

KIRTLAND AIR FORCE BASE ALBUQUERQUE, NEW MEXICO

Quarterly Pre-Remedy Monitoring and Site Investigation Report for July – September 2011

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

December 2011



**377 MSG/CEANR
2050 Wyoming Blvd. SE
Kirtland AFB, New Mexico 87117-5270**

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

**QUARTERLY PRE-REMEDY MONITORING AND
SITE INVESTIGATION REPORT
JULY – SEPTEMBER 2011**

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

December 2011

Prepared for

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

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Delivery Order 0002

Prepared by

Shaw Environmental & Infrastructure, Inc.
7604 Technology Way, Suite 300
Denver, Colorado 80237

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Commander

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PREFACE

This Quarterly Pre-Remedy Monitoring and Site Investigation Report for July – September 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 July through September 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 Pamela Moss, Diane Agnew, Gary Hecox, Melissa Halick, and Kim Truong.



Thomas Cooper, PG, PMP
Shaw Environmental & Infrastructure, Inc.
Project Manager

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ACRONYMS AND ABBREVIATIONS

°F	degrees Fahrenheit
3D	three-dimensional
AFB	Air Force Base
APH	air-phase petroleum hydrocarbons
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
CO ₂	carbon dioxide
CSS	Colorado silica sand
DAF	dilution attenuation factor
DO	dissolved oxygen
DOT	U.S. Department of Transportation
DPT	direct-push technology
DRE	destruction removal efficiency
DRO	diesel range organics
EDB	1,2-dibromoethane/ethylene dibromide
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)
HWB	Hazardous Waste Bureau (NMED)
ICE	internal combustion engine

ACRONYMS AND ABBREVIATIONS (continued)

ID	identification
IDW	investigation-derived waste
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
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
PAH	polycyclic aromatic hydrocarbon
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
RCRA	Resource Conservation and Recovery Act
ROI	radius of influence
RSI	Remediation Service International
RTK	real-time kinematic

ACRONYMS AND ABBREVIATIONS (concluded)

scfm	standard cubic feet per minute
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
1,2,4-TMB	1,2,4-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 findings in this quarterly report are 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 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 will further delineate these pathways.

- Soil concentrations define the soil residual non-aqueous phase liquid (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 TPH soil concentrations 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.
- The time-series analysis of the vapor concentration data since 2007 show 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 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 quarter, 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 towards 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. The third quarter plume maps for 1,2-dibromoethane (EDB) and total petroleum hydrocarbons (TPH)-gasoline range organics (GRO) confirm this plume migration direction and general velocity.
- 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

Parameter	Units	Average Value ^a	Standard Deviation	Minimum Value ^b	Maximum Value ^b
Groundwater Velocity	Ft/yr	95	NM	18	340
50-Year Downgradient Migration Distance	Ft	4,750	NM	900	17,000

Notes:

^aGeometric mean used for hydraulic conductivity.

^bMean \pm 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 but not to the depth extent observed in the initial sampling of the new monitoring wells. Subsequent sampling is required to confirm or refute these initial results.
- Based on the analysis of the degradation indicator compounds and the spatial extent of the organic compounds, it appears that microbial degradation is slowing the migration rate and 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 is the one compound that has migrated the full length of the monitoring well network and is found in the Shallow, Intermediate, and Deep Zones in the farthest downgradient well cluster. TPH-GRO is also found in the farthest downgradient wells.
- The concentration patterns of both EDB and TPH-GRO indicate two release periods of NAPL containing EDB.
- The extent of EDB groundwater contamination is not defined at this time. However, a simple migration calculation shows that EDB has a low retardation factor of $R = 1.03$. This means that EDB will migrate at a velocity of 0.97 times the groundwater flow velocity. EDB will migrate at essentially the same velocity as the groundwater. 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 hydraulic properties are higher than these average values, the EDB plume could be several times longer.
- 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.

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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 July through September 2011.

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

- 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 quarterly report text; however, cumulative information will be presented in the report appendices. Reporting requirements specified in the letter dated June 4, 2010, from the NMED-HWB include the following:

- 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 Third Quarter report for July through September 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
- 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, Response to Comments
- Appendix J, Additional Cross Sections
- Appendix K, NAPL and Soil Hydraulic Property Laboratory Reports

In the following discussions, the term non-aqueous phase liquid (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.

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2. SVE REMEDIATION SYSTEM PERFORMANCE

This section describes the operations and performance of the BFF SVE system during the reporting period from July through September 2011. The SVE and SVM wells are presented on Figure 2-1.

Detailed operations data and calculations are presented in Appendix A for the four 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 about 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 is connected through manifold piping to nine SVE wells (SVEWs), SVEW-01 through SVEW-09, shown on Figure 2-1. The SVE units installed on the groundwater monitoring wells are directly connected to the wellheads. Table 2-1 lists the SVEWs used for active extraction during July through September 2011.

2.1.2 Vapor Monitoring and Sampling

During the reporting period, vapor samples from vapor extraction and monitoring wells and SVE system inlet and exhaust ports were 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).

Soil-vapor samples for laboratory analysis were collected from all SVE and SVM wells (including new soil-vapor wells) during the Third Quarter 2011. Laboratory analytical data packages for vapor samples collected during the Third Quarter 2011 are provided on compact disc at the end of this report.

Appendix B-3 presents the Data Quality Evaluation Report for the SVE unit data collected during Third Quarter 2011. Appendix B-3 also contains a listing of sample delivery groups (column labeled “SDG”) showing which analytical data package contains specific vapor samples.

Samples for laboratory analysis of the combined influent soil vapor, pre-catalytic converter, and post-catalytic converter exhaust streams were collected during the reporting period. These samples were collected into pre-evacuated Bottle-Vac canisters. The canisters were packaged and shipped under chain of custody to RTI Laboratories, Inc. in Livonia, Michigan, for the following analyses:

- Volatile organic compounds (VOCs) including acetone, 1,2-dibromoethane (EDB), 1,2-dichloroethane, 1,2,4-trimethylbenzene (1,2,4-TMB), 1,3,5-trimethylbenzene, methyl tert-butyl ether, and methyl ethyl ketone (or 2-butanone) by EPA Method TO-15;
- Fixed gases (oxygen, nitrogen, carbon monoxide, carbon dioxide, and methane) by ASTM International [ASTM]-D2504; and
- Air-phase petroleum hydrocarbons (APH) by Massachusetts Department of Environmental Protection (MA DEP) method.

The Third Quarter 2011 SVE unit analytical results and concentrations of contaminants of concern in the extracted influent vapor were not available at the time of this report. Table 2-3 summarizes analytical results from the previous quarterly report (May 2011). During May 2011, the highest total VOC concentrations detected in vapor extracted from Unit 249 (ST-106) and Unit 345 (KAFB-1066) are 5,377 and 5,944 ppmv, respectively. Vapor extracted from Unit 344 (KAFB-1068) has a VOC concentration of 3,636 ppmv. Vapor extracted from Unit 335 (KAFB-1065) has the lowest VOC concentration of 2,243 ppmv.

2.1.3 Calculation of Destructive Removal Efficiency

Field or laboratory analytical data from the SVE system influent and exhaust samples provide information on the treatment efficiency of each SVE unit. The treatment destruction removal efficiency (DRE) for each unit is calculated as:

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

The DRE values for each unit are presented in Table 2-3.

2.1.4 Calculation of Hydrocarbon Remediation Attributable to Natural Attenuation through Bioventing

The Air Force Center for Engineering and the Environment has published guidance to account for the attenuation of petroleum hydrocarbons by bioventing (Leeson and Hinchee, 1996a and b). The mass of petroleum hydrocarbons biodegraded can be calculated using the following equation:

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

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 (scfm))
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

During the July through September 2011 reporting period, extraction wells SVEW-01 and SVEW-05 were used for vapor extraction (Table 2-1). Active extraction wells open to the SVE system are adjusted to extract the highest VOC concentration vapor from the subsurface. Engines 1 and 2 of Unit 249 were

operational 96 and 91% of the time, respectively. Routine system maintenance was performed on the engines in accordance with the site-specific *Operations and Maintenance Manual for the Soil Vapor Extraction Systems* (USAF, 2009a). A summary of the major maintenance activities, nonroutine maintenance or repair activities, and system downtime during the reporting period is presented in Appendix A.

