KIRTLAND AIR FORCE BASE
ALBUQUERQUE, NEW MEXICO

Resource Conservation and Recovery Act
Facility Investigation Report
Vadose Zone
Bulk Fuels Facility Spill
Solid Waste Management Units ST-106 and SS-111

March 2014

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KIRTLAND AIR FORCE BASE
ALBUQUERQUE, NEW MEXICO

RESOURCE CONSERVATION AND RECOVERY ACT FACILITY INVESTIGATION REPORT VADOSE ZONE BULK FUELS FACILITY SPILL SOLID WASTE MANAGEMENT UNITS ST-106 AND SS-111 KIRTLAND AIR FORCE BASE, NEW MEXICO

March 2014

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

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

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This Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) has been prepared for the Bulk Fuels Facility located within the western portion of Kirtland Air Force Base, New Mexico (U.S. Environmental Protection Agency identification number NM9570024423/HWB-KAFB-10-004). This report is specific to the Vadose Zone, Solid Waste Management Unit (SWMU) ST-106 and was conducted to fulfill RCRA permit requirements for the SWMU. The primary purpose of this Vadose Zone RFI is to determine the nature and extent of contaminants of concern that may be present at SWMU ST-106, and to provide the necessary site characterization to evaluate and select the corrective measures required to address vadose contamination, which will be performed during the Corrective Measures Evaluation phase.

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Tom D. Miller

TOM D. MILLER, Colonel, USAF
Commander, 377th Air Base Wing

This document has been approved for public release.

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377th Air Base Wing Public Affairs

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PREFACE

This Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) Report was prepared by CB&I Federal Services LLC (hereafter referred to as CB&I) for the U.S. Army Corps of Engineers (USACE), under Contract No. W912DY-10-D-0014, Delivery Order 0002. It pertains to vadose zone characterization activities associated with the Kirtland Air Force Base Bulk Fuels Facility Spill, Solid Waste Management Unit SS-111, located in Albuquerque, New Mexico. This RFI Report was prepared in accordance with 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, RCRA, 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, and *Base-Wide Plans for Investigations Under the Environmental Restoration Program* (Tetra Tech, 2004).

This work was performed under the authority of the USACE, Contract No. W912DY-10-D-0014, Delivery Order 0002. Mr. John McBee is the Project Manager for the USACE Albuquerque District. Mr. Wayne Bitner, Jr. is the Kirtland Air Force Base Restoration Section Chief, and Mr. Michael Amdurer is the CB&I Project Manager. This RFI Report was prepared by Ms. Diane Agnew and Dr. Gary Hecox.

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CB&I Federal Services LLC
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CONTENTS

Section **Page**

CONTENTS (continued)

Section **Page**

CONTENTS (continued)

REFERENCES

CONTENTS (concluded)

APPENDICES

FIGURES

Figure

FIGURES (continued)

Figure

FIGURES (continued)

Figure

FIGURES (concluded)

Figure

TABLES

Table

ACRONYMS AND ABBREVIATIONS

%	percent
°F	degrees Fahrenheit
$\mu g/m^3$	microgram per cubic meter
ARCH	air-rotary casing hammer
AFB	Air Force Base
APH	air-phase petroleum hydrocarbons
amsl	above mean sea level
AST	aboveground storage tank
ASTM	ASTM International
AvGas	aviation gasoline
BFF	Bulk Fuels Facility
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, xylenes
CATOX	catalytic oxidizer
CB&I	CB&I Federal Services LLC
CFR	Code of Federal Regulations
CME	Corrective Measures Evaluation
COC	contaminant of concern
CY	calendar year
DPT	direct-push technology
DRO	diesel range organic
EDB	1,2-dibromoethane/ethylene dibromide
EPA	U.S. Environmental Protection Agency
EPH	extractable petroleum hydrocarbons
ERP	Environmental Restoration Program
FFOR	Former Fuel Offloading Rack
feet/day	feet per day
g/mol	gram per molecule
GRO	gasoline range organic
GWM	groundwater monitoring
GWQB	Ground Water Quality Bureau (NMED)
HWB	Hazardous Waste Bureau (NMED)
ICE	internal combustion engine
ID	identification
IDW	investigation-derived waste
inHg	inch of mercury
inWC	inches of water column

ACRONYMS AND ABBREVIATIONS (continued)

JP-4	jet propellant grade 4
JP-8	jet propellant grade 8
KAFB	Kirtland AFB
L	liter
mg/kg	milligram per kilogram
mL	milliliter
mL/g	milliliter per gram
MW	molecular weight
NAPL	non-aqueous phase liquid
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
O.D.	outside diameter
PAH	polynuclear aromatic hydrocarbons
PID	photoionization detector
ppbv	part per billion by volume
ppm	parts per million
ppmv	part per million by volume
Praxis	Praxis Environmental Technologies, Inc.
QA	quality assurance
QAPjP	Quality Assurance Project Plan
QC	quality control
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
ROI	radius of influence
rpm	revolution per minute
RSL	regional screening level
scfm	standard cubic feet per minute
SOP	standard operating procedure
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
SWMU	Solid Waste Management Unit

ACRONYMS AND ABBREVIATIONS (concluded)

TCLP	Toxicity Characteristic Leaching Procedure
TPH	total petroleum hydrocarbons
TPH-DRO	total petroleum hydrocarbons as diesel range organics
TPH-GRO	total petroleum hydrocarbons as gasoline range organics
TVPH	total volatile petroleum hydrocarbons
USAF	U.S. Air Force
USACE	U.S. Army Corps of Engineers
VA	Veterans Affairs
VOC	volatile organic compound
VPH	volatile petroleum hydrocarbons

EXECUTIVE SUMMARY

CB&I Federal Services LLC (hereafter referred to as CB&I) was tasked by the U.S. Army Corps of Engineers (USACE) to perform a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) at the Bulk Fuels Facility (BFF) located within the western portion of Kirtland Air Force Base (AFB), New Mexico (U.S. Environmental Protection Agency identification number NM9570024423/HWB-KAFB-10-004). The BFF is comprised of two solid waste management units (SWMUs), 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 is designated as SWMU ST-106. The non-aqueous phase liquid (NAPL)-impacted groundwater component of the project is designated as SWMU SS-111.

This report is specific to SWMU ST-106 to fulfill RCRA permit requirements for the SWMU. Groundwater data will be addressed separately in the Groundwater Zone RFI (submitted under separate cover), which is specific to SWMU SS-111. The work for the Vadose Zone RFI was performed under Contract No. W912DY-10-D-0014, Delivery Order 0002.

The primary purpose of this Vadose Zone RFI is to determine the nature and extent of contaminants of concern (COCs) that may be present at SWMU ST-106, and provide the necessary site characterization to evaluate and select the corrective measures required to address vadose zone contamination, which will be performed during the Corrective Measures Evaluation (CME) phase. The key data and findings presented in this Vadose Zone RFI Report are summarized as follows:

Site Background and Setting

- The BFF was used for fuel storage and processing as early as 1951, and contained aviation gasoline, jet propellant grade 4 fuel, and jet propellant grade 8 fuel. The use of aviation gasoline and jet propellant grade 4 was phased out in 1975 and 1993, respectively. The original BFF was used until

1999, when below-grade line leakage along the Former Fuel Offloading Rack was discovered. A temporary facility was installed, and a new facility was completed in 2012.

- Contamination in the surface soil, subsurface soil, and groundwater appears to be a result of various releases that have occurred over the operational history of the facility. Some releases are more specifically defined, whereas others are not well documented and are inferred to have been ongoing for unknown periods of time.

- An investigation was conducted in 2000 in response to discovery of the below-grade line fuel leakage. Total petroleum hydrocarbons (TPH) was identified in the surface and subsurface soil samples collected during the investigation at levels above the New Mexico Environmental Department NMED total petroleum hydrocarbons Screening Guideline of 1,000 mg/kg**.**

- Four internal combustion engine (ICE) soil vapor extraction (SVE) units were operational as an interim measure at ST-106 until December 21, 2012 when they were permanently shut down. These units were fully decommissioned in June 2013. A new SVE system with a catalytic oxidizer (CATOX) unit was installed at the BFF to replace the ICE SVE units. The official operational date of the SVE system following shakedown tests and ROI testing was March 15, 2013.

Scope of RFI Activities

- Two shallow soil (less than 20 feet below ground surface) sampling tasks were completed during the RCRA Facility Investigation: soil samples were collected around the footprint of the former above-ground fuel tanks and along the former fuel offloading rack (FFOR) and pipelines.

- A total of 285 SVM and Soil Vapor Extraction Wells (SVEW) were installed between October 2000 and October 2013. These 285 individual wells are located in 64 separate clusters.

  - During December 2010 and August 2011, 210 SVMWs were installed at 35 locations with each location consisting of a cluster of six monitoring wells.

  - Seventy five wells (SVM and SVEW) were installed by previous contractors between October 2000 and May 2010. These 75 wells were installed at 29 locations with each location ranging from a single monitoring well to a cluster of up to four monitoring wells.

- The deep soil investigation at ST-106 included the installation of soil vapor monitoring (SVM) and PneuLog® wells.

  - Four PneuLog® well clusters (KAFB-106148, KAFB-106149, KAFB-106150, and KAFB-106151) were installed during Third Quarter CY 2011, and five PneuLog® well clusters were installed during Fourth Quarter CY 2011 (KAFB-106152, KAFB-106153, KAFB-106154, KAFB-106155, and KAFB-106156).

  - PneuLog® well clusters KAFB-106148, KAFB-106149, and KAFB-106150 were tested during Second Quarter CY 2012 using Praxis' pneumatic well logging technology. In consultation with, and agreement from NMED, only these three clusters were logged due to their location above the historic NAPL plume.

- Soil cuttings were lithologically logged during the shallow soil boring advancement and during installation of the SVMWs and PneuLog® wells.

- Deep soil borehole samples were collected using a split-spoon sampler during drilling of the 35 SVMW clusters, as well as during drilling of groundwater monitoring wells KAFB-106061, KAFB-106062, KAFB-106078, and KAFB-106081.

- Two radius of influence (ROI) tests were conducted at ST-106 during the vadose zone investigation to characterize the vadose zone and inform SVE requirements.

- Quarterly soil vapor sampling is conducted at 285 SVM and SVEW monitoring points (64 well clusters).

Investigation Results

- Based on the detailed lithologic logs, there are two depositional units present at SWMU ST-106, with considerable variability within each unit. The upper 100 to 200 feet of soil consist of younger silty deposits. The upper portion of the Santa Fe Group is directly below these silty deposits, and consists of loose, unconsolidated, highly porous and permeable interbedded sand and gravel with some clay lenses.

- The following 10 COCs have been identified in the soil at SWMU ST-106: 1,2,4-trimethylbenzene, benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenz(a,h)anthracene, ethylbenzene, indeno(1,2,3-cd)pyrene, naphthalene, TPH-DRO, and TPH-GRO.

- VOCs have been consistently detected in the quarterly soil vapor samples.

- Shallow (0 to 20 ft bgs) soil investigation results shows volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) above 2012 residential soil screening levels (SSLs). Additionally, 238 shallow soil samples had TPH-gasoline range organic (GRO) or diesel range organic (DRO) concentration greater than the NMED TPH Screening Guideline of 1,000 mg/kg. The samples exceeding screening levels are primarily located along the former FFOR pipeline north and west of Building 1033.

- One split-spoon soil sample, representing the interval 400 to 450 ft bgs (collected at 447 to 448.5 bgs), was identified with a TPH-(GRO+DRO) concentration greater than the NMED TPH Screening Guideline of 1,000 mg/kg –at location KAFB-106120.

- PneuLog® vadose zone testing generated distinctive permeability and vapor concentration profiles. In general, the permeability increases with depth, consistent with the lithologic data where the upper 250 feet of the vadose zone is finer-grained than the deeper intervals. In addition, the results for two of the three PneuLog® tests (KAFB-106149 and KAFB-106150) show increasing vapor hydrocarbon concentrations with depth.

- Data from the ROI tests showed an ROI of approximately 350 and 300 feet for the 450 ft bgs SVM wells and the 484 ft PneuLog well, respectively.

Nature and Extent of Contamination

- The area of highest COC contamination is along the western arm of the former fuel line in the area of known leakages east of the FFOR. There are two areas where the source of contamination has been delineated:
  - The first is west of the 90˚ bend in the pipeline towards the FFOR.
  - The second is located approximately 150 to 230 ft west of the 90˚ bend in the former pipeline.

- Based on split spoon sampling results, only TPH-GRO was identified in the deep soil at concentrations exceeding the NMED SSLs in one sample. No other deep soil samples collected between 2011 and 2013 exceeded NMED SSLs. In addition, no available deep soil sample analytical results collected between 2006 and 2011 had exceedances of regulatory criteria.

- The highest benzene and total VOC concentrations at the 50 and 150 foot depths are located in proximity to known spill locations. The Total VOC and benzene vapor cross sections at this depth interval depict an area of concentration greater than 1,000 ppmv approximately 500 feet wide directly beneath the FFOR. A second zone of concentrations greater than 1,000 ppmv is delineated from approximately 400 feet bgs to the top of the water table (currently at approximately 500 ft bgs), and is approximately 600 to 700 ft wide.

- The maximum concentrations of benzene and total VOCs in samples collected at 350 and 450 feet bgs are located approximately 1,200 feet to the south and east of the FFOR in all quarters. This indicates movement of contaminants in a southeasterly direction as they moved downward through the soil column.

Contaminant Fate and Transport

- Water-table changes have impacted the distribution and migration of vadose zone contamination. Water levels have declined approximately 140 feet (from 4,953 feet to 4,811 feet in elevation currently) since 1949 with the majority of the water-level decline (over 100 feet) since 1975.

- As the water table declined due to regional groundwater extraction, the NAPL followed the water table downward. Over time, this had the effect of creating a residual NAPL smear zone from nominal depths of 400 to 500 feet bgs.

