

KIRTLAND AIR FORCE BASE ALBUQUERQUE, NEW MEXICO

Quarterly Pre-Remedy Monitoring and Site Investigation Report for October – December 2011

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

April 2012



**377 MSG/CEANR
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**KIRTLAND AIR FORCE BASE
ALBUQUERQUE, NEW MEXICO**

**QUARTERLY PRE-REMEDY MONITORING AND
SITE INVESTIGATION REPORT
OCTOBER – DECEMBER 2011**

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

April 2012

Prepared for

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

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Delivery Order 0002

Prepared by

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PREFACE

This Quarterly Pre-Remedy Monitoring and Site Investigation Report for October – December 2011 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 Air Force, dated April 2, June 4, August 6, and December 10, 2010.

This work was performed under the authority of the USACE Contract No. W912DY-10-D-0014, Delivery Order 0002. All work was conducted from October through December 2011. 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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Project Manager

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ACRONYMS AND ABBREVIATIONS

°F	degrees Fahrenheit
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
Chugach	Chugach Management Services
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
GWM	groundwater monitoring
GWQB	Ground Water Quality Bureau (NMED)

ACRONYMS AND ABBREVIATIONS (continued)

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
°K	degrees Kelvin
KAFB	Kirtland AFB
LAS	Log ASCII Standard
LNAPL	light non-aqueous phase liquid
µg/L	microgram per liter
µg/m ³	microgram per cubic meter
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
QA	quality assurance
QAPjP	Quality Assurance Project Plan
QC	quality control

ACRONYMS AND ABBREVIATIONS (concluded)

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

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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 from 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, 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 planned PneuLog testing for the First 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).
- 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.

Groundwater and NAPL

- Historical water level data from well KAFB-3 show that the groundwater table has declined 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.
- Rising groundwater levels continue to result in decreases in NAPL thickness and observations in monitoring wells. During the Third and Fourth Quarters 2011, NAPL was consistently observed only in 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 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 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.

- 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

^a Geometric mean used for hydraulic conductivity.

^b Mean ±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.

- Groundwater analytical data for new monitoring wells indicate that organic compounds are present in some Intermediate and Deep Zone wells.
- 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.
- 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) in samples from 28 of 51 shallow wells, 11 of 27 of intermediate wells, and 2 of 28 deep wells during the Fourth Quarter 2011 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) during Third and Fourth Quarters 2011.
- The concentration patterns of both EDB and TPH-GRO indicate two release periods of NAPL containing EDB.
- 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.

- Based on a screening process that accounts for frequency of detection and comparison between maximum detected concentrations and NMED and EPA regulatory screening levels, the following analytes are determined to be groundwater COCs: EDB; 1,2-dichloroethane (EDC); benzene; toluene; ethylbenzene; arsenic; manganese; mercury; nitrogen (nitrate plus nitrite); and selenium.
- 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, EDC has been observed above EPA MCL of 5.0 µg/L in samples from 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, 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), 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 to 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). 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 October through December 2011. 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):

- 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 Fourth Quarter 2011 report for October through December 2011, 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 Results
- 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 October through December 2011. 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 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 SVE units installed on the groundwater monitoring wells were directly connected to the wellheads (KAFB-1065, KAFB-1066, and KAFB-1068).

During Fourth Quarter 2011, all units were shut down on October 4 through December 31, 2011, for the preparation of the ROI tests. RSI Units 335-E1 and E2 were used for the ROI testing and were disconnected from well KAFB-1065 and moved to the SVM wells KAFB-106121, KAFB-106149, and KAFB-106117. Table 2-1 shows that all four SVE units were not active after October 4 through the end of December 2011.

Because SVE systems were not operational during the Fourth Quarter 2011 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). Each quarter, a summary of the major maintenance activities, non-routine maintenance or repair activities, and system downtime during the reporting period is presented in Appendix A1.

2.1.2 Vapor Monitoring and Sampling

Vapor samples from SVE system inlet and exhaust ports were collected on October 3 and October 4, 2011, and analyzed using the field Horiba Mexa 554J emissions analyzer for petroleum hydrocarbon concentration in parts per million by volume (ppmv) and for percent oxygen (O₂), carbon monoxide (CO), and carbon dioxide (CO₂) (Table 2-2). Monthly vapor samples and field measurements were not collected during the months of November and December 2011 because the units were inactive due to the ROI testing.

Influent and effluent vapor samples were collected from the SVE units (combined influent soil vapor, pre-catalytic converter, and post-catalytic converter exhaust streams) into pre-evacuated Bottle-Vac canisters and Tedlar™ bags and shipped under chain of custody to RTI Laboratories, Inc., a U.S. Department of Defense (DoD) Environmental Laboratory Accreditation Program (ELAP)-certified laboratory, in Livonia, Michigan, for the following list of analyses:

- Volatile organic compounds (VOCs) including acetone, 1,2-dibromoethane (EDB), 1,2-dichloroethane (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 International [ASTM]-D2504 (ASTM, 2010); and
- Air-phase petroleum hydrocarbons (APH) by Massachusetts Department of Environmental Protection (MA DEP) method (MA DEP, 2008).