The DRE values for SVE-Unit 249 are 97 and 99% for Engines E1 and E2, respectively, based on the Horiba field measurements collected during the August 2011 sampling event (Table 2-3).

2.2.2 Hydrocarbon Recovery and Degradation

The ST-106 SVE System (Unit 249) extracted approximately 7,846 NAPL-equivalent gallons from July through September 2011 (Table 2-4) and approximately 222,900 gallons of NAPL have been removed from the vadose zone by SVE Unit 249 from July 2003 through September 2011 (Table 2-4). As presented on Figure 2-2, the recovery rate of this system has essentially remained constant since late 2006. The somewhat steeper slope to the mass recovery versus time graph in 2011 represents a change in which vadose zone wells are used as extraction wells.

With an assumed average flow rate of 46 scfm and an operational runtime of 94% for the reporting period, using the equation described in Section 2.1.4, an estimated 2,466 NAPL-equivalent gallons were treated by bioventing during the Third Quarter 2011 event from July through September 2011.

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).

2.3.1 System Operation

During the reporting period, the individual SVE systems (Units 335, 345, and 344) located at wells KAFB-1065, KAFB-1066, and KAFB-1068, respectively, were operational. The operational time percentages for each unit are presented as follows:

Well/Unit	Engine 1 Operational Percentage	Engine 1 Operational Percentage	Average Operational Percentage
KAFB-1065 (RSI Unit 335)	78	38 (E2 was off in September 2011)	58
KAFB-1066 (RSI Unit 345)	85	23 (E2 was off in August and September 2011)	54
KAFB-1068 (RSI Unit 344)	63	56	60

The systems were not operational 100% of the time because they periodically had to be taken offline for routine and nonroutine engine maintenance and repairs and engine controller malfunction. Engine 2 of Unit 335 was shut down during the month of September 2011; Engine 2 of Unit 345 was shut down for the months of August and September 2011. Appendix A summarizes the major maintenance activities, nonroutine maintenance or repair activities, and system downtime during the reporting period.

The DRE values for three SVE units during the May 2011 sampling event (Table 2-3) are listed as follows:

- SVE Unit 335: 96 and 99% for Engines E1 and E2, respectively
- SVE Unit 345: 99 and 99.9 % for Engines E1 and E2, respectively
- SVE Unit 344: 92 and 97% for Engines E1 and E2, respectively

2.3.2 Hydrocarbon Recovery and Degradation

Based on the system computer PLC recorder, the KAFB-1065 SVE system (Unit 335) extracted approximately 456 NAPL-equivalent gallons from July through September 2011, and approximately

85,400 gallons of NAPL have been removed from the vadose zone by Unit 335 from August 2008 through September 2011 (Table 2-5). With an average flow rate of 16 scfm and an operational runtime of 58%, approximately 476 NAPL-equivalent gallons were treated by bioventing during the Third Quarter 2011 event. 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.

The KAFB-1066 SVE system (Unit 345) extracted approximately 5,085 NAPL-equivalent gallons from July through September 2011, and approximately 63,800 gallons of NAPL have been removed from the vadose zone by Unit 335 from March 2009 through September 2011 (Table 2-6). With an average flow rate of 39 scfm and an operational runtime of 54%, approximately of 322 NAPL-equivalent gallons were treated by bioventing during the Third Quarter 2011 event. As presented on Figure 2-2, the recovery rate of this system has remained constant over the last two years and currently demonstrates adequate remedial effectiveness.

The KAFB-1068 SVE system (Unit 344) extracted approximately 1,790 NAPL-equivalent gallons from July through September 2011, and approximately 57,000 gallons of NAPL have been removed from the vadose zone by Unit 335 from March 2009 through September 2011 (Table 2-7). With an average flow rate of 52 scfm and an operational runtime of 60%, approximately of 754 NAPL-equivalent gallons were treated by bioventing during the Third Quarter 2011 event. 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

Maintenance activities for the SVE and treatment systems generate both nonhazardous and Resource Conservation and Recovery Act (RCRA) hazardous wastes. Liquid condensate is another waste stream associated with SVE operation. The liquid condensate is primarily generated during cooler-season 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. During this reporting period, insufficient liquid condensate was generated to require offsite disposal.

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. Disposal documentation for waste generated during this reporting period 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 combustion 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 approaches 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, 2011a).

Tables 2-5 through 2-7 present the propane consumption and ratio of gallons of propane used per NAPL-equivalent gallon of contaminated vapor recovered.

- For ST-106 Unit 249, the ratio is 0.56 gallons of propane used per gallon of NAPL recovered. This is consistent with the long-term remedial performance of this system, and no adjustments will be made; however, propane usage will be closely observed to ensure that the system is operating effectively.
- Unit 335 (KAFB-1065) is consuming 12.8 gallons of propane for each gallon of NAPL recovered. This unit should be shut down based on marginal remedial effectiveness and moved to another location based on the SVE Optimization Plan results.
- Unit 345 (KAFB-1066) is consuming 0.16 gallons of propane for each gallon of NAPL recovered. This is consistent with the long-term remedial performance of this system, and no adjustments will be made.
- Unit 344 (KAFB-1068) is consuming 3.2 gallons of propane for each gallon of NAPL recovered. One engine on this unit will be shut down and the performance monitored. If remedial performance continues to decline, this unit will be pulsed or shut down and moved to another location based on the SVE Optimization Plan results.

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3. SITE INVESTIGATION

3.1 Site Investigation Objectives

This quarterly report presents the monitoring methods and results for Third Quarter 2011 activities performed at the Kirtland AFB BFF Spill site for the period of July 1, 2011 through September 30, 2011. BFF Spill groundwater investigation and monitoring are currently being implemented in conjunction with the vadose zone investigation and interim measures for ST-106 and SS-111. Approved work plans (USACE, 2011b, c, and d) for these three projects provide guidance for the work activities performed during the 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 elaborated 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 July through September 2011 include geophysical logging, well installations, surveying, investigation at the FFOR, slug testing, and quarterly groundwater monitoring and sampling activities. These activities are discussed in the following sections, and associated information is presented in Appendices D, G, and H of this report. Appendices D (electronic files in Excel format) and G present cumulative tables of field sampling data locations and well construction details. The tables are updated each quarter as new data locations are established and wells installed. Detailed discussions of field investigation activities this quarter are presented in the following sections.

3.2.1 Geophysical Logging

Ongoing geophysical logging is being 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 is to refine the conceptual site model in order to optimize the placement of SVE well, groundwater extraction wells, and future monitoring wells. The geophysical logs will also be incorporated into the site geologic model once all the newly installed wells have been logged.

Colog performed the initial geophysical logging in December 2010 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, 2011b) 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, which was also logged by Colog, as a QC measure to ensure the comparability of the geophysical data from both contractors.

During the Third Quarter 2011, geophysical logging was conducted at 10 GWM wells and 9 SVM wells at the BFF Spill site (Table 3-1). A quantitative evaluation of the geophysical logs will be conducted following the completion of the final geophysical logging event at Kirtland AFB and will be included in the future quarterly reports.

3.2.1.1 Geophysical Well Logging – Field Program

During the Third Quarter 2011, geophysical logging was conducted at 10 GWM wells and 9 SVM wells by Jet West. The probes used by Jet West included a dual-spaced induction probe and a 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, 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 Environmental & Infrastructure, Inc. (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 Shaw QC forms, Jet West geophysical logs, and other associated documentation are included in Appendices G-5 through G-7

The induction tool field calibration was performed at the beginning and end of each day. 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 in order to avoid any interferences. Average conductivity readings were recorded over 100 samples. The attached natural gamma tool also measured the background 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 log 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 data 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. Geophysical Logging QC Forms are included in Appendix G-5.

