as ST-106. The phase-separated, hydrocarbon (PSH)-impacted groundwater component of the project is designated as SS-111.

This report has been prepared to summarize ongoing site investigation, remedial, and pre-remedy monitoring activities at ST-106 and SS-111, BFF Spill site, Kirtland AFB, New Mexico (U.S. Environmental Protection Agency [EPA] Identification [ID] Number NM9570024423/HWB-KAFB-10-004). As specified by the New Mexico Environment Department (NMED) – Hazardous Waste Bureau (HWB) in its regulatory letter, dated June 4, 2010, to Kirtland AFB (NMED, 2010a; Appendix I-4), quarterly reporting for ST-106 and SS-111 has been integrated due to the interrelated nature of the sites and the applicability of different data sets for characterization and remediation activities at the BFF Spill site.

On April 2, 2010, regulatory control of the BFF Spill site was transferred from the NMED Ground Water Quality Bureau (GWQB) to the NMED-HWB (NMED, 2010b; Appendix I-4). Historically, semiannual reports have presented data regarding ongoing remediation of ST-106 vadose zone contamination associated with the FFOR and ongoing characterization and interim remediation instituted to begin recovery of PSH on the groundwater at SS-111. Activities and data related to ST-106 were conducted as the Stage 2 abatement action under the NMED-GWQB–approved *Stage 2 Abatement Plan for the Bulk Fuels Facility (ST-106)* (U.S. Air Force [USAF], 2002). This plan identified soil-vapor extraction (SVE) as the preferred abatement option to be implemented at ST-106 to attain abatement standards and requirements set forth in Section 4103 of Title 20, New Mexico Administrative Code (NMAC),

Chapter 6, Part 2. ST-106 remediation was initiated before the discovery of PSH impacts to groundwater. Following the discovery of SS-111, Kirtland AFB instituted PSH recovery directly from the aquifer surface at three well locations, using the same SVE technology approved for the Stage 2 abatement action for ST-106. These actions were conducted as interim measures while site characterization activities continue.

This quarterly remediation, site investigation, and pre-remedy monitoring report describes the operation, maintenance, and performance of interim remedial measures as well as site characterization and monitoring activities completed at the BFF Spill site during the period of January through March 2012.

Quarterly reports present data and information related to ongoing activities at the BFF Spill site, including the following:

- Groundwater and vadose zone investigations,
- Pre-remedy groundwater and soil-vapor monitoring,
- Interim measure investigation at the FFOR, and
- SVE unit monitoring and maintenance.

Quarterly reports will continue to allow information regarding successive investigation phases to be regularly disseminated to stakeholders, presented in context with other site-related data. Data collected during each quarter will be presented in the related quarterly report text; however, cumulative data or data collected from previous quarterly reports will be presented in the appendices. In addition, all text will remain cumulative where necessary for the period of the site investigation. Reporting requirements specified in the letter from the NMED-HWB, dated June 4, 2010, include the following (NMED, 2010a; Appendix I-4):

- Field and laboratory analytical results for groundwater, soil, and soil vapor;
- Laboratory analysis of soil-vapor samples collected from the SVE systems;
- Graphs showing trends of major contaminants versus time;

-
- A table of surveyed well locations;
 - Descriptions of the installation of groundwater and soil-vapor monitoring (SVM) wells (SVMWs) (if applicable);
 - Measurements of light non-aqueous phase liquid (LNAPL), also referred to as PSH;
 - A table of water levels and water-level map;
 - Plume contaminant maps and cross-sections;
 - Geologic and geophysical logs of wells and boreholes (if applicable);
 - Operation, maintenance, and performance data for remedial measures;
 - Quality assurance (QA)/quality control (QC) data; and
 - Projected activities and future recommendations (also included in specific sections)

These requirements are incorporated into this First Quarter 2012 report for January through March 2012, as applicable. The following appendices provide information that supplements this quarterly report:

- Appendix A, Summary of SVE System Operation, Maintenance, Repair, and Hydrocarbon Recovery Calculations
- Appendix B, Data Quality Evaluation Reports and Data Packages
- Appendix C, Waste Disposal Documentation
- Appendix D, Well Installation Forms
- Appendix E, Historical Data Summaries
- Appendix F, Time-Series Plots
- Appendix G, Field Sampling Data and Records
- Appendix H, Slug Test Results
- Appendix I, Correspondence
- Appendix J, Additional Cross-Sections
- Appendix K, NAPL (Non-Aqueous Phase Liquid) and Soil Hydraulic Property Laboratory Reports
- Appendix L, Radius of Influence (ROI) Test Report
- Appendix M, Geophysical Records

In the following discussions, the term NAPL is used to describe the mixture of separate phase organic liquid that has been observed in the subsurface. Because this NAPL is less dense than water, it is sometimes referred to as LNAPL. In this discussion the term NAPL is used for convenience.

2. SVE REMEDIATION SYSTEM PERFORMANCE

This section describes the operations and performance of the BFF SVE system during the reporting period from January through March 2012. The four SVE units were not operational during the First Quarter 2012 (January through March 2012) in preparation for Pneulog well testing during Second Quarter 2012. The SVE and SVM well locations are presented on Figure 2-1. Quarterly operations data and calculations are presented in Appendix A for the four SVE systems.

2.1 SVE Remediation System Description, Monitoring, and Calculations

2.1.1 Description of System

Each of the four SVE and treatment systems in use at the BFF consists of trailer-mounted units that include specialized on-board computer controllers, sensors, and a pair of 460-cubic-inch displacement Ford Model LSG-875 internal combustion engines (ICEs). These ICEs have been modified and remanufactured to the specifications of Remediation Service International (RSI). Within each SVE system, the programmable logic controller (PLC) uses the engines as the vacuum pump to extract vapor from the vadose zone, and the internal combustion process along with the catalytic converters on each engine provide treatment of the hydrocarbon vapors.

Operation of each unit is controlled by the PLC through adjustments to the influent soil vapor, ambient air, and a supplemental fuel source valve. The PLC adjusts the feed from the vapor well, ambient air, and supplemental fuel source valve to maintain the proper air/fuel ratio to support combustion in the engine. Propane is used as the fuel source during engine starting and warm-up, after which the system consumes recovered petroleum hydrocarbon vapors from the soil as the primary fuel source, using propane as needed to help stabilize engine performance. The higher the influent soil-vapor concentration, the less supplemental fuel is used for operations. These four units are operating under air permit NMAC Permit Number 1984 issued by the Albuquerque Environmental Health Department on April 30, 2009.

For system performance analysis, the PLC calculates various operational parameters including the hydrocarbon mass recovery in pounds per period and NAPL-equivalent gallons per period. To simplify system reporting and calculations, the PLC for each unit is downloaded on or around the last day of each month and compiled into a database. For consistency with historical reporting, the cumulative mass recovery values reported in the following sections are those calculated by the PLC and are not determined from the influent laboratory analytical results.

The ST-106 FFOR SVE unit (RSI Unit 249) was installed in April 2003 (fully operational in July 2003); the Kirtland AFB (KAFB)-1065 unit (RSI Unit 335) was installed in August 2008; and the KAFB-1066 (RSI Unit 345) and KAFB-1068 (RSI Unit 344) units were installed in March 2009. The ST-106 unit (RSI Unit 249) is connected through manifold piping to nine SVE wells (SVEWs), SVEW-01 through SVEW-09 (locations shown on Figure 2-1). In previous quarters, the remaining three SVE units were installed on the groundwater monitoring wells that were directly connected to the wellheads (KAFB-1065, KAFB-1066, and KAFB-1068).

During First Quarter 2012, all units were shut down from January 1 through March 31, 2012, for the preparation of Pneulog well testing. Table 2-1 shows that all four SVE units were not active after October 4, 2011 (Fourth Quarter 2011), through the end of March 2012 (First Quarter 2012).

Because SVE systems were not operational during the First Quarter 2012 event, routine system maintenance was not performed on the engines in accordance with the site-specific *Operations and Maintenance Manual for the Soil Vapor Extraction Systems* (USAF, 2009a). Generally, when the SVE units are operational, a summary of the major maintenance activities, non-routine maintenance or repair activities, and system downtime during the reporting period is presented in Appendix A-1.

2.1.2 Vapor Monitoring and Sampling

Monthly influent and effluent vapor samples were not collected during the months of January, February, or March 2012 because the units were inactive due to the preparation for the Pneulog well testing.

2.1.3 Calculation of Destruction Removal Efficiency

As previously stated, all SVE units were shut down during First Quarter 2012; therefore, the four SVE units were not operational. Typically, when units are operational, field or laboratory analytical data from the SVE system influent and exhaust samples will provide information on the treatment efficiency of each SVE unit. When data are available, the treatment destruction removal efficiency (DRE) for each unit is calculated as follows:

$$DRE = \frac{\text{Influent Conc.} - \text{Effluent Conc.}}{\text{Influent Conc.}} \times 100.$$

2.1.4 Calculation of Hydrocarbon Remediation Attributable to Natural Attenuation by Bioventing

Because the SVE units were not operational during First Quarter 2012, the calculations of hydrocarbon removal due to natural attenuation by bioventing could not be calculated. The Air Force Center for Engineering and the Environment has published guidance to account for the attenuation of petroleum hydrocarbons by bioventing (Leeson and Hinchee, 1996a and b). When data are available, the mass of petroleum hydrocarbons biodegraded can be calculated using the following equation (Appendix A-2):

$$HC_{Bio} = (C_{V,bkgd} - C_{V,O_2}) / ((100 \times Q \times C \times \rho_{O_2} \times MW_{O_2}) \times (\text{kg}/1,000\text{g}) \times (1,440 \text{ min}/\text{day}))$$

Where:

HC_{Bio} = Mass of hydrocarbons biodegraded (kilograms per day)

$C_{V,bkgd}$ = Concentration of oxygen in background, uncontaminated area (%)

C_{V,O_2} = Concentration of oxygen in extracted off-gas (%)

Q = Flow rate (standard cubic feet per minute)

C = Mass ratio of hydrocarbon to oxygen degraded based on stoichiometry (1/3.5)

ρ_{O_2} = density of oxygen (moles/liter)

MW_{O₂} = Molecular weight of oxygen (grams/mole)

2.2 ST-106 FFOR SVE System (Unit 249)

The following sections summarize the operations and remedial performance for the ST-106 (FFOR) SVE Unit 249.

2.2.1 System Operation

This SVE unit was not operated during the period of January through March 2012. This unit was shut down in October 2011 in preparation for both the ROI and Pneulog well testing, which are required for the vadose zone investigation as described in the Interim Measures Work Plan (USACE, 2011a).

2.2.2 Hydrocarbon Recovery and Degradation

The ST-106 SVE System (Unit 249) has cumulatively extracted approximately 222,960 gallons of NAPL from the vadose zone from July 2003 through March 2012 (Table 2-2). As presented on Figure 2-2, the recovery rate of this system has remained approximately constant since late 2006. Because this unit was not active during this quarter, hydrocarbon recovery and degradation could not be calculated.

2.3 SS-111 SVE System (Units 335, 344, and 345)

The following sections summarize operations and remedial performance for the SS-111 SVE system consisting of three operational RSI units (335, 344, and 345).

2.3.1 System Operation

During the January through September 2011 reporting period, the individual SVE systems (Units 335, 345, and 344) were connected to wells KAFB-1065, KAFB-1066, and KAFB-1068, respectively. As mentioned in Section 2.1.1, all units were shut down during Fourth Quarter 2011 and First Quarter 2012.

2.3.2 Hydrocarbon Recovery and Degradation

The KAFB-1065 SVE system (Unit 335) has cumulatively extracted approximately 85,373 gallons of NAPL from the vadose zone from August 2008 through March 2012 (Table 2-3). As presented on Figure 2-2, the recovery rate of this system has declined markedly in the last two years and currently demonstrates only marginal remedial effectiveness.

Approximately 63,878 gallons of NAPL (cumulative) have been removed from the vadose zone by the KAFB-1066 SVE system (Unit 345) from March 2009 through March 2012 (Table 2-4). As presented on Figure 2-2, the recovery rate of this system has remained fairly constant over the last two years and currently demonstrates adequate remedial effectiveness.

In addition, approximately 57,024 gallons of NAPL (cumulative) have been removed from the vadose zone by the KAFB-1068 SVE system (Unit 344) from March 2009 through March 2012 (Table 2-5). As presented on Figure 2-2, the recovery rate of this system has declined over the last two years and currently shows signs of decreasing remedial effectiveness.

2.4 Waste Generation

No waste was generated during January through March 2012 because none of the SVE units were operational in preparation for Pneulog well testing. When SVE systems are operational, maintenance activities for treatment systems can generate both nonhazardous and Resource Conservation and

Recovery Act (RCRA) hazardous wastes. Liquid condensate is the primary waste stream associated with

SVE operation. The liquid condensate is primarily generated during cooler months (typically October through April) as warm, moisture-laden, subsurface soil vapor moves up the extraction wells to the cooler ground surface where it condenses in the system piping.

Waste generated at the site is disposed of in compliance with the site-specific waste management procedures outlined in the site-specific Operations and Maintenance Plan (USAF, 2009a). Procedures in the Operations and Maintenance Plan comply with the *Investigation-Derived Waste Management Plan, Environmental Restoration Program, Kirtland Air Force Base, Albuquerque, New Mexico*, issued in 2009 (USAF, 2009b), that incorporates specific direction and consideration of the waste streams generated in association with the BFF Spill site remediation. A discussion of investigation-derived waste (IDW) from the operation of the SVE systems is discussed in Section 6, and disposal documentation for all waste generated each quarter is provided in Appendix C.

2.5 SVE and Treatment System Operational Summary

Operational changes and additional infrastructure modifications continue to be evaluated to optimize the operation of the ST-106 and SS-111 interim SVE and treatment systems. The goal of the optimization efforts is to extract the maximum amount of combustible constituents (fuel and oxygen) from the subsurface, thereby maximizing overall mass recovery rates and achieving the highest possible total mass removal from the four combined SVE systems in their current configurations. Work planning efforts continue to identify additional modifications to the SVE approach in use at the site, which may modify the use of current SVE systems or supplement this approach with other remediation methods in the future. Recommendations for optimization are presented in the *SVE Optimization Plan, Bulk Fuels Facility (BFF) Spill, Solid Waste Management Units ST-106 and SS-111, Kirtland AFB, Albuquerque, New Mexico* (USACE, 2011b).

Tables 2-2 through 2-5 present the propane consumption and ratio of gallons of propane used per NAPL-equivalent gallon of contaminated vapor recovered.

- Unit 249 (ST-106) was not in operation from October 2011 through March 2012; however, based on the July to September 2011 operational period, Unit 249 is consuming 0.56 gallons of propane on average for each gallon of NAPL recovered.
- Unit 335 (KAFB-1065) was not in operation from October 2011 through March 2012; however, based on the July to September 2011 operational period, Unit 335 is consuming 12.8 gallons of propane on average for each gallon of NAPL recovered.
- Unit 345 (KAFB-1066) was not in operation from October 2011 through March 2012; however, based on the July to September 2011 operational period, Unit 345 (KAFB-1066) is consuming 0.16 gallons of propane on average for each gallon of NAPL recovered.
- Unit 344 (KAFB-1068) was not in operation from October 2011 through March 2012; however, based on the July to September 2011 operational period, Unit 344 (KAFB-1068) is consuming 3.2 gallons of propane on average for each gallon of NAPL recovered.

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3. SITE INVESTIGATION

3.1 Site Investigation Objectives

This quarterly report presents the monitoring methods and results for First Quarter 2012 field activities performed at the Kirtland AFB BFF Spill site for the period of January 1, 2012 through March 31, 2012. Where appropriate, the text and data presented in this section are cumulative from First Quarter 2011 through First Quarter 2012. The groundwater investigation is currently being implemented in conjunction with the vadose zone investigation, interim measures, and LNAPL containment measures for ST-106 and SS-111. Approved work plans (USACE, 2011a, c, and d) for these three projects and approved letter addenda (Appendix I-2) stating requirements for the installation of the LNAPL containment well and two SVE wells provide guidance for the work activities performed during each quarter.

Additionally, the activities described herein comply with the NMED technical directives to Kirtland AFB for performing interim measures for the BFF Spill (ST-106 and SS-111) as stated in the August 6, 2010 (NMED, 2010c; Appendix I-4) and December 10, 2010 (NMED, 2010d; Appendix I-4) letters from the NMED to Kirtland AFB. This section describes in detail the monitoring methods used and activities performed to characterize and monitor the groundwater and soil at the BFF Spill site. Sections 4 and 5 present the monitoring results for the vadose zone and groundwater, respectively.

3.2 Site Investigation Activities

Site investigation activities performed during January through March 2012 include the installation of two SVE wells, well surveying, and quarterly groundwater and soil vapor sampling activities. No geophysical logging, ROI testing, or slug testing was conducted during the period of January through March 2012; however subsequent sections are presented to maintain a cumulative approach to the quarterly reporting task. Appendices D and G are updated each quarter and present cumulative lithologic logs, well completion diagrams, well development records, and field sampling records.

3.2.1 Geophysical Logging

Geophysical logging was conducted at newly installed, deep groundwater monitoring (GWM) wells and the 3-inch SVM wells at the BFF Spill site to define the lithologic and hydrogeologic characteristics of geologic units. The goal of the geophysical investigation was to refine the conceptual site model in order to optimize the placement of SVE, groundwater extraction, and future monitoring wells. In December 2010, Colog performed the initial geophysical logging at 29 existing wells. Subsequently, Jet West Geophysical Services (Jet West) was contracted in early 2011 to perform the remainder of the geophysical logging at Kirtland AFB. The approved Groundwater Investigation Work Plan (USACE, 2011d) discusses the geophysical well logging program for each contractor, including the probes used and the general field activities and QC procedures used during the project. Jet West logged KAFB-10624 on March 22, 2011, which was also logged by Colog, as a QC measure to ensure the comparability of the geophysical data from both contractors.

In its letter dated September 28, 2011, the NMED stated concern that the geophysical logs collected by both Colog and Jet West were not calibrated and therefore are not useful. Upon receipt of the NMED letter, an inquiry was conducted and the Colog geophysical data were reviewed. It was determined that the Colog geophysical data were not calibrated and therefore should not be used in this investigation. However, Jet West geophysical logs have been verified as being calibrated and can be used for qualitative analysis; pre- and post-shop calibrations, as well as daily calibrations, have been documented for all Jet West logging events (Appendix M).

In December 2011, Shaw Environmental & Infrastructure, Inc. (Shaw) submitted a comment response table (Appendix I-3) in the Third Quarter 2011 report to the NMED in response to the letter of September 28, 2011. A second letter was received from the NMED on February 17, 2012, detailing additional concerns regarding Jet West calibrations. An official response to this letter will be submitted during the subsequent quarterly reporting period. Additional meetings and discussions are required with

the NMED to reach resolution of the outstanding comments and concerns on the geophysical logging completed to date.

3.2.1.1 Geophysical Well Logging – Field Program

During the First Quarter 2012 event, no geophysical logging was conducted. This section describes the field program during the first three quarters of 2011. Table 3-1 provides a cumulative list of when each borehole was logged using required geophysical techniques as stated in the Groundwater Investigation Work Plan (USACE, 2011d).

The geophysical probes used by Jet West included a dual-spaced induction probe and neutron probe, both attached with a natural gamma tool. The general field activities included conducting daily calibration/instrument functionality checks at the beginning and end of the day; setting up the radiation warning signs; performing equipment decontamination around each well; and collecting repeat data over depths of interest that were determined from the first logging run for each probe. Shaw personnel performed field oversight of the geophysical logging process by using a QC form that documented daily instrument calibrations/instrument functional checks, logging depth, after survey depth error (ASDE), etc (Appendix M).

The induction tool field calibration was performed at the beginning and end of each day (Appendix M-1). The induction tool was placed in a 4-foot-tall “jig” to hold the tool in a horizontal position above the ground. The field team ensured the probe was far enough away from cultural features to avoid interference. Average conductivity readings were recorded over 100 samples. The attached natural gamma tool also measured the background counts over 100 samples. A calibration disc of known conductivity was placed over the medium and deep induction receiver coils and 100 samples were recorded. A calibration sleeve was also placed over the natural gamma crystal and data were recorded.

The neutron tool field calibration consisted of placing the probe in a jig in order to measure the background counts without the neutron source attached to the tool. The field calibration of the natural gamma tool was also performed without the neutron source attached for the background and calibration sleeve measurements. After the neutron source was attached to the tool, a calibration sleeve was placed over the neutron detector and 100 samples were recorded. Radiation warning cones were placed around the test area while the neutron source was removed from the storage canister. During well logging activities the following information was documented on the QC form:

- The starting depth in relation to ground surface prior to tool being lowered down into the well
- The total depth of the well once the tool had reached the bottom
- The start time of the log when the tool was being brought up from the well
- The average logging speed of the tool as the tool progressed up the well
- Zones of interest that could be used for the repeat log section
- The end time when the tool reached the original position at the top of the well
- ASDE
- The interval (minimum of 100 ft) selected for the repeat log

The geophysical data were reviewed in the field for agreement between the original and repeat log runs following data collection. Significant zones or “anomalies” were reviewed to verify that they were occurring at similar depth in both the original and repeat logs, as well as to verify that the two logs had similar log characteristics over the logging depth. Jet West archived the data for processing and supplied Shaw with Log ASCII Standard (LAS) files of the unfiltered and filtered log data, as well as PDF (portable document format) files of the final processed data within approximately one week of the completion of logging activities.