Laboratory analytical data packages for vapor samples collected during the Fourth Quarter 2011 event 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 Fourth Quarter 2011 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.

The October 2011 SVE unit field and analytical results for the extracted influent and effluent vapor are summarized in Table 2-3. During October 2011, the highest total VOC concentrations detected in influent vapor was from Unit 345 (KAFB-1066) at 11,929 ppmv. The total VOC concentrations detected in influent vapor extracted from Unit 249 (ST-106) was 6,408 ppmv. Total VOC concentration detected in influent vapor extracted from Unit 344 (KAFB-1068) was 3,811 ppmv and influent vapor extracted from Unit 335 (KAFB-1065) increased to 3,732 ppmv during the October 2011 sampling event.

2.1.3 Calculation of Destructive Removal Efficiency

All SVE units were shut down on October 4, 2011, after the monthly vapor sampling event. Therefore, the four SVE units were not operational during the period from October through December 2011.

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 (October 2011 only), the treatment destruction removal efficiency (DRE) for each unit is calculated as follows:

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

The DRE values for October 2011 for each unit are presented in Table 2-3. During October 2011, all units had a DRE value above 96%.

2.1.4 Calculation of Hydrocarbon Remediation Attributable to Natural Attenuation through Bioventing

Because the SVE units were not operational during Fourth Quarter 2011, the calculations of hydrocarbon removal due to natural attenuation through 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 Hincee, 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_{O_2} = 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 October through December 2011. This unit was shut down in October 2011 in preparation for the ROI testing, which is required for the Vadose Zone Investigation as described in the Interim Measures Work Plan (USACE, 2011a).

The DRE values for SVE-Unit 249 are 96.3 and 99.3% for Engines E1 and E2, respectively, based on the Horiba field measurements collected during the October 2011 sampling event (Table 2-3).

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 December 2011 (Table 2-4). 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

The following sections summarize operations and remedial performance for the SS-111 SVE system consisting of three operational RSI units (335, 344, and 345). One of these SVE ICE units, Unit 335, was used in the ROI testing to create a vacuum on a test well to determine the permeability of the vadose zone for vapor.

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 on October 4, 2011, for the preparation of the ROI testing. In November and December 2011, Unit 335 was moved from well KAFB-1065 and connected to wells KAFB-106121, KAFB -106149, and KAFB-106117. Units 344 and 345 remained in the shutdown mode during Fourth Quarter 2011.

The DRE values (based on the Horiba field measurements) for three SVE units during the October 2011 sampling event (Table 2-3) are listed as follows:

- SVE Unit 335: 96.4 and 98.9% for Engines E1 and E2, respectively
- SVE Unit 345: 97.6 and 98.9 % for Engines E1 and E2, respectively
- SVE Unit 344: 96.2 and 99.7 % for Engines E1 and E2, respectively

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 December 2011 (Table 2-5). 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 Unit 345 from March 2009 through December 2011 (Table 2-6). 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 Unit 344 from March 2009 through September 2011 (Table 2-7). As presented on Figure 2-2, the recovery rate of this system has declined over the last two years and currently shows signs of declining remedial effectiveness.

2.4 Waste Generation

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.

All 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 *Kirtland AFB, Environmental Restoration Program, Investigation-Derived Waste Management Plan*, issued in 2009 (USAF, 2009b), which 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 2-4 through 2-7 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 during the October to December 2011 period; however, based on the July to September 2011 operation 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 during the October to December 2011 period; however, based on the July to September 2011 operation 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 during the October to December 2011 period; however, based on the July to September 2011 operation period, Unit 345 (KAFB-1066) is consuming 0.16 gallons of propane on average for each gallon of NAPL recovered. This is consistent with the long-term remedial performance of this system, and no adjustments will be made for the future operation.
- Unit 344 (KAFB-1068) was not in operation during the October to December 2011 period; however, based on the July to September 2011 operation 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 Fourth Quarter 2011 field activities performed at the Kirtland AFB BFF Spill site for the period of October 1 through December 31, 2011. Where appropriate, the text and data presented in this section are cumulative from First Quarter 2011 through Fourth Quarter 2011. 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 an approved letter addendum (Appendix I-2) stating requirements for the installation of the LNAPL containment well 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) and December 10, 2010 (NMED, 2010d) 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 October through December 2011 include the installation of the LNAPL containment well, surveying, ROI testing, and quarterly groundwater and soil vapor monitoring and sampling activities. No geophysical logging or slug testing was conducted during the period of October through December 2011; 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) and 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 cannot be used quantitatively. However, Jet West geophysical logs have been verified as being calibrated and can be used for both qualitative and quantitative 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 in the Third Quarter 2011 report to the NMED (USACE, 2011e) 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.