- Groundwater levels below SWMU ST-106 have risen between 7.5 and 10 feet since 2009 due to conservation practices. As the water table started rising, the NAPL that could flow into monitoring wells (i.e., NAPL residing on the water table) became trapped below the water table. Although the remaining NAPL is currently trapped below the water table, the NAPL “body” can act as a potential source of contamination to adjacent soil and soil vapor if groundwater levels fluctuate.

- The highest benzene and total VOC soil vapor concentrations at the 50 and 150 foot depths are located directly below the FFOR, and the area of the known spill locations. The maximum concentrations of benzene and total VOCs in samples collected at 350 and 450 feet bgs are located to the south and east of the FFOR, demonstrating movement of contaminants in a southeasterly direction in addition to downward migration toward the water table. This migration pathway is likely due to a combination of lithologic constraints and changing water table elevations.

- Due to the varying physical and chemical properties of each contaminant as the NAPL travels through the vadose zone, COCs are detected at various depths from the NAPL source. The total VOC's have vapor hotspots that do not directly correspond with the benzene hotspots. This suggests that COCs are moving out of the NAPL body at different rates governed by their physiochemical properties.

- Quarterly soil vapor analytical data, FFOR soil sampling data, and PneuLog testing data indicate a zone of higher vapor concentrations originating beneath the FFOR (SVEW-01 through SVEW-09) and terminating at the water table to the southeast.

- Since First Quarter of CY 2011, the amount of biodegradation occurring in the vadose zone at the BFF has been estimated using The Air Force Civil Engineer Center – Environmental Center of Excellence published guidance. Between January 2011 and June 2013, approximately 42,900 gallons of hydrocarbons have been degraded via biodegradation.

Conclusions

- Based on the results of analytical samples for soil and soil vapor, soil boring logs, PneuLog® testing, and ROI testing, the nature and extent of contamination have been adequately defined at SWMU ST-106, with the exception of 1,2-dibromoethane/ethylene dibromide (EDB) in soil vapor.

- EDB in soil vapor was analyzed using the EPA Method TO15 in accordance with the approved Vadose Zone Work Plan. The detection limits afforded by this method resulted in numerous non-detects for EDB in soil vapor each quarter. As a result, EDB soil vapor data is presented as "dot maps" rather than contoured plume maps, and quantitative evaluation of EDB in soil vapor requires additional data.

- Shallow soil contamination (to a depth of 20 feet bgs) was delineated during the FFOR sampling task. The majority of shallow soil contamination is located in two discreet areas along the former pipeline from Building 1033 to the FFOR. These locations roughly correspond to known spill locations. The delineation of hydrocarbon contamination in shallow soil, in conjunction with the soil vapor analytical data, confirms the pipeline near the FFOR as a source of contamination at ST-106.

- A total of 10 COCs have been identified in soil at SWMU ST-106; these are compounds with detections greater than their applicable screening levels. The primary contaminants of concern in soil at SWMU ST-106 are 1,2,4 trimethylbenzene, PAHs, and TPH based on results of shallow and deep soil sampling between 2006 and 2013.

- Quarterly sampling results demonstrated that total area of VOC and benzene soil vapor contaminant plumes have been decreasing since Second Quarter CY 2011.

- No screening levels exist for soil vapor and therefore no soil vapor COCs have been identified for ST-106 as part of the Vadose Zone RFI. The Risk Assessment (to be delivered as a separate document) will evaluate risk-based criteria for soil vapor remediation.

- The RFI data collected meet the quality requirements set forth in the BFF Spill Quality Assurance Project Plan (QAPjP) as well as the applicable work plans and letters listed in Section 1 and are sufficient for informing future actions at SWMU ST-106. Analytical soil and soil vapor sampling, soil boring logs, PneuLog® testing, and ROI testing were the primary data sources for completing the RFI.

Recommendations

- Completion of a Risk Assessment (submitted under separate cover);
- Perform one quarter of soil vapor sampling for EDB using the CARB422Mod analysis. Due to the analytical methods used in quarterly soil vapor sampling (USACE, 2011a), quantitative evaluation of EDB in soil vapor remains a data gap for ST-106.
- Complete a CME for SWMU ST -106 to identify applicable cleanup standards, determine remedy evaluation criteria, and propose a preferred remedy to address contamination that poses a risk to human health and the environment.

1. INTRODUCTION

CB&I Federal Services LLC (hereafter referred to as CB&I) was tasked by the U.S. Army Corps of Engineers (USACE) to perform a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) at the Bulk Fuels Facility (BFF) located within the western portion of Kirtland Air Force Base (AFB), New Mexico (U.S. Environmental Protection Agency [EPA] identification number [ID#] NM9570024423/HWB-KAFB-10-004) (Figure 1-1). The BFF is comprised of two solid waste management units (SWMUs), 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 Off-Loading Rack (FFOR) is designated as SWMU ST-106. The non-aqueous phase liquid (NAPL)-impacted groundwater component of the project is designated as SWMU SS-111.

This report is specific to SWMU ST-106 to fulfill RCRA permit requirements for the SWMU. Groundwater is addressed within a separate Groundwater Zone RFI Report for SWMU SS-111 (USACE, 2014). The work for the Vadose Zone RFI Report was performed under Contract No. W912DY-10-D-0014, Delivery Order 0002, and in accordance with the Vadose Zone Investigation Work Plan (USACE, 2011a), the additional documents listed in Section 1.2, and correspondence in Appendix A.

1.1 Purpose and Objectives

The primary purpose of the Vadose Zone RFI is to determine the nature and extent of contaminants of concern that may be present at SWMU ST-106. The primary purpose of this Vadose Zone RFI Report is to present the results of the RFI activities and the information collected to assess the potential risks to human health and the environment. The information gathered during the RFI was necessary to accomplish the following objectives:

- To characterize the nature and extent of contamination within SWMU ST-106 (the vadose zone).
- To provide the necessary site characterization to evaluate and select the corrective measures required to address vadose zone contamination, which will be performed during the Corrective Measures Evaluation (CME) phase.

1.2 Regulatory History and Regulatory Criteria

This SWMU ST-106 Vadose Zone RFI Report was prepared in accordance with all applicable federal, state, and local laws and regulations, and site-specific directives, including the following:

- New Mexico Hazardous Waste Act New Mexico Statutes Annotated, 1978
- New Mexico Hazardous Waste Management Regulations, 20.4.1 NMAC
- RCRA
- Base-Wide Plans for Investigation under the Environmental Restoration Program (ERP), Standard Operating Procedures (SOPs)
- Hazardous Waste Treatment Facility Operating Permit, EPA ID No. NM9570024423 dated July 2010
- Four directive letters from NMED dated April 2, June 4, August 6, and December 10, 2010 (Appendix A)
- Regulatory correspondence between the NMED and the Air Force regarding the BFF Spill at Kirtland AFB (Appendix A)

In addition, the Vadose Zone RFI Report was prepared in accordance to the following documents:

- Pre-Remedy Monitoring and Soil-Vapor Extraction System Operation and Maintenance Work Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated February 2011 (USACE, 2011b).
- Interim Measures Work Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated March 2011 (USACE, 2011c).
- Vadose Zone Investigation Work Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated March 2011 (USACE, 2011a).
- Quality Assurance Project Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated August 2011 (USACE, 2011d).
- Soil-Vapor Extraction Optimization Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated September 2011 (USACE, 2011e).

- Indoor Air Evaluation Work Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated November 2011 (USACE, 2011f).
- Former Fuel Offloading Rack Excavation and Step-Out Conflicts Addendum to Interim Measures Work Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated February 2012 (USACE, 2012a).
- Soil Vapor Extraction System Components Partial Design Interim Measures Work Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, Addendum, dated April 2012 (USACE, 2012b).
- Pre-Remedy Monitoring and Soil-Vapor Extraction System Operation and Maintenance Work Plan Addendum for Monitoring Program Optimization, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated January 2013 (USACE, 2013a).
- Former Fuel Offloading Rack Step-Out Conflicts Addendum to Interim Measures Work Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated April 2013 (USACE, 2013b).
- Phase II Remediation Interim Measures Plan Soil-Vapor Extraction Treatment System Design, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated August 2013(USACE, 2013c).
- Soil-Vapor Extraction System Expansion Work Plan Part I: Candidate Well Identification and Pilot testing, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated October 2013 (USACE, 2013d).

1.3 Report Organization

This Vadose Zone RFI Report was prepared in accordance with the requirements of Section 6.2.4.3 "Investigation Reports" of the Hazardous Waste Treatment Facility Operating Permit. The following table presents the permit requirements and the corresponding section of this report:

Hazardous Waste Facility Permit Requirements	RFI Report Section
Title Page and Signature Block	Report Documentation Page, 40 CFR 270.11 Document Certification, and Preface
Executive Summary	Executive Summary
Table of Contents	Table of Contents
Introduction	Section 1.0 Introduction
Background Information	Section 2.0 Background Information and Section 3.0 Site Settings
Scope of Activities	Section 4.0 Scope of Activities
Field Investigation Results	Section 5.0 Field Investigation Results
Regulatory Criteria	Section 1.2 Regulatory History and Regulatory Criteria
Site Contamination	Section 5.0 Field Investigation Results and Section 6.0 Contaminant Fate and transport
Conclusions and Recommendations	Section 7.0 Conclusions and Recommendations

Figures and tables are provided in separate tabs following the body of the report.

Appendices to this report include the following:

Appendix A	Correspondence Letters
Appendix B	Well Installation Forms
Appendix C	Historical Data Summaries
Appendix D	PnueLog® Evaluation Report
Appendix E	Field Sampling Data and Records
Appendix F	Geophysical Records
Appendix G	Radius of Influence Testing Results
Appendix H	Data Quality Evaluation Reports and Data Packages
Appendix I	Time Series Plots
Appendix J	Waste Disposal Documentation
Appendix K	NAPL Calculations
Appendix L	Cross Sections

2. BACKGROUND INFORMATION

2.1 Site Description

Kirtland AFB is located in Bernalillo County in central New Mexico, southeast of and adjacent to the City of Albuquerque and the Albuquerque International Sunport (Figure 1-1). The approximate area of the base is 52,287 acres, and it is bordered by Albuquerque to the north and west, the Isleta Pueblo Reservation to the south, and the Cibola National Forest to the east.

The BFF is located in the western portion of Kirtland AFB, and is comprised of two SWMUs, designated as ST-106 and SS-111. The vadose zone component of the BFF is designated as SWMU ST-106. The NAPL-impacted groundwater component of the BFF is designated as SWMU SS-111. The BFF currently contains bulk storage for jet propellant grade 8 (JP-8), diesel fuel, and unleaded gasoline. A new fueling infrastructure was installed between 2011 and 2012, replacing the fuel infrastructure that was discovered to be leaking in November 1999. A temporary, alternate system was utilized while a new system was designed and constructed. JP-8 is currently stored in two aboveground storage tanks (ASTs) (2.1 and 2.4 million gallons) that replaced the original ASTs in 2011. The fuel delivered to the JP-8 off-loading rack (Building 2405) is conveyed to the Pump House (Building 1033) via aboveground transfer lines. Refueling trucks routinely fill up at the facility and transport fuel as needed to the base flightline.

2.2 Operational History of BFF

Historical aerial photography reveals that the BFF area was used for fuel storage and processing as early as 1951 (CH2M HILL, 2001). At that time, the fueling area was separated into a distinct tank-holding area where bulk shipments of fuel were received (near the location of existing well KAFB-1066), and a separate fuel-loading area where individual fuels trucks were filled. The fuel-loading area was approximately 250 feet north of the tank-holding area.

Subsequent aerial photographs indicate that construction of the facility and associated infrastructure took place from 1951 until 1953. Once completed, the facility operated until it was removed from service in 1999, as a result of below-grade line leakage along the off-loading rack (CH2M HILL, 2001). A temporary, alternate loading rack was used while new, replacement infrastructure was designed and constructed. Bulk storage for JP-8 and aviation gasoline (AvGas) was managed in the eastern portion of the facility. A 250-gallon underground storage tank was located near the Pump House, Building 1033 (CH2M HILL, 2001). The three types of fuel handled by the BFF were AvGas, jet propellant grade 4 (JP-4), and JP-8. The use of AvGas and JP-4 at Kirtland AFB was phased out in 1975 and 1993, respectively. JP-8 was handled through the FFOR until the leak was discovered in 1999, after which it was handled through a temporary rack until a new replacement rack was completed in 2011.

Contamination in the subsurface soil and groundwater appears to be a result of various releases that have occurred over the operational history of the facility. Conceptually, releases could have occurred when fuel was transferred from railcars, through the FFOR to the Pump House, and then to the bulk fuel storage containers on the south end of the site (Tanks 2420 and 2422). Fuel transfer from the railcars to the Pump House was performed under vacuum transfers. Transfer of fuel from the Pump House to the bulk storage containers was performed under pressurized conditions. Some releases are more specifically defined, whereas others are not well documented and are inferred to have been ongoing for unknown periods of time. There are three known discharges resulting from the failure of belowground transfer lines and a cam-lock coupling failure that were discovered during pressure tests performed in November 1999 (CH2M HILL, 2001). The probable release points have been investigated and are summarized below.

In November 1999, pressure testing on the buried 14-inch diameter transfer line between the off-loading rack and the Pump House (Building 1033) was conducted under the direction of Kirtland AFB Environmental Management after staining was noted at the surface. A line-integrity test was conducted, and the line and a valve failed. Subsequently, an adjacent parallel 14-inch line failed the pressure test.

Integrity checks of remaining buried lines at the facility were performed after these findings of the pipe leaks. The pressure tests concluded that subsurface fuel leakage has likely been occurring for an extended period of time (KAFB, 1999).