Subsequent to the geophysical well logging activity, two additional QC reviews were performed on the data delivered by Jet West. No additional data processing was performed by Shaw on the Jet West geophysical data. The QC regimen is described in the following sections.

3.2.1.2 Field Quality Control Review

The Wireline Summary Sheet (Shaw QC form) was used in the field to document parameters for each logging run and field calibration/instrument functional checks for each probe used. Field calibration and instrument functional checks were transferred to a Microsoft® Excel spreadsheet and assessed in graphical form. Digital readouts of the logs were reviewed in real time by the logging engineer and Shaw QC geophysicist to determine repeat interval(s) and ensure measurements from each probe are reasonable in terms of the expected response. At the end of borehole logging operations each day, raw digital data and hard-copy printouts from the probes were transferred to the Shaw QC geophysicist for backup, and the data were also transferred to Shaw's geophysical subcontractor, Jet West processing center, for additional analysis and processing.

3.2.1.3 Data Processing Quality Control Review

Jet West processed the data for each logging tool and generated an LAS file and hard-copy printouts of the final processed data for each well. The LAS files were reviewed for consistent format and the filtered files were transferred to the project Geographic Information System (GIS) team for incorporation into the RockWare software. After review of the LAS file format, the filtered data for each probe were also transferred into Microsoft® Excel to aid the NMED in its review of the geophysical logs. Limited processing in Excel was performed by Shaw and included smoothing of the natural gamma data (if necessary) and plotting of the induction and neutron data on logarithmic scales. Excel logging curves were then visually compared with the curves from the hard-copy PDF files of the final processed data from Jet West to ensure consistency.

3.2.1.4 Requirements for Log Analysis and Recommendations

As previously discussed, the current logs from Jet West support basic stratigraphic correlation for significant zones over the area of interest for the project, which is consistent with the original Statement of Work. Because the Colog geophysical logs were not calibrated, the logs that were collected in

December 2010 from the original 29 wells will not be used in this investigation. However, the Jet West geophysical logs can be used for log analysis. Jet West performed pre-project shop calibrations as well as field calibrations of the probes, as required by the Groundwater Investigation Work Plan (USACE, 2011d). Field calibrations and daily field logs are presented in Appendix M.

Based on the procedural errors identified in the Colog processing sequence, as well as the differences in the design and field operation of the probes (Colog vs. Jet West), the recommended course of action to support the project objectives is to use the Jet West probes to re-log eight of the wells (KAFB-1065, -1066, -1067, -1068, -10610, -10611, -10612, -10617), which were previously logged by Colog and for which there is no Jet West-logged well located nearby.

3.2.2 Well Installation

3.2.2.1 Groundwater Monitoring Wells

No new groundwater monitoring wells were installed during First Quarter 2012. All 78 GWM wells specified in the final, approved Groundwater Investigation Work Plan (USACE, 2011d) were completed during the first three quarters of 2011.

During the first three quarters of 2011, GWM wells were completed by the subcontractor drilling companies, WDC Exploration and Wells (69 wells) and Yellow Jacket Drilling (9 wells). The GWM wells were installed at all 28 NMED-prescribed locations, at depths specified for these locations in the Groundwater Investigation Work Plan (USACE, 2011d) and in accordance with Table 4 of the NMED-HWB August 6, 2010 letter (NMED, 2010c; Appendix I-4). The number and types of wells installed and surveyed are as follows:

- 22 water table wells – Shallow Zone
- 28 intermediate wells – Intermediate Zone (see discussion at end of Section 3.2.2.1)
- 28 deep wells – Deep Zone

Each monitoring well was completed in a separate borehole in clusters of three wells spaced no more than 50 ft apart. Before drilling, each borehole was investigated for utility clearance to 5 ft with a hand auger or an air-knife to ensure no utilities were present. Borehole advancement (drilling) was performed using the air rotary casing hammer (ARCH) drilling method. The ARCH method uses steel-insulator casing, advanced with a drill bit/rod, to prevent borehole collapse and seal off any contaminated zones to avoid cross-contamination of stratigraphic units. The boreholes were drilled using an 11-³/₄-inch outside diameter (O.D.) drive casing to a depth of approximately 200 ft below ground surface (bgs), and 9-⁵/₈-inch O.D. casing was advanced to the total depth of the borehole. These drive casing sizes effectively advance a 12-inch-diameter borehole to approximately 200 ft bgs and a 10-inch-diameter borehole from approximately 200 ft bgs to the total depth of the borehole.

During borehole advancement, the soil cuttings were logged every 5 ft by the site geologist. The soil samples were described according to the Unified Soil Classification System (USCS) (ASTM International [ASTM] D2487-11 [ASTM, 2011]). Other details, such as changes in lithology, color, moisture content, consistency, detailed lithology of individual gravel units, mineralogy, observed contamination, odor, and depth to groundwater, were also noted on the soil boring log. Soil classification logs for GWM wells completed during the first three quarters of 2011 are included in Appendix D-1.

All monitoring wells were constructed using 5-inch-diameter, Schedule 80 polyvinyl chloride (PVC) riser pipe and 0.010-slot, Schedule 80 PVC well screen with a 5-ft blank schedule 80 PVC sump. The shallow (water table) monitoring wells were installed with 20 or 30 ft of screen, and the intermediate and deep monitoring wells were fitted with 15-ft-length screens as prescribed for wells completed below the water table. Following placement of the well screen and riser pipe, a 10/20 Colorado silica sand (CSS) filter pack was tremied to approximately 2 ft above the top of the well screen followed by approximately 1 ft of fine sand seal consisting of 20/40 CSS. A bentonite seal (approximately 30 to 40 ft), consisting of 3/8-inch bentonite chips, was placed above the filter pack. The bentonite chip seal was hydrated in lifts

using a “clean” water source. A high-solids bentonite grout was placed above the bentonite seal to near ground surface. A cement surface seal was placed above the bentonite grout to the ground surface. Well completion diagrams for all completed GWM wells are provided in Appendix D-1.

All installed groundwater monitoring wells were developed within 30 days of installation. Initial development consisted of swabbing and bailing for approximately 2 hours until the sediment load was reduced as much as possible. Following initial development, the well was continuously pumped using an electric submersible pump. Temperature, pH, specific conductivity, and turbidity were monitored during pumping, and readings were taken after every well casing volume during purging. The volume of water introduced into the formation during drilling was removed from the well during development. The well was developed until the column of water in each well was free of visible sediment, and the pH, temperature, turbidity, and specific conductance had stabilized within 10%. Development and purge water was containerized for each well at the BFF site, labeled as IDW, and sampled for waste disposal.

All completed groundwater monitoring well locations are shown on Figure 3-1. Table 3-2 presents the completion information for each well, surveyed elevations and coordinates, well casing material, and screen depths and elevations. Well installation reports for each well (Appendix D-1) consist of soil boring logs, well completion diagrams, and well development records.

During Second Quarter 2011, continuous core soil samples were collected from six boreholes (wells KAFB-106059, -106060, -106063, -106078, -106080, -106081) for NAPL mobility testing (USACE, 2011e). The continuous core soil samples were collected by pushing a 4-inch-wide by 5-ft-long acetate sleeve into undisturbed soil. Table 3-3 presents the well locations, sample intervals, sample numbers, and USCS symbols (ASTM, 2011) for the continuous core soil samples.

As stated in the Second Quarter 2011 report (USACE, 2011e), all three wells at Cluster 5 (GWM-5) were installed such that the tops of the screens are too shallow relative to the requirements specified in the Groundwater Investigation Work Plan (USACE, 2011d). As a result, the water table well (KAFB-106041) is dry, and the intermediate well (KAFB-106042) and deep well (KAFB-106043) do not meet work plan requirements. The screens in all three wells were set based on an erroneous water level measurement causing the screen placements to be off by approximately 12 to 15 ft. The error was most likely due to the combination of water added during drilling and formation material coming up in the 9-5/8-inch drive casing that formed a “plug” in the bottom of the drive casing. The plug holds water in the casing and causes mounding of water, resulting in an erroneous water level measurement. The Field Work Variance for GWM-5 is included in Appendix I-1 and summarized in the following table:

Well ID	Water Level (ft BTOC)	Work Plan Requirements for Screened Interval Depth	Height of Water and Screen as Installed (ft)	Screened Interval (ft BTOC)
KAFB-106041 (water table well)	472.43	Top of screen 5 ft above water level; 15 ft below water table	Dry, water level below bottom of screen	449–469
KAFB-106042 (intermediate well)	468.93	Top of screen 15 ft below water table	Top of screen 0.07 ft below water table	469–483.5
KAFB-106043 (deep well)	468.90	Top of screen 85 ft below water table	Top of screen 74.1 ft below water table	543–557.3

BTOC below top of casing

Currently, KAFB-106042 is designated as a shallow well during data analysis as its screen currently intersects the water table. This designation replaces KAFB-106041 with KAFB-106042 as the Shallow Zone well, while still maintaining the previous designation of the Deep Zone well (KAFB-106043) at this cluster. Because KAFB-106042 does intersect the water table, the vertical extent of the plume at Cluster 5 can be determined by collecting analytical data for the Shallow and Deep Zones.

3.2.2.2 *Soil Vapor Monitoring Wells*

No new SVM wells were installed during First Quarter 2012. All proposed SVM wells were installed and completed during the first three quarters of 2011. This section presents a detailed explanation of the SVM well installation and procedures followed during the first three quarters of 2011.

All SVMW locations are shown on Figure 3-2. Each nested well location consists of six individual (one 3-inch-diameter and five 3/4-inch-diameter), Schedule 80, PVC SVMWs that were installed in the same borehole. Nested wells included a 10-ft-length of machine-slotted (0.050-inch) screen. Planned depths for the bottom of the nested well screens were 25, 50, 150, 250, 350, and 450 ft bgs. In some cases, the screened intervals were adjusted based on lithology observed during borehole advancement (e.g., screens were placed in transmissive zones). If proposed vapor-monitoring screened intervals were observed to be within fine-grained lithologic intervals (clay or silt), screened intervals were adjusted up or down to the nearest coarser-grained unit. Screens separated by 100 ft (150, 250, 350, and 450 ft bgs) were adjusted by no more than 25 ft, and screens separated by 25 ft (25 and 50 ft bgs) were adjusted by no more than 5 ft. Table 3-4 presents the well completion information for the SVMWs and the actual depths of the screened intervals.

A filter pack consisting of Tacna 0.25-8 washed gravel was placed from the bottom of the screen to approximately 2 ft above the top of screen around the lowest nested well. A 3/8-inch bentonite chip seal was installed from the top of the filter pack to just below the screen for the next lowest well. Bentonite seals were hydrated every foot for the first 10 ft using a clean water source. This process was repeated for each nested well screen/riser pipe with the exception of the last (25-ft) well. Bentonite was placed to within 5 ft bgs followed by a cement seal to the ground surface. Nested SVMWs were completed at ground surface in steel, flush-mounted, protective covers (well vaults) with gasketed, bolt-down covers. The well vaults were completed with a 4- by -4-foot concrete pad, sloped to direct runoff away from the well.

As with the GWM wells (Section 3.2.2.1), soil cuttings were logged every 5 ft by the site geologist. Soil samples were described according to the USCS (ASTM, 2011). Other details, such as changes in lithology, color, moisture content, consistency, detailed lithology of individual gravel units, mineralogy, observed contamination, odor, and depth to groundwater, were also noted on the soil boring log. Soil boring logs and well completion diagrams for the SVMWs are provided in Appendix D-1.

Soil samples were collected during borehole advancement in accordance with the Vadose Zone Investigation Work Plan (USACE, 2011c) and the NMED-HWB letter, dated August 6, 2010 (NMED, 2010c; Appendix I-4). Soil samples were collected every 10 ft for the first 50 ft and every 50 ft thereafter to the total depth of the borehole. Discrete soil samples were collected using a stainless-steel, 2-inch O.D., split-spoon sampler driven into undisturbed soil using a 140-pound hammer falling 30 inches until either approximately 2 ft was penetrated or 100 blows within a 6-inch interval had been applied as required by ASTM D1586-08a (*Standard Test Method for Standard Penetration Test [SPT] and Split-Barrel Sampling of Soils* [ASTM, 2008]).

Soil samples were shipped to Gulf Coast Analytical Laboratories, Inc. in Baton Rouge, Louisiana, for analysis of volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), total petroleum hydrocarbons (TPH)-gasoline range organics (GRO), TPH-diesel range organics (DRO), and lead. The analytical results for soil samples are presented in the Third Quarter 2011 report (USACE, 2011f) and are provided in this report in Appendix E-1.

3.2.2.3 Pneulog Wells

No new Pneulog wells were installed during First Quarter 2012. Four Pneulog well clusters (KAFB-106148, KAFB-106149, KAFB-106150, and KAFB-106151) were previously installed during Third Quarter 2011, and five Pneulog well clusters were installed during Fourth Quarter 2011 (KAFB-106152, KAFB-106153, KAFB-106154, KAFB-106155, and KAFB-106156). All Pneulog well

clusters are shown on Figure 3-2. Each well cluster consists of three “nested” 3-inch-diameter well casings with three screened intervals at approximately 500 to 355, 350 to 205, and 200 to 25 ft bgs. All nine well clusters were surveyed during Fourth Quarter 2011. Table 3-5 presents the well locations, elevations, depths, and screen intervals.

Before drilling, each well location was tested for utility clearance to 5 ft using a hand auger. As described in Section 3.2.2.1, drilling was completed by the ARCH method, which used an 11-³/₄-inch O.D. drive casing to a depth of approximately 150 ft bgs and a 9-⁵/₈-inch O.D. casing to total depth. Each well consists of a single borehole drilled to just above the water table (approximately 488 ft bgs), with each borehole containing three “nested” 3-inch-diameter well casings. All well casings are flush-threaded, Schedule 80 PVC casing with three screened intervals at approximately 500 to 355, 350 to 205, and 200 to 25 ft bgs with factory-slotted PVC 0.050 slot screen. A filter pack consisting of Tacna 0.25-8 washed gravel was placed in the annular space between the well casing/screen and the borehole from the bottom of the borehole to approximately 2 ft above the top of the screened interval, with approximately 1 to 2 ft of a bentonite chip seal between each screen interval.

During borehole advancement, the soil cuttings were logged every 5 ft by the site geologist. The soil samples were described according to the USCS (ASTM, 2011). Other details, such as changes in lithology, color, moisture content, consistency, detailed lithology of individual gravel units, mineralogy, observed contamination, odor, and depth to groundwater, were also noted on the soil boring log. Soil boring logs and well completion diagrams are presented at the end of Appendix D-1.

3.2.2.4 LNAPL Containment Well

A technical evaluation of the proposed well location(s) and well quantity(ies) was conducted as a result of discussions with the NMED on November 3, 2011. Subsequent to that evaluation, it was determined that a single containment well would be sufficient for containing the NAPL plume, thus meeting the primary

objective of the containment system and work plan. A Letter Addendum to the LNAPL Containment Interim Measures Work Plan was submitted for NMED review and approval on November 16, 2011 (Appendix I-2); this letter also requested approval for a change in the screen length to accommodate the documented rising water table. The Letter Addendum was partially approved by the NMED on December 1, 2011. In accordance with the Letter Addendum, one containment well (KAFB-106157) was installed during Fourth Quarter 2011 (Figure 3-2). This well location was surveyed during First Quarter 2012. Table 3-5 presents the well location, elevation, depth, and screen interval for the LNAPL containment well.

Before drilling activities commenced, On Point Utility Inc. surveyed the area for any existing underground utilities. Once cleared, the well location was also tested for utility clearance to 5 ft using a hand auger. Drilling was completed by the ARCH method, which used a 13-5/8-inch O.D. drive casing to a depth of approximately 220 ft bgs, and an 11-3/4-inch drive casing to a total depth of approximately 545 ft. During borehole advancement, the soil cuttings were logged every 5 ft by the site geologist. The soil samples were described according to the USCS (ASTM, 2011). Other details, such as changes in lithology, color, moisture content, consistency, detailed lithology of individual gravel units, mineralogy, observed contamination, odor, and depth to groundwater, were also noted on the soil boring log.

The well casing is 8-5/8-inch welded stainless steel with stainless steel centralizers. The well screen is 8-5/8-inch 0.30 slot wire wrapped stainless steel set in a 20-ft section and a 70-ft section separated by 10 ft of casing. The bottom of the sump is set at approximately 545 ft bgs and is 5 ft in length. An engineered 10-20 sand filter pack was installed in the annular space between the well casing screen and the borehole from the bottom of the borehole to approximately 10 ft above the top of the screened interval. The filter pack was slurried with clean potable water and tremied into place to prevent bridging and to ensure continuous placement, while the drive casing was slowly removed. An approximately 35-ft hydrated bentonite seal was emplaced above the sand filter pack and incrementally hydrated with potable

water in 1-ft lifts. After the last lift was hydrated for 2 hours, a cement grout with a weight density no less than 12.5 pounds per gallon was emplaced by tremie pipe to approximately 1.5 ft bgs. The grout weight density was measured twice during placement to certify the grout specification.

Section 5.3.1 of the original LNAPL Containment Interim Measures Work Plan (USACE, 2011g) describes a series of pump tests that would be performed on the containment well. In the Letter Addendum to the LNAPL Containment Interim Measures Work Plan (Appendix I-2), Shaw proposed replacing the pump tests with an enhanced well development plan in order to collect the required data and complete the full design of the containment system. In its letter dated December 1, 2011, approving the installation of the single containment well and screen design, the NMED requested additional information on the enhanced well development before approval could be issued. In response to the NMED request, a letter addendum to the LNAPL Containment Interim Measures Work Plan (Appendix I-2) was submitted on January 25, 2012, describing the enhanced well development proposal. In this letter, Shaw states that the enhanced well development will be used to determine the well-specific capacity needed to complete the design of the full containment system. The enhanced well development will entail the following activities:

- Standard purging and swabbing of the well screen will be performed, as described in Section 6.3.6 of the Work Plan (USACE, 2011g);
- The well will be pumped for 4 to 8 hours using the well development pump to remove sediment from the well;
- An 8-hour constant discharge pumping test will be conducted to determine the specific capacity of KAFB-106157. The well development pump will be used for this test and the rate will be between 15 and 25 gallons per minute. The well will be undisturbed for a minimum of 12 hours prior to the start of the 8-hour pumping test;
- A pneumatic slug test will be performed following the procedures in Section 5.1.2 of the Work Plan (USACE, 2011g).

The NMED submitted a response to the letter addendum on February 24, 2012, stating that it is in agreement with the overall technical aspects of conducting an enhanced well development; however, further information detailing the specific approach and activities is required. The approach for well development, as well as any permit requirements, will be documented and submitted for NMED approval in the Revised Final LNAPL Containment Interim Measures Work Plan Part I – Characterization.

3.2.2.5 Soil Vapor Extraction Wells

A technical evaluation of the proposed SVE well locations, design, and installation was conducted as a result of discussions with the NMED on November 3, 2011. A Letter Addendum to the Final Interim Measures Work Plan was submitted for NMED review and approval on November 16, 2011 (Appendix I-2), which discusses the proposed well locations and design. The Letter Addendum was approved by the NMED on December 23, 2011. In accordance with the Letter Addendum, two SVEWs (KAFB-106160 and KAFB-106161) were installed and surveyed during First Quarter 2012 (Figure 3-2). Table 3-5 presents the locations, elevations, depths, and screen intervals for the SVEWs.

Before drilling activities commenced, On Point Utility Inc. surveyed the area for any existing underground utilities. Once cleared, the well locations were also tested for utility clearance to 5 ft using a hand auger. Drilling was completed by the ARCH method, which used a 13-5/8-inch O.D. drive casing to a depth of approximately 200 ft bgs, and an 11-3/4-inch drive casing to the total depth of approximately 540 ft. The well casing is 6-inch stainless steel with stainless steel centralizers. The well screen is 6-inch, 0.050-slot wire-wrapped stainless steel set in a 50-ft section and a 40-ft section separated by 10 ft of casing. From the bottom of the 40-ft section of the 6-inch, 0.050-slot screen, a 6-inch, 0.030-slot wire-wrapped stainless steel screen is continued to 525 ft bgs. The bottom of the sump is set at 530 ft bgs and is 5 ft in length. An engineered 8-12 sand filter pack was installed in the annular space between the 6-inch, 0.030-slot screen and the borehole from the bottom of the borehole to approximately 2 ft below the top of the 6-inch, 0.030-slot screened interval. An engineered 0.25/8 sand filter pack was installed in

the annular space between the 6-inch, 0.050-slot well casing screen and the borehole from the top of the 8-12 sand filter pack to 5 ft above the top of the 6-inch, 0.050-slot screened interval. The filter pack was slurried with clean potable water and tremied into place to prevent bridging and to ensure continuous placement, while the drive casing was slowly removed.

An approximately 5-ft hydrated bentonite seal was emplaced approximately 44 ft above the 8-12 sand filter pack and incrementally hydrated with potable water in 1-ft lifts. An additional 30-ft hydrated bentonite seal was emplaced above the 0.25/8 sand filter pack and incrementally hydrated with potable water in 1-ft lifts. After the last lift was hydrated for 2 hours, a cement grout with a weight density no less than 12.5 pounds per gallon and composed of 6% bentonite was emplaced by tremie pipe to approximately 5 ft bgs. The grout weight density was measured twice during placement to certify the grout specifications.