3.2.1.3 Data Processing Quality Control Review

Jet West, processed the data for each logging tool and generated a LAS file and hard-copy printouts of the final processed data for each well. The Jet West Geophysical Logs are included in Appendix G-6 as hard-copy PDF files. 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. The Excel spreadsheets are included in Appendix G-7 of this report. 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

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. However, the use of the well logging data for quantitative assessment requires the data be 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. Both contractors performed pre-project shop calibrations as well as field calibrations of their probes as required by the Groundwater Investigation Work Plan (USACE, 2011b).

Throughout the duration of the project, the logging data for each contractor have been presented in standard units. The units for the induction probe are presented in ohm meters, and the neutron and natural gamma tools are presented in API units. Even though the data from the different contractors is 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 in 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 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 8 of the wells (KAFB-1065, -1066, -1067, -1068, -10610, -10611, -10612, -10617) which were previously logged by Colog, for which there is no Jet West logged well located nearby..

3.2.2 Well Installation

3.2.2.1 Groundwater Monitoring Wells

During the Third Quarter 2011 event, 29 GWM wells were completed by the subcontractor drilling companies: WDC Exploration and Wells (23 wells) and Yellow Jacket Drilling (6 wells). The GWM wells were installed at 10 NMED-prescribed locations, at depths specified for these locations in the Groundwater Investigation Work Plan (USACE, 2011b) 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 during this reporting period are as follows:

- 9 water table wells – Shallow Zone
 - KAFB-106032, KAFB-106035, KAFB-106038, KAFB-106041, KAFB-106052, KAFB-106055, KAFB-106085, KAFB-106094, KAFB-106106
- 10 intermediate depth wells – Intermediate Zone
 - KAFB-106033, KAFB-106036, KAFB-106039, KAFB-106042, KAFB-106053, KAFB-106057, KAFB-106086, KAFB-106095, KAFB-106103, KAFB-106105
- 10 deep wells – Deep Zone
 - KAFB-106034, KAFB-106037, KAFB-106040, KAFB-106043, KAFB-106054, KAFB-106058, KAFB-106087, KAFB-106096, KAFB-106104, KAFB-106107

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). 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 Third Quarter 2011 are included in Appendix D-1. No soil samples (split spoon or continuous core) were collected during drilling activities in Third Quarter 2011.

All monitoring wells were constructed using 5-inch-diameter, Schedule 80 polyvinyl chloride (PVC) riser pipe and 0.010-slot, Schedule 80 PVC well screen with a 5 ft blank schedule 80 PVC sump. The shallow (water table) monitoring wells were installed with 20 or 30 ft of screen, and the intermediate and deep monitoring wells were fitted with 15-ft-length screens as prescribed for wells completed below the water table. Following placement of the well screen and riser pipe, a 10/20 Colorado Silica Sand (CSS) filter pack was tremied to approximately 2 ft above the top of the well screen followed by approximately 1 ft of fine sand seal consisting of 20/40 CSS. A bentonite seal (approximately 30 to 40 ft), consisting of 3/8-inch bentonite chips, was placed above the filter pack. The bentonite chip seal was hydrated in lifts using a “clean” water source. A high-solids bentonite grout was placed above the bentonite seal to near ground surface. A cement surface seal was placed above the bentonite grout to the ground surface. Well completion diagrams for the 29 completed 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 investigation-derived waste (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. Only wells that were installed, surveyed, and developed during the Third Quarter 2011 reporting period are included in this report. Well installation reports for each well (Appendix D-1) consist of soil boring logs, well completion diagrams, and well development records.

During the Second Quarter 2011, continuous core soil samples were collected from six boreholes (wells KAFB-106059, -106060, -106063, -106078, -106080, -106081) for NAPL mobility testing. The continuous core soil samples were collected by pushing a 4-inch-wide by 5-foot-long acetate sleeve into undisturbed soil. Table 3-3 presents the well locations, sample intervals, sample numbers, and USCS symbols for the continuous core soil samples. The discussion and evaluation of these data are presented in Section 5.5.

The three groundwater wells at Cluster 5 (KAFB-106041, -106042, and -106043) were installed from May 10 to June 6, 2011, but were not surveyed before the end of the Second Quarter 2011 event, due to issues with the surface completions. However, the surface completions were redone and the wells were surveyed during the Third Quarter 2011 event and are addressed in this report.

As stated in the second quarterly 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, 2011b). 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 G-9 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

Monitoring data for a minimum of one quarter will be collected from the closest GWM well clusters, GWM-8, GWM-10, and GWM-28, to determine whether a data gap exists, requiring another well to be drilled.

3.2.2.2 Soil-Vapor Monitoring Wells

A total of seven SVMW clusters were installed during the Third Quarter 2011 event. 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. The following summarizes the SVMWs that were completed, the corresponding NMED number, and the location area:

- Tank Farm
 - KAFB-106120 (SVM-13)
 - KAFB-106122 (SVM-15)
 - KAFB-106124 (SVM-17)
 - KAFB-106125 (SVM-18)
 - KAFB-106126 (SVM 19)
 - KAFB-106127 (SVM-20)

- Far Field – KAFB-106136 (SVM-02)

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. 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 Third Quarter 2011 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), TPH-gasoline range organics (GRO), TPH-diesel range organics (DRO), and lead. The analytical results for soil samples collected during Third Quarter 2011 are discussed in Section 4 (Vadose Zone Sampling and Monitoring).

3.2.2.3 PneuLog Wells

Four PneuLog wells (KAFB-106148, KAFB-106149, KAFB-106150, and KAFB-106151) were installed during the Third Quarter 2011; however, these wells were not surveyed before the end of the third quarter reporting period. Therefore, all lithologic logs and well construction data associated with these wells will be reported in the fourth quarterly report for 2011.

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. 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 and well construction details will be reported in the fourth quarterly report for 2011.

3.2.3 Surveying

During the Third Quarter 2011 event, 29 GWM wells and 7 SVM wells were installed and surveyed in accordance with the Groundwater Investigation Work Plan (USACE, 2011b) and the NMAC *Minimum Standards for Surveying in New Mexico* (NMAC Title 12, Chapter 8, Part 2). 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, 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 GWM and SVM wells using a Topcon RTK (real time kinematic) GPS (global positioning system) unit. This instrument is a survey-grade GPS rover unit and base station that is tied to known control points with horizontal and vertical accuracies of approximately 0.01 ft. At each well location, the survey team would remove the vault cover and all well caps and collect data points of the wells and related surfaces. Survey points collected at all wells include the ground surface north of the well pad, the well pad north of the well's outer steel casing, the steel casing on the northern edge (marked with black permanent marker), and the northern edge of the inner PVC casings. In cases where a dedicated Bennett sample pump was installed, the northern edge of the sampling point on top of the well cap was surveyed.

Nomenclature used for the elevation measurement points are as follows: ground or asphalt, concrete well pad, case, and PVC. At SVMW locations, in addition to the above, 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-106111-250). 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 3-5 presents the survey data for Third Quarter 2011 well installations.

3.2.4 FFOR Investigation

Soil sampling along the former fuel line at the FFOR that commenced during the Second Quarter 2011 event continued through August 17, 2011, and is ongoing. 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 is being 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, 2011d). During the Third Quarter 2011 event, from July 1 through September 30, 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.

During Third Quarter 2011, a total of 152 boreholes were completed bringing the total number of boreholes completed in the Second and Third Quarters 2011 to 288 boreholes (Figure 3-3). A total of 318 original DPT sampling locations are outlined in the Final Interim Measures Work Plan (USACE, 2011d). Twenty-five remaining boreholes are located in the vicinity directly west of Building 1033 (Figure 3-3). Shaw was unable to complete these boreholes due to ongoing construction in the area by Chugach Management Services (Chugach). Once Chugach has completed operations in this area, these boreholes will be completed.

The remaining 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. Work is ongoing with the drilling subcontractor to core the concrete sleeve so that total depth may be achieved. Two borehole locations immediately south of the pump house were moved to avoid high-voltage electrical lines in the area (Figure 3-4). The new locations for KAFB-FWV-5 were chosen with input from Kirtland AFB and NMED (verbal approval received at October 20, 2011 meeting). Additional step-out locations will be added as needed based on analytical data evaluation. The borehole numbers, collection dates, and coordinates are presented in Table 3-6.