Currently, JP-8 is stored in two ASTs (2.1 and 4.2 million gallons), diesel fuel is stored in two ASTs (one 5,000-gallon AST and one 10,000-gallon AST), and unleaded gasoline is stored in one 10,000-gallon AST. The site currently operates with one JP-8 off-loading rack located in the southwest corner of the facility, west of the fuel-loading structure (Building 2404). This rack was placed into service following the November 1999 piping failure at the FFOR (ST-106). A second small off-loading rack (Building 2401) is used for the delivery of diesel and unleaded gasoline motor vehicle fuels. Fuel delivered to the JP-8 off-loading rack is conveyed to the Pump House (Building 1033) via aboveground transfer lines. The fuel is then pumped to the JP-8 ASTs by piping of varying sizes that runs aboveground for approximately 750 feet and runs belowground for approximately 300 feet. Figure 2-1 depicts the infrastructure present at the eastern portion of the BFF source area.

2.3 Previous Investigations

In November 1999, three known discharges were discovered during pressure testing of the lines that transferred fuel from the JP-8 off-loading rack (Building 2405) to the Pump House. A summary of subsequent investigations is provided in the following subsections, with a focus on the information pertinent to the vadose zone characterization at ST-106.

2.3.1 Stage 1 Abatement Plan Report (CH2M HILL, 2001)

Stage 1 Abatement Plan activities were conducted in 2000 and included the following: collection of surface (defined in the report as less than 40 feet below ground surface [bgs]) and subsurface soil samples, completion of a soil gas screening survey, and the installation of groundwater well (KAFB-106-1). Additionally, soil borings SB-28A, SB-29A, and SB 30 through SB 34 were completed as soil vapor monitoring well nests. The Stage 1 Abatement Plan Report (CH2M HILL, 2001) states that total petroleum hydrocarbons (TPH) were identified in the surface and subsurface soil samples collected during the investigation. Surface soil samples collected near the off-loading rack had maximum TPH concentrations ranging from 34,000 milligrams per kilogram (mg/kg) to 51,000 mg/kg. The maximum concentration detected in the subsurface was from boring SB-26, which was 114,000 parts per million (ppm) of TPH in the sample from 270 feet bgs. A groundwater sample was collected from the newly installed well KAFB-1061, and results of the groundwater samples showed no contaminants above screening levels.

2.3.2 Stage 2 Abatement Plan for the Bulk Fuels Facility (ST-106) (CH2M HILL, 2002)

A Stage 2 Abatement Plan describes the geology, hydrogeology, and surface water hydrology of the site, and the waste characteristics of JP-4 and JP-8. This Abatement Plan also presented potential abatement options for the contaminated soil and soil gas in the vadose zone and contaminated groundwater in the saturated zone. The report proposed a SVE pilot-scale test to evaluate the viability of using SVE technology to remove volatile organic compounds (VOCs) from the vadose zone and prevent further migration of those contaminants. The report recommended the installation of an additional groundwater monitoring well for inclusion in the quarterly monitoring program. This well was proposed for installation between the site and both the Veterans Affairs well and the Kirtland AFB water supply well, KAFB-15.

2.3.3 Soil Vapor Extraction Pilot-Scale Test at the Bulk Fuels Facility, November 6, 2003 (CH2M Hill, 2003)

The Report on the Soil Vapor Extraction Pilot-Scale Test at the Bulk Fuels Facility (CH2M Hill, 2003) describes the SVE pilot-scale test conducted at the BFF. Furthermore, the report states that the pilot-scale test incorporated an SVE and treatment system utilizing internal combustion engine (ICE) technology rather than the traditional blower and catalytic or thermal oxidation technology. In addition, the report states that the treatment unit for both the pilot-scale test and full-scale system will be comprised of a trailer-mounted pair of computer-controlled 460-cubic-inch displacement ICEs. The report recommended that a total of nine soil-vapor extraction wells (SVEWs), screened at various depths, be used at the western and eastern ends of the FFOR. The nine wells would include one 4-inch-diameter extraction well and eight 2-inch-diameter wells.

2.3.4 Stage 2 Abatement Plan, Summary, and Performance Report for the Soil Vapor Extraction and Treatment System, Bulk Fuels Facility (ST-106) (CH2M HILL, 2006a)

The Stage 2 Abatement Plan Report was prepared to document the construction and start-up of the SVE and treatment system, as well as the first year of operation, optimization, and monitoring. Construction of the SVE and treatment system was performed in two stages: extraction well drilling, and system installation and start-up. Eight extraction wells were installed during August and September 2003. Wells were constructed of 2-inch-diameter stainless steel with screens at varying depths from 45 to 60 feet bgs down to 445 to 460 feet bgs; complete construction details are provided in the 2006 report. System installation and start-up was performed from April through September 2004, and the first year of operation and monitoring was performed from October 2004 through September 2005. Soil vapor samples were collected from the extraction wells following well installation and again during system start-up and the first year of operation. During the start-up period, soil vapor samples were collected from the extraction wells, combined system inlet flow, engine exhaust, and local vapor monitoring wells. Soil vapor samples were collected for analysis of VOCs, TPH, acetone, and the fixed gases, i.e., oxygen, nitrogen, carbon monoxide, carbon dioxide, and methane.

Thirty soil samples were collected during installation of the extraction wells and analyzed for VOCs, semi-volatile organic compounds (SVOCs) and TPH. The report states that benzene, toluene, total xylenes, total petroleum hydrocarbons as diesel range organics (TPH-DRO), and total petroleum hydrocarbons as gasoline range organics (TPH-GRO) were detected at concentrations exceeding the

NMED residential soil screening levels (SSLs). On the east end of the FFOR, the maximum TPH-(DRO + GRO) concentration was 38,000 mg/kg at 60 feet bgs in SVEW-02/03. At SVEW-04/05, the maximum concentration of TPH-GRO was 1,200 mg/kg at 220 feet bgs. The maximum concentration of TPH-DRO was found in the upper 80 feet bgs, with 27,000 mg/kg at 40 feet bgs, and 21,000/28,000 mg/kg (duplicate samples) at 80 feet bgs. At SVEW-06/07, the concentration of TPH-GRO increased with depth from 640 mg/kg at 60 feet bgs to 3,300 mg/kg at 160 feet bgs. The TPH-DRO concentration increased from 13,000 mg/kg at 60 feet bgs to 24,000 mg/kg at 100 feet bgs. On the west end of the FFOR, the maximum TPH-(DRO + GRO) concentration was 36,700 mg/kg at 20 feet bgs in SVEW-08/09. The report recommended continued quarterly monitoring of the vapor and continued operation of the SVE systems.

2.3.5 Stage 1 Abatement Plan Report, East Side of the Kirtland AFB Bulk Fuels Facility (CH2M HILL, 2006b)

The Stage I Abatement investigation report presents the results of a 2005 shallow surface soil investigation conducted on the east site of the BFF. As part of the investigation, soil samples were collected from the following areas:

- Former Wash Rack Drain Field
- Three fuel-storage ASTs
- Former Fuel/Water Evaporation Pond
- Recovered Liquid Fuel Collector Tank
- Primary fuel-storage ASTs and tank bottom water-holding tanks

The investigation included the following:

- Excavation of three test pits (TP-06, TP-07, and TP-08) and advancement of a direct-push borehole (SB-04) to 50 feet bgs at the Former Fuel/Water Evaporation Pond. There were no exceedances of the NMED residential SSLs in any samples collected at this location.
- Excavation of five test pits (TP-01, TP-02, TP-03, TP-04, and TP-05) and advancement of two direct-push boreholes (SB-01 to 50 feet bgs and SB-02 to 25 feet bgs) at the Former Wash Rack Drain Field. There were no exceedances of the NMED residential SSLs in any samples collected at this location.

- Advancement of one direct-push borehole (SB-03 to 25 feet bgs) and one hand-auger borehole (SB-10 to 2 feet bgs) by the three fuel-storage ASTs (Tanks 2427, 2428, and 2429). There were no exceedances of the NMED residential SSLs in any samples collected at this location.
- Advancement of one direct-push borehole (SB-05 to 25 feet bgs) at the Recovered Liquid Fuel Collector Tank. There were no exceedances of the NMED residential SSLs in any samples collected at this location.
- Advancement of four direct-push boreholes (SB-06 to 45 feet bgs, SB-07 to 50 feet bgs, SB-08 to 48 feet bgs, and SB-09 to 25 feet bgs) by the primary fuel-storage ASTs (Tanks 2420 and 2422) and tank bottom water-holding tanks. TPH-DRO was detected in exceedance of the NMED TPH guideline of 1,000 mg/kg (NMED, 2012) in two samples from SB-09; concentrations of 2,400 mg/kg (15 to 17 feet bgs) and 1,800 mg/kg (25 to 27 feet bgs) were detected.

Additionally, temporary soil-vapor monitoring points were installed in all direct-push boreholes and monitored for hydrocarbon concentrations with field monitoring equipment for several quarters. Hydrocarbon vapor readings at SB-09 were identified in the report as “elevated” with concentration of 2,780 ppmv.

2.3.6 Previous Contractor Quarterly and Semiannual Reports at the Bulk Fuels Facility

Monitoring reports have been submitted on a quarterly and annual basis by following the predetermined schedule presented in the Stage 2 Abatement Plan, Summary and Performance Report for the Soil Vapor Extraction and Treatment System, Bulk Fuels Facility (ST-106), Kirtland Air Force Base (CH2M Hill, 2006a). Quarterly and semiannual reporting incorporates information and data collected in support of ongoing remediation and site characterization activities related to SWMUs ST-106 and SS-111 and can be found in the Kirtland Administrative Record, located at the Central New Mexico (CNM) Community College-Montoya Campus Library in Albuquerque.

A brief chronology of the previous SVE systems is presented below:

- CH2M HILL completed construction on an SVE system using an ICE unit for combustion of extracted vapor in July 2004. The system extracted vapor from wells SVEW-01 through SVEW-09 within the FFOR area.

- On August 13, 2008, a second interim SVE ICE system was installed using the existing groundwater monitoring well KAFB-1065.
- Two additional SVE ICE systems were installed at wells KAFB-1066 and KAFB-1068 on March 5, and 26, 2009 respectively. These two systems, along with the system at KAFB-1065, are referenced as the "SS-111 SVE Systems."
- In October 2011, the four SVE ICE systems were shut down for the preparation of radius of influence (ROI) testing. Based on an evaluation of system performance during operations in 2011, the four units were re-located in order to increase system performance. During April 2012, Remediation Service International Unit 335 was moved to KAFB-106149-484, RSI Unit 344 was moved to KAFB-106161, and Remediation Service International Unit 345 was moved to KAFB-106160. The ST-106 unit was connected through manifold piping to nine SVEWs, SVEW-01 through SVEW-09.
- All four ICE SVE units were permanently shut down on December 21, 2012 and fully decommissioned in June 2013. A new SVE system with a catalytic oxidizer (CATOX) unit was installed at the BFF to replace the ICE SVE units. ROI testing for the new SVE unit began on January 29, 2013 and concluded on March 7, 2013, to determine the optimum setting at which the SVE would operate. The official operational date of the SVE system following shakedown tests and ROI testing was March 15, 2013. Figure 2-2 illustrated the final locations of the ICE SVE units and the location of the current CATOX unit.

2.4 Data Gaps

Data gaps related to the nature of fuel contamination and the extent of contamination resulting from past operational history at the BFF were identified in the Vadose Zone Investigation Work Plan (USACE, 2011a) and are as follows:

- Determine the amount of fuel that exists within the vadose zone.
- Identify the source of the NAPL fuel plume.
- Characterize the vadose zone hydrogeology and its relationship to the groundwater.
- Characterize the geology and extent of contamination in the soil (soil has to determine distribution, fate, and migration of soil contaminants and vapors).
- Characterize contaminants within soil around fuel storage tank and piping.
- Characterize the contaminants within soil around the FFOR.
- Determine the amount and source areas of fuel in the vadose zone (e.g., tanks, pipes, FFOR).

3. SITE SETTING

3.1 Physiography

Kirtland AFB is located within the Albuquerque Basin, immediately southeast of the City of Albuquerque in Bernalillo County. The base covers diverse terrain ranging from mountainous relief to the east in the foothills of the Manzanita Mountains to plains in the western portion of the base. Kirtland AFB is approximately 52,287 acres in area. The topography of the BFF project site is relatively flat, ranging from 5,314 feet above mean sea level (amsl) to 5,364 feet amsl.

Land use within the base is currently industrial, including military and U.S. Department of Energy operations, research and development facilities, medical facilities, open space, military family housing, and community facilities. At the time of this investigation, Kirtland AFB did not own any facilities off base; however, the eastern portion of the base is primarily Cibola National Forest land, which was withdrawn from public use for military purposes. The BFF is currently used for bulk storage of JP-8, diesel fuel, and unleaded gasoline. Refueling trucks routinely fill up at the BFF and transport fuel as needed to the base.

3.2 Climate

The Albuquerque area is dominated by a sunny, arid to semi-arid, low humidity, high-altitude climate. In summer, daily high temperatures in the vicinity of Kirtland AFB average 90 degrees Fahrenheit (°F) with low temperatures averaging 62°F. In winter, daily high temperatures average 58°F and daily lows average 38°F (National Climate Data Center, 2006). Rainfall for the Albuquerque area averages 8.3 inches per year. The summer monsoon season (July through October) accounts for one-half of the annual rainfall. Prolonged periods of continuous precipitation are rare. The snow season extends from November to early April. Snowfall is not uncommon in winter months, but seldom exceeds 3 inches at lower elevations.

Meteorological data collected at the Albuquerque International Sunport show that the prevailing wind direction from May through October is south or southeast, and the mean wind speed is 7 to 9 knots. From November through April, the prevailing wind direction is north or northeast, and the mean wind speed is 6 to 9 knots (Tetra Tech, 2004). Strong winds occur primarily in late winter and early spring.