Following the completion of the final geophysical logging event at Kirtland AFB, a quantitative evaluation of the geophysical logs will be conducted and included in the future quarterly reports. In addition, the geophysical logs will also be incorporated into the site geologic model discussed in Section 7.

3.2.1.1 Geophysical Well Logging – Field Program

During the Fourth Quarter 2011 event, no geophysical logging was conducted. This section describes the field program during the previous three quarters of 2011. Table 3-1 provides 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 a daily calibration/instrument functionality check 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.

The induction tool field calibration was performed at the beginning and end of each day (Appendix M). 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 Quantitative Log Analysis

As previously discussed in the Third Quarter 2011 Report, the current logs from both Colog and 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 cannot be used in a quantitative analysis. However, the Jet West geophysical logs can be used in a quantitative log analysis, once the data has been standardized. Standardization requires the following: (1) each probe is calibrated and checked in the field using field calibrations/instrument functional checks; and (2) the resulting data are presented in standard units. 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.

The units for the induction probe are presented in ohm meters, and the neutron and natural gamma tools are presented in American Petroleum Institute (API) units. Even though the data from the different contractors are presented in the same standard units, there are differences in the actual measurement values (e.g., Well 10624), the most notable of which are from the neutron and induction probes. While the shape of the log curves (i.e., deflections at significant changes in lithology) is consistent for the probes used by each logging contractor for this well, the data as presented may not allow for a more detailed, quantitative comparison that is necessary based on the revised project goals.

The differences in measurement values can likely be attributed to one or more of the following factors:

- Error(s) in unit conversions
- Lack of proper application of field (or shop) calibration information during processing activities and related errors in data processing
- Differences in probe design and/or data acquisition methodology

Based on a thorough review of the processing sequence for the Colog data, it was ascertained that the major cause for the difference in measurement values for the induction and neutron probes is attributed to lack of calibration and procedural errors during data processing. Colog used the instrument functional check data to process the neutron probe data instead of the actual calibration data from the calibration

sleeve. Colog used the conductivity values designated on the calibration discs in the field during processing of the induction probe; however, based on recommendations from the instrument manufacturer after the Shaw inquiry, Colog decided to use the calibration values supplied in the equipment manual. In November 2011, Colog provided Shaw with reprocessed data for the neutron and induction probes.

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, 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 Fourth Quarter 2011. All 78 proposed GWM wells 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). The number and types of wells installed and surveyed are as follows:

- 22 water table wells – Shallow Zone
- 27 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 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 the 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 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

Previous quarterly reports (USACE, 2011e and 2011f) state that a minimum of one quarter of monitoring data will be collected from the closest GWM well clusters, GWM-9, GWM-10, and GWM-28, to determine whether a data gap exists due to the erroneous screen depths at Cluster 5. 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. A more in-depth discussion of

Cluster 5 is presented in Section 5.3.1, which addresses the extent of the Kirtland AFB BFF groundwater plume and the analytical detections and nondetections for wells at this cluster.

3.2.2.2 Soil Vapor Monitoring Wells

No new SVM wells were installed during Fourth Quarter 2011. 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 soil vapor monitoring wells 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). 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 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*

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). 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 and all lithologic logs and well construction data are presented at the end of Appendix D-1. 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 using 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.

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 in the well design to accommodate the documented rising water table. The Letter Addendum was 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. This well location was not surveyed during Fourth Quarter 2011; therefore, the soil boring log and completion diagram are not included in Appendix D-1. This information will be provided in the following quarterly report after the location has been surveyed by a licensed surveyor.

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 using 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 below the ground surface. 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 of 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. The containment well KAFB-106157 will be developed, pending approval of the proposed approach by the NMED.

3.2.3 Surveying

During Fourth Quarter 2011, nine Pneulog wells were surveyed in accordance with the Groundwater Investigation Work Plan (USACE, 2011d) 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 Pneulog 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 Pneulog 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 casings.

Nomenclature used for the elevation measurement points are as follows: ground or asphalt, concrete well pad, case, and PVC. At the Pneulog well locations, points were taken on the five 1-inch PVC casings for each location. These are listed as PVC plus the depth of the well (i.e., KAFB-106152-200). 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 PVC well(s) 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 survey data from all four quarters in 2011.

3.2.4 FFOR Investigation

3.2.4.1 Field Activities

The objective of the FFOR soil 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). 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.

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 of 10% to verify the accuracy of field sampling procedures. The QC samples included field duplicate, equipment rinse blank, matrix spike and matrix spike duplicate samples, and trip blank and field blank samples for VOC analysis. 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 received.