DPT sampling initiated during Second Quarter 2011 and continued eastward along the FFOR and then turned south, terminating at the area under construction by Chugach. 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, 2011d).

Three suspected leak locations have been 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 3-4), 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. A total of 152 boreholes were sampled during the Third Quarter 2011 event (July 1 through September 30, 2011). The QA/QC samples were collected at a frequency of 10% to verify the accuracy of field sampling procedures. The QC samples included field duplicates, matrix spike and matrix spike duplicates, trip blanks, and field blanks for VOCs and equipment rinse blank samples. 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, 2011d).

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 in the fourth quarterly report for 2011.

3.2.5 Slug Testing

Slug testing commenced on July 19, 2011 and was completed on October 4, 2011. Tests were performed by the subcontractor WDC Exploration and Wells. Slug tests were conducted at selected wells (Figure 3-5) to obtain hydraulic conductivity data to support modeling the extent of LNAPL, dissolved-phase migration, and groundwater flow velocities across the site. The data will be 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.

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

Table 3-7 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. Figure 3-6 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 Table 3-7 indicate the variability that exists between slug-test results. The variability arises primarily because of the non-unique nature of curve-fit data analysis.

3.2.6 Quarterly Groundwater Sampling Field Activities

Several dedicated Bennett sample pump systems were removed from wells to facilitate slug testing. These dedicated systems were later reinstalled for sampling operations. Existing dedicated Bennett sample pump systems were pulled as needed to evaluate the current condition, repaired as indicated, and then reinstalled for operations. New dedicated Bennett pump sampling systems were also received from the manufacturer and installed in monitoring wells. 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 July through September 2011:

- July 14 and July 15, 2011 – Dedicated Bennett sampling pump systems were removed from monitoring wells KAFB-10610, KAFB-10617, KAFB-10618, KAFB-10613, KAFB-10620, and KAFB-10621 in preparation for slug testing or for repairs.
- July 25, 2011 – Dedicated Bennett pump sampling systems were installed in monitoring wells KAFB-106076, KAFB-106083, and KAFB-106084.

- July 26, 2011 – A dedicated Bennett sampling pump system was installed in monitoring well KAFB-106082, and dedicated Bennett pump systems were reinstalled in KAFB-10617, KAFB-10618, and KAFB-10619.
- July 27 and July 28, 2011 – Dedicated Bennett sampling pump systems were pulled from the wells, repairs made, and systems reinstalled at KAFB-106044, KAFB-10610, KAFB-10615, and KAFB-106101. Dedicated Bennett sample pump systems were removed from wells KAFB-106079 and KAFB-10625.
- July 29, 2011 – The dedicated Bennett sampling pump system was reinstalled in KAFB-10621.
- August 12, 2011 – Dedicated Bennett pump sampling systems were reinstalled in wells KAFB-106079 and KAFB-10625.
- August 16, 2011 – The existing Bennett sample pump was pulled from well KAFB-106028, the tubing bundle repaired, and the system reinstalled. The Bennett sampling pump system with an added suction tube was reinstalled in KAFB-10613.
- August 17, 2011 – New Bennett sampling pump systems were installed in monitoring wells KAFB-106042, KAFB-106067, and KAFB-106069.
- August 18, 2011 – New Bennett sampling pump systems were installed in monitoring wells KAFB-106068, KAFB-106099, and KAFB-106100.
- August 19, 2011 – New Bennett sampling pump systems were installed in monitoring wells KAFB-106073, KAFB-106074, and KAFB-106075.
- August 22, 2011 – New Bennett sampling pump systems were installed in monitoring wells KAFB-106049, KAFB-106050, and KAFB-106051.
- August 23, 2011 – New Bennett sampling pump systems were installed in monitoring wells KAFB-106070, KAFB-106071, and KAFB-106072.
- August 24, 2011 – New Bennett sampling pump systems were installed in monitoring wells KAFB-106097 and KAFB-106098. The Bennett sample pump in KAFB-10613 was partially removed and the tubing bundle shortened, then reinstalled.
- August 29, 2011 – New Bennett sampling pump systems were installed in monitoring wells KAFB-106043, KAFB-106065, and KAFB-106066.
- September 1, 2011 – The dedicated Bennett sampling pump system was removed from KAFB-106059 for inspection prior to repairs.
- September 6, 2011 – The dedicated Bennett sampling pump system was pulled from well KAFB-106076, repaired, and replaced. The dedicated Bennett sampling pump system was pulled from well KAFB-106059, repaired, and replaced.
- September 27, 2011 – Bennett sample pump systems were removed from KAFB-1069, KAFB-106059, and KAFB-106076 after repeated systems failures so sampling could be completed using the portable Bennett sample pump reel.

No additional monitoring well maintenance activities were performed during the period from July through September 2011.

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4. VADOSE ZONE SAMPLING AND MONITORING

In the following sections, the three-dimensional (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.

- RockWorks 3D inverse-distance-weighting gridding algorithm of logarithms of concentrations was used for development of all vadose zone 3D plumes and soil concentrations. 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 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 soil and vapor concentrations.
- The vadose zone boring, SVM well, and GWM well analytical data soil sampling locations used in this analysis are presented and labeled on Figure 4-2. Vapor samples are only available 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 Table 4-1 or in the second quarterly report for 2011 (USACE, 2011e). Vapor data used are presented in Tables 4-2 and 4-3.
- Sampling analytical results within 25 ft of a given cross-section line are posted on the cross-sections. 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, on the plan-view maps, multiple samples may be posted for a single borehole and elevation.
- Note that a number of soil samples were collected from below the water table. As such, these are not technically from the vadose zone. However, for completeness, all soil samples are evaluated and discussed in this section.
- For contouring purposes, where applicable, the NMED SSL dilution attenuation factor (DAF) 20 values (NMED, 2009) are used as the lowest concentration contour.
- Because the SSL DAF 20 value for EDB (0.000316 milligrams per kilogram [mg/kg]) is less than the EPA SW8260B soil analytical detection limit (detection limits range from 0.0004 to 0.01 mg/kg on undiluted soil samples), EDB contour analysis is not presented, but the respective elevation concentrations are posted on the maps and cross-sections.

4.1 Soil Sampling Results

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 a wide range of organic compounds.

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, 2011f), and appropriate data qualifiers are appended to the analytical data in the project database. The Third Quarter 2011 analytical laboratory results are presented in Table 4-1, and the data validation results are presented in the Data Quality Evaluation Report included in Appendix B-2, which also presents the Data Quality Evaluation Report for the Second Quarter 2011 soil sampling results not available prior to end of second quarter. The comprehensive analytical database is presented in Excel format in Appendix E. Accuracy and precision for the Second and Third Quarter 2011 soil analytical results indicate 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 2011 data set shows only three samples with a TPH-GRO+DRO 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, concentrations of 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. Table 4-2 presents the soil analytical concentrations used in the 3D analysis.

For 3D spatial analysis of soil analytical data, the 2011 soil boring data were combined with historical data from 2007 – 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 results are presented on Figures 4-3 through 4-58.