3.3 Regional Geology

The geology of the Kirtland AFB area varies in accordance with the regional geology. The eastern portion of the base is mountainous with elevations reaching 7,900 feet amsl. These mountains are composed of Precambrian metamorphic, igneous (primarily granite), and Paleozoic sedimentary rock (primarily marine carbonates). The western portion of the base (which includes the BFF) lies within the Albuquerque Basin. Geologic features in this area of the basin include travertine, unconsolidated and semi-consolidated piedmont deposits, as well as aeolian, lacustrine, and stream channel deposits.

In general, the surficial geology is characterized by recent deposits (mixtures of sandy silt and silty sand with minor amounts of clay and gravel), 1.6 to 5.3-million-year-old Ortiz gravel (alluvial piedmont sand and gravel deposits), and the Santa Fe Group (a mixture of sand, silt, clay, gravel, cobbles, and boulders). Generally, the northern and western portions of Kirtland AFB lie within the unconsolidated geologic units of the recent alluvial piedmont sand and gravel deposits and the Santa Fe Group. Eastern portions of Kirtland AFB are characterized by fractured and faulted bedrock covered by a thin layer of piedmont slope alluvium (bedrock is generally buried by less than 200 feet of alluvium). Kirtland AFB lies within the eastern portion of the Albuquerque structural basin, which contains the through-flowing Rio Grande. The basin is approximately 90 miles long and 30 miles wide. The deposits within the Albuquerque Basin consist of interbedded gravel, sand, silt, and clay. The thickness of basin-fill deposits in most of the basin exceeds 3,000 feet, though the thickness varies considerably due to highly-faulted basin area (Connell, 2008).

Geologic materials of primary importance within the basin are the Santa Fe Group and the piedmont slope deposits. The Santa Fe Group consists of beds of unconsolidated to loosely-consolidated sediments and interbedded volcanic rocks. The materials range from boulders to clay and from well-sorted stream channel deposits to poorly-sorted slope wash deposits. Coalescing alluvial fans of eroded materials from the surrounding mountains were unconformably deposited over the Santa Fe Group, extending westward from the base of the Sandia and Manzano mountains to the eastern edge of the Rio Grande floodplain. The fan sediments range from poorly-sorted mud flow material to well-sorted stream gravel; the beds consist of channel fill and interchannel deposits. The fan deposits range in thickness from 0 to 200 feet and thicken toward the mountains. The Upper Santa Fe Group (USF-1) lies under the alluvial fans and valley alluvium with the depositional facies called USF-1(Hawley et al., 1995). As shown in Table 3-1, the alluvial fans are present from ground surface to approximately 86 feet bgs, then a transition occurs where the alluvial fans and USF-1 are interfingered to a depth of 117 feet bgs, under which USF-1 is present to a depth of greater than 500 feet bgs (Connell, 2008).

3.4 Regional Hydrogeology

The groundwater system at Kirtland AFB and in the Albuquerque area lies within the Albuquerque Basin, also referred to as the Middle Rio Grande Basin; the basin is part of the Rio Grande Rift. As the Rio Grande Rift spread, the Albuquerque Basin filled with sediments several miles thick, most of which are referred to as the Santa Fe Group. The unit consists of unconsolidated sediments that thin toward the basin boundary. Edges of the basin are marked by normal faults.

Generally, the upper unit of the Santa Fe Group contains the most productive portion of the regional aquifer that supplies groundwater to the City of Albuquerque, the VA Medical Center, and Kirtland AFB. The unit is characterized by piedmont slope, river, and floodplain deposits. The ancestral Rio Grande formed a large aggradational plain in the central basin, depositing a mix of coarse- to fine-grained sands, silts, and clays with variable bed thicknesses.

Basin-fill deposits make up the aquifer in the Albuquerque Basin. Hydraulic conductivity values range from 0.25 feet per day (feet/day) to 50.0 feet/day due to large variations in the lithology of the basin-fill deposits. Clay layers have relatively low hydraulic conductivity, whereas gravel and cobble deposits have relatively high hydraulic conductivity. Deposits of interbedded gravel, sand, silt, and clay have intermediate hydraulic conductivity (Tetra Tech, 2004).

This principal aquifer underlies Kirtland AFB with the basin fill in this area that consists of alluvial fan deposits and valley alluvium that overlies the Santa Fe Group. The Santa Fe Group consists of unconsolidated and semi-consolidated sands, gravels, silts, and clays. The layer overlying the Santa Fe Group consists of alluvial fan deposits associated with erosion of upland areas and valley alluvium associated with stream development. The alluvium varies in thickness from a few feet near the mountains on the east side of the base to greater than 2,100 feet at a location 5 miles southwest of the Kirtland AFB airfield (Tetra Tech, 2004).

Surface recharge in the regional aquifer originates primarily from mountain-front and tributary sources to the northeast. Mountain-front recharge emanates from surface runoff or shallow underflow originating from the mountains adjacent to the basin that infiltrate the upper portion of the aquifer system near the mountain fronts. Mountain-front recharge in the Albuquerque area primarily originates from the Sandia, Manzanita, and Manzano Mountains along the eastern edge of the basin (McAda and Barroll, 2002). Tributary recharge occurs as seepage from streams and arroyos to the Rio Grande and other surface flows extending into the Middle Rio Grande Basin. Tributary streams within and upstream of Albuquerque that likely contribute recharge to the aquifer beyond the mountain front include the Santa Fe River, Galisteo Creek, and Tijeras Arroyo (McAda and Barroll, 2002).

Based on meteorological data collected at the Albuquerque International Sunport weather station between January 2000 and September 2013, the average precipitation during the winter months (October through

March) is 0.53 inches per month. During the wetter, summer months (April through September), the average precipitation is 0.88 inches per month. The average monthly evapotranspiration rate range from 0.38 inches in January to 7.17 inches in July. Due to the relatively high evapotranspiration rates, recharge from the ground surface is typically negative (evapotranspiration is greater than precipitation). The average recharge rate for the winter months (October through March) is -0.53 inches, and during the warmer summer months, the average recharge is -4.46 inches.

In addition to surface recharge, subsurface recharge occurs as groundwater inflows from adjacent basins or mountains. Subsurface recharge to the aquifer emanates from the vicinity of the Jemez Mountains, Española Basin, and Hagan Embayment in the north-northeastern part of the basin, and from Sierra Lucero to the San Juan Basin in the western portion of the Middle Rio Grande Basin (McAda and Barroll, 2002). Subsurface recharge is the primary source of recharge to the aquifer.

3.4.1 Groundwater Withdrawal and the Potentiometric Surface Depression

Ninety-four municipal and local-water supply wells draw on the regional aquifer; however as of May 2013 only 70 wells were operational. Based on 2012 data from the Albuquerque Municipal Water Supply District the average daily pump rate is approximately 48.5 million gallons per day, accounting for dry and wet season fluctuations. Groundwater withdrawal fluctuates with seasonal demand and based upon contribution to demand by diverted surface water. From 1950 through 2009, groundwater withdrawal resulted in a decline in the potentiometric surface of greater than 120 feet to the northeast of SWMU ST-106 as determined by Falk et al., 2011, or approximately 140 feet based on a review of historical water-table elevations. This is the area of maximum decline in the Santa Fe Group aquifer system in the Albuquerque area, and as a result, has created a significant potentiometric surface depression in this area. Historically, groundwater flow in this area was to the south. Due to groundwater withdrawal in the Albuquerque area and the resulting potentiometric surface depression, groundwater flow at SWMU ST-106 is currently to the northeast (Falk et al., 2011) (Figure 3-1).

In 2009, the city of Albuquerque implemented water-conservation practices that have resulted in rising water levels in the area of the potentiometric surface depression (Beman, 2013).

3.4.2 City of Albuquerque Production Zone

A majority of the City of Albuquerque production wells in the area of SWMU ST-106 is completed toward the bottom of the Upper Santa Fe Group and into the Middle Santa Fe Group (Connel et al, 1998). The geology of the Upper Santa Fe is composed of poorly-to-well-graded sand with discontinuous lenses of gravels and fines. The Middle Santa Fe Group is comprised of alluvial, eolian, and playa-lake deposits. The unit can be up to 10,000 feet thick and forms the lower portion of the principal aquifer system of the Rio Grande Basin (Hawley, 1996).

Generally, wells in this zone are completed 500 feet or more below the 2009 water table elevation (i.e. the top of the well screen is typically greater than 1,000 feet bgs, with the deepest screen being over 1,700 feet bgs). This zone is characterized by lateral, continuous portions of silty sand and clay layers that are approximately 250 feet thick, and located approximately 700 feet bgs.

3.5 Regional Vadose Zone

The vadose zone at Kirtland AFB is a significant part of the total hydrogeologic system. The vadose zone east of the Tijeras/Hubbell Spring/Sandia fault complex ranges from approximately 50 feet in thickness in arroyos and valleys to several hundred feet thick near faults. On the west side of the faults, the unsaturated zone is up to 500 feet thick. Vadose zone thickness has changed over time as water has been pumped from the aquifer, and as resource-conservation practices have been put in place. 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 approximately 140 feet higher than the current water table. Beginning in the 1970s, pumping wells were installed and put into use, which increased depth to water from the surface and therefore, increased the size of the vadose zone. As stated Section 3.4.1, beginning in 2009, water-conservations practices were put into place, which lead to a shrinking of the vadose zone as the water table elevation has risen. Water levels have risen approximately 7.5 to 10 feet in different areas since 2009.

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4. SCOPE OF ACTIVITIES

This section presents details of the field and analytical activities completed by CB&I as part of the investigation at SWMU ST-106. Work was completed in accordance with the work plans and documents listed in Section 1.2, as well as with specific guidance documents discussed in this section.

4.1 Shallow Soil Investigation

Two shallow soil (less than 20 feet bgs) sampling tasks were completed during the RFI: sampling around the footprint of the former aboveground fuel tanks and sampling along the FFOR and pipelines. Sampling around the former fuel tanks was performed as specified in the Vadose Zone Investigation Work Plan (USACE, 2011a). The FFOR sampling was performed as part of an interim measure directed in the correspondence dated December 10, 2010, from the NMED to Kirtland AFB (NMED, 2010b), and in accordance with the Interim Measures Work Plan (USACE, 2011c). Both sampling tasks were performed using direct-push technology (DPT).

In accordance with Vadose Zone Investigation Work Plan (USACE, 2011a) and Interim Measures Work Plan (USACE, 2011c) directions for borehole and step-out locations, 354 soil borings were advanced as part of both the fuel tank and FFOR shallow soil sampling tasks. Sampling took place from First Quarter calendar year (CY) 2011 through Third Quarter CY 2013 with a total of approximately 1,750 soil samples collected. Soil borings were advanced to 20 feet and sampled every 5 feet for SVOCs, VOCs, TPH-GRO, TPH-DRO, and lead. The following sections detail the logging, sampling, and surveying activities associated with the shallow soil investigation. Results of the shallow soil investigation are discussed in Section 5.1.

Former Fuel Tanks

The scope for sampling around the former fuel tanks was to characterize contaminants within soil in this area in accordance with the data gaps listed in the Vadose Zone Investigation Work Plan (USACE, 2011a). Five shallow soil borings were advanced around the footprint of the former fuel tanks (Figure 4-1). All sampling around the former fuel tanks was performed as specified in the Vadose Zone Investigation Work Plan.

FFOR

The scope for FFOR sampling work was to determine the shallow soil excavation interim measures per the Interim Measures Work Plan (USACE 2011c). The borings were located so as to delineate the possible surface source area of the fuel. The FFOR shallow soil sampling task was performed in Second and Third Quarters CY 2011, Second Quarter CY 2012, and Second and Third Quarters CY 2013. Figure 4-1 illustrates the locations of the FFOR shallow soil borings and quarters in which the work was performed.

4.1.1 Geologic Logging

Geologic logging during borehole advancement during shallow soil sampling was performed in accordance with procedures outlined in the Vadose Zone Investigation Work Plan (USACE, 2011a) and Interim Measures Work Plan (USACE, 2011c). Before drilling, boreholes were investigated for utility clearance to 5 feet with a hand auger to ensure no utilities were present. Shallow borings were advanced using DPT to 20 feet bgs with a 3-inch-diameter by 4-foot-long, acetate-lined, open-barrel sampler. The DPT subcontractor personnel cut the acetate sleeve encasing the sample, and soil samples were collected from the sleeve. The samples were lithologically logged every 5 feet by the site geologist and were described according to the Unified Soil Classification System (ASTM International [ASTM] D2487-11 [2011]). Color, moisture content, consistency, detailed lithology of individual gravel units, mineralogy, observed contamination, odor, and changes in lithology were also noted on the soil boring log. Soil boring logs for all 354 shallow soil borings installed in 2011, 2012, and 2013 are included in Appendix B.

The samples were field-screened for VOCs using a photoionization detector (PID) in accordance with the Vadose Zone Investigation Work Plan (USACE, 2011a) and Interim Measures Work Plan (USACE, 2011c). PID readings were primarily used for health and safety purposes, and values were documented on the soil boring log with their corresponding interval. The soil boring logs are included in Appendix B.

4.1.2 Shallow Soil Sampling

Shallow soil samples were collected from the surface and every 5 feet to the total depth. Soil samples were analyzed for the following:

- TPH-GRO and TPH-DRO – Method SW846 8015B
- VOCs – Method SW846 8260B
- SVOCs – Method SW846 8270D
- Lead – Method SW846 6010C

Soil analytical results are provided in Appendix C, and are discussed in Section 5.1. 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, 2011d), and appropriate data qualifiers are appended to the analytical data in the project database.

4.1.3 Shallow Soil Boring Surveying

Shallow soil borings were surveyed prior to advancement to ensure proper placement in relation to the fuel tanks and pipelines in accordance with the Vadose Zone Investigation Work Plan (USACE, 2011a) and Interim Measures Work Plan (USACE, 2011c). At each soil boring, the elevation and coordinates at the ground surface (either top of asphalt or natural ground, depending on the location of the boring) were surveyed, and data were recorded in the project database. The surveyed locations are shown on Figure 4-1. A total of 354 soil borings was advanced.