During borehole advancement, the soil cuttings were logged every 5 ft by the site geologist. The soil samples were described according to the USCS (ASTM, 2011). Other details, such as changes in lithology, color, moisture content, consistency, detailed lithology of individual gravel units, mineralogy, observed contamination, odor, and depth to groundwater, were also noted on the soil boring log. Soil boring logs and well completion diagrams are presented at the end of Appendix D-1.

The SVEW design was constructed for multi-purpose applications, and as such, was screened across the water table, providing an option to adapt the well for future groundwater extraction if required. If a technical decision based on data collected from this investigation determines that SVEW will be used for dual purpose - a combination of LNAPL extraction and SVE extraction – and is approved by NMED, then well development will be in accordance with the Letter Addendum to the Interim Measures Work Plan submitted on November 16, 2011.

3.2.3 Surveying

During First Quarter 2012, the LNAPL containment well and two SVE wells were surveyed in accordance with the Interim Measures Work Plan (USACE, 2011) and the NMAC *Minimum Standards for Surveying in New Mexico* (12.8.2 NMAC). All wells were surveyed by a New Mexico-licensed professional land surveyor from Albuquerque Surveying Co., Inc. Horizontal coordinates are based on the New Mexico State Plane Coordinate System, Central Zone (North American Datum of 1983), as published by the National Geodetic Survey. Elevations are determined to the nearest 0.01 ft and referenced to the 1988 National Geodetic Vertical Datum, which were obtained from permanent benchmarks.

A subcontracted two-man crew surveyed the three wells using a Topcon RTK (real-time kinematic) GPS (global positioning system) unit. This instrument is a survey-grade GPS rover unit and base station that is tied to known control points with horizontal and vertical accuracies of approximately 0.01 ft. At each well location, the survey team would remove the vault cover and all well caps and collect data points of the wells and related surfaces. Survey points collected at all wells include the ground surface north of the well pad, the well pad north of the well's outer steel casing, the steel casing on the northern edge (marked with black permanent marker), and the northern edge of the inner PVC or stainless steel well casing.

Nomenclature used for the elevation measurement points are as follows: ground or asphalt, concrete well pad, case, and PVC/steel. Once all survey points were obtained for each location, a depth measurement was collected from the top of the outer steel casing down to the inner well using a steel tape measure. This measurement served as an elevation check for QC purposes during data processing by the licensed surveyor. Table 3-6 presents all survey data acquired through the end of the First Quarter 2012.

3.2.4 FFOR Investigation

The objective of the FFOR soil investigation sampling is to identify areas of shallow soil containing LNAPL or hazardous constituents that exceed NMED soil screening levels (SSLs) as part of the NMED-directed interim measure investigation. The work was performed as specified in the correspondence dated December 10, 2010, from the NMED to Kirtland AFB (NMED, 2010d) and with procedures outlined in the Final Interim Measures Work Plan (USACE, 2011a).

3.2.4.1 Field Activities

During the Second and Third Quarters 2011, from June 2 through August 17, 2011, direct-push technology (DPT) was utilized to collect soil samples along the former pipeline at the FFOR to the pump house (Building 1033) and from Building 1033 to the former aboveground storage tanks. DPT activities were performed by the subcontractor, JR Drilling, a licensed New Mexico drilling company. A total of 288 boreholes were completed during this time period.

During Third Quarter 2011, five boreholes were not completed due to refusal when the DPT rig came into contact with the underground concrete sleeve that formerly housed the fuel pipeline ST-106 (Figure 3-3). Work is ongoing with the drilling subcontractor to core the concrete sleeve so that total depth may be achieved. The completed borehole numbers, collection dates, and coordinates are presented in Table 3-7.

During Fourth Quarter 2011, the remaining FFOR soil investigation samples could not be collected due to ongoing military construction and excavation by Chugach Management Services in this area. The area remaining to be completed is directly west of the pump house (Building 1033) (Figure 3-3). In addition, 16 step-out locations were determined by analytical data evaluation in accordance with the Final Interim Measures Work Plan (USACE, 2011a) and are also presented in Figure 3-3. On March 1, 2012, NMED approved KAFB's modified approach to complete DPT work in the area of the excavation, as well as complete the first round of step-outs. The remaining investigation sample locations, as well as the 16 step-

out locations, are planned to be completed by the end of Second Quarter 2012 and additional step-outs will be identified in future quarters as needed.

3.2.4.2 Procedure

DPT sampling was initiated at the westernmost point of the FFOR, continued eastward, and then turned south, terminating at the area currently under construction by Chugach Management Services. The entirety of the DPT sampling from the former storage tanks to Building 1033 was then completed, working from the easternmost point to the westernmost point. Sampling locations between the FFOR and Building 1033 were spaced on 10-ft centers directly over the location of the former pipeline, and 5 ft to either side as directed in the NMED correspondence (NMED, 2010d) and as described in the Final Interim Measures Work Plan (USACE, 2011a).

Three suspected leak locations were previously identified along the pipeline at approximately 18, 150, and 200 ft from the west end of the FFOR (Figure 3-3). These three locations were marked in a 5-ft grid to better evaluate the area of the suspected leaks. Sampling locations along the former pipeline south of Building 1033 to the former fuel storage tanks were marked 20 ft apart along two lines oriented parallel to the pipe centerline and no more than 5 ft from the pipe centerline (Figure 3-3), as outlined in the work plan.

Shallow borings were advanced to 20 ft bgs using a 3-inch-diameter by 4-foot-long, acetate-lined, open barrel sampler. Soil samples were collected from the surface and every 5 ft to the total depth of 20 ft and were logged every 5 ft by the site geologist. The soil samples were described according to the USCS (ASTM, 2011) and other details, such as changes in lithology, color, moisture content, consistency, detailed lithology of individual gravel units, mineralogy, observed contamination, odor, and depth to groundwater, were also noted on the soil boring log (Appendix D-3).

The QA/QC samples were collected at a frequency specified in the Interim Measures Work Plan to verify the accuracy of field sampling and analytical procedures. The QC samples included field duplicates, equipment rinse blanks, matrix spike and matrix spike duplicate samples, and trip blank and field blank samples (VOC analysis only). Sample collection methods for sampling from the DPT core are summarized as follows:

- **Step 1.** Once sampling depth was reached, the open barrel sampler was pulled up smoothly and opened. Each 5-ft interval was logged according to the USCS by a qualified geologist. Descriptions of soil, such as color, classification, thickness, odor, and headspace readings were recorded on Soil Boring Logs (Appendix D-3). The DPT subcontractor personnel then cut the acetate sleeve encasing the sample. The sampling technician determined the appropriate sample interval, as approved by the geologist, and collected the soil in a stainless steel sampling bowl.
- **Step 2.** For each soil sample, two sodium bisulfate TerraCore volatile organic analysis (VOA) vials, two methanol TerraCore VOA vials, one 2-ounce (oz.) jar for percent moisture, one 16-oz. jar, and one Mason jar for headspace were filled with soil from the depth interval and covered with aluminum foil. A headspace reading was collected from the Mason jar through the aluminum foil cover using a photoionization detector. Headspace readings were recorded on both the Soil Classification Logs and Sample Collection Logs for each sample.
- **Step 3.** The TerraCore kit (which included the four VOA vials and the 2-oz. jar in a foam holder) were placed inside a 1-gallon Ziploc bag with bubble wrap. A preprinted label was affixed to the inside of the bag to prevent water damage. The 16-oz. jar was placed into a Ziploc bag with a label affixed directly to jar. The jar lid was then sealed with packing tape to prevent water from entering the sample. After properly packing and checking each sample, the samples were immediately placed into a cooler on ice. Sampling equipment was decontaminated after every sample by using deionized water and Alconox to ensure that no cross-contamination occurred.
- **Step 4.** After the completion of a borehole, the coolers containing the samples for that borehole were taken to the project field office trailer where they were placed into a sample refrigerator. The samples remained in the refrigerator until they were packed and ready for shipment to the laboratory.

After the completion of each borehole, sample names, times, dates, and depth intervals are logged into ShawView (an Oracle-based Environmental Information Management System), and an associated chain-of-custody form is produced for that day. The chain-of-custody forms are reviewed against the samples as a QC procedure to ensure sample names, dates, and times correspond. Samples are packaged and shipped in accordance with the Interim Measures Work Plan (USACE, 2011a).

FFOR soil samples were shipped to Gulf Coast Analytical Laboratories, Inc., located in Baton Rouge, Louisiana, for analysis. Samples were analyzed for VOCs, SVOCs, TPH-GRO, TPH-DRO, and lead. FFOR soil sampling analytical data will be presented once all sampling has been completed and analytical data has been validated.

3.2.5 Slug Testing

No slug testing was performed during First Quarter 2012. Slug testing was performed on 37 wells during Third Quarter 2011, and the following sections reiterate the slug testing activities for that reporting period. Slug tests were conducted at selected wells (Appendix H) to obtain hydraulic conductivity data to support modeling the extent of LNAPL, dissolved-phase migration, and groundwater flow velocities across the site. The data were used to obtain an estimate of the spatial variability of the hydraulic conductivity of the aquifer system across the site and to assist in the design of subsequent pumping tests. Appendix H contains the complete report on the slug test procedures, data plots, and results.

3.2.5.1 Procedure

Hydraulic conductivity, specific storage, and general aquifer characteristics were derived from observation and interpretation of water-level responses to stresses applied to the aquifer system through the introduction of a slug into or withdrawal of the slug from the water within a well. Two types of slugs were used, a mechanical slug and a pneumatic slug. The mechanical slug was built using a steel pipe filled with sand that was mechanically lowered into and removed from the groundwater. To perform pneumatic slug tests, the wellhead was sealed and air pumped into the well. After the desired pressure level was reached and the water level stabilized, the pressure was released and the water level was allowed to re-equilibrate.

Mechanical tests were performed in wells screened across the water table, wells where the pneumatic wellhead would not fit on the well, and where the well construction was such that it could not maintain

stable air pressure. Pneumatic tests were performed in all other wells. Mechanical tests were performed in 18 wells and pneumatic tests were performed in 19 wells.

3.2.5.2 Data Analysis

Water-level responses to the slug introduction or withdrawal were interpreted using the software package AQTESOLV (HydroSolve, 2011) to determine hydraulic conductivity, specific storage, and the ratio between vertical and horizontal hydraulic conductivity. Each test was analyzed using multiple methods, and the best fit solution was chosen for each well.

3.2.5.3 Field Quality Control

Slug tests were repeated on four wells to verify consistency of test procedures. Two of the wells were screened across the water table, and field QC tests were mechanical as the initial tests had been. For the two wells screened below the water table, field QC tests were both pneumatic and mechanical to compare the test types. Data were analyzed by the same method as the initial tests.

3.2.5.4 Results

Appendix H shows the hydraulic conductivity (K), specific storage (S_s) and anisotropy ratio (K_v/K_h) for each well, along with the results for the field QC tests. Appendix H presents the horizontal and vertical spatial variability of hydraulic conductivity across the site. The aquifer in the vicinity of the Kirtland AFB wells has a geometric mean hydraulic conductivity of 71 ft/day with a minimum of 40 ft/day and a maximum of 129 ft/day. These values are within the ranges expected for units ranging in grain size from silty sand to gravel. Geometric mean specific storage is 0.0001 ft^{-1} and the geometric mean anisotropy ratio is 0.01.

Analyses of the field QC data in Appendix H indicate the variability that exists between slug-test results.

The variability arises primarily because of the non-unique nature of curve-fit data analysis. The

difference was taken between the solutions for the initial and QC tests for all test and solution types in each of the four QC wells. These differences were all found to be within two standard deviations of the mean, which is within acceptable margin of error. For each test, the solutions chosen for the initial and QC tests were within the same order of magnitude. These results show that slug testing was performed consistently and yielded valid and consistent data.

3.2.6 Quarterly Groundwater Sampling Field Activities

Existing dedicated Bennett sample pump systems were pulled as needed to evaluate the current condition, repaired, and then reinstalled for operations. No new dedicated Bennett pump sampling systems were installed in wells during the First Quarter 2012. Table 3-8 summarizes the Bennett pump sampling systems installed for BFF Spill site wells. The following describes the well maintenance activities that occurred from January through March 2012:

- March 21, 2012 – Dedicated Bennett pump sampling system on KAFB-10624 required repairs to the surface tubing connections; removed dedicated Bennett pump sampling systems from KAFB-106076; and tubing burst just above the nylon splice and KAFB-1062 needed minor pump repairs,
- March 22, 2012 – Dedicated Bennett pump sampling system was reinstalled in monitoring well KAFB-1062; attempted to remove the Bennett pump sampling system from KAFB-10612; and removed the Bennett pump sampling system KAFB-10626 for repairs. Please refer to the following paragraph on the repair activities and outcome relating to KAFB-10612.
- March 27, 2012 – Dedicated Bennett pump sampling system was removed from monitoring well KAFB-10613 for repairs.

During First Quarter 2012, groundwater from KAFB-10612 could not be sampled due to pump failure. The sampling operations were tentatively suspended until the pump could be repaired or removed and replaced. On March 22, 2012, HydroGeologic Services (HGS) attempted to remove and repair the failed pump system; however, the one-inch sounding tube broke at the surface and dropped approximately eight feet into the well casing. Because there was limited space in the well casing to retrieve the sounding tube, HGS had to remove the tubing bundle and pump. While the tubing bundle and pump were being removed,

it was observed that most of the pump was detached from the tubing bundle and remained at the bottom of the well. The tubing bundle and top cap of pump were removed and it was determined that the cause of pump failure and detachment was due to extensive corrosion. An additional attempt was made to remove the sounding tube from the surface connection, but unfortunately, the tube slipped off the retrieval tool and also fell into the well casing. A camera was subsequently used to document the location of the sounding tube, which confirmed that the tube had fallen to approximately 200 ft below the top of casing.

On May 4, 2012, HGS attempted to retrieve the sounding tube and the rest of the pump. During this attempt, approximately 225 feet of the one-inch sounding tube was retrieved. Several attempts were made with various fishing tools with various lengths and weights to retrieve the remaining segments; however the attempts were unsuccessful. The remaining portions of the sounding tube and pump are approximately 430 feet below the top of casing. In subsequent quarters, additional efforts to acquire video recordings will be made to determine whether the well is recoverable, and if so, the appropriate actions necessary to repair the well.

3.2.7 Quarterly Soil-Vapor Sampling Field Activities

During the First Quarter 2012 soil-vapor sampling activities, samples from SVM/SVE wells were collected and analyzed using the field Horiba Mexa 554J emissions analyzer for petroleum hydrocarbon concentrations in units of ppmv and for percent O₂, CO, and CO₂. The soil-vapor samples were collected into pre-evacuated Bottle-Vac canisters and Tedlar™ bags and shipped under chain of custody to RTI Laboratories, Inc. in Livonia, Michigan, a DoD EL Accreditation P-certified laboratory, for the following list of analyses:

- VOCs including acetone; EDB; EDC; 1,2,4-trimethylbenzene (TMB); 1,3,5-TMB; methyl tert-butyl ether, and methyl ethyl ketone (or 2-butanone) by EPA Method TO-15 (EPA, 1999),

- Fixed gases (O₂, nitrogen, CO, CO₂, and methane) by ASTM-D2504 (ASTM, 2010), and
- APH by MA DEP (2008) method.

Laboratory analytical data packages for soil vapor samples collected during the First Quarter 2012 are provided on compact disc in Appendix B-4. Appendix B-3 presents the Data Quality Evaluation Report for the soil vapor data collected during First Quarter 2012 and also includes a reference table as an attachment that identifies each sample location, sample date, sample number, and associated sample delivery group assigned by the laboratory.

3.2.8 SVE Radius of Influence Testing

No SVE ROI testing was conducted during First Quarter, 2012. The following sections reiterate the procedures used during the SVE ROI testing conducted during Fourth Quarter 2011 and describe the data analysis that took place during First Quarter 2012. SVE ROI testing commenced on November 2, 2011, and was completed on December 16, 2011. Five single well tests and three five-day tests were performed to provide detailed, site-specific information to aid in the quantitative assessment and modeling of SVE vadose-zone remediation and subsequent optimization of the existing system.

Data were collected to be incorporated into the three-dimensional (3D) analysis of remediation prospects for the vadose zone contamination using existing SVE wells and RSI SVE units. This analysis will involve vapor concentration distribution, lithology, and 3D numerical modeling of vapor flow. The ongoing quarterly field and analytical vapor concentration monitoring data for existing SVMWs and SVEWs will be used as chemical data input for the analysis. The collected data will also be used to design a more effective SVE system. Appendix L contains the complete report on ROI test procedures and data.

3.2.8.1 Procedure

All operating SVE units were shut down for the entire month of October 2011 prior to the start of ROI testing (November and December 2011) to allow the site system to equilibrate. Single well tests were performed on five potential SVEWs, and three five-day tests were conducted using the selected SVEWs (Figure 3-4). A summary of the tests performed, including dates and the list of monitoring wells, is presented in Table 3-9.

Test nomenclature is as follows:

- Test types were designated with “SWT” for single well tests and “5DT” for five-day tests.
- Well ID follows the test type.
- Extraction well depth is designated for wells where the well ID is assigned to multiple wells at different depths in a cluster.

For instance, the single well test using the 450-ft depth well in cluster KAFB-106121 as the extraction well is designated “SWTKAFB106121-450,” while the five-day test using SVEW-05 as the extraction well is designated “5DTSVEW-05.”

RSI SVE Unit 335 was configured for use as a mobile unit for tests using KAFB-106121-450, KAFB-106117-450, and KAFB-106149-484 as extraction wells. This configuration consisted of having propane available at the various test locations and using hoses to connect the RSI SVE unit to specific extraction wells. The RSI unit was used to complete both the single well and five-day tests at KAFB-106121-450 and then moved, along with the propane tank, to a location adjacent to both wells KAFB-106117-450 and KAFB-106149-484, where it was used to complete all tests at those wells. RSI SVE Unit 249 was used for all tests at wells SVEW-01 and SVEW-05 as it was already in place at that location.

A test wellhead was constructed for use on extraction wells KAFB-106121-450, KAFB-106117-450, and KAFB-106149-484 (Figure 3-5). The wellhead is a 4-inch-diameter, 11.7-ft-long PVC pipe attached by a 90-degree bend to a well seal and equipped with one port into which the hot-wire anemometer and the Horiba Mexa-584L probe (when vapor does not require dilution) could be inserted and a sampling port from which vacuum pressure could be read and vapor collected for dilution when required. In addition, the wellhead contains a pressure gauge for obtaining readings in units of inches of mercury. Extraction wells SVEW-01 and SVEW-05 are connected to a wellhead setup that is already in place (Figure 3-6), each with a sampling port from which vacuum pressure can be read and vapor collected for dilution when required, as well as a port into which the hot-wire anemometer and Horiba Mexa-584L probe can be inserted (when vapor does not require dilution). Vapor dilution was required when total hydrocarbons reached or exceeded 8,000 milligrams per kilogram (ppm). All data for these tests consisted of field measurements only; no samples were collected.

Single Well Tests

Each of the five potential SVEWs proposed for ROI testing was tested to determine well flow characteristics. At the beginning of each test, the RSI SVE unit was started and connected to the wellhead to begin extraction.

Flow and vacuum were measured every 30 minutes from the start of the test until 1100 minutes, and then hourly until 1600 minutes. Flow, velocity, and temperature were measured using a Dwyer hot-wire anemometer with the probe positioned at the center of the pipe perpendicular to air flow direction. Vacuum was measured using a Magnehelic pressure gauge of the most appropriate available range reading in units of inches water column (inWC). The gauge ranges available were 0 to 1, 0 to 2, 0 to 4, 0 to 20 and 0 to 60 inWC. When vacuum pressure exceeded a reading of -60 inWC (negative inWC), the vacuum reading was obtained from the RSI SVE units. Magnehelic pressure gauges are equipped with positive and negative ports to read both positive and vacuum pressures.

Vapor measurements were obtained hourly from the start of the test until 1600. A Horiba Mexa-584L was used to measure CO, CO₂, O₂, and total hydrocarbons. Vacuum pressure readings on all other well depths within the cluster containing the extraction well were obtained every 30 minutes from the start of the test until 1100, and then hourly until 1600. Magnehelic pressure gauges of the most appropriate available range reading in units of inWC were used to measure vacuum pressure. Vacuum pressure was recorded as a positive value, and positive pressure was recorded as a negative value (i.e., a negative vacuum).

After the readings scheduled for 1600 were taken, the RSI SVE unit was shut off, and engine data for the duration of the test was downloaded from the RSI SVE unit. After the field and engine data were collected, plots of the test data over time were prepared. Results for the single well tests were used to select extraction wells for the five-day tests.

Five-Day Tests

Three 5-day tests were performed to determine the vertical and horizontal ROI. Extraction wells were selected for these tests based on the results obtained from the single well tests. The wells selected were KAFB-106121-450, SVEW-05, and KAFB-106149-484. Table 3-9 shows the monitoring wells selected for each test. At the beginning of each test, the RSI SVE unit was started and connected to the wellhead to begin extraction.

On the first day of the test, all monitoring and extraction well readings were taken hourly. For test 5DTKAFB106149-484, readings were obtained approximately every 90 minutes, as there were more wells than could be monitored in an hour. On the second and third days, all readings were obtained twice daily, and on the fourth and fifth days readings were obtained once daily.