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

- TPH soil maps for the five elevations are presented on Figure 4-3 and cross-sections on Figures 4-11 through 4-16. 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. 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 feet above msl. 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 in 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)	Volume (cubic ft)	Volume (cubic yards)	Volume (%)	Cumulative Volume (%)
5,400	5,300	47,675,000	1,800,000	6.2%	6.2%
5,300	5,200	136,087,500	5,000,000	17.3%	23.5%
5,200	5,100	107,587,500	4,000,000	13.8%	37.4%
5,100	5,000	155,062,500	5,700,000	19.7%	57.1%
5,000	4,900	200,637,500	7,400,000	25.6%	82.7%
4,900	4,800	134,337,500	5,000,000	17.3%	100.0%
Total:		781,387,500	28,900,000		

- Benzene soil plan-view maps are presented on Figure 4-4 with the cross-sections on Figures 4-17 through 4-22. Benzene soil concentrations greater than the DAF 20 SSL concentration of 0.037 mg/kg 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. A sizable area of benzene contamination is present at the 5,100 ft elevation, but only a small area with concentrations greater than 0.037 mg/kg is present at the 5,000-ft elevation. 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 are presented on Figure 4-5 with the cross-sections on Figures 4-23 through 4-28. 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 are presented on Figure 4-6 with the cross-sections on Figures 4-29 through 4-34. At the 4,900-ft elevation, there are two small areas with concentrations greater than the DAF 20 SSL concentration of 0.29 mg/kg. There are no areas with concentrations greater than 0.29 mg/kg at higher elevations (shallower depths).
- Lead soil plan-view maps are presented on Figure 4-7 with the cross-sections on Figures 4-35 through 4-40. There are only sporadic vadose zone detections of lead greater than the DAF 20 SSL concentration of 10 mg/kg with no apparent pattern to the detections.
- Naphthalene soil plan-view maps are presented on Figure 4-8 with the cross-sections on Figures 4-41 through 4-46. At the 4,900-ft elevation, there are two areas with concentrations greater than the DAF 20 SSL concentration of 0.0084 mg/kg. There are no areas with concentrations greater than 0.0084 mg/kg at higher elevations (shallower depths). The two naphthalene areas that exceed the DAF SSL of 0.0084 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 are presented on Figure 4-9 with the cross-sections on Figures 4-47 through 4-52. 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 (Table 4-2).
- Xylene soil plan-view maps are presented on Figure 4-10 with the cross-sections on Figures 4-53 through 4-58. At the 4,900-ft elevation, two soil samples have concentrations greater than the DAF 20 SSL of 3.5 mg/kg. 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 of the results are less than 3.5 mg/kg.

4.2 Vadose Zone Vapor Monitoring Results

The SVE monitoring/remediation system currently consists of 272 individual vapor 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 2-1.

Soil-vapor hydrocarbon concentration (ppmv), percent O₂, percent CO, percent CO₂, and pressure were measured at the SVE wells during Third Quarter 2011 sampling using a Horiba Model MEXA 584 L portable auto emissions analyzer. Horiba field measurements for SVE wells are presented in Table 2-2. Pressure measurements that indicate the vadose zone is subject to vacuum are reported in Table 2-2 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 Third Quarter 2011 vapor samples were collected from SVE and SVM wells using pre-evacuated Bottle-Vac canisters sampled through sampling ports installed at the top of each individual well casing for offsite laboratory analysis. 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, 2011f) and shipped to RTI Laboratories, Inc. in Livonia, Michigan, for the following list of analytical parameters:

- VOCs – EPA Method TO15
- APH – MA DEP
- Fixed gases – ASTM Method D2504

Field QC samples were collected in accordance with the BFF Spill QAPjP and include field duplicate samples and trip blanks for VOCs.

Third 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 are presented in Table 4-3 for Third Quarter 2011. The data validation results

are presented in the Data Quality Evaluation report included in Appendix B-3. Accuracy and precision for the Third Quarter 2011 SVE vapor analytical results indicate data are of sufficient quality to achieve the BFF project data quality objectives.

4.3 Soil-Vapor Data Evaluation

As presented in Table 4-4, during Third Quarter 2011, 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-64%) ranges; benzene (90%), toluene (97%), xylenes (76%), cyclohexane (95%), heptane (88%) and hexane (C6N, FOD 92%). Detected vapor concentrations range from a few hundred up to 3 million parts per billion by volume (ppbv) for specific compounds and detected TPH concentrations range from approximately 10,000 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) up to 100 million $\mu\text{g}/\text{m}^3$.

Third Quarter 2011 laboratory analytical vapor total VOC and benzene values (Table 4-5) from vapor wells were used to generate 3D vapor plumes from which plan-view maps and cross-sections were generated. In the grid analysis, nondetected results were incorporated using one-half the 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 $\mu\text{g}/\text{m}^3$ to ppbv formula is as follows:

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

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

$0.080205 = \text{Universal Gas Constant in (atm L)/(mol K)}$

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

$MW = \text{molecular weight of compound}$

Molecular weight 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°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 4-59 because there is insufficient space on the plan-view concentration maps to clearly show well names along with the concentrations.

Figure 4-60 presents the five plan-view maps of the vapor total VOC distribution and Figure 4-61 presents the benzene plan-view maps at the selected elevations beneath the BFF Spill site. Figures 4-62 through and 4-67 present six total VOC cross-sections and Figures 4-68 through 4-73 present the benzene cross-sections through the vadose zone vapor plume. As illustrated in the 10 maps and 12 cross-sections, the vadose zone total VOC vapor concentrations can be characterized as follows:

- Total VOC vapor concentrations at the elevation of 5,300 ft above msl (approximately 50 ft bgs) are less than 1,000 ppmv except for three small areas with concentrations between 1,000 and 10,000 ppmv at cluster well locations SVEW-08/09, SVMW-11, and KAFB-106112.
- At lower elevations, down to 5,000 ft above msl, the extent of the total VOC vapor plume remains essentially constant with minor changes in the areal extent of the 100- to 1,000-ppmv and 1,000- to 10,000-ppmv concentration footprints.

- The benzene vapor concentration 1- and 10-ppmv 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.
- The most dramatic change is at the elevation of 4,900 ft above msl, 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 KAFB-106114, KAFB-106116, KAFB-106117, and KAFB-106128.
- 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 Vapor Concentrations Over Time

The 2007 through 2011 soil-vapor time-series concentration graphs with four or more samples and selected compounds presented in Table 4-4 are presented in Appendix F-4. There are no data for September 2007 through January 2010 because vapor laboratory analytical samples were not collected for this time period. TPH-GRO concentration results in $\mu\text{g/L}$ were converted to ppbv by multiplying $\mu\text{g/L}$ 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 only been marginal changes in concentration 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 across the water table and extends 5 to 10 ft below the 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. Table 5-1 presents a comparison of top of screen and September 2011 water table elevations wells in the Shallow Zone.
- **Intermediate Zone.** This is the aquifer zone that is monitored by wells that extend 15 to 30 ft below the 2009 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 2009 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 (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 Third Quarter 2011 include the following:

- KAFB-1061 through KAFB-10628; and KAFB-3411 (installed for investigation of another adjacent site and provides a monitoring location upgradient of the FFOR).
- KAFB-106029 through KAFB-106104, (except KAFB-106041, which is dry), newly installed (January – September 2011). These are all the newly planned monitoring wells with the exception of cluster number 28, KAFB-106105, KAFB-106106, and KAFB-106107, which were not installed and developed in time to be sampled during the third quarter.

- 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 July 6 and September 29, 2011. All samples were collected in accordance with the Groundwater Investigation Work Plan (USACE, 2011b) and BFF Spill QAPjP (USACE, 2011f). Sampling was performed using either dedicated Bennett sample pumps (43 wells) or a portable Bennett pump sampling system (64 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 for pH, conductivity, temperature, alkalinity, dissolved oxygen [DO], turbidity, and oxidation-reduction potential [ORP]) during well purging, testing for alkalinity, and collecting groundwater samples for laboratory analysis. After collection of water quality measurements, the wells were purged at an approximate rate of 1.0 liter per minute. Sample collection at 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 Third Quarter 2011 were analyzed by Empirical Laboratories, Nashville, Tennessee, for the following list of parameters:

- VOCs – EPA SW8026B
- EDB – EPA SW8011
- SVOCs – EPA SW8270C
- TPH- GRO and DRO – EPA SW8015B
- Polycyclic aromatic hydrocarbons (PAHs) – 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 plus 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, 2011f) and included trip and ambient blanks for VOCs, field duplicate samples, 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 5-2; the data validation results are presented in the Data Quality Evaluation report included in Appendix B-1. Accuracy and precision for the Third Quarter 2011 groundwater analytical data indicate data are of sufficient quality to achieve the BFF Spill project data quality objectives.

5.2 Liquid Level Data

On a monthly basis, liquid levels are measured in all completed wells (Figure 5-1 and Table 5-3), 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 each well.