3.2.5 Slug Testing

No slug testing was performed during Fourth Quarter 2011. 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 at 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 slug 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 water for the slug testing. 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 as needed, and then reinstalled for operations. New dedicated Bennett pump sampling systems were also received from the manufacturer and installed in 20 monitoring wells during Fourth Quarter 2011. Table 3-8 summarizes the Bennett pump sampling systems installed for BFF Spill site wells. The following describes the well maintenance and new pump installation activities that occurred from October through December 2011:

- October 24, October 25, and October 26, 2011 – Dedicated Bennett pump sampling systems were installed in monitoring wells KAFB-106035, KAFB-106036, KAFB-106037, KAFB-106091, KAFB-106092, KAFB-106093, KAFB-106085, KAFB-106086, and KAFB-106087.
- October 28, 2011 – Dedicated Bennett pump sampling systems were installed in monitoring wells KAFB-106038, KAFB-106039, and KAFB-106040.
- December 8 and December 9, 2011 – Dedicated Bennett pump sampling systems were removed from monitoring wells KAFB-106077, KAFB-106078, KAFB-106064, and KAFB-10610 for repairs. Repairs were made to a connection at the surface at well KAFB-3411 without having to remove the pump.
- December 12, 2011 – Dedicated Bennett pump sampling system was removed from monitoring well KAFB-10619, a suction tube was installed, and the system reinstalled. Dedicated Bennett sampling pump systems were removed from monitoring well KAFB-106069.
- December 13, 2011 – Dedicated Bennett pump sampling system was reinstalled with 30 feet of nylon tubing spliced in just above the pump on monitoring well KAFB-106076. A dedicated Bennett pump sampling system was removed from monitoring well KAFB-10622.
- December 19, 2011 – Dedicated Bennett pump sampling system was reinstalled with 30 feet of nylon tubing spliced in just above the pump on monitoring well KAFB-1069.
- December 20, 2011 – Dedicated Bennett pump sampling systems were installed in monitoring wells KAFB-106103 and KAFB-106104.
- December 21 and December 22, 2011 – Dedicated Bennett pump sampling systems were installed in monitoring wells KAFB-106088, KAFB-106089, KAFB-106090, KAFB-106052, KAFB-106053, and KAFB-106054.
- December 28, 2011 – Dedicated Bennett pump sampling system was reinstalled with 30 feet of nylon tubing spliced in just above the pump on monitoring well KAFB-106059.

No additional monitoring well maintenance activities were performed during the period from October through December 2011.

3.2.7 Quarterly Soil-Vapor Sampling Field Activities

During the Fourth Quarter 2011 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 ELAP-certified laboratory, for the following list of analyses:

- VOCs including acetone; EDB; EDC; 1,2,4-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 Fourth Quarter 2011 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 Fourth Quarter 2011 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

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, and then hourly until 1600. 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.

3.2.8.2 Data

Data from the ROI testing is provided in Appendix L. The results of the data evaluation will be presented in the quarterly report for First Quarter 2012.

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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 SVM and SVE well 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 Fourth Quarter 2011 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 the previous quarter (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 Third Quarter 2011 analytical laboratory results are presented in Appendix E-1, and 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 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 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 consisting of between two and six 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 Fourth Quarter 2011 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 Fourth Quarter 2011 soil vapor samples were collected from SVE and SVM wells using pre-evacuated Bottle-Vac canisters and TedlarTM 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.

Fourth Quarter 2011 SVE and SVM vapor analytical data were validated for precision, accuracy, representativeness, comparability, and completeness in accordance with the Kirtland AFB BFF Spill QAPjP, and appropriate data qualifiers are appended to the analytical data in the project database. The analytical laboratory results for the Fourth Quarter 2011 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 Fourth Quarter 2011 SVE vapor analytical results indicate data are of sufficient quality to achieve the BFF Spill project data quality objectives.

4.3 Soil-Vapor Data Evaluation

Fourth Quarter 2011 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. 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 two 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 cluster KAFB-106117.
- 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 5.5.1]), where the extent of the overall vapor 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

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. 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

4.5 Vapor Concentrations Over Time

The 2007 through 2011 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 monthly 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 monthly 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 Fourth Quarter 2011 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).
- 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 October 3 and December 22, 2011. 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 (75 wells) or a portable Bennett pump sampling system (32 wells). Dedicated pumps continue to be installed for sampling in all GWM wells at the BFF Spill site.

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 Fourth Quarter 2011 were analyzed by Empirical Laboratories in Nashville, Tennessee, a DoD ELAP-certified laboratory, for the following list of parameters according to 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; and
- 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 volumes 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 (Full Screening Analysis) and 5-3 (Summary of COCs) list the groundwater COCs based on analytical results for groundwater samples.

5.2 Liquid Level Data

On a monthly basis, liquid levels are measured in all KAFB-BFF Spill site wells (Table 5-4), 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. Beginning in the First Quarter 2012, liquid levels will be measured quarterly instead of monthly.