Flow and vacuum measurements on the extraction well were obtained using the same procedures as for the single well tests. Vacuum pressure on monitoring wells was measured using Magnehelic pressure gauges of the appropriate ranges for test 5DTKAFB106121-450 and a Dwyer digital manometer for tests 5DTSVEW-05 and 5DTKAFB106149-484. Vacuum pressure was recorded as a positive value, and negative pressure was recorded as a negative value (i.e., a negative vacuum pressure).

Vapor measurements were obtained using the same procedures as for the single well tests. For test 5DTKAFB106149-484, an Orion 4-gas meter was used to measure hydrogen sulfide and percent lower explosive limit of vapors from the extraction well.

The RSI SVE unit was shut down after the measurements were obtained on the fifth morning to end the test. The data from all three tests will be evaluated to determine the horizontal and vertical ROI using 3D methods for data analysis. This data will be used to determine how to optimize SVE at the BFF Spill site. All data collected during ROI testing is presented in Appendix L.

3.2.8.2 Data Analysis

Data collected during the ROI tests are overprinted by the vadose zone's response to changes in barometric pressure. As the barometric pressure increased, vacuum pressure in the wells screened within the vadose zone increased. This effect is particularly strong for the deeper parts of the vadose zone, which are not able to equilibrate with the atmosphere as quickly as the more shallow regions. Consequently, the barometric pressure had a much stronger effect on vacuum pressure in wells being monitored than the RSI SVE units that were used during ROI testing (Figure 3-7).

In order to determine the ROI for each extraction well, the affect of the barometric pressure was removed from the data. Hourly barometric pressure was available for download from a weather station located at the Albuquerque International Sunport, which is adjacent to Kirtland AFB.

First, the barometric efficiency of the monitoring wells was determined. Barometric efficiency is a measurement of how vacuum pressure in a well responds to a change in barometric pressure, and is calculated by dividing the change in vacuum pressure by the change in barometric pressure for a given period of time. Vacuum pressure was observed at seven individual 450 ft depth wells during times where RSE SVE units were off. For KAFB 106121-450, data was also used from the times where RSI SVE units were running for tests 5DTSVEW-05 and 5DTKAFB106149-450. This well is greater than 600 feet away from the extraction wells for those two tests, and therefore well outside the anticipated ROI. The vacuum pressure in KAFB 106121-450 can be assumed to be responding only to changes in barometric pressure during those two tests.

For each of the seven observation wells, the vacuum pressure was plotted against barometric pressure and a best-fit line was matched to each. Correlation coefficients of the data to the best-fit lines ranged from $r = 0.0871$ to 0.996 , indicating a very good match to the data. The slope of the best-fit line is the calculated barometric efficiency. Slopes ranged from -0.7 to -0.8 , indicating that the barometric efficiency is very consistent across the BFF at 450 ft bgs (Figure 3-8). Observation well KAFB 106121-450 had 17 data points, while the other wells had only 4 or 5 each. The greater number of data points means that the results from KAFB 106121-450 are more meaningful than the results from the other wells. Calculated barometric efficiency at KAFB 106121-450 was -0.7 with a correlation coefficient of $r = 0.952$. Since this well had significantly more data point than the other wells, is a good fit to the data, and has a result similar to the remaining 6 wells, the barometric efficiency calculated here was chosen to apply across the BFF for the 450 ft depth.

Next, a vacuum pressure at a chosen mid-point for each round was estimated using the observed vacuum pressures and the calculated barometric efficiency. In each monitoring round, the vacuum pressure on each monitoring well was measured once. Depending on the locations and number of wells selected as monitoring wells for each test, this could take anywhere from 30 to 90 minutes. Because the barometric

pressure was changing rapidly during some periods of testing, it was necessary to estimate a vacuum pressure at a mid-point time for each round to accurately compare the responses of the monitoring wells. The vacuum pressure on each well was interpolated or extrapolated for the chosen mid-point time for each round using the methods described below.

Interpolation

Where a well was monitored within 2 hours before and after the selected mid-round time, the vacuum pressure at that time was interpolated. This was the case for measurements taken on Day One of each ROI test, with the exception of wells monitored in the first round after the mid-round time and wells monitored in the last round prior to the mid-round time. Interpolation was performed using the following equation:

$$P_{t_m} = \frac{P_{t_1} - P_{t_0}}{t_1 - t_0} \times (t_m - t_0)$$

Where:

P_{t_m} = Interpolated pressure at the selected mid-round time.

P_{t_1} = Measured pressure at the first time the well was monitored after the mid-round time.

P_{t_0} = Measured pressure at the last time the well was monitored before the mid-round time.

t_1 = The first time the well was monitored after the mid-round time.

t_0 = The last time the well was monitored before the mid-round time.

t_m = The selected mid-round time.

Extrapolation

In cases where a well was not monitored within two hours before and after the selected mid-round time, it was necessary to extrapolate the vacuum pressure at the mid-round time. This was the case for the wells monitored in the first round on the first day after the mid-round time and wells monitored in the last round on the first day prior to the mid-round time, as well as for all wells from all monitoring rounds conducted on subsequent days of each test. The barometric efficiency of -0.7 was used to do this.

First, the barometric pressure at the selected mid-point time was interpolated using the same method described in the previous section. Hourly barometric pressure is available for download from a weather station located at the Albuquerque International Sunport, which is adjacent to the Kirtland AFB. The following equations were used to extrapolate the vacuum pressure at each well:

$$\begin{aligned} 1. P_{t_m} &= P_{t_0} + (-0.7 \times [B_{t_m} - B_{t_0}]) \\ 2. P_{t_m} &= P_{t_1} - (-0.7 \times [B_{t_1} - B_{t_m}]) \end{aligned}$$

Where:

B_{t_m} = Barometric pressure at the selected mid-round time.

B_{t_1} = Measured pressure at the first time barometric pressure was recorded after the mid-round time.

B_{t_0} = Measured pressure at the last time barometric pressure was recorded after the mid-round time.

-0.7 = Barometric efficiency.

Equation 1 was used where the vacuum pressure in the given monitoring round was recorded prior to the selected mid-round time, while equation 2 was used where the vacuum pressure in the given monitoring round was recorded after the selected mid-round time.

For tests 5DTSVEW-05 and 5DTKAFB106149-450, well KAFB 106121-450 was chosen as the background monitoring well due to its distance of greater than 600 feet away from the extraction wells for those two tests; the estimated ROI for the wells was approximately 300 feet, making KAFB-106121-450 well outside the zone of influence. The vacuum pressure in KAFB 106121-450 over the duration of those tests can be assumed to be responding only to changes in barometric pressure. For test 5DTKAFB106121-450, well KAFB 106131-450 was chosen as the background monitoring well, as it was the well most distant from the extraction well for this test. KAFB 106131-450 is 380 ft from KAFB 106121-450. The difference in vacuum pressure between each 450 ft well and the selected background monitoring well was calculated at each mid-point time for each of these two tests. Basic statistical analyses were performed on the differences in vacuum pressure for each monitoring round.

For each round of monitoring, the range of differences in vacuums between the monitoring wells and the background monitoring well was calculated. The range was divided into 5 equal sections and a bar graph was created to observe the distribution. If all of the wells were responding only to barometric pressure or to barometric pressure and the affects of soil vapor extraction, a normal distribution is expected. If some of the wells were responding only to barometric pressure while others were also responding to the effects of the induced soil vapor extraction, a bi-modal distribution is expected. In order To determine which wells were responding to the affects of the induced soil vapor extraction when a bi-modal distribution was found, a count of the number of rounds and the number of days each well had a greater than average difference in vacuum pressures was made. A well was considered to be greater than average for a monitoring day if it was greater than average on more than half of the monitoring rounds that day.

3.2.8.3 Results

Test 5DTKAFB106149-484 Results

The background monitoring well chosen for test 5DTKAFB106149-484 was KAFB 106121-450, 643 ft from the extraction well. Only data from wells screened within the same interval as the extraction well were used in this analysis (Table 3-10). As the screened interval on well KAFB 106149-484 is from 354 to 484 ft bgs, this included only the 450 ft depth monitoring wells.

The distributions for each round of monitoring for test 5DTKAFB106149-484 data were found to be right-skewed (Figure 3-9). One monitoring well, KAFB 106117-450, located 29 ft from KAFB 106149-484, was greater than two standard deviations above the mean of the differences in vacuum pressures in every monitoring round. The data from this well was consistently skewing the distribution. This indicates that the induced soil vapor extraction was having a strong affect on KAFB 106117-450.

In order to determine the affect of soil vapor extraction on the remaining wells, the data from KAFB 106117-450 was removed from the data set and new bar graphs were created (Figure 3-10). A bi-modal distribution was apparent for 7 of the 11 monitoring rounds, 5 of which occurred after the first day of testing, indicating that some of the wells were responding only to barometric pressure while others were also responding to the soil vapor extraction. In order to determine which wells were responding to soil vapor extraction, a count of the number of rounds and the number of days each well had a greater than average difference in vacuum pressures was made (Table 3-11). A well was considered to be greater than average for a monitoring day if it was greater than average on more than half of the monitoring rounds that day. The average used for this count excluded the data from KAFB 106117-450.

Well KAFB 106116-450, 161 ft from the extraction well, was greater than average for 100% of the monitoring rounds and 100% of the monitoring days. KAFB 106119-450, 201 ft from the extraction well, was greater than average for 82% of the monitoring rounds and 100% of the monitoring days. KAFB 106128-450, 205 ft from the extraction well, was greater than average for 73% of the monitoring rounds and 90% of the monitoring days. KAFB 106112-450, 221 ft from the extraction well, was greater than average for 55% of the monitoring rounds and 50% of the monitoring days. SVMW-15, 227 ft from the extraction well, was above average for 91% of the monitoring rounds and 70% of the monitoring days.

After the first day, vacuum pressure was above average for five of the six remaining rounds, or three of the remaining four days, and was below average on the final day of monitoring. KAFB 106114-450, which is 317 ft from the extraction well, was above average for 45% of the monitoring rounds and 20% of the monitoring days. After the first day, vacuum pressure was above average only for the last two monitoring rounds and monitoring days. KAFB 106129-450, which is 393 ft from the extraction well, was greater than average for only 18% of the monitoring rounds and 10% of the monitoring days. KAFB 106113-450, which is 402 ft from the extraction well, and KAFB 106111-450, which is 429 ft from the extraction well, were not greater than average for any of the monitoring rounds or days.

Wells with a greater than average difference in vacuum pressure for the majority of the monitoring were most likely situated within the ROI of the extraction well. This included wells KAFB 106117-450, KAFB 106116-450, KAFB 106119-450, KAFB 106128-450, and SVMW-15. Of these, the most distant is SVMW-15 at 227 ft from the extraction well. KAFB 106112-450, which is 221 ft from the extraction well, was greater than average for approximately half of the monitoring. It was, however, greater than average for four of the six monitoring rounds that occurred after the first day, indicating that it may have been experiencing the effects of SVE. Wells SVMW-15 and KAFB 106112-450 are located at very similar distances from the extraction well, though on different radii extending from the extraction well, with SVMW-15 being only 6 ft farther away. SVMW-15 shows a definite response to SVE, while KAFB 106112-450 possibly shows a weak response, indicating that these two wells are on the edge of the ROI for SVE from KAFB 106149-484. This places the horizontal ROI at approximately 220 to 230 ft for a five-day period of extraction. KAFB 106114-450 was greater than average on the last two days of testing, which could be a result of the ROI extending over 300 ft after four days of extraction. However, additional data would be necessary before a conclusive statement could be made.

Test 5DTKAFB106121-450 Results

ROI test 5DTKAFB106121-450 used well KAFB 106131-450, which is 381 ft from the extraction well, as the background monitoring well, as it was the most distant well monitored during the test. Only the data from 450-ft-depth wells were used for analysis as this is the depth from which soil vapor is being extracted (Table 3-10).

A bi-modal distribution was observed in 11 out of the 13 rounds of monitoring for ROI test 5DTKAFB106121-450, indicating that some of the wells were responding only to changes in barometric pressure, while others were also responding to SVE (Figure 3-11). To determine which wells were responding to SVE, a count of the number of rounds and the number of days for each well had a greater than average difference in vacuum pressures was made (Table 3-12). Vacuum pressure for a well was

considered to be greater than average for a monitoring day if it was greater than average on more than half of the monitoring rounds that day.

Wells KAFB 106123-450, which is 61 ft from the extraction well, and KAFB 106122-450, which is 75 ft from the extraction well, both had greater than average differences in vacuum for 100% of the monitoring rounds and monitoring days. Well KAFB 106120-450, which is 95 ft from the extraction well, only had a greater than average difference in vacuum for 8% of the monitoring rounds and 20% of the monitoring days. Well KAFB 106113-450, which is 261 ft from the extraction well, also had a greater than average difference in vacuum pressure for 8% of the monitoring rounds, but 0% of the monitoring days. Well KAFB 106114-450, which is 362 ft from the extraction well, had a greater than average difference in vacuum pressure for 38% of the monitoring rounds, but only 30% of the monitoring days.

Only wells KAFB 106123-450 and KAFB 106122-450 showed an observable response to SVE. This indicates that the ROI for this five-day test is at least 75 ft, but is most likely less than 95 ft as well. KAFB 106120-450 showed no observable response to the SVE.

Test 5DTSVEW-01 Results

ROI test 5DTSVEW-01 used well KAFB 106121-450, which is 964 ft from the extraction well, as the background monitoring well. KAFB 106121-450 was monitored only once per day during this test. Consequently, only the first monitoring round per day was used in this analysis.

Only data for wells screened in the same portion of the vadose zone as the extraction well were used in this analysis (Table 3-10). Extraction well SVEW-05 is screened from 445 to 460 ft bgs. Three of the wells monitored were screened in this portion of the vadose zone. KAFB 106148-484 is screened from 354 to 484 ft bgs, SVEW-09 is screened from 445 to 460 ft bgs, and KAFB 106119-450 is screened from 440 to 450 ft bgs.

Due to the limited number of observation wells available for analysis of this test, a distribution graph would not render meaningful data and was therefore not created. Consequently, only counts of the number of monitoring rounds for which each well had a greater than average difference in vacuum pressure were made (Table 3-13).

Well KAFB 106148-484, which is 96 ft from the extraction well, had a greater than average difference in vacuum pressure for 20% of the monitoring rounds and days. SVEW-09, which is 183 ft from the extraction well, had a greater than average difference in vacuum pressure for 40% of the monitoring rounds and days. KAFB 106119-450, which is 203 ft from the extraction well, had a greater than average difference in vacuum pressure for 60% of the monitoring rounds and days.

No meaningful conclusions about the ROI of extraction well SVEW-05 can be made from this analysis of the data. During Second Quarter 2012, vacuum pressure will be monitored in the nine Pneulog wells and the dedicated extraction wells (KAFB-106160 and KAFB-106161) while SVE is occurring. These data will be reported and analyzed in future quarterly reports to further the understanding of the ROI of extraction wells within the BFF Spill site.

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4. VADOSE ZONE SAMPLING AND MONITORING

In the following sections, the 3D analysis of the soil and vadose zone vapor plume concentrations are evaluated by presenting the results of the 3D plume modeling in a series of two-dimensional horizontal plan view maps at different elevations and north-south and east-west cross-sections through the contaminated soil area and vadose zone vapor plume. Figure 4-1 presents the SVMW and SVEW locations.

- RockWorks 3D inverse-distance-weighting gridding algorithm of logarithms of concentrations was used for development of all vadose zone 3D plumes. A horizontal exponent of 2 and a vertical weighting exponent of 4 were used in conjunction with horizontal and vertical gridding extent ranges of 300 and 50 ft, respectively. All applicable data points are used in the gridding. For nondetected results, one-half the method detection limit concentration was used in the gridding.
- By presenting all plan-view maps on one drawing, the reader can readily see concentration changes with elevation across the vapor plume without resorting to 3D views that may be difficult to understand.
- In a similar manner, the cross-sections through the 3D plumes present the vertical distribution of vapor concentrations.
- Vapor samples are available only for the SVM/SVE wells. For clarity in presentation, the data location symbols are presented on the respective plan-view maps without labels.
- The soil data used in this evaluation are presented in the report for Second Quarter 2011 (USACE, 2011e). Vapor data used for First Quarter 2012 are presented in Tables 4-1 and 4-2.
- Sampling analytical results within 25 ft of a given cross-section line are posted on the cross-sections. Analytical data within 25 ft of the 5,300-ft elevation map or 50 ft of the other four elevation maps are posted on the plan-view maps. For this reason multiple samples may be posted on the plan-view maps for a single borehole and elevation.

4.1 Soil Sampling Results

All soil sampling activities were completed by the end of Third Quarter 2011; therefore, all results and conclusions in this section related to soil sampling results are reiterated from that quarterly report (USACE, 2011f). During installation of the various SVM and GWM wells and drilling of the boreholes, soil samples were collected from beneath the BFF Spill site area and analyzed for VOCs, SVOCs, lead,

and TPH. Soil analytical results are presented in the Third Quarter 2011 report (USACE, 2011f) and are provided in this report in Appendix E-1. Soil sampling data packages are provided in Appendix B-4.

The soil analytical data were validated for precision, accuracy, representativeness, comparability, and completeness in accordance with the BFF Spill Quality Assurance Project Plan (QAPjP) (USACE, 2011h), and appropriate data qualifiers are appended to the analytical data in the project database. The data validation results are presented in the Data Quality Evaluation Report included in Appendix B-2. Accuracy and precision for the Second and Third Quarter 2011 soil analytical results indicate that the data are of sufficient quality to achieve the BFF Spill project data quality objectives.

Based on previous experience at other NAPL sites, soil TPH concentrations are typically greater than 1,000 mg/kg in NAPL zones. The Kirtland AFB BFF Spill project 2011 data set shows only three samples with a TPH-GRO+DRO concentration greater than 1,000 mg/kg (KAFB-106078, 400 to 450 ft bgs; KAFB-106120, 400 to 450 ft bgs; and KAFB-106147, 0 to 5 ft bgs) and the vast majority of the soil sampling results are less than 100 mg/kg. Similarly, soil concentrations reported for other compounds are relatively low. For example, the highest benzene concentration is 3 mg/kg, and most of the benzene soil detections are less than 0.01 mg/kg. The low-level concentrations of TPH compounds are not typical for a NAPL site.

For 3D spatial analysis of soil analytical data, the 2011 soil boring data were combined with historical data from 2007 to 2010 into a comprehensive data set. Using RockWorks 3D interpolation methods, individual 3D TPH (GRO+DRO), benzene, EDB, ethylbenzene, lead, naphthalene, toluene, and total xylene soil contaminant volumes were created. From these 3D volumes, plan-view maps at elevations of 5,300; 5,200; 5,100; 5,000; and 4,900 ft above mean sea level (msl) (corresponding to approximate depths of 50, 150, 250, 350, and 450 ft bgs) and six cross-sections were created by cutting sections at appropriate

elevations and locations across the 3D volumes. The maps are presented in the Third Quarter 2011 report (USACE, 2011f) and are provided in Appendix J-2 of this report.

The extent of soil contamination for each of the compounds evaluated is summarized as follows:

- TPH soil maps for the five elevations and cross-sections are presented in Appendix J-2. As illustrated, the overall footprint and TPH concentrations do not change markedly from elevations of 5,300 ft down to 5,000 ft above msl (50 to 350 ft bgs). At an elevation of 4,900 ft above msl, just above the groundwater table, the area of soil concentrations between 10 and 100 mg/kg increases to cover the majority of the soil contamination area. The volume of soil contaminated at a TPH concentration greater than 10 mg/kg is 29 million cubic yards with 12.4 million cubic yards (43%) at or below an elevation of 5,000 ft above msl (350+ ft bgs). As apparent on the cross-sections, the TPH soil contamination appears to be more complex than the associated TPH vapor concentrations described in Section 4.2. Part of this may be the result of sampling locations, but the main contributing factor is that once NAPL from a surface release becomes stable, the soil contamination distribution is unlikely to change appreciably with most of the contamination fixed in place. Vapor contamination, on the other hand, can migrate under pressure gradients resulting from barometric pressure changes and remediation SVE efforts.

**Estimated Volumes of Contaminated Vadose Zone with Soil TPH
Concentrations Greater than 10 mg/kg**

Top Elev. (ft)	Bottom Elev. (ft)	Bottom Elev. (ft bgs)	Volume (cubic ft)	Volume (cubic yards)	Volume (%)	Cumulative Volume (%)
5,400	5,300	50	47,675,000	1,800,000	6.2%	6.2%
5,300	5,200	150	136,087,500	5,000,000	17.3%	23.5%
5,200	5,100	250	107,587,500	4,000,000	13.8%	37.4%
5,100	5,000	350	155,062,500	5,700,000	19.7%	57.1%
5,000	4,900	450	200,637,500	7,400,000	25.6%	82.7%
4,900	4,800	550	134,337,500	5,000,000	17.3%	100.0%
Total:			781,387,500	28,900,000		

- Benzene soil plan-view maps and cross-sections are presented in Appendix J-2. Benzene soil concentrations greater than the dilution attenuation factor (DAF) 20 SSL concentration of 0.037 mg/kg (NMED, 2009) at the 5,300- and 5,200-ft elevations are limited to two soil samples at a nominal elevation of 5,200 ft above msl (150 ft bgs). A sizable area of benzene contamination is present at the 5,100-ft elevation (250 ft bgs), but only a small area with concentrations greater than 0.037 mg/kg is present at the 5,000-ft elevation (350 ft bgs). The largest area of benzene contamination greater than 0.037 mg/kg is at the 4,900-ft elevation, near the top of the water table and, as presented in the review of historical water levels (Section 5.5.1), near the elevation of the water table 50 to 60 years ago. Note that a small area with concentrations greater than 0.1 mg/kg is present in the northern portion of the benzene-contaminated area that has no sampling location. This high-concentration area is the result of interpolation of the concentration gradients on either side of the 0.1-mg/kg area. The concentration gradients from the south, west, and north increase toward the 0.1-mg/kg area, resulting in the location of this contour. This would be similar to calculating upward slopes on three sides of a hill to determine the approximate elevation of the top of the hill without

actually measuring the top elevation. Therefore, the presence of this 0.1-mg/kg area is interpolated and not observed.