4.2 Deep Soil Investigation

The deep soil investigation included the installation of soil-vapor monitoring wells (SVMWs) and PneuLog® wells. The well locations are shown on Figure 4-2. Soil samples were collected during the installation of the SVMWs and four groundwater monitoring wells (KAFB-106061, KAFB-106162, KAFB-106078, KAFB-106081). The following sections detail geologic logging, well installation, sampling, and surveying activities performed during the deep soil investigation. The results of soil samples collected during the installation of the four groundwater monitoring wells are also discussed in this section; all other information for these four wells can be found in the SWMU SS-111 Groundwater Zone RFI Report (USACE, 2014).

4.2.1 Geologic Logging during Drilling

During borehole advancement, drill cuttings were collected from the air-rotary casing hammer (ARCH) drill rig "cyclone" at 5-foot depth intervals and at changes in lithology/color. The cuttings were lithologically logged by the site geologist and were described according to the Unified Soil Classification System (ASTM D2487-11 [2011]). Color, moisture content, consistency, detailed lithology of individual gravel units, mineralogy, observed contamination, odor, and changes in lithology, and depth to groundwater (if applicable) were also noted on the soil boring log. Soil classification logs for all 35 soil-vapor monitoring well (SVM) boreholes and 9 PneuLog® boreholes advanced in 2011 to 2012 are included in Appendix B.

The cuttings were field-screened for VOCs using a PID, as specified in the Vadose Zone Investigation Work Plan (USACE, 2011a), Interim Measures Work Plan (USACE, 2011c), and the Kirtland AFB Base-Wide Standard Operating Procedure B3.1 (Photoionization Detectors and Organic Vapor Analyzers).

Because the ARCH drilling method used air to lift cuttings from the borehole and created varying amounts of frictional heat, some VOCs were driven off before field screening. Therefore, PID readings were primarily used for health and safety purposes. PID reading values were documented on the soil boring log with their corresponding interval.

4.2.2 Soil Vapor Monitoring Wells

In total, the SVM network at ST-106 consists of 285 SVMWs and SVEWs installed between October 2000 and October 2013. These 285 individual wells are located in 64 separate clusters. During December 2010 and August 2011, 210 SVMWs were installed at 35 locations with each location consisting of a cluster of six monitoring wells. The SVMWs were installed in accordance with the NMED-approved Vadose Zone Investigation Work Plan (USACE, 2011a). The remaining 75 wells were installed by previous contractors between October 2000 and May 2010. These 75 wells were installed at 29 locations with each location ranging from a single monitoring well to a cluster of up to four monitoring wells.

Before drilling, boreholes were investigated for utility clearance to 5 feet with a hand auger or an air-knife to ensure no utilities were present. Borehole advancement (drilling) was performed using the ARCH method. The ARCH method uses a steel-insulator casing, advanced with drill bit/rod, to prevent borehole collapse. The boreholes for the SVMWs were drilled as a 11¾-inch outside diameter (O.D.) casing that telescopes down to 9⅝-inch O.D. casing at 150 feet. These drive casing sizes effectively advance a 12-inch-diameter borehole to approximately 200 feet bgs, and a 10-inch-diameter borehole from approximately 200 feet bgs to the total depth of the borehole. Soil boring logs and well completion diagrams are presented in Appendix B.

Each nested well location consists of six individual (one 3-inch-diameter and five ¾-inch-diameter) Schedule 80, polyvinyl chloride SVMWs that were installed in the same borehole. Nested wells included a 10-foot-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 feet bgs, respectively. 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 feet (150, 250, 350, and 450 feet bgs, respectively) were adjusted by no more than 25 feet, and screens separated by 25 feet (25 and 50 feet bgs) were adjusted by no more than 5 feet. Table 4-1 presents the well completion information for the SVMWs and the actual depths of the screened intervals.

4.2.3 PneuLog® Wells

4.2.3.1 Installation

Four PneuLog® well clusters (KAFB-106148, KAFB-106149, KAFB-106150, and KAFB-106151) were installed during Third Quarter CY 2011, and five PneuLog® well clusters were installed during Fourth Quarter CY 2011 (KAFB-106152, KAFB-106153, KAFB-106154, KAFB-106155, and KAFB-106156). The PneuLog® wells were installed in accordance with techniques specified in the NMED-approved Interim Measures Investigation Work Plan (USACE, 2011c). PneuLog® well clusters are shown on Figure 4-2. Each well cluster consists of three “nested” 3-inch-diameter well casings with three screened intervals; each with approximately 150 feet of screen. All nine well clusters were surveyed during Fourth Quarter CY 2011. Table 4-2 presents the well locations, elevations, depths, and screen intervals. Soil boring logs and well completion diagrams are presented in Appendix B.

Before drilling, each well location was tested for utility clearance to 5 feet using a hand auger. Borehole advancement (drilling) was performed using the ARCH drilling techniques. The boreholes for the PneuLog® wells were drilled using an 11¾-inch O.D. drive casing to a depth of approximately 150 feet bgs, and a 9⅝-inch O.D. casing was advanced to the total depth of the borehole. Each well consists of a single borehole drilled to just above the water table (approximately 488 feet bgs), with each borehole containing three “nested” 3-inch-diameter well casings. Nested wells included approximately 150 feet of machine-slotted (0.050-inch) screen. Planned screened intervals for the nested wells were approximately 25 feet bgs to 200 feet bgs, 205 feet bgs to 350 feet bgs, and 355 feet bgs to 500 feet bgs.

4.2.3.2 PneuLog® Testing

During Second Quarter CY 2012, PneuLog® wells KAFB-106148, KAFB-106149, and KAFB-106150 were tested using PneuLog® technology developed by Praxis Environmental Technologies, Inc. (Praxis). As approved in the NMED letter of October 2, 2013 (NMED, 2013) wells KAFB-106148, KAFB-106149, and KAFB-106150 were the only wells chosen for testing due to their locations above the footprint of the NAPL plume (Figure 4-2).

Praxis' technology uses pneumatic well logging to measure the vertical air permeability and chemical concentration profiles in wells screened for SVE. Down-hole instruments simultaneously measure cumulative air flow and chemical vapor concentrations along the depth of the well screen. Praxis personnel performed the testing in accordance with the NMED-approved Interim Measures Work Plan (USACE, 2011c) with oversight provided by on-site CB&I personnel. The results of the PneuLog® evaluation are summarized in Section 5.2.2, and the full evaluation is presented in Appendix D.

4.2.4 Split-Spoon Sampling

Deep soil borehole samples were collected using a split-spoon sampler during drilling of the 35 SVMW clusters, as well as during drilling of groundwater monitoring (GWM) wells KAFB-106061, KAFB-106062, KAFB-106078, and KAFB-106081. Soil samples were collected during borehole advancement in accordance with the Vadose Zone Investigation Work Plan (USACE, 2011a) and the NMED-HWB letter dated August 6, 2010 (NMED, 2010c). Soil samples were collected every 10 feet for the first 50 feet and every 50 feet 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 feet 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 analyzed for the following:

- TPH gas and diesel by method SW846 8015B
- VOCs by method SW846 8260B
- Semi-volatile organic compounds (SVOCs) by method SW846 8270D
- Lead by method SW846 6010C

The Vadose Zone Investigation Work Plan (USACE, 2011a) states that in addition to soil samples analyzed for TPH-DRO and TPH-GRO, soil samples from two deep borings will be collected and analyzed for volatile petroleum hydrocarbons (VPH) and extractable petroleum hydrocarbons (EPH) (Massachusetts Department of Environmental Protection, 2004a and 2004b). For these soil boring samples, TPH-GRO and TPH-DRO were analyzed in place of VPH and EPH. Although VPH and EPH provide a wider range of aliphatic hydrocarbons than TPH-DRO and TPH-GRO, the analysis of VOCs and SVOCs provide necessary data on any potential chemicals exceeding regulatory limits. Soil analytical results are provided in Appendix C, and are discussed in Section 5.2. The soil analytical data were validated for precision, accuracy, representativeness, comparability, and completeness in accordance with the BFF Spill QAPjP (USACE, 2011d), and appropriate data qualifiers are appended to the analytical data in the project database.

4.2.5 Well Surveying

SVMWs and PneuLog® wells were surveyed following well construction. At each well, the elevation and coordinates at the ground surface (either top of asphalt or natural ground, depending on the location of the well) on the concrete pad, at the top of the protective casing, and at the top of the polyvinyl chloride were taken. The surveyed locations are shown on Figure 4-2, and survey plates are presented in Appendix E. The total number and types of wells installed and surveyed during the current vadose zone investigation are as follows:

- 210 SVMWs since December 2010 (35 well clusters with six nested wells each)
- 27 PneuLog® wells since July 2011(9 well clusters with three nested wells each)

4.2.6 Geophysical Logging

Geophysical logging was conducted in accordance with the approved Vadose Zone Investigation Work Plan (USACE, 2011a). The geophysical logs provided additional information to help correlate subsurface stratigraphic cross-sections, which were based on geologic logs for existing and newly installed monitoring wells and borehole samples.

Table 4-3 provides a cumulative list of each borehole, well type, geophysical tools, date logged, and logging company used, as specified in the Vadose Zone Investigation Work Plan (USACE, 2011a). Logs for all boreholes that were geophysically logged are provided in Appendix F. The following wells were geophysically logged as part of the investigation at ST-106:

- 29 GWM wells installed prior to December 2010
- 23 GWM wells installed since December 2010. Installation of GWM wells is discussed in the Groundwater Zone RFI Report (USACE, 2014) submitted concurrently with this Vadose Zone RFI Report
- 35 SVMW clusters installed since December 2010

Geophysical logging methods included gamma, neutron, and electromagnetic induction logging and was conducted in accordance with industry standard practice, including ASTM D5753 (Standard Guide for Planning Borehole Geophysical Logging), ASTM D6274-01 (2007) (Standard Guide for Conducting Borehole Geophysical Logging – Gamma), ASTM D6726-01 (2007) (Standard Guide for Conducting Borehole Geophysical Logging – Electromagnetic Induction) and ASTM D6127 (Standard Guide for Conducting Borehole Geophysical Logging: Neutron) in accordance with Section 4.2.3 of the Vadose Zone Investigation Work Plan (USACE, 2011a). Information on quality control, field calibration, and logging activities can be found in Appendix F.

4.3 Quarterly Soil Vapor Sampling

Quarterly soil vapor sampling is conducted in accordance with the approved Vadose Zone Investigation Work Plan (USACE, 2011a) and the NMED-accepted QAPjP (USACE, 2011d).

Quarterly soil vapor sampling is conducted at 285 SVM and SVEW monitoring points (64 well clusters) for off-site laboratory analysis. The SVMWs and SVEWs sampled include the following:

- 75 wells (29 well clusters) installed prior to 2011 that consist of consecutively numbered wells SVEW-01 through SVEW-13 (one monitoring well each), well clusters SVMW-01 through SVMW-15 (three to four monitoring wells each) and KAFB-106028 (four monitoring wells)
- 210 SVMWs (35 well clusters with six wells each) at wells installed during 2011 that consist of consecutively numbered well clusters KAFB-106108 through KAFB-106142

The vapor samples were collected using pre-evacuated Vac™ canisters and Tedlar™ bags sampled through sampling ports installed at the top of each individual well casing for off-site laboratory analysis. Soil vapor samples were analyzed for the following list of analytical parameters:

- VOCs – EPA Method TO15
- Air-phase petroleum hydrocarbons – Massachusetts Department of Environmental Protection
- Fixed gases – ASTM Method D2504

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

The SVE and SVM analytical data were validated for precision, accuracy, representativeness, comparability, and completeness in accordance with the BFF Spill QAPjP (USACE, 2011d), and appropriate data qualifier are appended to the analytical data in the project database.

4.4 Radius of Influence Testing

Two ROI tests were conducted at ST-106 during the vadose zone investigation to characterize the vadose zone and to inform SVE requirements. The first ROI test was conducted during Third Quarter CY 2011, and was used to test the ROI of the portable ICE SVE units in accordance with the Soil Vapor Extraction Optimization Plan (USACE 2011e). The second ROI test was conducted during First Quarter CY 2013 at the start-up of the new CATOX SVE system.

In order to determine the ROI for each test, the following data were used:

- Vacuum pressure at the observation wells, including a background monitoring well which was greater than 350 feet from the SVEW, and therefore expected to be outside of the ROI
- Barometric pressure, which was downloaded from a weather station at the Albuquerque International Sunport adjacent to Kirtland AFB
- The barometric efficiency for each well type (Section 5.2.4)

Using the method described in Appendix G, the barometric pressure and barometric efficiency were used to estimate the vacuum pressure at each observation well. Because the background well for each ROI test was expected to be outside of the ROI, the vacuum pressure measured in the background well would only respond to changes in barometric pressure, and not by influences from SVE. As such, the vacuum pressure from the background well was subtracted from the vacuum pressure in the observation wells to remove the impact of barometric pressure from the observations. The resulting values are referred to as the corrected observed vacuum.

4.4.1 Radius of Influence Testing Using the ICE SVE Systems

All operating ICE SVE units were shut down for 1 month prior to the start of testing to allow the vadose zone to return to equilibrium. Single-well tests were performed on five potential SVEWs, and three 5-day tests were conducted using the selected SVEWs (Table 4-4). A full description of the ROI test using the

ICE SVE systems, including all data collected, is presented in Appendix G. The larger-scale CATOX ROI provided more comprehensive data for ST-106 and is discussed below.