5.2.1 Groundwater Levels

Groundwater level data are presented in Table 5-4, and groundwater level contour maps for October, November, and December 2011 for the Shallow, Intermediate, and Deep Zones are presented in

Figures 5-2 through 5-11. 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 month'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 because of the effect that barometric pressure has on the water levels within the aquifer underneath the Kirtland AFB BFF Spill site (Section 7.3).

- Field technicians recorded the serial number/ID of the water level meter used to collect the measurements on the field form for water level measurements.
- Field technicians measured water levels and did a field-check to verify that measurements within a given cluster were within plus or minus 0.5 ft. If not, then they re-measured the water levels in the cluster. This QC evaluation was documented on the water level measurement field form.
- All field measurements were submitted to the Field Sampling Coordinator for QC, who checked to make sure the measurements were within plus or minus 0.5 ft of each other for a given cluster. If it was determined that this was not the case, the wells were flagged and measured again the following day. This QC evaluation was documented on the water level measurement field form.
- Additionally, the Field Sampling Coordinator compared the measurements against the measurements from the preceding month. If any measurements failed a plus or minus 1.0-ft check, they were marked and measured again the following day. This QC evaluation was documented on the water level measurement field form. Beginning in the First Quarter 2012, water levels will be measured once per quarter. The procedure described above will be followed, with the exception that the measurements will be compared against the measurements from the preceding quarter rather than month.

- The field and Field Sampling Coordinator QC checks were repeated for all measurements collected, including re-measurement of wells. Once The Field Sampling Coordinator verified that the data collected met the QC metrics, they signed the form and submitted it for entry into the database. The Field Sampling Coordinator redlined any measurements that should not be entered into the database.
- All measurements (including re-measurements) were 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 5-10, 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 and third quarterly reports for 2011 (USACE, 2011e and 2011f). 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 5-11, 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. Only nine well clusters have vertical gradients that consistently show an upward or downward gradient across all three well in a given cluster. The other 19 clusters do not show a consistent vertical gradient across all three wells in a given cluster. 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 5-4, during the October through December 2011 reporting period, NAPL was observed in seven wells during the quarter. NAPL was observed in three wells (KAFB-1065, KAFB-106059, and KAFB-106076) during all three months; once in KAFB-1069 (October) and KAFB-10628 (November) and twice in KAFB-1066 (October and November) and KAFB-1068 (October and December) (Figures 5-12 through 5-14). Observed thicknesses range from 0.01 to 1.38 ft and generally decline in thickness during the course of the reporting period.

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 Fourth Quarter 2011 analytical findings based on the results presented in Table 5-1 and the associated maps generated from these data (Figures 5-15 through 5-38).

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 5-15 and 5-16, respectively, for this compound group. Deep Zone well concentrations are presented on Figure 5-17. 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 56,000 µg/L. The downgradient extent of the TPH-GRO plume is approximately 3,200 ft north of the edge of the historical NAPL area. The extent of TPH-GRO concentrations greater than 150 µg/L in the northeastern portion of the Shallow Zone plume is not currently defined.
 - 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 13,000 µg/L in the NAPL area. The TPH-GRO plume extends approximately 2,500 ft downgradient of the NAPL area.
 - TPH-GRO was detected at one well within the Deep Zone with a concentration of 320 µg/L. There were no detections of TPH-GRO in the regional water supply wells.
- **TPH-DRO.** The well concentrations and concentration contours for the Shallow and Intermediate Zones are presented on Figures 5-18 and 5-19, respectively, for this compound group. Deep Zone well concentrations are presented on Figure 5-20. 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 99,000 µg/L. The downgradient extent of the TPH-DRO plume is approximately 2,500 ft northeast of the edge of the historical NAPL area. The extent of TPH-DRO plume is not currently defined in the northeastern portion of the Shallow Zone.
 - 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 22,000 µg/L within the historical NAPL area. The intermediate TPH-GRO plume extends approximately 2,500 ft downgradient of the NAPL area. The extent of TPH-DRO plume is not currently defined in the northeastern portion of the Intermediate Zone.

- TPH-DRO was detected in samples from three Deep Zone wells with the highest concentration of 230 µg/L (qualified with “J” as an estimated concentration) reported for well KAFB-106058. Most results for the Deep Zone are below the detection limit.
- **1,2-Dibromoethane.** EPA SW8011 analytical method data was used in preparing the EDB concentration contours. Although some results were J-qualified as a result of sample precision and calibration outliers, the data are usable for plume definition. Because of the importance of the far downgradient KAFB-106055 well cluster, both the SW8011 and SW8260 method results are posted for the wells in this cluster.

The concentrations and concentration contours for the Shallow and Intermediate Zones are presented on Figures 5-21 and 5-22, respectively, for EDB. Deep Zone well concentrations are presented on Figure 5-23. The EPA maximum contaminant level (MCL) of 0.05 µg/L (EPA, 2009) was used for the lower concentration contour limit.