- EDB soil plan-view maps with the cross-sections are presented in Appendix J-2. Because the analytical detection limits for EDB soil analyses are overall greater than the DAF 20 SSL concentration and the vast majority of EDB results are nondetections, contour analysis is not conducted for this compound.
- Ethylbenzene soil plan-view maps with the cross-sections are presented in Appendix J-2. At the 4,900-ft elevation (450 ft bgs), there are two small areas with concentrations greater than the DAF 20 SSL concentration of 0.29 mg/kg (NMED, 2009). There are no areas with concentrations greater than 0.29 mg/kg at higher elevations (shallower depths).
- Lead soil plan-view maps with the cross-sections are presented in Appendix J-2. There are only sporadic vadose zone detections of lead greater than the DAF 20 SSL concentration of 10 mg/kg (NMED, 2009) with no apparent pattern to the detections.
- Naphthalene soil plan-view maps with the cross-sections are presented in Appendix J-2. At the 4,900-ft elevation (450 ft bgs), there are two areas with concentrations greater than the DAF 20 SSL concentration of 0.084 mg/kg (NMED, 2009). There are no areas with concentrations greater than 0.084 mg/kg at higher elevations (shallower depths). The two naphthalene areas that exceed the DAF SSL of 0.084 mg/kg are collocated with the benzene and naphthalene areas with concentrations greater than the respective DAF 20 SSLs at the 4,900-ft elevation.
- Toluene soil plan-view maps with the cross-sections are presented in Appendix J-2. Even though there are numerous detections of toluene at all elevations, no toluene sampling results exceed the DAF 20 SSL concentration of 28 mg/kg (NMED, 2009).
- Xylene soil plan-view maps with the cross-sections are presented in Appendix J-2. At the 4,900-ft elevation (450 ft bgs), two soil samples have concentrations greater than the DAF 20 SSL of 3.5 mg/kg (NMED, 2009). There are numerous other xylene detections less than 3.5 mg/kg at the 4,900-ft elevation. At the other elevations, the majority of the sampling results are nondetections and all the results are less than 3.5 mg/kg.

4.2 Vadose Zone Vapor Monitoring Results

The soil vapor monitoring/remediation system currently consists of 272 individual vapor wells (SWM and SVE wells) plus the vapor data from four operational SVE units. Most of the wells are installed in 55 SVM well clusters that contain between two to six individual wells at different depths in each cluster. Cluster well locations are shown on Figure 4-1.

Soil-vapor hydrocarbon concentration (ppmv), percent O₂, percent CO, percent CO₂, and pressure were measured at the SVE wells during First Quarter 2012 sampling using a Horiba Model MEXA 584 L

portable auto emissions analyzer. Horiba field measurements for SVE wells are presented in Table 4-1. Pressure measurements that indicate the vadose zone is subject to vacuum are reported in Table 4-1 as negative numbers. Measurements that indicate the vadose zone is subject to positive pressure are shown as positive numbers. Measurements that indicate the vadose zone is at equilibrium with ambient atmospheric pressure and have neither pressure nor vacuum (zero gauge reading) are reported as being at atmospheric pressure.

The First Quarter 2012 soil vapor samples were collected from SVE and SVM wells using pre-evacuated Bottle-Vac canisters and Tedlar™ bags sampled through sampling ports installed at the top of each individual well casing. Soil vapor samples were collected in accordance with the Vadose Zone Investigation Work Plan procedures (USACE, 2011c) and Kirtland AFB BFF Spill QAPjP requirements (USACE, 2011h). Soil vapor samples were shipped to RTI Laboratories, Inc. in Livonia, Michigan, for the following list of analytical parameters:

- VOCs – EPA Method TO-15 (EPA, 1999)
- APH – MA DEP method (MA DEP, 2008)
- Fixed gases – ASTM Method D2504 (ASTM, 2010)

Field QC samples were collected in accordance with the BFF Spill QAPjP (USACE, 2011h) and include field duplicate samples and trip blanks for VOCs.

First Quarter 2012 soil vapor analytical data were validated for precision, accuracy, representativeness, comparability, and completeness in accordance with the Kirtland AFB BFF Spill QAPjP (USACE, 2011h), and appropriate data qualifiers are appended to the analytical data in the project database. The analytical laboratory results for the First Quarter 2012 event are presented in Table 4-2. The data validation results are presented in the Data Quality Evaluation Report included in Appendix B-3.

Accuracy and precision for the First Quarter 2012 soil vapor analytical results indicate data are of sufficient quality to achieve the BFF Spill project data quality objectives.

4.3 Soil-Vapor Data Evaluation

First Quarter 2012 laboratory analytical vapor total VOC and benzene results reported for vapor wells (Figure 4-2) were used to generate 3D vapor plumes from which plan-view maps and cross-sections were generated (Figures 4-3 through 4-16). In the grid analysis, nondetected results were incorporated using one-half the method detection limit as the concentrations used to calculate total VOC concentrations. For the laboratory analytical data, the total VOC concentration was calculated by totaling the individual compound vapor concentrations plus the TPH results. The TPH conversion from units of micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) to parts per billion by volume (ppbv) formula is as follows:

$$ppbv = \mu\text{g}/\text{m}^3 \cdot \frac{0.08205 \cdot T}{MW}$$

Where:

ppbv = vapor concentration in parts per billion by volume vapor

$\mu\text{g}/\text{m}^3$ = micrograms of compound per cubic meter of air

0.08205 = Universal Gas Constant in (atm L)/(mol K)

T = vapor temperature in degrees Kelvin ($^{\circ}\text{K}$) = 273.15 + degrees Celsius

MW = molecular weight of compound

The MW of 65.15 grams per molecule (g/mol) was used for C5-C8 aliphatic hydrocarbons, 142.3 g/mol for C9-C12 aliphatic hydrocarbons, and 120.2 g/mol for C9-C10 aromatic hydrocarbons in the above equation. A temperature 293.15 $^{\circ}\text{K}$ was used for temperature.

From these two 3D plumes, plan-view maps at elevations of 5,300; 5,200; 5,100; 5,000; and 4,900 ft above msl (corresponding to approximate depths of 50, 150, 250, 350, and 450 ft bgs) were created by creating horizontal plan-view “slices” at appropriate elevations, and six vertical cross-sections were cut

through the 3D plume at the same locations used for the soil cross-sections (Figure 4-3 and 4-4).

Concentrations are posted on the plan-view maps and cross-sections using the same posting procedure used on the soil maps. Vadose zone vapor data locations are presented on Figure 4-2 because there is insufficient space on the plan-view concentration maps to clearly show well names along with the concentrations.

Figure 4-3 presents the five plan-view maps of the vapor total VOC distribution and Figure 4-4 presents the benzene plan-view maps at the selected elevations beneath the BFF Spill site. Figures 4-5 through 4-10 present six total VOC cross-sections and Figures 4-11 through 4-16 present the six benzene cross-sections through the vadose zone vapor plume. As illustrated in the 10 maps and 12 cross-sections, the vadose zone total VOC vapor concentrations can be characterized as follows:

- Total VOC vapor concentrations at the elevation of 5,300 ft above msl (approximately 50 ft bgs) are less than 1,000 ppmv except for three small areas with concentrations between 1,000 and 10,000 ppmv counter interval in the area around well location SVEW-08/09 (along the westernmost portion of the underground fuel transfer lines) and at the well clusters KAFB-106117 and KAFB-106118.
- At lower elevations, down to 5,000 ft above msl (approximately 350 ft bgs), the extent of the total VOC vapor plume remains essentially constant with minor changes in the aerial extent of the 100- to 1,000-ppmv and 1,000- to 10,000-ppmv concentration contour footprints.
- The benzene 1- and 10-ppmv vapor concentration contours follow a similar pattern in terms of location of the 10-ppmv contour and the overall plume footprint as defined by the 1-ppmv contour and is similar to the VOC footprints.
- The most dramatic change is at the elevation of 4,900 ft above msl (approximately 450 ft bgs), immediately above the groundwater table (and the elevation at which the water table was 50 to 60 years ago [Section 5.6.1]), where the extent of the overall VOC plume is somewhat larger than it is at shallower elevations; however, the areas covered by the 100- to 1,000-ppmv and 1,000- to 10,000-ppmv concentration footprints have noticeably expanded, and an area of total VOC concentrations greater than 10,000 ppmv are present in the vicinity of vapor well clusters SVMW-15/SVEW-13, KAFB-106112, KAFB-106116, KAFB-106117, KAFB-106128, and KAFB-106130.
- At the 4,900-ft elevation, the benzene 100-ppmv contour covers a larger area than the contour for total VOCs greater than 10,000 ppmv, but the overall benzene footprint covers approximately the same area as the total VOC plume at this elevation.

4.4 Selection of Vadose Zone Constituents of Concern

During the Fourth Quarter 2011, a constituent of concern (COC) screening analysis was performed on soil vapor data to distinguish which compounds were the most frequently detected within the vadose zone.

The discussion and results described in this section are reiterated from the previous quarter.

For the vapor COC screening analysis, a compound was considered to be a COC if the following criteria were met:

1. The total samples for a given parameter during the period of February 2007 and September 2011 was greater than 20, and
2. More than 10% of the analytical results were detected for a given parameter.

As presented in Tables 4-3 (Full Screening Analysis) and 4-4 (Summary of COCs), the *primary* compounds detected in soil vapor are aliphatic hydrocarbons in the C5-C8 range (frequency of detection [FOD]–98%) and diesel range aliphatic compounds (C9-C12; FOD–53%); benzene (FOD–88%), toluene (FOD–92%), xylenes (FOD–75%), cyclohexane (FOD–93%), heptane (FOD–87%) and n-hexane (C6N, FOD–89%). Detected vapor concentrations range from a few hundred up to 3 million ppbv for specific compounds, and detected TPH concentrations range from approximately 10,000 to greater than 100 million $\mu\text{g}/\text{m}^3$.

The vadose zone COCs are as follows:

Compound Name	CAS No.	Compound Name	CAS No.
1,2,4-TMB	95-63-6	Heptane	25339-56-4
1,3,5-TMB	108-67-8	Isopropanol	67-63-0
2-Butanone	78-93-3	m,p-Xylenes	136777-61-2
Acetone	67-64-1	Methylene Chloride	75-09-2
Benzene	71-43-2	n-Hexane	110-54-3
C5-C8 Aliphatic Hydrocarbons	ALI-05-08H	Propene	#N/A
C9-C10 Aromatic Hydrocarbons	ARO-09-10H	Propylene	115-07-1
C9-C12 Aliphatic Hydrocarbons	ALI-09-12H	Toluene	108-88-3
Cyclohexane	110-82-7	Xylene, o-	95-47-6
Ethylbenzene	100-41-4	Xylenes, total (in lieu of m,p,o-Xylenes)	1330-20-7

CAS Chemical Abstracts Service

4.5 Vapor Concentrations Over Time

The 2007 through First Quarter 2012 soil vapor time-series concentration graphs with four or more samples and selected compounds are presented in Appendix F-4. Historical TPH-GRO concentration results in micrograms per liter ($\mu\text{g/L}$) were converted to ppbv by multiplying the $\mu\text{g/L}$ results by 308, assuming a TPH-GRO molecular weight of 78 g/mol. TPH aromatic and aliphatic compound concentrations were converted from $\mu\text{g/m}^3$ to ppbv using the procedure described in Section 4.3.

While there are fluctuations in concentrations of selected vapor compounds, the one conclusion that can be reached from these time-series graphs is that, overall, the ongoing SVE efforts have not had a discernable effect on vadose zone vapor concentrations. Even in extraction wells SVEW-01-260 and SVEW-05-460, which have been operating the longest, there have been only marginal changes in concentrations since 2007. Benzene in SVEW-01-260 declined from 350,000 to 120,000 ppbv over four years of SVE remediation, and benzene concentrations in SVEW-05-460 declined from 394,000 to 120,000 ppbv. Also apparent in the vapor data trend chart is that the TPH-GRO results from 2007 through 2010 are not consistent with the other vapor concentrations or the 2011 TPH aliphatic C5-C8 concentrations. It would be expected that TPH-GRO concentrations would be greater than or equal to the concentrations of the individual compounds. However, it is apparent that the TPH-GRO concentrations are less than a number of the individual compounds, particularly benzene and toluene. There is no obvious explanation for this discrepancy.

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5. GROUNDWATER MONITORING

Groundwater monitoring consists of collecting quarterly liquid level groundwater elevation and LNAPL measurement data and performing quarterly groundwater sampling for field chemical parameters and offsite laboratory analysis. In the following discussions, the aquifer beneath the Kirtland AFB BFF Spill site has been classified into the following four zones for purposes of data analysis:

- **Shallow Zone.** This is the monitored zone that intersects the water table and extends 5 to 10 ft below the 2011 measured water table. If the water table continues to rise (Section 5.2), a number of these wells may become flooded (water level above the top of screen) within the next several years.
- **Intermediate Zone.** This is the aquifer zone that is monitored by wells that extend 15 to 30 ft below the 2011 measured water table elevation. As the water table rises, this zone will become deeper in the aquifer.
- **Deep Zone.** This is the aquifer zone that is monitored by wells that extends 30 to 100 ft below the 2011 measured water table elevation. As the water table rises, this zone will become deeper in the aquifer.
- **Regional Aquifer.** This is the aquifer zone where most of the water supply wells in the area are completed. Generally these wells are completed 500 ft or more below the 2009 water table elevation (typically greater than 1,000 ft bgs).

5.1 Quarterly Pre-Remedy Groundwater Monitoring

The groundwater investigation and monitoring program includes collecting quarterly groundwater elevation and LNAPL measurement data and conducting quarterly groundwater sampling at BFF Spill site monitoring wells and nearby production wells. Groundwater elevation data and LNAPL thickness measurements are presented and discussed in Section 5.2. The groundwater wells sampled during First Quarter 2012 include the following (Figure 5-1):

- Wells installed prior to 2011: KAFB-1061 through KAFB-10628; and KAFB-3411 (installed for an investigation of another adjacent site and provides a monitoring location upgradient of the FFOR). Well KAFB-10612 could not be sampled due to pump failure as discussed in Section 3.2.4.
- Wells installed during 2011: KAFB-106029 through KAFB-106107 with the exception of well KAFB-106041, which is dry.

- KAFB-3, KAFB-15, and KAFB-16: KAFB drinking water production wells.
- VA-2 – Veterans Affairs (VA) Medical Center drinking water production well.

Groundwater sampling was conducted between January 1 and March 31, 2012. All samples were collected in accordance with the Groundwater Investigation Work Plan (USACE, 2011d) and BFF Spill QAPjP (USACE, 2011h). Sampling was performed using either dedicated Bennett sampling pumps or a portable Bennett pump sampling system.

Groundwater sampling included purging one well bore volume and monitoring field parameters for stabilization of temperature, pH, and specific conductance to within an estimated 10% prior to collecting water quality measurements. Field parameters that were recorded prior to collecting groundwater samples for laboratory analysis were pH, conductivity, temperature, alkalinity, dissolved oxygen (DO), turbidity, oxidation-reduction potential (ORP), and alkalinity.

After collection of water quality measurements, the wells were purged at an approximate rate of 1.0 liter per minute. Prior to sample collection, the Kirtland AFB production wells and the VA Medical Center groundwater production well are purged by flushing the dedicated sample line and then collecting the samples. Samples are collected through non-chlorinated taps from the production wells. Groundwater samples collected during First Quarter 2012 were analyzed by Empirical Laboratories in Nashville, Tennessee, a DoD ELAP-certified laboratory, for the following list of parameters, in accordance with EPA Methods (EPA, 1996; Clesceri et al., 1998):

- VOCs – EPA SW8026B
- EDB – EPA SW8011
- SVOCs – EPA SW8270C
- TPH-GRO and DRO – EPA SW8015B
- Polycyclic aromatic hydrocarbons – EPA SW8270C low-level method (VA-2 well only)
- Lead and major cations – EPA SW6010C
- Dissolved iron and manganese – EPA SW6010C
- Anions (chloride and sulfate) – EPA 300.0

- Nitrate/nitrite as nitrogen – EPA 353.2
- Ammonia nitrogen – SM [Standard Method] 4500NHB
- Total sulfide – SM 4500 S-2CF
- Carbonate/bicarbonate alkalinity – SM 2320B

Field QC samples were collected in accordance with the BFF Spill QAPjP (USACE, 2011h) and included trip and ambient field blanks for VOCs, field duplicate and equipment rinse blank samples, and extra sample volume collected and submitted for laboratory matrix spike and matrix spike duplicate QC measurements.

Groundwater analytical data were validated for precision, accuracy, representativeness, comparability, and completeness in accordance with the BFF Spill QAPjP, and appropriate data qualifiers are appended to the analytical data in the project database. The analytical laboratory results and field parameters are presented in Table 5-1; the data validation results are presented in the Data Quality Evaluation report included in Appendix B-1. Tables 5-2 through 5-7 list the groundwater COCs based on analytical results for samples from the shallow, intermediate, and deep zones within the aquifer.

5.2 Liquid Level Data

Commencing with First Quarter 2012, liquid levels are measured on a quarterly as opposed to monthly basis in all KAFB-BFF Spill site wells (Table 5-8), including those with active SVE systems. All liquid levels are measured with a Solinst Model 122 interface probe in wells that potentially contain NAPL or a Solinst Model 101 water-level meter for wells that do not contain NAPL. All instruments are checked for proper operation and cable integrity before use and are decontaminated between mobilizations for each well.

5.2.1 Groundwater Levels

Groundwater level data are presented in Table 5-8, and groundwater level contour maps for January 2012 for the Shallow, Intermediate, and Deep Zones are presented on Figures 5-2 through 5-4. Figure 5-5 shows

comprehensive groundwater levels including all wells currently under the monitoring program for the BFF Spill project. All water levels used to generate the contour maps have been corrected for NAPL thickness using the density correction described by Mayer and Hassanizadeh (2005, Eq. 4.5).

Water level measurement data are maintained in the project database. During the QC process, water levels are compared to historical water levels for each well. If the liquid level being measured differs by more than 2 ft from the previous quarter's liquid level and is inconsistent with liquid level changes in nearby wells, the liquid level is judged to be invalid. These data are posted as such on the maps and not used in the generation of liquid level contours.

Starting in Fourth Quarter 2011, Shaw implemented an improved QC process for the monthly water level measurements. Shaw followed the process described below to ensure that the water level data meet data quality requirements. This level of QC was required because of the flat groundwater gradients and the effect that barometric pressure has on the water levels within the aquifer underneath the Kirtland AFB BFF Spill site (Section 7.3). The following procedure was utilized throughout the First Quarter 2012 monitoring event and will remain in practice for future quarterly liquid level data collection.

- Field technicians are provided with a standardized field form for water level measurements.
- Field technicians record the serial number/ID of the water level meter used to collect measurements on the field form.
- Field technicians measure water levels and field-check to verify that measurements within a given cluster are within plus or minus 0.5 ft. If not, they then re-measure each water level in the cluster. This QC evaluation is documented on the water level measurement field form.
- All field measurements are submitted to the Field Sampling Coordinator for QC, who checks to make sure the measurements are within plus or minus 0.5 ft of each other for a given cluster. If it is determined that this is not the case, the wells are flagged and measured again the following day. This QC evaluation is documented on the water level measurement field form.
- Additionally, the Field Sampling Coordinator compares the measurements against the measurements from the preceding quarter. If any measurements fail a plus or minus 1.0-ft check, they are marked

and measured again the following day. This QC evaluation is documented on the water level measurement field form.

- The field and Field Sampling Coordinator QC checks are repeated for all measurements collected, including re-measurement of wells. Once The Field Sampling Coordinator verifies that the data collected has met the QC metrics, they sign the form and submit it for entry into the database. The Field Sampling Coordinator redlines any measurements that should not be entered into the database.
- All measurements (including re-measurements) are entered into the database along with associated flags noting that the QC checks were performed. The database entry form has an internal checking routine to flag any suspected data entry mistakes.

A comprehensive historical groundwater level table is presented in Appendix E-2, and water level elevation and NAPL thickness hydrographs are presented in Appendices F-1 and F-2.