5.2.1 Groundwater Levels

Groundwater level data are presented in Table 5-3, and groundwater level contour maps for July, August, and September 2011 for the Shallow, Intermediate, and Deep Zones are presented in Figures 5-2 through 5-10. 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 is maintained in the project data base. 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 with the Fourth Quarter 2011 monitoring event, Shaw will implement a process improvement for QC of the monthly water level measurements. Shaw is following the process described below to ensure that data meets data quality requirements. This level of QC is required because of the flat groundwater gradients and the effect that barometric pressure has on water levels at the site (Section 7.3).

- Field technicians will record the serial number/ID of the water level meter used to collect the measurements on the field form for water level measurements.
- Field technicians will measure water levels and do a field-check to verify that measurements within a given cluster are within plus or minus 0.5 ft. If not, then they will re-measure the water levels in the cluster. This QC evaluation will be documented on the water level measurement field form.
- All field measurements will be submitted to the Field Sampling Coordinator for QC, who will check to make sure the measurements are within plus or minus 0.5 ft of each other for a given cluster. If it is determined this is not the case, the wells will be flagged and measured again the following day. This QC evaluation will be documented on the water level measurement field form.
- Additionally, the Field Sampling Coordinator will compare the measurements against the measurements from the preceding month. If any measurements fail a plus or minus 1.0-ft check, they will be marked and measured again the following day. This QC evaluation will be documented on the water level measurement field form.
- The field QC check and Field Sampling Coordinator QC check will be repeated for all measurements collected, including re-measurement of wells. Once The Field Sample Coordinator verifies that the data collected meets the QC metrics, they will sign the form and submit it for entry into the database. The Field Sample Coordinator will redline any measurements that should not be entered into the database.
- All measurements (including re-measurements) will be entered into the database along with flags noting the QC checks that have been performed. The database entry form has an internal checking routine to flag any suspected data entry mistakes.

- All QC forms will be maintained in the project files for reference.
- The quarterly report tables will report all liquid level measurements for the reporting period. The values used in creating contour maps will be identified in the table.

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

As presented in the figures, the northern portion of the groundwater flow direction in the all three zones is approximately North 25° to 35° East, consistent with the data presented in the second quarterly report for 2011 (USACE, 2011e). 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 pairs indicate upward gradients. As additional cluster wells are 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, this may be difficult.

5.2.2 NAPL Thicknesses

As presented in Table 5-3, during the July through September 2011 time period, NAPL was observed in eight wells during the quarter. NAPL was observed in three wells (KAFB-1066, KAFB-1068, and KAFB-106076) during all three months; once in KAFB-1065 and KAFB-106064 (September) and twice

in KAFB-1069, KAFB-10628-510, and KAFB-106059 (August and September) (Figures 5-12 through 5-14). Observed thicknesses range from 0.04 to 2.42 ft.

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 data in Table 5-2. The water quality analysis used the following procedures:

- Field and laboratory analytical water quality results 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 distribution 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 are key Third Quarter 2011 analytical data findings based on the results presented in Table 5-2 and the associated maps generated from these data. The data in Table 5-2 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 Fourth Quarter 2011 will be used to further refine the thickness of the contaminant plumes.

Compound-specific dot and plume maps were prepared for TPH-GRO, TPH-DRO, EDB, benzene, toluene, xylenes, 1,2,4-TMB, 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 micrograms per liter ($\mu\text{g/L}$) 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 62,000 $\mu\text{g/L}$. 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 $\mu\text{g/L}$ 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 17,000 $\mu\text{g/L}$ (J+ estimated value biased high) in the NAPL area. The TPH-GRO plume extends approximately 2,500 ft downgradient of the NAPL area.
 - TPH-GRO was detected at a concentration of approximately 63 $\mu\text{g/L}$ (J-qualified result) in one Deep Zone well. 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 $\mu\text{g/L}$ 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 52,000 $\mu\text{g/L}$. The downgradient extent of the TPH-DRO plume is approximately 2,500 ft north of the edge of the historical NAPL area.
 - TPH-DRO concentrations in the Intermediate Zone correlate with the TPH-DRO plume in the Shallow Zone. The highest concentration in the Intermediate Zone is 13,000 $\mu\text{g/L}$ (J-estimated value biased low) in the NAPL area. The TPH-GRO plume extends approximately 2,500 ft downgradient of the NAPL area.
 - All TPH-DRO concentrations in samples from the Deep Zone wells are below the detection limit.

- **EDB.** Data used in preparing the EDB concentration contours included data from both the EPA SW8260B and EPA SW8011 analytical methods, in order to ensure the highest level of data quality for contouring. Although EDB data were used selectively, a data comparability assessment was performed on all Third Quarter 2011 data generated for both methods during validation and all EDB data were proven to meet project data quality objectives. In addition, EDB data for both methods was compared to historical data, if available, to ensure no anomalous data results were reported. The EDB data used were selected according to the following data selection protocol in sequence: (1) unqualified EPA SW8011 detected results; (2) unqualified EPA SW8260B results; (3) qualified EPA SW8011 detected results; and (4) qualified EPA SW8011 nondetected results. The data used in the plume analysis are presented in Table 5-4.

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

- As presented, the highest EDB concentrations are in the historical NAPL area with the highest detected concentration at 370 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 2.2 (J+) µg/L and the plume extends at least 2,500 ft downgradient of the historical NAPL area.
- There are two detections of EDB in the Deep Zone in the northeast flow direction. The Deep Zone detections in the second quarterly report for 2011 (USACE, 2011e) were not repeated in the Third Quarter.
- The extent of EDB in groundwater is not currently defined to the northeast. The furthest downgradient monitor well has an EDB concentration of 1.3 µg/L—compared to 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 this well.
- Based on the groundwater flow directions and velocities defined in Section 5.6, the current monitor 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 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 5,200 µg/L. The downgradient extent of the benzene plume in the Shallow Zone is approximately 500 ft north of the edge of the historical NAPL area or approximately one-sixth the extent of the TPH-GRO plume.
 - In the Intermediate Zone, the sample from two wells, KAFB-106065 and KAFB-106080, have benzene concentrations greater than 5 µg/L, and benzene was detected at less than 5 µg/L in samples from six other Intermediate Zone wells.
 - Benzene was not detected in any Deep Zone wells sampled during 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 New Mexico groundwater standard of 750 µg/L 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 19,000 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 nine Intermediate Zone wells at concentrations ranging from less than 1 to 170 µg/L.
 - In the Deep Zone, no toluene concentrations exceed the groundwater standard (750 µg/L), but toluene was detected in samples from eight Deep Zone wells at concentrations less than 1 µg/L.

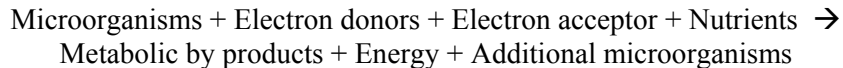
- **m,p-Xylenes.** The concentrations for the Shallow, Intermediate, and Deep Zone wells are presented on Figures 5-30, 5-31, and 5-32, respectively. The EPA MCL of 10,000 µg/L was used for the lower concentration contour limit.
 - In the Shallow Zone, no m,p-xylene concentrations exceed the MCL with the m,p-xylene detections within or immediately downgradient of the historical NAPL area. The highest detected m,p-xylene concentration is 3,800 µg/L.
 - In the Intermediate Zone, no m,p-xylene concentrations exceed the MCL, but m,p-xylene was detected in samples from six Intermediate Zone wells at concentrations ranging from less than 1 to 190 µg/L.
 - No m,p-xylene was detected in the Deep Zone based on the Third Quarter 2011 data.

- **1,2,4-TMB.** 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. 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 plume are within the historical NAPL area with the highest detected concentration at 640 µg/L.
 - In the Intermediate Zone, 1,2,4-TMB was detected in samples from two wells, including one with a concentration greater than 35 µg/L below the NAPL area.
 - In the Deep Zone, no 1,2,4-TMB was detected in samples from any wells.