4.4.2 Radius of Influence Testing Using the CATOX SVE System

ROI testing began on January 28, 2013 and continued for 7 weeks. The goal of ROI testing was to determine the ROI of the CATOX SVE system that began operation on March 15, 2013, and to further characterize the vadose zone. The CATOX SVE system was plumbed into two SVEWs, KAFB-106160 and KAFB-106161 (Figure 4-3). Prior to beginning the ROI test, all ICE SVE units were shut down on December 21, 2012, and the vadose zone was allowed to equilibrate over the following 3 days. From December 24, 2012 through January 8, 2013, background monitoring was conducted to characterize the response of the vadose zone to barometric pressure without the influence of SVE.

The ROI test of the CATOX SVE system was conducted in three phases:

1. Shakedown testing was conducted to determine the maximum running conditions of the CATOX SVE system.
2. A step-test consisting of three week-long steps was conducted to determine the optimal running conditions of the CATOX SVE system.
3. Four-week monitoring was conducted at the optimal conditions to refine the ROI.

Data collected during all phases of testing are provided in Appendix G.

Shakedown Testing

Shakedown testing was performed on January 22 and 23, 2013 to determine the maximum running conditions of the SVE system. Initially, the motor speed was set to 1,400 revolution per minute (rpm), the well vapor valves were fully closed, and all dilution valves were fully open. The well vapor valves were then opened incrementally, and the dilution valves were closed incrementally. With each adjustment, measurements of temperature, pressure, differential pressure, and PID readings were recorded from set locations on the CATOX SVE system (Table 4-5).

From this test, it was determined that the maximum running conditions were as follows (Section 5.3.2):

- Motor speed: 1,400 rpm
- Well vapor valves: fully open
- Well dilution valves: half open
- Chain wheel dilution valve: fully closed

Step-Test

The step-test consisted of three steps, each of which lasted for 5 days. For all steps, the valves were left in the positions determined by the shakedown testing, and the motor speed was incrementally increased as described below:

- Step 1 was conducted from January 28 through February 1, 2013 with the CATOX SVE system motor speed set to 700 rpm.
- Step 2 was conducted from February 4 through February 8, 2013 with the CATOX SVE system motor speed set to 1,050 rpm.
- Step 3 was conducted from February 11 through February 15, 2013 with the CATOX SVE system motor speed set to 1,400 rpm.

Observation wells used for the step-test are listed in Table 4-6.

The following measurements were collected during each step:

- Vacuum pressure at each monitoring well
- Vacuum pressure at each extraction well
- Differential pressure at each extraction well, which was used to calculate flow rate
- Total hydrocarbons at each extraction well

- Temperature and differential pressure prior to vapor entering the CATOX SVE system, downstream of the convergence of the two vapor streams from the extraction wells. These data were used to calculate the total flow rate and dilution air flow rate from the wellheads, and were collected beginning February 5, 2013.
- Total hydrocarbons prior to vapor entering the CATOX SVE system, downstream of the convergence of the two vapor streams from the extraction wells. These data were collected beginning February 5, 2013.

During each test, all data were collected three times on each of the first 3 days and twice on the fourth and fifth days.

4-Week Monitoring

Following the step-test, the optimal motor speed was determined to be 1,050 rpm (Section 5.3.2). The same set of observation wells was used for the 4-week monitoring as for the step-test. All of the monitoring measurements made during the step-test were also made during the 4-week monitoring.

In addition to the measurements collected during the step-test, the following measurements were made beginning on February 27, 2013:

- Carbon monoxide, carbon dioxide, and oxygen were collected at the extraction wells and prior to the vapor entering the CATOX SVE system, downstream of the convergence of the two vapor streams from the extraction wells.
- Vapor data, including total hydrocarbons, carbon monoxide, carbon dioxide, and oxygen downstream of the final location where dilution air is let into the system.

The motor speed was set to 1,050 rpm, and data were collected four times per week for 2 weeks. After 2 weeks, the lower explosive limit meter was re-calibrated, and it was determined that the motor speed could safely be increased to 1,400 rpm. The increase in motor speed was made, and data were collected four times per week for the remaining 2 weeks.

4.4.2.1 Additional CATOX SVE Monitoring

Vacuum pressure was collected at all monitoring wells (Table 4-7) once per week during April and May of 2013 to further define the ROI of the CATOX SVE system.

Based on the results of the ROI tests (Section 5.3.2), it was determined that the ROI could be most accurately observed if all monitoring wells were constructed similarly to one another. The SVMWs constructed by CB&I are all completed similarly to one another, and are the majority of SVMWs at the BFF. As a result, SVM wells constructed by CB&I were chosen preferentially over PneuLog® wells as observation points. In all observation well clusters, the 450- and 350-foot wells were used as monitoring points. The 250-foot wells in the selected observation clusters were expected to be outside of the ROI, and so were not selected as monitoring points with the exception of the three observation wells closest to each extraction well (KAFB-106116, KAFB-106117, and KAFB-106128) and in the background monitoring well (KAFB-106121). All data collected during CATOX SVE monitoring is provided in Appendix G.

4.4.3 Barometric Fluctuations

During ROI testing, it was observed that barometric pressure changes have a significant impact on the vacuum pressure observed in the vadose zone (Section 5.3). Changes in vacuum pressure due to SVE were overprinted by changes in background pressure due to barometric fluctuations. Background monitoring was conducted in December 2011 and December 2012 to quantify the barometric efficiency of the vadose zone. Barometric efficiency is the measure of how vacuum pressure at a given location changes in response to barometric pressure fluctuations.

In December 2011, background monitoring was conducted at seven SVMW clusters at depths of 450, 350, 250, 150, 50, and 25 feet bgs. In December 2012, background monitoring was conducted at six

SVMW clusters at depths of 450, 350, and 150 feet bgs; and at nine PneuLog® well clusters at depths of 484, 350, and 200 feet bgs.

Barometric pressure was downloaded from a weather station located at the Albuquerque International Sunport, which is adjacent to Kirtland AFB. Data from the weather station is logged hourly. To determine the barometric pressure at the exact time vacuum pressure was measured during ROI testing, barometric pressure was interpolated using the method described in Appendix G.

Vacuum pressure was plotted against barometric pressure at the time of monitoring for each well type and depth (Figures 4-4 and 4-5). A best-fit line was fit to each set of data. The slope of the best-fit line is the barometric efficiency for each well depth and type. The barometric efficiency is used to further characterize the vadose zone, and to correct vacuum pressures collected during ROI testing for barometric fluctuations.

4.5 Quality Assurance and Quality Control

The accuracy and integrity of the RFI data were ensured through the implementation of internal QC measures in accordance with the QAPjP (USACE, 2011d), as accepted by NMED. Quality assurance and QC activities, including field QC, laboratory QC, data management, and data validation, were integrated into the investigation program established for the RFI. The data presented have been through this process and are fully usable as qualified. The Data Quality Evaluation Reports are located in Appendix H. Daily Quality Control Reports (DQCR), were completed in accordance with the approved Vadose Zone Investigation Work Plan (USACE, 2011a). Four field work variances were generated during field work activities and are located in Appendix A-1.

4.6 Investigation Derived Waste

Investigation-derived waste (IDW) was characterized using data obtained from the analysis of environmental samples collected during the investigation that generated the waste, through analysis of samples collected directly from the waste, through knowledge of the waste-generating process, or through a combination of these methods. To determine proper waste management requirements for waste generated during project activities, all waste streams were sampled and characterized in accordance with Title 40 Code of Federal Regulations (CFR) 262.11 and state regulations.

Waste management decision-making at Kirtland AFB is made in accordance with the following federal and state regulations:

- 40 CFR Parts 260-299, EPA regulations for identification and management of hazardous waste
- 40 CFR Part 761, EPA regulations for management of polychlorinated biphenyls
- 49 CFR Parts 100-178, U.S. Department of Transportation rules for hazardous materials transport
- 20 NMAC Chapter 9, New Mexico Solid Waste Management Regulations
- 20 NMAC Chapter 4, New Mexico Hazardous Waste Management Regulations
- 20 NMAC Chapter 9, New Mexico Special Waste Requirements Regulations
- 20 NMAC Chapter 6, New Mexico Water Quality Control Commission Regulations

4.6.1 Soil IDW

Drill cuttings resulting from SVMW installation, SVEW installation, PneuLog® well installation, and shallow soil borings were containerized in plastic-lined steel roll-off containers, and held in a dedicated location on the base pending laboratory analysis for waste characterization and disposal. Approximately 10 to 15 cubic yards of drill cuttings were placed in each 20-cubic–yard roll-off container. A composite sample was collected from each roll-off container associated with each well location and sent to the subcontractor laboratory for analysis of the following parameters in accordance with the Kirtland AFB Base-Wide IDW Management Plan (Tetra Tech, 2004) and the Kirtland AFB Construction and Demolition Landfill Acceptance Memorandum (USAF, 2009):

- Toxicity Characteristic Leaching Procedure (TCLP) VOCs and SVOCs
- TCLP pesticides and herbicides
- TCLP metals
- Ignitability, corrosivity, and reactivity
- Benzene, toluene, ethylbenzene, xylenes (BTEX) compounds
- TPH-GRO and TPH-DRO

Based on the results, the soil was classified as hazardous, non-hazardous special waste, or non-hazardous clean, which determined the disposal location.

4.6.2 IDW Water from Decontamination of Drilling Equipment

Decontamination IDW water generated during well installation and shallow soil sampling activities was collected and stored in 250-gallon polyurethane containers pending analysis. Composite samples were collected from each tote and analyzed for VOCs, SVOCs, TPH-DRO, TPH-GRO, and lead. Based on the analytical results, IDW water was classified as hazardous, non-hazardous Notice of Intent, or non-hazardous clean, and disposed of accordingly. It water was classified as non-hazardous or requiring a notice of intent, the appropriate Notice of Intent approval was received where necessary and the water was discharged to the ground surface ensuring that it did not enter a watercourse for surface water (Section 5.5.2.2).

Table 4-8 summarizes the sampling and disposal of each decontamination water container. The following regulations, standards, and guidance, in addition to any site and/or base-specific requirements, were evaluated prior to discharging wastewater:

- RCRA Subtitle C (40 CFR 260 through 280)
- Clean Water Act, 33 United States Code 1251-1376
- Safe Drinking Water Act, 42 USC 300
- NMED Standards for Groundwater 20 NMAC 6.2.3103

5. FIELD INVESTIGATION RESULTS

This section presents the analytical results of the field investigation activities completed by CB&I as part of the investigation at SWMU ST-106. In addition, analytical data from previous contractor investigations from May 2006 through January 2010 have been incorporated into the applicable discussions below. Soil sample results collected by others prior to 2006 (e.g., 2002) were not used due to data quality and detection-limit issues.

5.1 Shallow Soil Investigation

5.1.1 Geologic Logging Results

Soil boring logs for the 354 shallow soil borings are located in Appendix B. Generally, the geology from 0 to 20 feet bgs consists of silty sands and silts with some clay. The lithology varies slightly between the area northwest of Building 1033 and the area to the southeast near the former fuel tanks. North of Building 1033 and directly south of Building 1033 (Figure 4-1), the lithology is generally sandy silt, or silt with sand, that transitions to silt between 3and 5feet bgs. The sand content of the soil decreases until it transitions to lean clay generally between 10 and 15 feet bgs. This clay layer, between 1 and 5 feet in thickness, transitions back to silt or elastic silt by 20 feet bgs.

Southeast of Building 1033 (Figure 4-1) along the former pipeline and near the former fuel tanks, the clay layer is also observed, generally between 8 and 15 feet bgs, although not as regularly as to the areas northwest of Building 1033. In this area, the lithology is more often classified as silt and sandy silt.

5.1.2 Shallow Soil Sample Results

In total, 1,784 shallow soil samples were collected during the FFOR and fuel tank sampling tasks. Table 5-1 summarizes the results of the shallow soil investigation. The full analytical results of the shallow soil samples are located in Appendix C-1.

Results were compared to the 2012 NMED residential SSLs. If no residential SSL existed for a specific analyte, results were compared to the EPA Region 9 Regional Screening Levels (RSL) for that analyte (USACE, 2011d; NMED, 2012). Results were compared to these screening levels for the purposes of characterization as part of this Vadose Zone RFI Report. Figures 5-1 through 5-5 illustrate where sample concentrations exceeded NMED SSLs or EPA RSLs at each sample depth.

Lead was detected in 1,739 samples with a maximum concentration of 286 mg/kg, which does not exceed the NMED SSL of 400 mg/kg. At the sampling locations around the former fuel tanks, no samples returned results that exceeded the specific regulatory criteria for SVOCs and VOCs. However, at FFOR investigation locations, multiple samples exceeded either 2012 NMED residential SSLs or EPA RSLs for SVOCs and VOCs. The majority of the samples exceeding screening levels are located along the former FFOR pipeline north and west of Building 1033 (Figures 5-1 through 5-5). Historical soil samples were all collected from deeper than 20 ft bgs and are discussed as part of the deep soil investigation (Figure 5-6). The spatial extent of contamination is discussed in greater detail in Section 5.4.2.

Of the VOC compounds detected, 1,1,2-trichloroethane; 1,2,3-trichloropropane; ethylbenzene; and naphthalene exceeded regulatory criteria (Table 5-1). 1,2-dibromoethane (EDB) was not detected in any shallow soil samples. 1,1,2-trichloroethane and 1,2,3-trichloropropane exceeded their respective NMED residential SSLs, but these chemicals are chlorinated solvents and are not fuel-related contaminant; therefore, they are not discussed in this section.

- There is no NMED residential SSL for 1,2,4-trimethylbenzene, but the EPA RSL of 62 mg/kg was exceeded in 62 locations with a maximum concentration of 351 mg/kg. 1,2,4-trimethylbenzene exceeded the EPA RSL at the following intervals: 5 to 6 feet bgs, 10 to 11 feet bgs, 15 to 16 feet bgs, and 20 to 21 feet bgs. The majority of samples (40 out of 62 locations) exceeding the NMED SSL were located at the 20-to-21-foot bgs sample interval.
- Ethylbenzene was detected at concentrations exceeding the NMED residential SSL of 68.4 mg/kg at eight locations with a maximum concentration of 227 mg/kg at 20 to 21 feet bgs.