As presented in Figures 5-2 through 5-4, the northern portion of the groundwater flow direction in all three zones is approximately North 25° to 35° East, consistent with the data presented in the second, third and fourth quarterly reports for 2011 (USACE, 2011e, 2011f, 2012). This is a critical addition to the understanding of groundwater flow directions in the northern portion of the groundwater plume. Prior to installation of the new wells, it was assumed that the groundwater flow direction was approximately along a line connecting KAFB-10625 and KAFB-10626 or a direction of approximately North 20° East. This revised groundwater flow direction is also reflected in the updated compound plumes discussed in Section 5.3. Additional water level and sampling data will refine the plume flow direction over the next several quarters.

As presented on Figure 5-5, it is unclear from well cluster to well cluster what the vertical gradients are across the site between the Shallow, Intermediate, and Deep Zones. Some well pairs indicate downward gradients while other well pairs indicate upward gradients. As wells continue to be monitored, better definition of these vertical gradients may be possible; however, because of the slight differences in water level elevations between wells in a given cluster and because the difference between the water levels is within the margin of error, this may be difficult.

5.2.2 NAPL Thicknesses

As presented in Table 5-8, during the January through March 2012 reporting period, NAPL was observed in two wells in January (KAFB-106059 and KAFB-106076). Figure 5-6 shows the NAPL thicknesses measured in January to be 0.72 ft in KAFB-106059 and 0.46 ft in KAFB-106076.

5.3 Groundwater Quality Data

The analysis of groundwater quality data has been divided into organic compounds that are derived from the NAPL (fuel) plume and other compounds that relate to microbial degradation of those fuel-related compounds. This section presents a narrative discussion of the distribution of organic compounds based on the analytical data presented in Table 5-1. The water quality analysis used the following procedures:

- Field and laboratory analytical water quality data were posted on “dot” maps using a graduated color scheme with postings of well names and concentrations beside the dot. This allows for visual point pattern analysis of concentration distributions for each compound evaluated. For the color scheme, the lowest concentration break is set at the applicable regulatory value, if such a value exists.
- Shallow Zone concentration plume contour maps were prepared for compounds with sufficient detections to warrant interpolation of contours. For all contour maps, an inverse distance weighting algorithm was used for the interpolations. The specific weighting and range values used are dependent on the data and are presented as notes on the individual maps.
- Using a combination of the dot and contour maps, a preliminary qualitative evaluation of fate and transport was conducted. Quantitative fate and transport analysis will be conducted as additional wells are installed and additional degradation data are collected.

5.3.1 Organic Compound Results

The following section describes the key First Quarter 2012 analytical findings based on the results presented in Table 5-1 and the associated maps generated from these data (Figures 5-7 through 5-30).

The analytical data in Table 5-1 indicate that the vast majority of the groundwater contamination is concentrated in the Shallow Zone, but detections of some compounds are present in the Intermediate and Deep Zones as described in this section. Additional data collected during subsequent quarterly monitoring events will be used to further refine the thickness and vertical extent of the compound-specific contaminant plumes.

Compound-specific dot and plume maps were prepared for TPH-GRO (Gasoline Range Organics), TPH-DRO (Diesel Range Organics), EDB (1,2-Dibromoethane), benzene, toluene, total xylenes, 1,2,4-TMB (1,2,4-Trimethylbenzene), and naphthalene.

- **TPH-GRO.** The well concentrations and concentration contours for the Shallow and Intermediate Zones are presented on Figures 5-7 and 5-8, respectively, for this compound group. Deep Zone well concentrations are presented on Figure 5-9. Because no regulatory limit is established for TPH-GRO, the reporting limit of 150 µg/L was used for the lower concentration contour limit.
 - The highest Shallow Zone TPH-GRO concentrations are in the historical NAPL area with the highest detected concentration at 36,000 µg/L. The downgradient extent of the TPH-GRO plume is approximately 2,500 ft north of the edge of the historical NAPL area.
 - TPH-GRO concentrations in the Intermediate Zone correlate with the TPH-GRO plume in the Shallow Zone. The highest concentration in the Intermediate Zone is 9,300 µg/L in the NAPL area. The TPH-GRO plume extends approximately 2,500 ft downgradient of the NAPL area.
 - TPH-GRO was not detected at any Deep Zone wells during First Quarter 2012.
- **TPH-DRO.** The well concentrations and concentration contours for the Shallow and Intermediate Zones are presented on Figures 5-10 and 5-11, respectively, for this compound group. Deep Zone well concentrations are presented on Figure 5-12. Because no regulatory limit is available for TPH-DRO, 150 µg/L was used for the lower concentration contour limit.
 - The highest Shallow Zone TPH-DRO concentrations are in the historical NAPL area with the highest detected concentration at 160,000 µg/L. The downgradient extent of the TPH-DRO plume is approximately 2,500 ft northeast of the edge of the historical NAPL area.
 - TPH-DRO concentrations in the Intermediate Zone correlate with the TPH-DRO plume in the Shallow Zone. The highest concentration in the Intermediate Zone is 9,500 µg/L within the historical NAPL area. The intermediate TPH-GRO plume extends approximately 2,500 ft downgradient of the NAPL area.
 - TPH-DRO was not encountered above the detection limit in any Deep Zone wells.
- **EDB.** EPA SW8011 analytical method data was used in preparing the EDB concentration contours. The concentrations and concentration contours for the Shallow and Intermediate Zones are presented on Figures 5-13 and 5-14, respectively, for EDB. Deep Zone well concentrations are presented on Figure 5-15. The EPA maximum contaminant level (MCL) of 0.05 µg/L (EPA, 2009) was used for the lower concentration contour limit.
 - As presented on Figure 5-13, the highest Shallow Zone EDB concentrations are in the historical NAPL area with the highest detected concentration at 210 µg/L. The downgradient extent of the EDB plume is at least 3,000 ft north of the edge of the historical NAPL area, but the full

downgradient extent is not defined at this time. The entire EDB plume is approximately 6,300 ft long including the NAPL area.

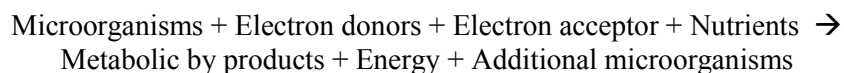
- The Intermediate Zone EDB plume correlates with the overall footprint of the Shallow Zone EDB plume. The highest concentration is 1.4 µg/L and the plume extends at least 2,500 ft downgradient of the historical NAPL area, but the full downgradient extent is not defined at this time.
 - There are two detections of EDB in the Deep Zone in the northeast flow direction. KAFB-106058 has a reported concentration of 0.56 µg/L and KAFB-106037 has a reported concentration of 0.18 µg/L (EPA Method SW8011). EDB was also detected in samples from these wells during Third and Fourth Quarter 2011 (USACE, 2011f and 2012).
 - The extent of EDB in groundwater is not currently defined to the northeast. The farthest downgradient monitoring well has a reported EDB concentration of 0.68 µg/L (KAFB-106042), which is above the regulatory MCL of 0.05 µg/L. Water supply well KAFB-3, with a screened interval at 450 to 900 ft bgs, pumping level at 550 ft bgs, and average annual pumping rate of approximately 200 gallons per minute, is located 4,200 ft downgradient in a North 50° East direction. No EDB has been detected in samples from this well. Based on the groundwater flow directions and velocities defined in Section 5.6, the current monitoring well network is not sufficient to determine the extent of EDB groundwater contamination
- **Benzene.** The concentrations and concentration contours for the Shallow Zone are presented on Figure 5-16 for this compound. Intermediate and Deep Zone well concentrations are presented on Figures 5-17 and 5-18, respectively. The EPA MCL of 5 µg/L (EPA, 2009) was used for the lower concentration contour limit.
 - In the Shallow Zone, the highest benzene concentrations are in the historical NAPL area with the highest detected concentration at 13,000 µg/L in two wells, KAFB-106079 and KAFB-1069. All but one of the benzene detections are within the extent of the historical NAPL area.
 - In the Intermediate Zone, only KAFB-106080 had a reported benzene concentration (2,700 µg/L) greater than the EPA MCL of 5 µg/L.
 - Benzene was not detected in samples from wells within the Deep Zone for this quarter.
 - **Toluene.** The concentrations and concentration contours for the Shallow Zone are presented on Figure 5-19 for this compound. Intermediate and Deep Zone well concentrations are presented on Figures 5-20 and 5-21, respectively. The NMED groundwater standard of 750 µg/L (20.6.4 NMAC) was used for the lower concentration contour limit.
 - In the Shallow Zone, the highest toluene concentrations and the majority of the toluene plume greater than the regulatory concentration are within the historical NAPL area with the highest detected concentration at 9,900 µg/L. Toluene detections above the NMED groundwater standard are reported only within the historical NAPL area.
 - In the Intermediate Zone, no toluene concentrations exceed the groundwater standard (750 µg/L), but toluene was detected in samples from seven Intermediate Zone wells at concentrations ranging from 1.8 to 710 µg/L.

- In the Deep Zone, no toluene concentrations exceed the groundwater standard (750 µg/L), but toluene was detected in samples from five Deep Zone wells at concentrations 5.1 µg/L or less.
- **Total Xylenes.** The concentrations for the Shallow, Intermediate, and Deep Zone wells are presented on Figures 5-22, 5-23, and 5-24, respectively. The NMED groundwater standard of 620 µg/L (20.6.4 NMAC) was used for the lower concentration contour limit.
 - In the Shallow Zone, xylene concentrations for seven wells exceed the NMED groundwater standard, with all total xylene exceedances within the historical NAPL area. The highest detected total xylene concentration is 4,300 µg/L.
 - In the Intermediate Zone, no xylene concentrations exceed the groundwater standard, but total xylenes were detected in samples from 11 Intermediate Zone wells at concentrations ranging from 0.9 to 350 µg/L.
 - Total xylene was detected in six wells within the Deep Zone for this quarter with concentrations ranging from 0.87 to 5.2 µg/L.
- **1,2,4-TMB.** The concentrations and concentration contours for the Shallow Zone are presented on Figure 5-25 for this compound. Intermediate and Deep Zone well concentrations are presented on Figures 5-26 and 5-27, respectively. Because no regulatory limit is available for 1,2,4-TMB, an arbitrary cutoff concentration of 35 µg/L was used for the lower concentration contour limit.
 - In the Shallow Zone, the highest 1,2,4-TMB concentrations and the total extent of the plume are within the historical NAPL area, with the highest detected concentration at 410 µg/L.
 - In the Intermediate Zone, 1,2,4-TMB was detected in samples from nine wells within the NAPL area and downgradient of the NAPL region, with the highest measured concentration at 100 µg/L.
 - 1,2,4-TMB was detected in five Deep Zone samples within, and downgradient of, the NAPL area. Concentrations range from 0.26 to 0.84 µg/L (all J-qualified results).
- **Naphthalene.** The concentrations and concentration contours for the Shallow Zone are presented on Figure 5-28 for this compound. Intermediate and Deep Zone well concentrations are presented on Figures 5-29 and 5-30, respectively. The EPA MCL of 30 µg/L (EPA, 2009) was used for the lower concentration contour limit.
 - In the Shallow Zone, all but two of the naphthalene detections are within the historical NAPL area with the highest detected concentration at 310 µg/L. Detections outside the historical NAPL area are less than the EPA MCL of 30 µg/L.
 - In the Intermediate Zone, naphthalene was detected in samples from four wells located within the NAPL area footprint and downgradient of the NAPL footprint. The highest concentration of 81 µg/L, which is greater than the EPA MCL of 30 µg/L, is within the historical NAPL region.

- Naphthalene was detected in only one sample from the Deep Zone wells for this quarter. A concentration of 0.35 µg/L (J-qualified result) was detected at KAFB-106084. This is below the EPA MCL of 30 µg/L.

5.3.2 Microbial Degradation Indicators

Fundamentally, microbial degradation occurs when bacteria metabolize organic compounds. In this process, electron donors release electrons and become more positively charged, electron acceptors receive electrons and become more negatively charged, and nutrients are consumed. Metabolism thereby increases the bacteria population according to the following general equation (Wiedermeier et al., 1999):



As a first step in determining the final remedy for the Kirtland AFB BFF fuel plume, a dot map evaluation of selected degradation indicator compounds (Table 5-9) was performed to relate various indicators to the extent of the NAPL area and dissolved plumes. For this first step, DO, ORP, ammonia, nitrate, iron (only dissolved [filtered] iron data were available, but as ferric iron is relatively insoluble in water, the majority of the dissolved iron is assumed to be ferrous iron), manganese, sulfate, sulfide, and alkalinity. For this report, dot maps of ammonia and sulfide were not prepared because these two compounds were not detected in a sufficient number of wells to allow meaningful map analysis.

- **DO.** Concentrations of this degradation indicator compound for the three aquifer zones are presented on Figures 5-31 through 5-33. Microbial degradation will result in decreased DO concentrations (Table 5-9).
 - In the Shallow Zone, DO concentrations overall are lower within and adjacent to the NAPL area and dissolved plume, indicating that microbial degradation is consuming oxygen from the groundwater. Away from the organic compound plume area, the DO concentrations are in the range of 7 to 10 milligrams per liter (mg/L), which is near the atmospheric saturation concentration at the elevation and temperature of the groundwater.
 - In the Intermediate Zone wells, DO depletion is observed in only two wells, KAFB-106065 and KAFB-106080, within the historical NAPL area, indicating a slow rate of microbial degradation consistent with the overall concentrations of most organic compounds in this zone. These two wells also had the highest Intermediate Zone benzene concentrations during this quarter and Third Quarter 2011. In addition, these wells also have the highest TPH-GRO, TPH-DRO,

- toluene, total xylene, TMB, and naphthalene concentrations in the Intermediate Zone for this quarter.
- In Deep Zone wells, DO depletion was not observed in any wells based on the First Quarter 2012 analytical results.
- **ORP.** Measurements of this degradation indicator compound for the three aquifer zones are presented on Figures 5-34 through 5-36. Microbial degradation will result in decreased ORP values (Table 5-9).
 - As with DO, the ORP concentrations in the Shallow Zone overall are lower within and immediately downgradient of the NAPL area, with most values within the plume ranging from slightly less than zero to -290 millivolts. Further downgradient within the plume area, the ORP becomes strongly positive with values greater than 100 millivolts. In comparing the ORP results with the various plume maps, it appears that microbial degradation is occurring within the Shallow Zone within the majority of the TPH-GRO plume area with the exception of the far downgradient area in the vicinity of well KAFB-106091.
 - In the Intermediate Zone wells, ORP less than 0 was observed in only four wells within or adjacent to the historical NAPL area, indicating a slow rate of microbial degradation consistent with the overall concentrations of most organic compounds in this zone.
 - In Deep Zone wells, ORP less than 0 was not observed in any wells during First Quarter 2012.
 - **Alkalinity.** Concentrations of this degradation indicator compound are presented on Figures 5-37 through 5-39. Microbial degradation can result in increased alkalinity concentrations. This is a result of elevated CO₂ concentrations, which result in the lowering of the pH, thereby causing an increased rate of mineral dissolution (Table 5-9).
 - The point pattern analysis indicates that alkalinity is elevated within and adjacent to the Shallow Zone NAPL area. Alkalinity concentrations farther away from the historical NAPL area are consistently lower than concentrations within the NAPL area.
 - In the Intermediate Zone wells, alkalinity is elevated in only one well within the NAPL area. Well KAFB-106080 shows an alkalinity concentration of 248 mg/L. This well also is among those with the highest TPH-GRO, TPH-DRO, benzene, toluene, total xylene, TMB, and naphthalene concentrations in the Intermediate Zone for this quarter and the previous quarter.
 - In Deep Zone wells, alkalinity concentrations are not elevated and show no pattern in relation to the NAPL area and individual plume constituents.
 - **Iron.** Concentrations of this degradation indicator compound are presented on Figures 5-40 through 5-42. Microbial degradation can result in increased iron concentrations as mineral dissolution reactions occur (Table 5-9).
 - In the Shallow Zone, iron is distinctly elevated in the NAPL area and the area of the dissolved plume immediately downgradient of the NAPL area. Because microbial degradation causes

increased iron groundwater concentrations, elevated iron concentrations indicate the presence of active microbial degradation of organic compounds.

- In the Intermediate Zone, iron was detected in samples from two wells, KAFB-106065 and KAFB-106080, both of which are inside the historical NAPL area and have had elevated benzene detections during the Third and Fourth Quarter 2011 events. In addition, KAFB-106080 also has the highest TPH-GRO, TPH-DRO, toluene, total xylene, TMB, and naphthalene concentrations in the Intermediate Zone for this quarter.
 - In the Deep Zone, iron concentrations are not elevated and show no pattern in relation to the NAPL area and individual plume constituents.
- **Manganese.** Concentrations of this degradation indicator compound are presented on Figures 5-43 through 5-45. Microbial degradation can result in increased manganese concentrations (Table 5-9).
 - In the Shallow Zone, manganese, like iron, is distinctly elevated in the NAPL area and the area of the dissolved plume immediately downgradient of the NAPL area. Manganese is elevated in samples from those wells with detections of TPH-GRO. Farther downgradient of KAFB-106085, increases in manganese are less apparent. Microbial degradation causes increased manganese groundwater concentrations indicating the presence of active microbial degradation of organic compounds in these areas.
 - In the Intermediate Zone, manganese is elevated in samples from three wells (KAFB-106047, KAFB-106065, and KAFB-106080) located inside and immediately adjacent to the historical NAPL area footprint.
 - In the Deep Zone, manganese concentrations are not elevated and show no pattern in relation to the NAPL area and individual plume constituents.
- **Nitrogen (Nitrate/Nitrite).** Concentrations of this degradation indicator compound are presented on Figures 5-46 through 5-48. Microbial degradation will cause decreases in nitrate/nitrite concentrations. More data from the new monitoring wells will be required to assess the viability of this electron acceptor as a degradation indicator.
 - No obvious pattern is apparent in the Shallow, Intermediate, and Deep Zone nitrate/nitrite results. Nitrate/nitrite may not be a robust degradation indicator, as it seems that background nitrate concentrations are sufficiently low, inhibiting any pattern recognition of the analytical results.
- **Sulfate.** Concentrations of this degradation indicator compound are presented on Figures 5-49 through 5-51. Microbial degradation can cause decreases in sulfate concentrations (Table 5-9).
 - No obvious pattern is apparent in the Shallow, Intermediate, and Deep Zone sulfate results. Sulfate may not be a robust degradation indicator, as it seems that background sulfate concentrations are sufficiently low, inhibiting any pattern recognition of the analytical results.

Based on this analysis of the degradation indicator compounds and the spatial extent of the organic compounds discussed in Section 5.3.1, it appears that microbial degradation is substantially slowing the migration rate and limiting the extent of a majority of the organic compounds, including benzene, toluene, and total xylenes. Additional evaluations are required to quantify the degradation rates and impact on future plume migration.

The effect of microbial degradation on EDB migration rates and extent is much more problematic with no obvious plume pattern of degradation compounds that indicate EDB degradation. Additional compound-specific data are required to determine whether microbial degradation is having any effect on EDB.

5.3.3 Piper and Stiff Diagram Inorganic Chemistry Evaluation

The major inorganic ion Piper and Stiff diagrams are presented on Figures 5-52 through 5-63. The diagrams are grouped by well location with respect to the NAPL area and color-coded by Shallow, Intermediate, Deep, and Regional Zones of the aquifer. From the Piper diagrams (Figures 5-52 through 5-55), it is apparent that the bicarbonate + carbonate ($\text{HCO}_3^- + \text{CO}_3$) concentrations within the contaminant plume are clustered in the range from 50 to 90% while the upgradient wells and those with nondetected results have bicarbonate concentrations ranging from 40 to 80%. This is to be expected because microbial degradation can cause bicarbonate concentrations to increase as CO_2 is generated in the degradation process. This will lower the pH thereby dissolving carbonate minerals in the aquifer. This will have the overall effect of increasing the bicarbonate/sulfate ratio. In the NAPL-area and plume area wells, there is an overall increase in calcium in the Shallow Zone wells compared to the Intermediate and Deep Zone wells. The highest contaminant concentrations are in the Shallow Zone so this is presumably where the microbial degradation is most active, resulting in more CO_2 increase and carbonate mineral dissolution and an increase in calcium concentrations.

The Stiff diagrams in Figures 5-56 through 5-63 show a similar pattern with the obvious increase in bicarbonate in the NAPL-area and downgradient plume wells. Overall, the Shallow Zone NAPL-area and plume wells have higher calcium and bicarbonate concentrations (in milliequivalents per liter) than the Intermediate and Deep Zone wells. Thus the calcium/bicarbonate increases observed in the Piper diagrams are observed in the Stiff diagrams.

5.3.4 Selection of Groundwater Constituents of Concern

During First Quarter 2012, a COC screening analysis was performed on groundwater data to identify which compounds were the most frequently detected within the aquifer. For the groundwater COC screening analysis, a compound was considered to be a COC if all of the following criteria were met:

1. The total number of samples for a given parameter during the period between January 2009 and March 2012 was more than 20.
2. More than 5% of the analytical results were detected for a given parameter.
3. The maximum concentration was greater than the lowest regulatory concentration established by the NMED or EPA. The lowest regulatory screening level used for each parameter was chosen based on a comparison between the EPA MCLs (EPA, 2009), NMED Groundwater Standards (20.6.4 NMAC), and New Mexico Human Health Standards for drinking water.