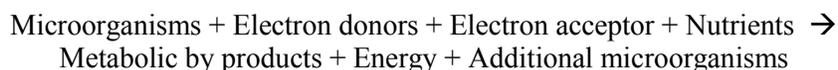
- As presented in Figure 5-21, the highest Shallow Zone EDB concentrations are in the historical NAPL area with the highest detected concentration at 190 µg/L. The downgradient extent of the EDB plume is at least 3,000 ft north of the edge of the historical NAPL area, but the full downgradient extent 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 1.1 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 0.57 µg/L and KAFB-106037 has a reported concentration of 0.24 µg/L (Method SW8011). EDB was also detected in samples from these wells during Third Quarter 2011 (USACE, 2011f).
- The extent of EDB in groundwater is not currently defined to the northeast. The furthest downgradient monitoring well has a reported EDB concentration of 0.65 µg/L, which is above the regulatory MCL of 0.05 µg/L. Water supply well KAFB-3, 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 5-24 for this compound. Intermediate and Deep Zone well concentrations are presented on Figures 5-25 and 5-26, 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 7,600 µg/L. All but four of the benzene detections are within the extent of the historical NAPL area.
- In the Intermediate Zone, the samples from KAFB-106080 and KAFB-106065 have reported benzene concentrations greater than 5 µg/L, and benzene was detected at less than 5 µg/L in samples from seven other Intermediate Zone wells.
- 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 5-27 for this compound. Intermediate and Deep Zone well concentrations are presented on Figures 5-28 and 5-29, 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 entire toluene plume greater than the regulatory concentration are within the historical NAPL area with the highest detected concentration at 14,000 µg/L. Toluene is detected only within the historical NAPL area footprint.
 - In the Intermediate Zone, no toluene concentrations exceed the groundwater standard (750 µg/L), but toluene was detected in samples from 12 Intermediate Zone wells at concentrations ranging from less than 1 to 310 µg/L.
 - In the Deep Zone, no toluene concentrations exceed the groundwater standard (750 µg/L), but toluene was detected in samples from nine Deep Zone wells at concentrations 1.7 µg/L or less.
- **Total Xylenes.** The concentrations for the Shallow, Intermediate, and Deep Zone wells are presented on Figures 5-30, 5-31, and 5-32, 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 at six wells exceed the NMED groundwater standard, with the total xylene detections within or immediately downgradient of the historical NAPL area. The highest detected total xylene concentration is 3,700 µg/L.
 - In the Intermediate Zone, no xylene concentrations exceed the groundwater standard, but total xylenes were detected in samples from six Intermediate Zone wells at concentrations ranging from 4.4 to 320 µg/L.
 - Total xylene was not detected in wells within the Deep Zone for this quarter.
- **1,2,4-Trimethylbenzene.** The concentrations and concentration contours for the Shallow Zone are presented on Figure 5-33 for this compound. Intermediate and Deep Zone well concentrations are presented on Figures 5-34 and 5-35, 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 450 µg/L.

- In the Intermediate Zone, 1,2,4-TMB was detected in samples from seven wells within the NAPL area and downgradient of the NAPL region, including one with a concentration greater than 120 µg/L.
- 1,2,4-TMB was detected in one Deep Zone sample from well KAFB-106066 with a concentration of 0.42 µg/L (J-qualified). No detections of 1,2,4-TMB were reported for samples from any of the other wells within the Deep Zone for this quarter.
- **Naphthalene.** The concentrations and concentration contours for the Shallow Zone are presented on Figure 5-36 for this compound. Intermediate and Deep Zone well concentrations are presented on Figures 5-37 and 5-38, respectively. The EPA MCL of 30 µg/L (EPA, 2009) was used for the lower concentration contour limit.
 - In the Shallow Zone, all but three of the naphthalene detections are within the historical NAPL area with the highest detected concentration at 280 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 five wells located within the NAPL area footprint and just north of the most northern edge of the NAPL footprint. The highest concentration of 94 µg/L, which is greater than the EPA MCL of 30 µg/L, is within the historical NAPL region.
 - Naphthalene was not detected in samples from wells within the Deep Zone for this quarter.

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 5-5) 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 5-39 through 5-41. Microbial degradation will result in decreased DO concentrations (Table 5-5).
 - 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 only in two wells, KAFB-106065 and KAFB-106080, within the historical NAPL area, indicating a slow rate of microbial degradation consistent with the overall low 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 Fourth Quarter 2011 analytical results.
- **ORP.** Measurements of this degradation indicator compound for the three aquifer zones are presented on Figures 5-42 through 5-44. Microbial degradation will result in decreased ORP values (Table 5-5).
 - 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 -269 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 only in three wells within or adjacent to the historical NAPL area, indicating a slow rate of microbial degradation consistent with the overall low concentrations of most organic compounds in this zone.
 - In Deep Zone wells, ORP less than 0 was not observed in any wells during Fourth Quarter 2011.