- Naphthalene was detected at concentrations exceeding the NMED residential SSL of 43.0 mg/kg at 16 locations (identified by both VOC and SVOC analysis) with a maximum concentration of 90.6 mg/kg. Exceedances were detected at the following intervals: 5 to 6 feet bgs, 15 to 16 feet bgs, and 20 to 21 feet bgs.

Of the SVOC compounds detected, polynuclear aromatic hydrocarbons (PAHs), benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene, all exceeded NMED SSLs (Table 5-1).

- N-nitroso-di-n-propylamine was detected at concentrations exceeding the EPA RSL of 0.07 mg/kg at 1 location with a concentration of 0.328 mg/kg at 5 to 6 feet bgs.
- The highest concentration of benzo(a)anthracene was 9.78 mg/kg, which exceeds the NMED residential SSL of 1.48 mg/kg. Benzo(a)anthracene exceeded the NMED SSL in a total of 7 samples collected between 2011 and 2013 at the following intervals: 0 to 1 foot bgs, 5 to 6 feet bgs, 10 to 11 feet bgs, and 15 to 16 feet bgs.
- Benzo(a)pyrene exceeded the NMED residential SSL of 0.15 mg/kg in 85 samples with a maximum detection of 9.04 mg/kg. Exceedances were found at the following intervals: 0 to 1 foot bgs, 5 to 6 feet bgs, 10 to 11 feet bgs, 15 to 16 feet bgs, and 20 to 21 feet bgs.
- Benzo(b)fluoranthene exceeded the NMED residential SSL of 1.48 mg/kg in 10 samples with a maximum detection of 9.85 mg/kg. Exceedances were found at the following intervals: 0 to 1 foot bgs, 5 to 6 feet bgs, 10 to 11 feet bgs, and 15 to 16 feet bgs.
- The maximum concentration of dibenzo(a,h)anthracene was 0.84 mg/kg, and the residential SSL for this analyte of 0.15 mg/kg was exceeded in 11 samples. Dibenzo(a,h)anthracene exceeded the NMED residential SSL at the following intervals: 0 to 1 foot bgs, 5 to 6 feet bgs, and 10 to 11 feet bgs.
- Indeno(1,2,3-cd)pyrene was detected at concentrations exceeding the NMED residential SSL of 1.48 mg/kg at 6 locations with a maximum concentration of 6.71 mg/kg. Indeno(1,2,3-cd)pyrene exceeded the NMED residential SSL at the following intervals: 0 to 1 foot bgs, 5 to 6 feet bgs, and 10 to 11 feet bgs.

The SWMU ST-106 data set shows 238 shallow soil samples with a TPH-(GRO or DRO) concentration greater than the NMED TPH Screening Guideline of 1,000 mg/kg for residential direct exposure for kerosene and jet fuel (NMED, 2012) (Table 5-1). Only one of these samples is located at the former fuel tanks: sample SB1735 at borehole KAFB-106147 at 5 feet bgs. The rest were detected during sampling at FFOR borehole locations. Detectable TPH-DRO was present in 932 of the 1,739 samples with concentrations ranging from 1.4 mg/kg to 19,000 mg/kg, while TPH-GRO was detected in 291 of the

1,739 samples with a concentration range of 0.70 mg/kg to 11,300 mg/kg. Locations exceeding TPH guidelines are not shown on Figures 5-1 through 5-5. TPH-GRO and TPH-DRO exceedances were found at the following intervals: 5 to 6 feet bgs, 10 to 11 feet bgs, 15 to 16 feet bgs, and 20 to 21 feet bgs.

5.2 Deep Soil Investigation

5.2.1 Geologic Logging Results

Cross-sections were developed based on soil boring logs taken during drilling to help identify geologic units or trends. The cross-section transects, A-A’, B-B’, C-C’, D-D’, and E-E’, are shown on Figure 5-7. The cross-sections show that the lithology consists of silty, younger deposits (Unit A) overlaying the Santa Fe Group (Unit B), a system of unconsolidated Tertiary-aged fluvial deposits (ancestral Rio Grande lithofacies), and alluvial deposits from the Middle Rio Grande Basin (Figures 5-8 through 5-12). Unit A is considered the shallow vadose zone, and Unit B is considered the deep vadose zone and the main unit containing the regional aquifer.

Unit A extends approximately from the surface to 100 to 200 feet bgs, and 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 feet in thickness as seen in KAFB-106135 (Figure 5-7. Sand deposits within this unit consist of silty, well-graded, and poorly graded sand intervals that range in thickness from 0 to 60 feet.

Underlying the silty slope deposit of Unit A is the upper portion of the Santa Fe Group (Unit B). This loose, unconsolidated, highly porous and permeable depositional unit comprises the primary aquifer for contaminants sourced from the BFF spill. As shown in the cross-sections, the upper portion of the Santa Fe Group is present at depths below 100 to 200 feet 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 feet. Discontinuous gravel lenses, likely channel deposits, can be up to 50 feet thick within some regions, particularly to the north of the site, and are of unknown lateral extent (Figures 5-9 and 5-10). Clay lenses are also observed heterogeneously within the Santa Fe Group with the most notable lens shown in the A-A’ cross-section (Figure 5-8).

5.2.2 PneuLog® Testing Results

The vapor and permeability profiles for data collected during PneuLog® testing are presented on Figures 5-13, 5-14, and 5-15, as well as the report submitted by Praxis (Appendix D). A full description of the results together with Praxis’ interpretations is presented in Appendix D. The following summarizes the testing results.

KAFB-106148 Cluster—The data profiles for borehole KAFB-106148 are provided on Figure 5-13. The summary statistics for the permeability data for this well are presented in Table 5-2.

- A thin, permeable interval was identified at the top of the screen (approximately 25 feet bgs) with a total volatile petroleum hydrocarbons (TVPH) concentration greater than 20,000 part per million by volume (ppmv).
- From 25 to 150 feet bgs, permeability was highly variable, ranging from 0.1 to more than 10 Darcys.
- From 150 to 267 feet bgs, the soil permeability was less heterogeneous and ranged from 2 to 10 Darcys. The soil TVPH vapor concentration was approximately 10,000 ppmv across this interval.
- From 267 to 283 feet bgs, a relatively low-permeability interval that had a TVPH concentration of almost 20,000 ppmv was encountered.
- From 300 to 340 feet bgs, the permeability was less than 0.1 Darcy, while the TVPH concentrations remained above 10,000 ppmv.
- From 350 to 478 feet bgs, the permeability was between 1 and 10 Darcys with an obvious decrease in depth. The soil TVPH vapor concentration also decreased across this interval. No appreciable flow was extracted from the bottom of the screen at 462 to 478 feet bgs.

KAFB-106149 Cluster—The data profiles for borehole KAFB-106149 are provided on Figure 5-14. The summary statistics for the permeability data for this well are presented in Table 5-2.

- In the shallow vadose zone above 150 feet bgs, a series of six thin, permeable intervals were dispersed in relatively low-permeability soil, which corresponded to consistently low soil TVPH vapor concentrations of less than 500 ppmv. In this interval, the permeability of the thin intervals was greater than 10 Darcys, while the remainder of the interval had a permeability of less than 1 Darcy.
- From 150 to 240 feet bgs, the permeability was in the range of 1 to 10 Darcys, and TVPH vapor concentrations gradually increased.
- From 240 to 320 feet bgs, the overall permeability decreased to less than 1 Darcy with three intervals of permeability greater than 1 Darcy, while the TVPH ranged from 5,000 to 14,000 ppmv.
- From 320 to 340 feet bgs, the permeability was less than 0.1 Darcy, while the TVPH concentrations remained below 10,000 ppmv.
- Below 350 feet bgs to the bottom of the well at 480 feet bgs, the overall permeability was in the range of 1 to 10 Darcys, while the TVPH concentrations increased to greater than 20,000 ppmv.

KAFB-106150 Cluster—The data profiles for borehole KAFB-106150 are provided on Figure 5-15. The summary statistics for the permeability data for this well are presented in Table 5-2.

- In the shallow vadose zone above 200 feet bgs, a series of thin, permeable intervals were dispersed in relatively low-permeability soil, which corresponded to consistently low soil TVPH vapor concentrations of less than 500 ppmv. In this interval, the permeability of the thin intervals was greater than 10 Darcys, while the remainder of the interval had a permeability of less than 1 Darcy.
- From 212 to 245 feet bgs, permeability increased, and the TVPH increased with depth to greater than 10,000 ppmv.
- Low-permeability soil was encountered from 245 to 284 feet bgs with permeability at the low end of what could be measured using PneuLog® technology at approximately 0.1 Darcy. This low-permeability interval produced little flow; however, the TVPH concentration was 30,000 ppmv. In its report, Praxis states that this interval also correlates well with similar low-permeability intervals with significant contamination identified in boreholes KAFB-106148 and KAFB-106149.
- The permeability of the soil from 284 to 336 feet bgs was between 1 and 10 Darcys, and the soil TVPH vapor concentration was approximately 6,000 ppmv.

- From 350 feet bgs to the bottom of the well at 480 feet bgs, the permeability was in the range of 1 to 10 Darcys, and the TVPH concentrations were slightly greater than 20,000 ppmv. The deep interval at KAFB-106150 demonstrated an overall trend of decreasing permeability with increasing depth, while the soil TVPH concentration increased to 445 feet bgs at which point, it decreased to the bottom of the well.

The complete PneuLog® testing report can be found in Appendix D.

The PneuLog® vadose zone testing generated distinctive permeability and vapor concentration profiles. In general, the permeability increases with depth, which is consistent with the lithologic data where the upper 250 feet of the vadose zone is finer-grained than the deeper intervals. The concentration profile for well KAFB-106148 shows higher concentrations in the upper 350 feet compared to the bottom 100 feet. This profile is consistent with the location of this well, which is closer to the initial FFOR release locations than the other two wells (Figure 4-2), and is consistent with spatial analysis of quarterly soil vapor sampling results (Section 5.4.2.3), which show higher vapor concentrations closer to the ground surface near the FFOR. In addition, the results for two of the PneuLog® tests (KAFB-106149 and KAFB-106150) show increasing vapor hydrocarbon concentrations with depth. These wells are further south and east of the FFOR, which is consistent with the quarterly soil vapor sampling results showing higher vapor concentrations closer to the water table southeast of the FFOR.

5.2.3 Split-Spoon Soil Sample Results

The results of soil sampling at SWMU ST-106 shows only one split-spoon soil sample with a TPH-(GRO+DRO) concentration greater than the NMED TPH Screening Guideline of 1,000 mg/kg for residential direct exposure for kerosene and jet fuel –sample KAFB-106120 representing the interval 400 to 450 ft bgs (collected at 447 to 448.5 bgs) (NMED, 2012). Detectable TPH-DRO was present in 434 of 466 samples with concentrations ranging from 1.4 mg/kg to 1,160 mg/kg, while TPH-GRO was only detected in 37 of the 466 samples with a concentration range of 0.78 mg/kg to 694 mg/kg.

VOCs, SVOCs, and lead results were compared against current NMED residential SSLs, or EPA RSLs if no SSL exists. No samples returned results that exceeded the specific regulatory criteria. Of the VOC compounds detected, 2-butanone; acetone; benzene; ethylbenzene; toluene; m,p-xylenes; and total xylenes had the most detections. The maximum concentrations for all BTEX compounds were below NMED residential SSLs (Table 5-3). The highest concentration of benzene was 2.76 mg/kg, which was below the NMED residential SSL of 15.38 mg/kg, and the maximum concentration of toluene was 20.5 mg/kg, which was below the SSL of 5274.4 mg/kg. The maximum concentration of ethylbenzene was 4.35 mg/kg, which was below the SSL of 68.44 mg/kg, and the maximum concentration of total xylenes was 20.2 mg/kg, which was below the SSL of 814.07 mg/kg. Bis(2-ethylhexyl)phthalate was the most frequently detected SVOC compound, detected in 377 or the 466 samples taken. The maximum concentration for bis(2-ethylhexyl)phthalate was 20.4 mg/kg, which was below the NMED residential SSL of 347.39 mg/kg. Finally, lead was detected in all 466 samples with a maximum concentration of 20.9 mg/kg, which was below the NMED residential SSL of 400 mg/kg. Analytical results are provided in Appendix C.

Historical soil sample results from previous investigations from 2006 through 2010 were also compared against the same current regulatory criteria. Between 2006 and 2011, soil samples were collected at 16 wells (KAFB-1065 through KAFB-10620), and 3 soil borings were installed at ST-106. Not all historical soil analytical data has been reported to the Environmental Resources Program Information Management System database. This section discusses all available historical soil analytical data. This data is from the five wells: KAFB-1066, KAFB-1067, KAFB-1068, KAFB-1069, and KAFB-10610. All reported samples are deeper than 20 feet bgs.

No analytical results exceeded regulatory screening levels. Of the VOC compounds detected, 1,1-dichloroethene; 2-butanone; benzene; naphthalene; and toluene had the most detections. The maximum concentrations for all BTEX compounds were below NMED residential SSLs (Table 5-3). The highest concentration of benzene was 0.04 mg/kg, which was below the NMED residential SSL of 15.38 mg/kg, and the maximum concentration of toluene was 0.69 mg/kg, which was below the SSL of 5274.4 mg/kg. Toluene was also the most frequently detected VOC compound, detected in 23 of the 86 samples collected (based on available data). TPH-DRO was detected in 67 out of 95 available sample results with a maximum concentration of 330 mg/kg, which was below the NMED TPH Screening Guideline of 1,000 mg/kg for residential direct exposure for kerosene and jet fuel. Analytical results are provided in Appendix C. TPH-GRO was detected in 9 out of 86 available sample results with a maximum detection of 23 mg/kg.