As presented in Table 5-2 (Full Screening Table) and 5-3 (Summary Table), the groundwater COCs for the shallow zone are listed as follows:

Parameter	CAS Number	Parameter	CAS Number
1,2-dibromoethane (edb)	106-93-4	Naphthalene	91-20-3
1,2-dichloroethane (edc)	107-06-2	Nitrogen, Nitrate (As N)	7727-37-9
Benzene	71-43-2	Phenol	108-95-2
Bis (2-ethylhexyl) phthalate	117-81-7	Sulfate (as SO ₄)	14808-79-8
Dibenzo(a,h)anthracene	53-70-3	Tetrachloroethene	127-18-4
Ethylbenzene	100-41-4	Toluene	108-88-3
Iron	7439-89-6	Trichloroethene	79-01-6
Manganese	7439-96-5	Xylenes, total	1330-20-7
Methylene chloride	75-09-2		

As presented in Table 5-4 (Full Screening Table) and 5-5 (Summary Table), the groundwater COCs for the intermediate zone are listed as follows:

Parameter	CAS Number
1,2-dibromoethane (edb)	106-93-4
Benzene	71-43-2
Ethylbenzene	100-41-4
Iron	7439-89-6
Manganese	7439-96-5
Naphthalene	91-20-3

As presented in Table 5-6 (Full Screening Table) and 5-7 (Summary Table), the groundwater COCs for the deep zone are listed as follows:

Parameter	CAS Number
1,2-dibromoethane (edb)	106-93-4
Bis (2-ethylhexyl) phthalate	117-81-7
Manganese	7439-96-5

Additional screening will be conducted every quarter to determine which, if any, of these inorganic analytes in the COC list are related to background concentrations. Constituents determined to be related to background will be deleted from the COC list. It is also noted that during recent monitoring events, EDC has been detected above the EPA MCL of 5.0 µg/L (EPA, 2009) in samples from only a few wells. As such, EDC may not remain on the groundwater COC list.

5.4 Production Well Data

As part of the BFF pre-remedy quarterly monitoring program, groundwater samples were collected and analyzed during First Quarter 2012 at the Kirtland AFB production wells KAFB-3, KAFB-15, and KAFB-16; and the VA production well VA-2. Although the production wells are deeper and the screened interval is not consistent with the BFF groundwater monitoring wells, they are being monitored to ensure that no contamination associated with the BFF Spill has impacted the drinking water aquifer in the area associated with the BFF Spill. Results for these wells during First Quarter 2012 were nondetections for BFF COCs including VOCs, SVOCs, and TPH compounds. The analytical results are presented along with all First Quarter 2012 groundwater monitoring results in Table 5-1.

5.5 NAPL and Soil Hydraulic Property Laboratory Test Results

During Third Quarter 2011, chemical and physical properties tests were conducted on NAPL and soil samples to quantify key parameters important to future analysis and modeling of NAPL and groundwater migration and determination of the overall contaminant source strength presented by the NAPL on or below the water table. Tests were conducted for total and effective porosity; hydraulic conductivity; grain-size; total organic carbon (TOC); air/water/NAPL capillary curve tests and calculation of van Genuchten parameters; and NAPL flash point, density, viscosity, and interfacial tension. Other than the capillary curve tests that were conducted on intact cores, all soil hydraulic properties were conducted on remolded samples. The results and laboratory reports are presented in Appendix K. No additional tests were conducted during subsequent quarters.

5.5.1 Soil Test Results

As stated in the Third Quarter 2011 report (USACE, 2011f), laboratory tests were conducted on remolded soil samples from screened intervals to measure porosity, hydraulic conductivity, TOC, and grain-size distribution. Table 5-10 summarizes the aquifer characteristics based on slug testing. Because soil test results are presented in the Third Quarter 2011 report, all figures and tables are provided in Appendix K. The results listed in this section are the same as those reported for Third Quarter 2011 (USACE, 2011f):

- The mean total porosity value is 34.1% with a standard deviation of $\pm 4.85\%$. The mean effective porosity value is 27.4% with a standard deviation of $\pm 4.87\%$.
- The geometric mean permeability is 4,700 milliDarcys with a median of 8,400 milliDarcys. The geometric mean hydraulic conductivity is 4.6×10^{-3} centimeters per second (cm/sec) (13 ft/day) with a median of 8.2×10^{-3} cm/sec (23 ft/day).
- The dominant grain size is medium sand with substantial samples of coarse sand and gravel. The grain-size distribution plots are presented in Appendix K-1.
- Overall, the TOC concentrations are low with an average concentration of 230 ± 77.5 mg/kg and a median TOC of 200 mg/kg.

- Appendix K presents the air/water/NAPL capillary test results and calculated van Genuchten parameters from the capillary tests. It is noted that from a definition standpoint, the air, water, and NAPL permeability values should be the same as permeability, which is defined as a soil properties parameter independent of the fluid used in the testing. However, this is obviously not the case with these results. From experience and discussions with the PTS Laboratory Director, Mr. Michael Brady, the results are similar to what is obtained at other sites. The ASTM test procedure accounts for fluid properties but there are obvious differences in actual permeability measured.

5.5.2 NAPL Test Results

During Third Quarter 2011, physical and chemical tests were conducted on the NAPL including density, viscosity, interfacial tension, and chemical PIANO (paraffins, isoparaffins, aromatics, naphthalenes, and olefins) plus specific tests for EDB, EDC, and lead. NAPL fluid properties are presented in Appendix K. The results listed in this section are the same as those reported for Third Quarter 2011 (USACE, 2011f):

- The NAPL viscosity is actually quite low at around 1.40 centipoises. The NAPL-air and NAPL-water interfacial tension values are similar to what has been observed at other fuel NAPL sites.
- The NAPL density values of 0.77 and 0.80 grams per cubic centimeter (g/cm^3) are about midway between what would be expected for a mixture of gasoline (density approximately 0.73 g/cm^3) and diesel (density (approximately 0.88 g/cm^3). One sample has the American Petroleum Institute (API) gravity of 51.6 and flashpoint of less than 70 degrees Fahrenheit ($^{\circ}\text{F}$), which is closer to gasoline (approximately 58 API gravity) than that of diesel (approximately 30 API gravity). The second sample has an API gravity of 44.7 with a flashpoint of 94°F , which is closer to diesel.
- The PIANO results are notable from the aromatic percentages of 18 and 29% for the two samples. These results indicate that while the NAPL has been in the subsurface for a number of years, there are still substantial volumes of aromatic compounds to provide a source of dissolved contamination for a long period of time.
- The chemical and physical NAPL analyses illustrate two distinct types of NAPL. The KAFB-106076 NAPL is closer in characteristics to jet fuel with an MW of 149 g/mol and density of 0.80 g/cm^3 . Benzene in this NAPL is 0.04 weight percent. The KAFB-1066 NAPL is closer in characteristics to gasoline with an MW of 127 g/mol and a density of 0.77 g/cm^3 . Benzene in this NAPL is 0.22 weight percent.
- The chromatograms of the two samples (Appendix K) indicate a highly weathered NAPL. The web site at http://www.swhydro.arizona.edu/archive/V6_N4/feature6.pdf presents examples of unweathered gasoline, diesel, and jet fuel chromatograms.
- The overall low soil concentrations described in Section 4.1 are indicative of low soil NAPL retention capacity (Pankow and Cherry, 1996). Based on TPH soil concentrations, residual soil saturation is less than $0.01 \text{ cm}^3\text{-NAPL/cm}^3\text{-soil}$ (as calculated using API TPH to NAPL saturation calculator; API, 2004). This can be expected given the medium- to coarse-grained sand size at the site and is in the range of sandy soil properties in the API NAPL/soil database (API, 2009).

5.6 Time-Series Data Analysis

Time-series graphs are presented in Appendix F. Water level and NAPL elevation hydrographs are presented in Appendix F-1, NAPL thickness graphs in F-2, groundwater concentration graphs in F-3, and soil-vapor concentration graphs in F-4. The summary evaluations of these time-series graphs are presented in the following sections. For concentration time-series graphs, only those wells with four or more sample points are used in the evaluations.

5.6.1 Groundwater Levels

Time-series hydrographs of groundwater and NAPL elevations are presented in Appendix F-1 for 2007 through First Quarter 2012. Based on analysis of these hydrographs, groundwater levels at the site have risen between 4 and 6 ft since 2009. This can be attributed to the water conservation practices implemented by the City of Albuquerque to reduce groundwater withdrawals, starting in 2008 and 2009.

Of particular importance to the conceptual site model and remediation design is the amount of water table decline that has occurred in the aquifer over the past 60 years. KAFB-3 (northeastern corner of Figure 5-1) is screened from a depth of 448 to 900 ft bgs. The initial depth to water was 407 ft and the current depth to water is 552 ft (Appendix E-2). The historical water levels over time were from the original installation and subsequent pump repair events when the repair contractor measured the depth to water. As shown, water levels have declined approximately 140 ft (4,953-ft downward to 4,811-ft elevation) since 1949 with the majority of the water level decline (over 100 ft) since 1975.

The timing and magnitude of this observed water level decline had a profound effect on the volume of contaminated soil and vapor in the vadose zone. Assuming that surface releases of fuel occurred starting in the mid-1960s, the NAPL would have reached the water table and capillary fringe sometime over the next decade and spread out horizontally in a downgradient direction. This would place the NAPL at an elevation of approximately 400 ft bgs. As the water table declined in the 1970s through the 1990s and,

presumably, additional NAPL was released from inadvertent leaks or spills, this created what essentially is a 100-ft-thick NAPL “smear zone” extending from a nominal depth of 400 ft to the current depth of 480 to 490 ft bgs. This explains why the highest soil and vapor concentrations (and presumably most of the contaminant mass) are primarily found at depths greater than 400 ft bgs.

The other hydrologic parameter that can be determined from the KAFB-3 data is the overall magnitude of the downward hydraulic gradient between the shallow and deeper parts of the aquifer. Using the 36-ft difference between the shallow and deep parts of the aquifer and using the mid-point of the current saturated portion of the well screen of 176 ft $((548-900 \text{ ft})/2)$ as the depth interval as the vertical distance, an overall vertical (downward) gradient of $-36'/176' = -0.2 \text{ ft/ft}$ is calculated. However it is apparent from the cluster well data discussed in Section 5.2.1 that the vertical gradients within the upper 100 ft of the aquifer are less than can be quantified from standard groundwater level measurements. Therefore, the overall vertical downward gradient is not uniformly distributed between the shallow and deeper portions of the aquifer. In the KAFB-3 boring log, two geologic intervals are described as sand with streaks of clay that may represent zones of vertical head loss between the shallow and deep parts of the aquifer. Geologic logs are not available for other water supply wells in the vicinity of the BFF Spill site.

5.6.2 NAPL Thickness

Based on the analysis of NAPL thickness data over time (Appendix F-2), it is apparent that the NAPL thickness observed in wells since 2009 has markedly declined as groundwater levels have risen. While this declining trend of NAPL thickness in wells could be mistaken to indicate that NAPL is no longer an issue at the site, because of the physics of NAPL migration, the reduction of NAPL thickness in wells more likely indicates that the NAPL interval is now flooded, with most of the NAPL being submerged below the water table. This is because the buoyancy force that could make the NAPL rise along with the rising water levels is controlled by the density difference between the fuel and water that causes the LNAPL to “float” on the water table.

Based on the NAPL data available for Kirtland AFB, this density difference is approximately 0.23 g/cm³. If the resulting buoyancy force is less than the displacement pressure (the capillary pressure required for NAPL to migrate into a soil pore space displacing the water), then the NAPL cannot rise when the water table rises.

5.6.3 Groundwater Concentrations

Time-series graphs for 2007 through First Quarter 2012 for selected groundwater parameters of TPH-GRO, TPH-DRO, benzene, ethylbenzene, toluene, total xylenes, naphthalene and EDB are presented in Appendix F-3. Because the results for the majority of the wells with four or more sampling events are nondetected, installed in or near the NAPL area, or were only installed a few years ago, the time-series graphs do not show any obvious concentration increasing or decreasing trends over time. Stable concentrations do not mean the plume is not migrating. Stable concentrations indicate that the portions of the groundwater plume monitored by the existing wells have stable concentrations downgradient of the NAPL area.

5.7 Groundwater Plume Migration Analysis

Because the extent of the EDB is not known at this time, an assessment of plume migration velocities is presented to evaluate possible extent of dissolve-phase EDB downgradient of the NAPL area. This analysis used Darcy's Law (Freeze and Cherry, 1979):

$$V = \frac{Ki}{n}$$

Where:

V = groundwater velocity
K = hydraulic conductivity
i = hydraulic gradient
n = porosity

The parameters in this analysis were derived from the aquifer slug tests and laboratory hydraulic parameter tests presented in Section 3. The parameters, values, and results are summarized as follows:

Parameter	Units	Average Value ^a	Standard Deviation	Minimum Value ^b	Maximum Value ^b
Hydraulic conductivity	ft/day	70	NM	40	129
Effective Porosity	Fraction	0.274	0.049	0.22	0.32
Gradient	Fraction	0.001	±0.0006	0.0004	0.0016
Fraction Organic Carbon	mg/kg	230	78	<100	380
Groundwater Velocity	ft/day	0.26	NM	0.05	0.94
Groundwater Velocity	ft/yr	95	NM	18	340
50-year downgradient migration distance	ft	4,750	NM	900	17,000

^aGeometric mean used for hydraulic conductivity.

^bMean ±1 standard deviation used for minimum and maximum for gradient and porosity values.

NM Not meaningful.

Minimum porosity value used to calculate maximum velocity and maximum porosity used to calculate minimum velocity.

This is a simplistic analysis of potential plume migration velocities and distances and it is unlikely EDB has migrated at distances close to the maximum distance calculated. However, these calculations do place the current plume extent within a frame of reference.

The farthest downgradient EDB-contaminated well is the KAFB-106055 well cluster. The Shallow, Intermediate, and Deep wells have reported EDB concentrations between 2.3 and 0.21 µg/L using analytical results from EPA Method SW8011 for First Quarter 2012. This cluster is located approximately 2,500 ft downgradient of the edge of the NAPL area.

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6. INVESTIGATION-DERIVED WASTE

6.1 Well Installation Investigation-Derived Waste

During First Quarter 2012, two SVE wells were installed at the BFF Spill site to support the groundwater and vadose zone investigations. As a result of the well installations, drill cuttings and decontamination water were generated, stored, and disposed of as described in the following sections.

6.1.1 Drill Cuttings

The two SVE wells associated with the BFF Spill site were drilled using the ARCH method, and the drill cuttings containerized in plastic-lined, steel, roll-off bins, pending laboratory analysis for waste characterization and disposal. Approximately 10 to 15 cubic yards of drill cuttings are generated per 20-cubic yard roll-off container. A composite sample is collected from each roll-off container and submitted for analysis to the subcontractor laboratory in accordance with the Kirtland AFB Construction and Demolition (C&D) Landfill Acceptance Memorandum dated January 2009 (USAF, 2009c). A request for disposal letter is provided to Kirtland AFB for disposal approval for each container, and approved roll-off bins are transported to the C&D landfill by a subcontractor. Analytical results for the BFF Spill project drill cuttings generated during First Quarter 2012 confirmed that the drill cuttings are not considered to be RCRA hazardous waste and meet the requirements for disposal at the C&D landfill (Appendix C-1).

During First Quarter 2012, soil cuttings from the DPT borehole advancement and sampling at the FFOR from June 2 to August 17, 2011, were also tested for disposal. The total TPH concentration for this sample was 129.2 mg/kg. As a result, this material did not meet the requirements for disposal in the C&D landfill based on the C&D landfill acceptance criteria (USAF, 2009c) and was disposed of offsite.

Table 6-1 details the sampling and disposal of the contents of each roll-off container generated during First Quarter 2012.

6.1.2 Decontamination and Development Water

Drill rig and associated equipment used in SVE well installations are decontaminated using hot, pressurized water. Decontamination water is collected and stored in 250-gallon totes. If these wells are developed, the decontamination water is combined with the well development water and stored in 1,500-gallon tanks. Wastewater is stored at the BFF Spill site pending analytical results for disposal in accordance with the *Kirtland AFB Bulk Fuels Development and Sampling Purge Water Decision Tree – 2/14/2011* (NMED, 2011). Once approval for discharge is obtained from NMED-GWQB and Kirtland AFB, the wastewater is discharged from the storage container to an approved location on the BFF Spill site, away from any water course. Table 6-2 details the sampling and disposal of each wastewater container.

6.2 Groundwater Sampling Investigation-Derived Waste

Quarterly groundwater sampling at the Kirtland AFB BFF Spill site monitoring wells generated IDW purge water. Purge water was stored at each monitoring well location or at the BFF Spill site pending analytical results and subsequent disposal determination in accordance with the *Kirtland AFB Bulk Fuels Development and Sampling Purge Water Decision Tree – 2/14/2011* (NMED, 2011). Purge water was stored in labeled, 55-gallon, polyethylene, open-top drums with sealable lids. For monitoring wells located on Kirtland AFB, the purge water drums were labeled, closed and sealed, and stored proximate to the well location or transported and stored at the BFF Spill site depending on well-site conditions. Purge water generated from sampling of monitoring wells located on property outside of Kirtland AFB was contained in drums, labeled, sealed, transported back to Kirtland AFB, and stored at the BFF Spill site, pending groundwater sampling analyses and IDW disposal determination. Exceptions to these procedures were for monitoring wells that historically, or presently, exhibit the presence of LNAPL on the groundwater. For these wells, purge water was stored at the well in 55-gallon, polyethylene, sealable, open-top, U.S. Department of Transportation (DOT) shipping drums and then manifested as hazardous waste for benzene, not otherwise specified, and removed from the site by a subcontracted waste

management firm for offsite disposal. Table 6-3 details the monitoring well, volume of purge water generated during the First Quarter 2012 sampling event, and storage location of purge water.

During First Quarter 2012, purge water for 13 wells was disposed of offsite as hazardous waste (KAFB-1065, KAFB-1066, KAFB-1068, KAFB-1069, KAFB-10610, KAFB-10614, KAFB-10628, KAFB-106059, KAFB-106065, KAFB-106076, KAFB-106079, KAFB-106080, and KAFB-106094). For all other monitoring wells, purge water was stored pending analytical results to determine final disposition, which will occur during Second Quarter 2012.

6.3 SVE Internal Combustion Engine Investigation-Derived Waste

The four SVE ICE systems were not in operation during First Quarter 2012. No IDW was generated from the SVE ICE systems for the duration of the Pneulog testing.

When SVE ICE systems are operating, the IDW generated can include nonregulated or recyclable materials associated with routine, scheduled engine maintenance including used air filters, used oil filters, spark plugs, motor oil, and anti-freeze. Additionally, during periods of cold temperatures, the ICE systems generate condensate from the extracted soil vapor, which is captured in integrated knock-out system drums and manifested as hazardous waste. Soil-vapor condensate generated by the SVE ICE systems is disposed of offsite as hazardous waste (Appendix C-2). All drums of condensate are manifested as hazardous waste for flammable liquids, not otherwise specified, and contain benzene and water.

During operations, scheduled maintenance of the SVE ICE systems occurs biweekly and consists of oil and filter changes at a minimum and additional maintenance tasks performed at monthly, quarterly, semiannual, and annual intervals. Waste oil and waste anti-freeze are stored in 55-gallon, DOT, closed-top, steel drums at the ST-106 SVE ICE location. Once full, the drums are picked up for recycling by a

vendor providing the service to Kirtland AFB. Drums stored onsite from previous quarters were picked up during First Quarter 2012.

7. CONCEPTUAL SITE MODEL

7.1 Regional Geology

The geology at Kirtland AFB ranges from mountainous in the eastern extent of the installation to the Albuquerque Basin in the western portion of the installation. The area lies within the Rio Grande Rift, a major tectonic zone that represents the continental extension during the Cenozoic. The tilted fault-block mountains in the eastern portion of Kirtland AFB are composed of Precambrian metamorphic and crystalline bedrock and Paleozoic sedimentary rock. The Kirtland AFB BFF Spill site is located in the western portion of the installation, within the Albuquerque Basin. The dominant lithology of the Albuquerque Basin includes unconsolidated and semiconsolidated sedimentary deposits.

The Albuquerque Basin contains the through-flowing Rio Grande. Basin-wide, the sedimentary deposits are primarily interbedded gravel, sand, silt, and clay. Well graded and poorly graded gravel and sand are heterogeneous in vertical and lateral extent throughout the basin. In addition, silt and clay layers are of variable thickness and laterally discontinuous. The thickness of the basin fill deposits is variable throughout the basin due to normal faulting, but is thicker than 3,000 ft in most of the basin (Kelley, 1977).

The geologic materials of interest for the Kirtland AFB BFF Spill site are the upper portion of the Santa Fe Group and the piedmont slope deposits. The Santa Fe Group consists of beds of unconsolidated to loosely consolidated sediments and interbedded volcanoclastic and mafic rocks. The sedimentary materials within the Santa Fe Group range from boulders to clays and from well sorted stream channel deposits to poorly sorted slope-wash deposits. Silty alluvial fan sediments were deposited unconformably over the Santa Fe Group and extend westward from the base of the Sandia and Manzano mountains. Within the alluvial deposits, materials range from poorly sorted mud flow material to well sorted stream

gravel. Beds consist of channel fill and interchannel deposits. The fan thicknesses range from 0 to 200 ft and thicken towards the mountains.