- **Alkalinity.** Concentrations of this degradation indicator compound are presented on Figures 5-45 through 5-47. Microbial degradation can result in increased alkalinity concentrations. This is a result of elevated CO₂ concentrations, which result in the lowering of the pH and thereby causing an increased rate of mineral dissolution (Table 5-5).
 - 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 a few wells within the NAPL area. Wells KAFB-106065 and KAFB-106080 show the highest alkalinity concentrations, with concentrations of 202 and 332 mg/L, respectively. These wells also have the highest TPH-GRO, TPH-DRO, benzene, toluene, total xylene, TMB, and naphthalene concentrations in the Intermediate Zone for this 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 5-48 through 5-50. Microbial degradation can result in increased iron concentrations as mineral dissolution reactions occur (Table 5-5).
 - 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 Shallow Zone NAPL area footprint and have elevated benzene detections during the Third and Fourth Quarter 2011 events. 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 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 5-51 through 5-53. Microbial degradation can result in increased manganese concentrations (Table 5-5).
 - 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 downgradient of well KAFB-106085. Farther downgradient, 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 5-54 through 5-56. 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 5-57 through 5-59. Microbial degradation can cause decreases in sulfate concentrations (Table 5-5).
 - 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 5-60 through 5-71. 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 5-60 through 5-63), it is apparent that the bicarbonate (HCO_3^-) concentrations within the contaminant plume are

clustered in the 60 to 90% bicarbonate while the upgradient and nondetect well results have bicarbonate concentrations ranging from 20 to 80%. This is to be expected because microbial degradation can cause bicarbonate concentrations to increase as CO₂ 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 CO₂ increase and carbonate mineral dissolution and an increase in calcium concentrations.

The Stiff diagrams in Figures 5-64 through 5-71 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 is observed in the Stiff diagrams.

5.3.4 Selection of Groundwater Constituents of Concern

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 2000 and September 2011 was more than 20 (Fourth Quarter 2011 data were not used in the analysis).
2. More than 10% 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 are listed as follows:

Compound Name	CAS No.
EDB	106-93-4
EDC	107-06-2
Arsenic	7440-38-2
Benzene	71-43-2
Ethylbenzene	100-41-4
Manganese	7439-96-5
Mercury	7439-97-6
Nitrogen, Nitrite	7727-37-9
Selenium	7782-49-2
Toluene	108-88-3

Additional screening will be conducted over the next year 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, EDC has been observed above EPA MCL of 5.0 µg/L (EPA, 2009) in samples from 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 Fourth Quarter 2011 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 infiltrated to the drinking water aquifer in the area associated with the BFF Spill. Results for these wells during Fourth Quarter 2011 were nondetect for BFF COCs including VOCs, SVOCs, and TPH compounds. The analytical results are presented along with all Fourth Quarter 2011 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 Fourth Quarter 2011.

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 5-6 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 of this report. The results listed in this section are the same as those reported for the previous quarter:

- 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 permeabilities 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 the previous quarter:

- 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 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. Thus, the majority of the wells installed in 2011 are not included in this analysis; however, these wells will be included in future evaluations.

5.6.1 Groundwater Levels

Time-series hydrographs of groundwater and NAPL elevations are presented in Appendix F-1 for 2007 through 2011. 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 site conceptual 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 548 ft. 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. 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 2011 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 either 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.

The one exception is well KAFB-10622 that shows definitive increases in EDB concentrations between 2009 and mid-2011. This is the only downgradient well (downgradient of the NAPL area) along the plume flow path that has sufficient sampling events over time to observe plume migration.

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 put 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 0.68 and 1.1 µg/L using results from EPA Method SW8260, and between 0.57 and 0.77 µg/L using analytical results from EPA Method SW8011. This cluster is located approximately 2,500 ft downgradient of the edge of the NAPL area.

A much more robust GIS-based numerical modeling plume migration analysis is planned for the next several months. The results of this analysis will be reported in a future quarterly report.

6. INVESTIGATION-DERIVED WASTE

6.1 Well Installation Investigation-Derived Waste

During Fourth Quarter of 2011, five Pneulog wells and one LNAPL containment well were installed at the BFF 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. The LNAPL containment well was not developed during Fourth Quarter 2011; therefore, it is not discussed in the following sections.

6.1.1 Drill Cuttings

The Pneulog wells and the containment well associated with the BFF 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 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 drill cuttings generated during Fourth Quarter 2011 confirmed that the drill cuttings are not considered to be RCRA hazardous waste and meet the requirements for disposal at the C&D landfill. Table 6-1 details the sampling and disposal of the contents of each roll-off container generated during Fourth Quarter 2011.