- **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 was used for the lower concentration contour limit.
 - In the Shallow Zone, all but two of the naphthalene detections are within the historical NAPL area with the highest detected concentration at 200 µg/L.
 - In the Intermediate Zone, naphthalene was detected in samples from two wells within the NAPL area footprint, both with concentrations greater than 30 µg/L.
 - In the Deep Zone, no naphthalene was detected in samples from any wells.

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, dots 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.
 - 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 9 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 a 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.
 - In Deep Zone wells, DO depletion was not observed in any wells based on the Third Quarter 2011 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.
 - 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 a -293 millivolts. Further downgradient within the plume area, the ORP becomes strongly positive with values greater than 200 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 wells KAFB-106091 and KAFB-106042.
 - 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. Wells KAFB-106065 and KAFB-106080 had the highest Intermediate Zone benzene concentrations.
 - In Deep Zone wells, ORP less than 0 was not observed in any wells based on the Third Quarter 2011 results.
- **Alkalinity.** Concentrations of this degradation indicator compound are presented on Figures 5-45 through 5-47. Microbial degradation can result in increased alkalinity concentrations.
 - The point pattern analysis indicates that alkalinity is somewhat elevated within the Shallow Zone NAPL area. No obvious pattern is apparent in the alkalinity data for plume areas away from the NAPL area.
 - No obvious pattern is apparent in the alkalinity data in the Intermediate and Deep Zones.

- **Iron.** Concentrations of this degradation indicator compound are presented on Figures 5-48 through 5-50. Microbial degradation can result in increased iron concentrations.
 - 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 concentrations.
 - Iron was not detected in the Deep Zone wells sampled during the Third Quarter 2011.

- **Manganese.** Concentrations of this degradation indicator compound are presented on Figures 5-51 through 5-53. Microbial degradation can result in increased manganese concentrations.
 - 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 definitely elevated in samples from those wells with detections of TPH-GRO downgradient to well KAFB-106070. Further 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 several wells inside the historical NAPL area footprint. Two of the wells, KAFB-106065 and KAFB-106080, have elevated benzene concentrations.
 - In the Deep Zone, manganese is not obviously elevated in any wells..

- **Nitrate.** Concentrations of this degradation indicator compound are presented on Figures 5-54 through 5-56. Microbial degradation will cause decreases in nitrate concentrations. More data from the new monitoring wells will be required to assess the viability of this electron acceptor as a degradation indicator.
 - In the Shallow Zone, nitrate appears to be somewhat depleted in the NAPL area and the area of the dissolved plume immediately downgradient of the NAPL area with most NAPL area nitrate concentrations are nondetected or low-concentration, J-qualified results. However, it appears that background nitrate concentrations are sufficiently low that this compound may not be a robust degradation indicator.
 - No obvious pattern is apparent in the Intermediate and Deep Zone nitrate 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.
 - In the Shallow Zone, sulfate appears to be somewhat depleted in the NAPL area. However, it appears that background sulfate concentrations are sufficiently low that this compound may not be a robust degradation indicator.
 - No obvious pattern is apparent in the Intermediate and Deep Zone sulfate results. Additional data from the new monitoring wells may clarify the sulfate pattern in these zones.

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 m,p-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 indicating 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 are resulting in a clustering of NAPL area and wells 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 CO_2 is generated in the degradation process. This will lower the pH thereby dissolving carbonate minerals in the aquifer. This will have the overall effect of increasing the bicarbonate/sulfate ratio. In the NAPL-area and plume area wells, there is an overall increase in calcium in the Shallow Zone wells compared to the

Intermediate and Deep Zone wells. The highest contaminant concentrations are in the Shallow Zone so this is presumably where the microbial degradation is most active resulting in more 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/Liter, meq/L) than the Intermediate and Deep Zone wells. Thus the calcium/bicarbonate increases observed in the Piper diagrams is observed in the Stiff diagrams.

In the 2011 fourth quarterly report, additional inorganic compound data evaluations will be performed to further illustrate the relationships between changes in the inorganic chemistry of the aquifer related to areas of organic compound microbial degradation. This will be done to define likely aquifer volumes where degradation is occurring.

5.4 Production Well Data

As part of the BFF pre-remedy quarterly monitoring program, groundwater samples were collected and analyzed during Third Quarter 2011 at the KAFB 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 in Third Quarter 2011 were non-detect for BFF COCs including VOCs, SVOCs, and TPH compounds. The analytical results are presented along with all Third Quarter 2011 groundwater monitoring results in Table 5-2.

5.5 NAPL and Soil Hydraulic Property Laboratory Test Results

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 are presented in Tables 5-6 through 5-12. Laboratory reports are provided in Appendix K.

5.5.1 Soil Test Results

Laboratory tests were conducted on remolded soil samples to measure porosity, hydraulic conductivity, TOC, and grain-size distribution.

- Porosity results are presented in Table 5-6. 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 $\pm 4.87\%$.
- Hydraulic conductivity results are presented in Table 5-7. 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).
- Grain-size results are presented in Table 5-8. 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.
- The TOC results are presented in Table 5-9. Overall, the TOC concentrations are low with an average concentration of 230 ± 77.5 mg/kg and a median TOC of 200 mg/kg.
- Table 5-10 presents the air/water/NAPL capillary test results and calculated van Genuchten parameters from the capillary tests. It is noted that while 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

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, 1,2-dichloroethane, and lead. NAPL fluid properties are presented in Tables 5-11 and 5-12.

- 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 $0.73 \text{ g}/\text{cm}^3$) and diesel (density approximately $0.88 \text{ g}/\text{cm}^3$). The API gravity of 51.6 and flashpoint of less than 70 degrees Fahrenheit ($^{\circ}\text{F}$) are closer to gasoline (approximately 58 API gravity) than that of diesel (approximately 30 API gravity). The API gravity of 44.7 with a flashpoint of 94°F 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 a molecular weight of 149 g/mol and density of $0.80 \text{ g}/\text{cm}^3$. Benzene in this NAPL is 0.04 weight percent. The KAFB-1066 NAPL is closer in characteristics to gasoline with a molecular weight of 127 g/mol and a density of $0.77 \text{ g}/\text{cm}^3$. Benzene in this NAPL is 0.22 weight percent.
- The chromatograms of the two samples (Figures 5-73 and 5-74) indicate a fairly 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 $0.01 \text{ cm}^3\text{-NAPL}/\text{cm}^3\text{-soil}$ (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—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. Figure 5-72 depicts the water level elevations since 1949 for the data at Kirtland AFB water supply well KAFB-3 (northeastern corner of Figure 5-1). This well 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- 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, m,p-xylene, 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, for most of the wells, the time-series graphs do not show any obvious concentration increases or decreases 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 has 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 (Shallow, Intermediate, and Deep wells have EDB concentrations between 0.71 and 1.3 µg/L), located 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.

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6. INVESTIGATION-DERIVED WASTE

6.1 Well Installation Investigation-Derived Waste

Groundwater monitoring wells, SVMWs, and Pneulog wells are being installed at the Kirtland AFB BFF Spill site to support the groundwater and vadose zone investigations. As a result of the well installations, drill cuttings and decontamination and development water are being generated, stored, and disposed of as described in the following sections.

6.1.1 Drill Cuttings

All monitoring and Pneulog wells associated with the BFF Spill site are being drilled using ARCH methods, and the drill cuttings are being containerized in plastic-lined, steel, roll-off containers pending laboratory analysis for waste characterization and disposal. Approximately 10 to 15 cubic yards of drill cuttings are being generated for each 20-cubic-yard, roll-off container. A composite sample is collected from each roll-off container for well installation cuttings and submitted to the subcontractor laboratory for analysis in accordance with the *Kirtland AFB Construction and Demolition (C&D) Landfill Acceptance Memorandum January 2009* (USAF, 2009c). For groundwater wells, a composite sample is collected for each well location. A “Request for Disposal” letter is provided to Kirtland AFB for approval for each container, and approved roll-off bins are transported to the C&D Landfill by a subcontractor. Analytical results for all of the drill cuttings except for one well generated during the Third 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. The cuttings in one roll-off container, Bellio Number 27 associated with well location KAFB-106150, did not meet the requirements for disposal at the C&D Landfill. The contents of this roll-off bin will be disposed of offsite as nonhazardous waste by Bellio Trucking, Inc. Table 6-1 details the sampling and disposal for each roll-off bin containing waste generated during the Third Quarter 2011 activities.