7.2 Site-Specific Geology

The NMED cross section transects, A-A', B-B', C-C', D-D', and E-E', are shown on Figure 7-1. The cross-sections show that the lithology consists of silty younger deposits (Unit A) overlaying the Santa Fe Group (Unit B); a system of unconsolidated Tertiary-aged fluvial deposits (ancestral Rio Grande lithofacies) and alluvial deposits from the Middle Rio Grande Basin (Figures 7-2 through 7-6). Unit A is approximately the top 100 to 150 ft bgs, which consists primarily of silt and silty sand with interbedded clay and poorly graded sand layers. Generally, this silty unit thickens eastward with the silt and clay layers varying from a few feet to 170 ft bgs in thickness as seen in KAFB-106135 (Figure 7-4). Sand deposits within this unit consist of silty, well graded, and poorly graded sand intervals that range in thickness from 0 to 60 ft.

Underlying the silty slope deposits of Unit A is the upper portion of the Santa Fe Group (Unit B). This loose, unconsolidated depositional unit is observed in the subsurface geology at the BFF Spill site and is highly porous and permeable. As presented in the cross-sections, the upper portion of the Santa Fe Group is present at depths greater than 100 to 150 ft bgs and primarily consists of interbedded sand and gravel layers. The sand is generally poorly- to well-graded and sand layers range in thickness from 1 to 250 ft. Discontinuous gravel lenses, likely channel deposits, can be up to 50 ft in thickness within some regions, particularly to the north, and are of unknown lateral extent (Figures 7-3 and 7-4). Clay lenses are also observed heterogeneously within the Santa Fe Group, with the most notable lens shown in the A-A' cross section (Figure 7-2). This clay lens is approximately 35 ft in thickness at a depth of approximately 255 ft bgs and is documented in the lithology logs for KAFB-106081 and KAFB-106066 (Figure 7-2 and Appendix D-1).

Geologic logs for existing and newly installed monitoring wells and geophysical logging data indicate a considerable amount of variability within the two depositional units. However, based on the lithologic logs and all five cross-sections, coarser materials, including gravel lenses, appear to be more concentrated in the northern portion of the study area (Figures 7-3 and 7-4), whereas finer, silt-rich sediments appear to be more ubiquitous in the southern portion of the site, near the FFOR area (Figures 7-5 and 7-6).

Presumably, the discontinuous silt and clay layers are zones of lower permeability and possibly can locally impede downward flow of water and NAPL through the sedimentary column. Whereas, the higher permeability sandy layers provide pathways for water and NAPL to easily migrate downward within the silty upper unit. Based on the detailed lithologic logs across the BFF Spill site, there appears to be no continuous silt/clay layers that impeded the downward migration of the NAPL.

7.3 Hydrology

The regional aquifer for the majority of the Albuquerque Basin is contained in the upper and middle units of the Santa Fe Group. The groundwater system at Kirtland AFB is also referred to as the Middle Rio Grande Basin. In general, the upper unit of the Santa Fe Group contains the most productive portion of the regional aquifer that supplies water to the City of Albuquerque, the VA, and Kirtland AFB.

Depths to water in the regional aquifer vary widely across the basin and are dependent on structural influence and pumping rates/volumes at production wells. Within the eastern extent of the basin, depths to water are approximately 190 ft bgs, whereas towards the western edge of the basin, depths to water are on the order of 450 to 570 ft bgs. Non-pumping depths to water measured at the BFF Spill site range from approximately 450 (Shallow Zone) to 544 ft bgs (Regional Aquifer). As discussed in Section 5.6.1, there is approximately a 36-ft downward head difference between the Shallow Zone and Regional Aquifer. This results in a non-uniform (downward) gradient of minus 0.2 ft/ft.

Historically, groundwater flow directions in the regional aquifer and at the BFF Spill site were generally westward toward the Rio Grande River. However, due to significant production well pumping for both the City of Albuquerque and Kirtland AFB, the groundwater flow direction for the BFF Spill site is approximately North 25° to 35° East. This change in downgradient flow of the aquifer is predominately due to high pumping rates at the production wells, Ridgecrest 5 and Ridgecrest 3, with pumping rates of approximately 1,500 and 1,100 gallons per minute, respectively.

Based on analysis of historical water table elevations, water levels have declined approximately 140 ft (4,953-ft downward to 4,811-ft elevation) since 1949 with the majority of the water level decline (over 100 ft) since 1975. However, in recent years, groundwater levels at the site have risen between 4 and 6 ft since 2009 due to conservation practices implemented by the City of Albuquerque and the San Juan-Chama Diversion Project completed in December 2008.

As previously discussed in Section 5.5.1, the physical aquifer properties were quantified on remolded soil samples from screened intervals within the aquifer in order to model the NAPL and groundwater migration through time at the BFF Spill site. Based on these results, the dominate grain size of the screened intervals is medium-sized sand, with a mean porosity of 34.1% and an effective porosity of 27.4%. The mean permeability and hydraulic conductivity are approximately 4,700 milliDarcys and 4.6×10^{-3} cm/sec, respectively.

7.4 Contaminant Fate and Transport Conceptual Model Contaminant

7.4.1 Vadose Zone

Based on the 3D distribution of soil and vapor concentration data in the vadose zone discussed in Section 4, a relatively simple vadose zone NAPL and vapor migration model becomes apparent:

- Based on historical analysis of water level data for water supply well KAFB-3, in the 1940s through most of the 1970s, the groundwater table was at a depth approximately 100 ft higher than the current

2012 water table. Beginning in 2009, the water table started rising in response to water conservation practices and municipal use of surface water resources. Water table changes have had a profound impact on the distribution of and future prognosis for vadose zone contamination.

- The low TPH and benzene soil concentrations and constant contaminant footprint at elevations of 5,000 ft above msl (350 ft bgs) and above and expansion of the aerial extent and increase in concentrations at the elevation of 4,900 ft above msl (450 ft bgs) are definitive indicators that NAPL did not spread out substantially as it migrated through the vadose zone until it encountered the historical capillary fringe and water table, where it spread out in horizontal directions. If the vertical NAPL migration occurred over a widespread area or had spread out along vadose zone capillary barriers, it would be expected that higher soil and vapor concentrations would be observed at shallower elevations.
- As surface or near-surface releases of NAPL occurred at the facility, the NAPL essentially migrated vertically downward with some minor horizontal movement related to the heterogeneities in the lithologic intervals. Once the NAPL encountered the historical capillary fringe above the water table at a nominal depth of 400 ft bgs, the NAPL spread out horizontally away from the release areas. The NAPL then accumulated on the water table and started migrating in a northeasterly direction following the downgradient groundwater flow direction.
- As the water table declined as a result of regional groundwater extraction, the NAPL from the initial and subsequent releases followed the falling water table downward. Over time, this had the effect of creating a residual NAPL smear zone from nominal depths of 400 to 500 ft bgs.
- As the water table started rising in 2009, the NAPL that would flow into wells (i.e., NAPL not already at residual saturation) became trapped below the water table. The reason is that the NAPL buoyancy force resulting from a density difference of 0.2 g/cm^3 is not sufficient to overcome the entry pressures and generate the upward hydraulic gradient required for the NAPL to rise along with the rising water table.
- Because vapor can migrate in the vadose zone, the vapor concentrations define the overall volume of the vadose zone that is affected by residual NAPL contamination in the soil. To a lesser extent, the vapor concentrations do define the areas of highest vadose zone contamination.
- Based on the 3D distribution of soil and vapor concentrations, the majority of the vadose zone contaminant mass is located within 100 ft above the present-day water table at depths of 400 to 500 ft bgs.
- Based on a screening process that accounts for FOD, the following compounds are determined to be COCs: 1,2,4-TMB; 1,3,5-TMB; 2-butanone; acetone; benzene; C5-C8 aliphatic hydrocarbons; C9-C10 aromatic hydrocarbons; C9-C12 aliphatic hydrocarbons; cyclohexane; ethylbenzene; heptane; isopropanol; m,p,o-xylenes; methylene chloride; n-hexane; propene; propylene; toluene; and total xylenes (in lieu of quantifying individual m,p,o-xylene isomers).
- The ROI testing on SVE wells conducted in November and December 2011 shows that the ROI of SVE in the BFF Spill site is most likely between 220 and 300 horizontal feet. This estimate is based on the analysis of ROI test 5DTKAFB106149-484. A vertical ROI has not yet been determined.

7.4.2 Groundwater

As with the vadose zone model, the groundwater contamination conceptual site model is relatively straightforward:

- Current groundwater flow directions are toward the KAFB-3 and Ridgecrest water supply wells (Ridgecrest-5 and Ridgecrest-3) with average groundwater velocity of 95 ft/yr and a range of 18 to over 300 ft/yr to the northeast at a direction of North 25° to 35° East. Overall, vertical groundwater flow direction is down — a downward flow velocity has not been determined at this time. As previously discussed in the Fourth Quarter 2011 report (USACE, 2012), EDB and TPH-GRO plume maps confirm this plume migration direction and general velocity. The EDB plume is moving at least 50 ft/yr to the northeast simply based on plume extent.
- As previously discussed in the Fourth Quarter 2011 report (USACE, 2012), the NAPL viscosity is such that NAPL should be able to flow to groundwater wells. However, the rising water table has resulted in much of the NAPL being trapped below the water table, and remediation NAPL recovery is likely to be problematic. NAPL chemistry defines the source strength for groundwater contamination. For example, the benzene concentration in the KAFB-1066 NAPL, similar to gasoline, is 2,200,000 µg/L; the benzene concentration in KAFB-106076 NAPL, similar to jet fuel, is 400,000 µg/L. Note that while EDB was not detected in either NAPL sample, the detection limit was 1,000 µg/L.
- As illustrated in the time-series concentrations for KAFB-1065 (the contaminated well with the longest data record) and the NAPL chemical composition, the NAPL on top of and below the water table will act as a persistent source of groundwater contamination for the indefinite future. Appendix F presents time-series plots.
- Microbial degradation of organic compounds has fundamentally limited the downward gradient of the vast majority of the individual compounds in the NAPL as well as the TPH-DRO compounds. Furthermore, there is sufficient organic carbon in the aquifer (average concentration of 230 mg/kg) to retard the migration of organic compounds that will partition onto carbon. The compounds that are currently being actively degraded and/or retarded include benzene, ethylbenzene, toluene, xylene, 1,2,4-TMB, and naphthalene. Other NAPL compounds are almost certainly being degraded and retarded; more definitive analysis will be conducted and presented in future monitoring reports.
- Based on a screening process that accounts for FOD (5%) and comparison between maximum detected concentrations and NMED and EPA regulatory screening levels, the following analytes are determined to be groundwater COCs:
- Based on a screening process that accounts for frequency of detection (5%) and comparison between maximum detected concentrations and NMED and EPA regulatory screening levels, the following analytes are determined to be groundwater COCs:
 - Shallow Zone: EDB; 1,2-dichloroethane (EDC); benzene; bis (2-ethylhexyl) phthalate; dibenzo(a,h)anthracene; ethylbenzene; iron; manganese; methylene chloride; naphthalene; nitrogen (nitrate as N); phenol; sulfate (SO₄); tetrachloroethene; toluene; trichloroethene; and xylenes (total).

- Intermediate Zone: EDB; benzene; ethylbenzene; iron; manganese; and naphthalene.
 - Deep Zone: EDB; bis (2-ethylhexyl) phthalate; and manganese.
- Additional screening will be conducted over the next year to determine which, if any, of these inorganic analytes in this COC list are related to background concentrations. Those constituents determined to be related to background will be deleted from the COC list. It is also noted that during recent monitoring events, EDC has been reported in samples from only a few wells. As such, EDC may not remain on the groundwater COC list in future quarters.
 - EDB has migrated the full length of the monitoring network and was detected above the EPA MCL (0.05 µg/L) in 30 of 51 shallow wells, 11 of 27 intermediate wells, and 2 of 28 deep wells during the First Quarter 2012 event. EDB is the one compound that was detected in the Shallow, Intermediate, and Deep Zones in the farthest downgradient well cluster (GWM 10; KAFB-106055, KAFB-106057, and KAFB-106058) for the last three quarters. (Figures 7-7 through 7-11). TPH-GRO is also found in the farthest downgradient wells, but as there is no established regulatory level for TPH-GRO, it is used primarily as a surrogate indicator compound for petroleum hydrocarbon contamination.
 - The concentration patterns of both EDB and TPH-GRO indicate two release periods of NAPL containing EDB. EDB concentrations (Shallow Zone) in the immediate vicinity of the NAPL plume mostly range from 1 to 10 µg/L, with hot spots of up to 210 µg/L. Approximately 500 ft downgradient of the northern edge of the NAPL plume, the concentrations decline to less than 1 µg/L, followed by concentration increases to greater than 1 µg/L at the downgradient edge of the monitoring well network. TPH-GRO (Intermediate Zone) has a similar pattern with high concentrations in the NAPL area, a low concentration area approximately 500 ft downgradient of the northern edge of the NAPL plume, and higher concentrations in the downgradient monitoring wells.
 - The extent of EDB groundwater contamination is not defined at this time. However, a simple migration calculation can lend some understanding of potential EDB plume extent. Using an EDB organic carbon partition coefficient (K_{oc}) of 28.2 milliliters per gram (EPA, 2006), a bulk soil density (ρ_b) of 2.1 g/cm³, fraction of organic carbon (f_{oc}) of 0.00023 grams/gram, and a total porosity (n) of 34.1%, EDB retardation is calculated as follows:

$$R = 1 + \frac{\rho_b}{n} \cdot (K_{oc} \cdot f_{oc}) = 1 + \frac{2.65 \cdot (1 - n)}{n} \cdot (K_{oc} \cdot f_{oc})$$

$$R = 1 + \frac{2.65(1 - 0.341)}{0.341} \cdot (28.2 \cdot 0.00023)$$

$$R = 1.03$$

- This indicates that EDB will migrate at a velocity of $1/1.03 = 0.97$ times the groundwater flow velocity. EDB will migrate at essentially the same velocity as the groundwater (average of 95 ft/yr with a maximum of over 300 ft/yr). Assuming a 50-year NAPL on water table time of 50 years and an average groundwater velocity of 95 ft/yr, this would make the EDB plume approximately 4,500 ft long if no EDB degradation is occurring. The observed EDB plume length downgradient of the NAPL area is 2,500 ft, and it is 3,000 ft from the downgradient monitoring wells to water supply well KAFB-3. However, if the overall gradient or hydraulic conductivity is higher than the average values for the BFF Spill site, the EDB plume could be considerably longer.

7.5 Data Gaps

One outstanding data gap is data related to the EDB degradation and fate and transport mechanisms. This data gap will be addressed using microbial and compound-specific isotope analyses in 2012. In addition, during the analysis and evaluation of data collected during the Third Quarter 2011 (July – August) sampling event, it was determined that additional data is needed at the downgradient portion of the 1,2-dibromethane (EDB) dissolved phase plume. The present spatial configuration of the farthest downgradient well cluster (GWM-10) has EDB concentrations greater than the EPA MCL of 0.05 µg/L, thus the downgradient extent of the EDB plume cannot be determined with the current well network. Therefore, a letter addendum to the Groundwater Investigation Work Plan (USACE, 2011d) proposing three additional groundwater monitoring wells downgradient of the farthest extent of the EDB plume was submitted to the NMED on March 16, 2012 (Appendix I-2).

8. PROJECTED ACTIVITIES AND RECOMMENDATIONS

Anticipated activities to be conducted during Second Quarter 2012 at the BFF Spill site include, but are not limited to, ongoing groundwater and soil vapor monitoring, Pneulog well testing, and FFOR soil sampling. All the BFF SVE systems will be turned on after the completion of Pneulog testing. In addition, activities associated with the monitoring and remediation at the BFF Spill site will be ongoing, including analytical testing, data validation, data management, and reporting.

8.1 Quarterly Monitoring Activities

Quarterly groundwater and soil vapor monitoring and related field activities will be ongoing during Second Quarter 2012 as follows:

- Depth to water and LNAPL measurements will be collected for existing monitoring wells on a quarterly basis.
- Quarterly groundwater sampling activities will include collecting samples from the existing 4-inch-diameter monitoring wells and new 5-inch-diameter monitoring wells that have been installed and developed during 2011.
- Quarterly sampling of SVMWs, SVEWs, SVE ICES, and GWM wells will begin on April 2, 2012, and continue throughout the second quarter ending June 30, 2012. Dedicated Bennett pump sampling systems will be installed in new 5-inch-diameter monitoring wells as the equipment is received from the manufacturer. By the end of the second quarter (June 30, 2012), it is anticipated that all of the new Bennett sample pump systems will have been received and approximately 95% of the systems are anticipated to have been installed.
- Pump system repairs and maintenance will be performed throughout the quarter as needed and as determined based on observations during monthly water-level measurement collection and groundwater sampling activities.
- Additional quarters of groundwater data collection are recommended prior to determining whether additional groundwater monitoring wells are necessary for plume delineation and to begin evaluation for future recommendations to reduce quarterly sampling parameters.

8.2 Drilling Program

Additional well installation is not projected to occur during Second Quarter 2012; however additional well installation will begin in the Third Quarter 2012 in accordance with the most recent guidance from NMED.

8.3 FFOR Investigation

FFOR soil investigation sampling will continue in the Second Quarter 2012. The originally planned borings will be completed with the advancement of borings around the excavated area next to the pump house. The plan for borehole advancement and sampling in this area (approved by the NMED on March 1, 2012) is illustrated on Figure 3-3. During this time the five boreholes, which were previously incomplete due to refusal, will be completed by advancing through the existing concrete sleeve and collecting the samples from beneath it. Finally, 16 step-out borings determined by analytical data evaluation in accordance with the Interim Measures Work Plan (USACE, 2011a) will be advanced during Second Quarter 2012. Following completion of the step-outs in the next quarter, further analytical data evaluation will determine whether more step-outs are necessary to delineate the contaminated zone.

8.4 SVE Systems

During the Second Quarter 2012 event, the SVE systems will be turned back on in early April, after Pneulog testing, and moved to the following locations: ST-106, KAFB-106149, KAFB-106160, and KAFB-106161. Based on the results for the First Quarter 2012 vapor analysis, these four locations are considered to be more optimum positions that will result in more efficient treatment of vadose zone contamination. The SVE systems will be monitored to ensure each SVE system is functioning at its maximum potential.

Praxis Environmental Technologies, Inc. will evaluate the air flow and soil vapor concentrations in three Pneulog wells at the Kirtland AFB BFF site during Second Quarter 2012. Pneumatic well logging will

be used to measure vertical air permeability and chemical concentration profiles at Pneulog wells KAFB-106148, KAFB-106149, and KAFB-106150. Performing these measurements at a representative number of wells can provide a 3D representation of the extent of chemicals in soil at a site, as well as the soil permeability distribution. These measurements, in conjunction with traditional measurements, will yield a thorough site evaluation.

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APPENDIX A

Summary of SVE System Operation, Maintenance, Repair, and Hydrocarbon Recovery Calculations

A-1. SVE and Treatment System Maintenance and Repair Summary

A-2. SVE and Treatment System Hydrocarbon Recovery Calculations

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APPENDIX B

Data Quality Evaluation Reports and Data Packages

- B-1. Data Quality Evaluation Report – Groundwater**
- B-2. Data Quality Evaluation Reports – Soil, Second and Third Quarter 2011**
- B-3. Data Quality Evaluation Report – Soil-Vapor**
- B-4. Groundwater, Soil, and Soil Vapor Data Packages**

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APPENDIX C

Waste Disposal Documentation

C-1. IDW Soil Disposal

C-2. Offsite Waste Disposal Manifest

C-3. Waste Disposal Analytical Data

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APPENDIX D

Well Installation Forms

D-1. Well Borehole Logs, Completion Diagrams, and Development Records

D-2. Shallow Soil Boring Logs

D-3. FFOR Shallow Soil Boring Logs

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APPENDIX E

Historical Data Summaries

E-1. Groundwater, Soil, and Soil-Vapor Historical Data

E-2. Groundwater and NAPL Depths and Elevations Historical Data

E-3. Report Tables in Excel Format

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APPENDIX F

Time-Series Plots

F-1. Water-Level Hydrographs

F-2. NAPL Thickness Time-Series Graphs

F-3. Groundwater Time-Series Graphs

F-4. Soil-Vapor Time-Series Graphs

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APPENDIX G

Field Sampling Data and Records

- G-1. Groundwater Purge Logs**
- G-2. Groundwater Sample Collection Logs**
- G-3. Soil-Vapor Purge Logs**
- G-4. Soil-Vapor Sample Collection Logs**
- G-5. Survey Plates**
- G.6. Water Level Measurement Field Forms**

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APPENDIX H

Slug Test Results

H-1. Slug Testing

H-2. Field Verification of Test Procedures

H-3. Individual Slug Test Analyses Sheets

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APPENDIX I

Correspondence

- I-1. Field Work Variances**
- I-2. Letter Addenda**
- I-3. Response to Comments Tables**
- I-4. NMED Correspondence Letters**

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APPENDIX J

Additional Cross-Sections

J-1. NMED Transects – Third and Fourth Quarters 2011

J-2. Soil Cross-Sections – Third Quarter 2011

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APPENDIX K

NAPL and Soil Hydraulic Property Laboratory Reports

K-1. PTS Laboratory Soil and NAPL Test Results

K-2. Core Laboratories NAPL Test Results

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APPENDIX L

Radius of Influence Test Report

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APPENDIX M

Geophysical Records

M-1. Geophysical Calibration Data

M-2. Geophysical Logging QC Forms

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