6.1.2 Decontamination and Development Water

Drill rig and associated equipment used in monitoring well and Pneulog well installations are decontaminated using hot, pressurized water. Decontamination water is collected and stored in 250-

gallon totes, then combined with well development water for groundwater wells and stored in 1,500-gallon tanks. Wastewater is stored at the BFF site pending analytical results for disposal in accordance with the *Kirtland AFB Bulk Fuels Development and Sampling Purge Water Decision Tree – 12/17/10* (NMED, 2010e). 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 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 – 12/17/10* (NMED, 2010e). 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 Fourth Quarter 2011 sampling event, and storage location of purge water. During Fourth Quarter 2011, 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 First Quarter 2012.

6.3 SVE Internal Combustion Engine Investigation-Derived Waste

The four SVE ICE systems were not in operation during Fourth Quarter 2011. Two of the SVE ICE systems were operated on and off to conduct ROI tests that ended on December 16, 2011. No IDW was generated from the SVE ICE systems for the duration of the ROI 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 are picked up for recycling on the vendor's route schedule. During Fourth Quarter 2011, there were no pickups of waste oil or anti-freeze because units were not in operation. Drums stored onsite from previous quarters await pickup during First Quarter 2012.

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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 of approximately 100 ft higher than the

current 2011 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 a within 100 ft bgs 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).

7.4.2 Groundwater

As with the vadose zone conceptual model, the groundwater contamination conceptual 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 Third Quarter 2011 report (USACE, 2011f), 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 Third Quarter 2011 report (USACE, 2011f), 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.
- 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 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 and comparison between maximum detected concentrations and NMED and EPA regulatory screening levels, the following analytes are determined to be groundwater COCs: EDB; EDC; benzene; toluene; ethylbenzene; arsenic; manganese; mercury; nitrogen (nitrate plus nitrite); and selenium. 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 in recent samples 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 28 of 51 shallow wells, 11 of 27 of intermediate wells, and 2 of 28 deep wells during the Fourth Quarter 2011. 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) during the Third and Fourth Quarters 2011. 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 (Figures 7-7 through 7-11).

- The concentration patterns of both EDB and TPH-GRO indicate two release periods of NAPL containing EDB. EDB concentrations in the immediate downgradient vicinity of the NAPL plume are approximately 1 µg/L. Approximately 1,000 ft farther downgradient, 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 has a similar pattern with high concentrations in the NAPL area, with a low concentration area approximately 1,000 ft downgradient 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 means 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 from 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. Another data gap previously discussed is the full characterization of the EDB 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. A letter addendum proposing additional monitoring wells downgradient of

the farthest extent of the EDB plume was submitted to the NMED on February 2, 2012 (Appendix I-2).

This proposal will help fully characterize and delineate the extent of the EDB plume.

8. PROJECTED ACTIVITIES AND RECOMMENDATIONS

Anticipated activities to be conducted during First Quarter 2012 at the BFF Spill site include, but are not limited to, ongoing groundwater and soil vapor monitoring, completion of SVE well installation (KAFB-106160 and KAFB-106161), and Pneulog well testing. All of the BFF SVE systems will be shut down during the entire first quarter in preparation for the 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 First Quarter 2012 as follows:

- Depth to water and LNAPL measurements will be collected for existing monitoring wells on a quarterly basis and for new monitoring wells as they become available after installation and development.
- 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 January 10, 2012, and continue throughout the first quarter ending March 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 first quarter (March 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. Some systems will require modifications prior to installation and therefore all pump installations will not be completed. If SVE ICE units are not operation, influent and effluent samples will not be collected.
- 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

During First Quarter 2012, two SVE wells (KAFB-106160 and 106161) will be installed in accordance with the letter addendum to the Interim Measures Work Plan (USACE, 2011a) submitted on November 16, 2011, and approved by the NMED.

8.3 SVE Systems

During the First Quarter 2012 the SVE systems will be shut down in preparation for the Pneulog testing. The SVE systems will not be turned on again until the start of Second Quarter 2012.

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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

B-1. Data Quality Evaluation Report – Groundwater, October – December 2011

B-2. Data Quality Evaluation Reports – Soil, Second and Third Quarter 2011

B-3. Data Quality Evaluation Report – Soil Vapor, October – December 2011

B-4. Groundwater and Soil Vapor Data Packages, October – December 2011

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APPENDIX C

Waste Disposal Documentation

C-1. IDW Soil Disposal

C-2. Offsite Waste Disposal Manifest

C-3. IDW 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, 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 October – December 2011

- 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**

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APPENDIX H

Slug Test Results

H-1. Results

H-2. Quality Control

H-3. Individual Analysis Data Sheets

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APPENDIX I

Correspondence

I-1. Field Work Variances

I-2. Letter Addenda

I-3. RTC Tables

I-4. NMED Correspondence Letters

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APPENDIX J

Additional Cross Sections

J-1. NMED Transects – Third Quarter 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 Results

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APPENDIX M

Geophysical Records

M-1. Geophysical Calibration Data

M-2. Geophysical Logging QC Forms

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