6.1.2 Decontamination and Development Water

Drill rig and associated equipment used in monitoring and Pneulog well installations are decontaminated using hot, pressurized water. The decontamination water for each location is collected and stored in 250-gallon totes, combined with well development water for groundwater wells, and stored in 1,500-gallon tanks. Wastewater is stored at the BFF Spill site pending analytical results for disposal in accordance with the *Kirtland AFB Bulk Fuels Development and Sampling Purge Water Decision Tree – 12/17/10* (NMED, 2010e). Once approval for discharge is obtained from the NMED-GWQB and Kirtland AFB, the wastewater is discharged from the storage container to an approved location at the BFF Spill site, away from any water course. Table 6-2 details the sampling and disposal of the contents 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 Third Quarter 2011 sampling event, and storage location of purge water. During Third 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, KAFB-106094). For all other monitoring wells, purge water was stored pending analytical results to determine final disposition, which will occur during Fourth Quarter 2011.

6.3 SVE Internal Combustion Engine Investigation-Derived Waste

SVE ICE systems were operating at four locations during Third Quarter 2011. SVE ICE systems are in operation at the FFOR, collectively known as ST-106, and on groundwater monitoring wells KAFB-1065, KAFB-1066, and KAFB-1068. The IDW generated by these SVE ICE systems 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. The condensate waste is removed by a subcontractor for disposal offsite.

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 Third Quarter 2011, there were no pickups of waste oil or anti-freeze. Drums stored onsite await pickup during Fourth Quarter 2011.

Soil-vapor condensate generated by the SVE ICE systems is disposed of offsite as hazardous waste. All drums of condensate are manifested as hazardous waste for flammable liquids, not otherwise specified, and contain benzene and water. No SVE ICE systems condensate hazardous waste pickups occurred during Third Quarter 2011.

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 a new transect 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. The top 100 to 150 ft (Figure 7-2 through 7-6) 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 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.

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. Underlying the silty slope deposits is the upper portion of the Santa Fe Group. This unconsolidated depositional unit is observed in the subsurface geology at the BFF Spill site and is highly permeable as discussed in Section 5.4. The upper portion of the Santa Fe Group is present at depths greater than 100 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 (Figure 7-1).

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. 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 450 (Shallow Zone) to 544 ft bgs (Regional Aquifer; Table 5-3). As discussed in Section 5.5.1, 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.

Groundwater flow directions in the regional aquifer historically were generally westward towards the Rio Grande River. Locally, at the BFF Spill site, the current groundwater flow direction is approximately North 25° to 35° East. Groundwater flow direction at the BFF Spill site is influenced by production well

pumping for both the City of Albuquerque and Kirtland AFB. Water levels at the site have risen 4 to 6 ft since 2009. These water level rises are attributed to the water conservation practices put into place by the Albuquerque Bernalillo County Water Utility Authority to reduce groundwater withdrawals from the aquifer. The groundwater gradient at the site varies from 0.0004 to 0.0016 ft/ft. with an average gradient of 0.001 ft/ft.

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 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 400 or 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 and above and expansion of the areal extent and increase in concentrations at the elevation of 4,900 ft above msl 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, 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 above the present-day water table at depths of 400 to 500 ft bgs.

7.4.2 Groundwater

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

- Current groundwater flow directions are towards the KAFB-3 and Ridgecrest water supply wells 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 discussed in Section 5.2.1, the third quarter 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.
- 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 diesel range TPH 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.
- EDB is the one compound that has migrated the full length of the monitoring well network and is found in the Shallow, Intermediate, and Deep Zones in the farthest downgradient well cluster (Figures 7-7 through 7-11). TPH-GRO is also found in the farthest downgradient wells, but there is no established regulatory level for TPH-GRO and is used primarily as a surrogate indicator compound for petroleum hydrocarbon contamination.
- The concentration patterns of both EDB and TPH-GRO indicate two release periods of NAPL containing EDB. EDB concentrations in the immediate downgradient vicinity of the NAPL 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 (mL/g) (EPA, 2006), a bulk soil density (ρ_b) of 2.1 g/cm³, fraction of organic carbon of 0.00023 g/g, 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 as discussed in Section 5.6.

7.5 Data Gaps

The only outstanding data gap is data related to the EDB degradation and fate and transport mechanisms.

This data gap can be address using microbial and compound-specific isotope analyses in 2012.

8. PROJECTED ACTIVITIES AND RECOMMENDATIONS

Anticipated activities to be conducted during Fourth Quarter 2011 at the BFF Spill site include, but are not limited to, ongoing groundwater and soil-vapor monitoring, completion of installation of GWM wells, SVMWs, Pneulog well installation, and radius of influence testing (ROI), in accordance with the Final Interim Measures Work Plan (USACE, 2011d). All of the BFF SVE systems will be shut down during the month of October in preparation for the ROI testing at the end of the quarter. 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 Fourth Quarter 2011 as follows:

- Depth to water measurements will be collected for existing monitoring wells on a monthly 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 prior to the end of November, allowing at least two weeks to elapse after well development and before sample collection.
- Quarterly sampling of SVMWs, SVEWs, SVE ICEs, and GWM wells will begin on October 3, 2011, and continue throughout the fourth quarter ending December 31, 2011. All newly installed wells will be sampled during this quarter.
- Dedicated Bennett sample pump systems will be installed in new 5-inch-diameter monitoring wells as the equipment is received from the manufacturer. By the end of the fourth quarter (December 31, 2011), it is anticipated that all of the new Bennett sample pump systems will have been received and approximately 90% of the systems are anticipated to be installed. Some systems will require modifications prior to installation and therefore all pump installations will not be completed.

- 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 if additional groundwater monitoring wells are necessary for plume delineation.

8.2 Drilling Program

During the Fourth Quarter 2011, the remaining Pneulog wells (KAFB-106152, -106153, -106154, -106155, and -106156) will be installed. Additionally, drilling will begin at the LNAPL containment well (KAFB-106157). No sampling will be done during drilling and installation of either the Pneulog wells or the LNAPL containment well.

8.3 SVE Systems

During the first month of the Fourth Quarter 2011, all SVE systems will be shut down for a 30-day period to allow the system to equilibrate in preparation for the ROI testing. A total of 8 ROI tests will be conducted during the Fourth Quarter 2011 consisting of 5 single-well tests and 3 five-day tests. The ROI testing will continue through the entire quarter followed by Pneulog well testing.

When the SVE systems are turned on at the end of the Fourth Quarter 2011, the following adjustments may be made:

- ST-106, Unit 249 – No adjustments are necessary.
- KAFB-1065, Unit 335 – Unit will be shut down as a result of marginal remedial effectiveness and moved to another location based on the SVE Optimization Plan (USACE, 2011a).
- KAFB-1066, Unit 345 – No adjustments are necessary.
- KAFB-1068, Unit 344 – Remedial performance is on the decline and will be monitored to determine whether the unit will be shut down and moved to another location based on the SVE Optimization Plan (USACE, 2011a).

Recommended adjustments to the SVE system will be implemented in accordance with the *Bulk Fuels Facility SVE Optimization Plan* (USACE, 2011a) currently under review by the NMED.

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APPENDIX A

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

A-1. SVE and Treatment System Maintenance Repair and Downtime 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, July – September 2011

B-2. Data Quality Evaluation Reports – Soil, April – September 2011

B-3. Data Quality Evaluation Report – Soil Vapor, July – September 2011

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APPENDIX C

Waste Disposal Documentation

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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 July – September 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. Geophysical Logging QC Forms**
- G-6. Jet West Geophysical Logs**
- G-7. Geophysical Well Log Spreadsheet**
- G-8. Survey Plates**
- G-9. Field Work Variances**

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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

Response to Comments

I-1. First RTC

I-2. Second RTC

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APPENDIX J

Additional Cross Sections

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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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