5.2.4 Geophysical Logging Results

Geophysical logs were compared against and correlated with soil boring logs used in the cross-sections (Figures 5-8 through 5-12). Geophysical logs, calibration data, and QC forms are located in Appendix F.

5.2.5 Quarterly Vapor Sample Results

Vapor samples were collected on a quarterly basis starting in First Quarter CY 2011. The most recent results presented in the report are from Second Quarter CY 2013. Samples are collected from the 25-, 50-, 150-, 250-, 350-, and 450-foot depth intervals at the SVMW clusters. Samples were analyzed for VOCs, air-phase petroleum hydrocarbons, and fixed gases. Summary details for analytical results by quarter and depth interval are presented in Tables 5-4 through 5-9. Table 5-10 lists EDB detections in each quarter, and the locations where each concentration were detected. In addition, soil vapor time series graphs are presented in Appendix I. There are no regulatory criteria for soil vapor concentrations. Soil vapor analytical concentrations are discussed in this section; maps illustrating the spatial extent of total VOCs, benzene, and EDB are discussed in Section 5.4.2.3.

5.2.5.1 25-Foot Interval

VOC analytes detected consistently in all quarters at the 25-foot interval of the SVMWs include 1,2,4-trimethylbenzene; 2-butanone; acetone; benzene; chloroform; cyclohexane; ethylbenzene; heptanes; hexane; m,p,o-xylenes; methylene chloride; toluene; and total xylenes. All other analyzed compounds were either detected inconsistently or non-detect for all quarters. The maximum concentration of benzene detected was 92,000 parts per billion by volume (ppbv) during the Second Quarter CY 2011 sampling. The maximum concentration for toluene was 230,000 ppbv in Third Quarter CY 2012. The maximum concentration for ethylbenzene was 36,000 ppbv, and the maximum concentration for total xylenes was 210,000 ppbv, with both maximum detections occurring in Fourth Quarter CY 2011. Lighter C5 through C8 aliphatic hydrocarbons had a maximum detection of 13,000,000 microgram per cubic meter ($\mu g/m^3$) (hydrocarbons are reported in $\mu g/m^3$ in accordance with the analytical method [Massachusetts Department of Environmental Protection, 2008]; all other compounds are reported in ppbv) during Second Quarter CY 2011 sampling. Heavier C9 through C12 hydrocarbons had a maximum concentration of 570,000 $\mu g/m^3$ during the Fourth Quarter CY 2011 sampling. C9 through C10 aromatic hydrocarbons have been inconsistently detected throughout sampling, but had a maximum concentration of 86,000 µg/m3, also during Fourth Quarter CY 2011 sampling. EDB was detected in samples in only three quarters: Second Quarter CY 2011, Third Quarter CY 2011, and Fourth Quarter CY 2012. The maximum concentration was 250 ppbv in Fourth Quarter CY 2012 at KAFB-106117 (Table 5-10).

5.2.5.2 50-Foot Interval

Consistent VOC detections at the 50-foot interval included 1,2,4-trimethylbenzene; 2-butanone; acetone; benzene; carbon tetrachloride; chloroform; cyclohexane; ethylbenzene; heptane; hexane; m,p,o-xylenes; methylene chloride; toluene; and total xylenes. Other compounds were either non-detect throughout sampling or inconsistently detected. The highest benzene concentration detected was 730,000 ppbv during First Quarter CY 2011. The maximum toluene concentration was 1,500,000 ppbv, and the maximum ethylbenzene concentration was 44,000 ppbv, both during Third Quarter CY 2011. The maximum total xylene detection was 110,000 ppbv in Fourth Quarter CY 2011. Lighter C5 through C8 aliphatic hydrocarbons had a maximum detection of 130,000,000 $\mu g/m^3$ during Third Quarter CY 2012 sampling. Heavier C9 through C12 hydrocarbons had a maximum concentration of 1,800,000 $\mu g/m^3$ during the Second Quarter CY 2012 sampling. C9 through C10 aromatic hydrocarbons have been inconsistently detected throughout sampling, but had a maximum concentration of 91,000 $\mu g/m^3$ in the Third Quarter CY 2011. EDB was detected in samples in three quarters: Second Quarter CY 2011, Fourth Quarter CY 2012, and First Quarter CY 2013.The maximum concentration was 190 ppbv in Fourth Quarter CY 2012 at KAFB-106114 (Table 5-10).

5.2.5.3 150-Foot Interval

Consistently detected contaminants at the 150-foot interval are the same as the 25- and 50-foot intervals, but also includes 1,3,5-trimethylbenzene; Freon 113; propylene; and trichloroethene, even though these compounds were typically detected in a limited number of wells. Second Quarter CY 2012 had the maximum benzene and toluene concentrations with 1,400,000 ppbv and 1,700,000 ppbv, respectively. The maximum ethylbenzene and total xylenes concentrations were detected during Second Quarter CY 2011 at 55,000 ppbv and 150,000 ppbv, respectively. For C5 through C8 aliphatic hydrocarbons, the maximum detection of 170,000,000 $\mu g/m^3$, which occurred during Fourth Quarter CY 2012, while C9 through C12 aliphatic hydrocarbons had a maximum of 3,000,000 $\mu g/m^3$ in Second Quarter CY 2011. Like the 25- and 50-foot intervals, C9 through C10 aromatic hydrocarbons were inconsistently detected, but had a maximum detection of 290,000 $\mu g/m^3$ in Third Quarter CY 2011. EDB was non-detect in all quarters with the exception of Third Quarter CY 2011and Fourth Quarter CY 2012 with a maximum concentration of 150 ppbv in Fourth Quarter CY 2012 at KAFB-106117 (Table 5-10).

5.2.5.4 250-Foot Interval

Consistently detected compounds at the 250-foot interval were the same as for the 150-foot interval. Benzene had a maximum concentration of 950,000 ppbv in Fourth Quarter CY 2012, as did toluene with a maximum concentration of 2,000,000 ppbv. Maximum concentrations of ethylbenzene and total xylenes were detected in Second Quarter CY 2012 at 60,000 ppbv and 140,000 ppbv, respectively. C5 through C8 aliphatic hydrocarbons had a maximum concentration of 150,000,000 µg/m^3 in Fourth Quarter CY 2012, and C9 through C12 aliphatic hydrocarbons had a maximum concentration of 3,600,000 µg/m^3 in Second Quarter CY 2011. Finally, C9 through C10 aromatic hydrocarbons were inconsistently detected and only detected in a small amount of wells, but had a maximum concentration of 860,000 µg/m^3 in Second Quarter CY 2011. EDB was detected in samples in three quarters: Second Quarter CY 2011, Third Quarter CY 2011, and Fourth Quarter CY 2012. The maximum concentration was 1,800 ppbv at SVMW-10 in Fourth Quarter CY 2012 (Table 5-10).

5.2.5.5 350-Foot Interval

Consistently detected compounds at the 350-foot interval are the same for the 250- and 150-foot intervals, with the exceptions of trichloroethene, which was only detected in two quarters (Third Quarter CY 2011 and Third Quarter CY 2013), and chloroform, which was detected in four quarters. For the BTEX compounds, benzene and toluene had maximum concentrations of 710,000 ppbv and 930,000 ppbv, respectively, in First Quarter CY 2012. Ethylbenzene had a maximum concentration of 27,000 ppbv in Second Quarter CY 2011, and total xylenes had a maximum concentration of 98,000 ppbv in Fourth Quarter CY 2012. C5 through C8 aliphatic hydrocarbons had a maximum concentration of 70,000,000 µg/m^3 in Second Quarter CY 2011, while C9 through C12 aliphatic hydrocarbons had a maximum concentration of 1,700,000 µg/m^3 in Second Quarter CY 2012. Finally, the maximum concentration for C9 through C10 aromatic hydrocarbons was 170,000 µg/m^3 in Third Quarter CY 2011. EDB was non-detect in all quarters with the exception of Fourth Quarter CY 2012, when it was detected in KAFB-106136 at a maximum concentration of 41 ppbv (Table 5-10).

5.2.5.6 450-Foot Interval

Consistently detected compounds at the 450-foot interval are 1,2,4-trimethylbenzene; 2-butanone; acetone; benzene; cyclohexane; ethylbenzene; heptane; hexane; m,p, and o-xylenes; propylene; toluene; and total xylenes. The maximum concentrations for the BTEX compounds are 2,100,000 ppbv for benzene, 1,900,00 ppbv for toluene, and 34,000 ppbv for ethylbenzene, all sampled in Second Quarter CY 2011, and 110,000 ppbv for total xylenes in Fourth Quarter CY 2011. For TPH compounds, C5 through C8 aliphatic hydrocarbons had a maximum concentration of 140,000,000 µg/m^3 in the First and Second Quarters CY 2011, C9 through C12 aliphatic hydrocarbons had a maximum concentration of 2,300,000 µg/m^3 in Second Quarter CY 2012, and C9 through C10 aromatic hydrocarbons had a maximum concentration of 46,000 µg/m^3 in Second Quarter CY 2011. EDB was non-detect in all quarters with the exception of Second and Third Quarters CY 2011. The maximum concentration detected was 1,800 ppbv in Second Quarter CY 2011 at KAFB-106116 (Table 5-10).

5.2.5.7 Summary of Quarterly Soil Vapor Sample Results

In general soil vapor concentrations are higher at deeper depths, with maximum concentrations generally in the 250 to 450 feet bgs interval, although there is variability in depths of maximum concentrations of individual contaminants, and variability from quarter to quarter. EDB results were non-detect at most depths in most quarters (due to masking from much higher concentrations of other VOCs) with the exception of some detections in Second and Third Quarters CY 2011,Fourth Quarter CY 2012, and First Quarter 2013. A spatial analysis of soil vapor data is provided in Section 5.4.2.

5.3 ROI Test Results and SVE System Performance

Two ROI tests were conducted at the Kirtland AFB BFF Spill Site to aid in the characterization of the vadose zone in accordance with the Interim Measures Work Plan (USACE, 2011c). The first was conducted during Third Quarter CY 2011, and was used to test the ROI of the portable ICE SVE units. The second ROI test was conducted during First Quarter CY 2013 at the start-up of the new CATOX

SVE system. Based on field observations, a well with an average corrected observed vacuum of at least 0.2 inches of water column (inWC) is considered to be at the edge of the ROI of the extraction well. Wells with an average corrected observed vacuum of approximately 0.2 inWC were observed to have higher corrected observed vacuums (and therefore, likely to be within the ROI) when the barometric pressure was low, and lower corrected observed vacuums (and therefore likely to be outside of the ROI) when the barometric pressure was high.

5.3.1 ICE SVE ROI Tests

A full description of the ROI test using the ICE SVE systems is described in Appendix G. Data collected during all tests is provided in Appendix G. The larger scale CATOX ROI provided more comprehensive data for ST-106 and is discussed below.

5.3.2 CATOX SVE ROI Test

ROI testing at the CATOX SVE system was performed in accordance with the methods described in Section 4.4.2. A complete discussion of the results and the data collected during the CATOX SVE ROI test are provided in Appendix G.

To determine the ROI of the CATOX SVE system, the corrected observed vacuum pressures for each well depth and type were plotted against radial distance from the nearest extraction well, and a best-fit line was fit to the data. The corrected observed vacuum pressure is the vacuum pressure with the barometric effects removed, and was calculated for the vacuum data observed at each of the observation and background wells. The distance at which the best-fit line crosses the corrected observed vacuum pressure of 0.2 inWC is the ROI observed in that well depth and type. The background well used to compare the CATOX SVE vacuum against the barometric fluctuations for both the step-test and 4-week monitoring was well KAFB-106121.

5.3.2.1 Step-Test

As stated in Section 4.2.2, three tests were run at increasing motor speeds with the motor set to 700 rpm for the first test, 1,050 rpm for the second test, and 1,400 rpm for the third test. Vacuum pressures and flow rates from the extraction wells during the step-tests are plotted on Figures 5-16 through 5-18. Hydrocarbon concentrations from the extraction wells during each step-test are plotted on Figures 5-19 through 5-21.

All of the three tests showed a consistent ROI for the 450-foot bgs SVMWs and the 484-foot PneuLog® wells with an ROI of approximately 350 and 300 feet, respectively. Data from the 450-foot bgs SVMWs and 484-foot bgs PneuLog® wells were plotted on Figures 5-22 through 5-24. The 350-foot bgs SVMWs showed an ROI of approximately 300 to 350 feet, whereas the 350-foot PneuLog® wells showed a smaller and less defined ROI ranging from 250 to 150 feet in tests 1 and 2, respectively. Data from the 350-foot bgs PneuLog® and SVMWs were plotted on Figure 5-25 through 5-27. For all three tests on the 200-foot bgs PneuLog® wells, a poor fit to the data was shown and was therefore not used to estimate an ROI. However, the 150-foot bgs SVMWs showed an ROI of 300 feet and 200 feet in tests 1 and 2, respectively. Data from the 200-foot bgs PneuLog® and 150-foot bgs SVMWs were plotted on Figure 5-28 through 30.

5.3.2.2 Four-Week Monitoring

Following the step-test, 4 weeks of ROI monitoring was conducted. During the first 2 weeks, the motor speed for the CATOX system was 1,050 rpm, and the motor speed was increased to 1,400 rpm for the final 2 weeks. The results of the monitoring are consistent with the results of the prior three tests. Vacuum pressures and flow rates from the extraction wells during the 4-week monitoring are plotted on Figures 5-31 and 5-32. Hydrocarbon concentrations from the extraction wells during the 4-week monitoring are plotted on Figures 5-33 and 5-34.

Data from the 484-foot bgs PneuLog® wells and the 450-foot bgs SVMWs showed the same ROI of 300 feet and 350 feet, respectively. The data for 484-foot bgs PneuLog® wells and the 450-foot bgs SVMWs were plotted on Figures 5-35 and 5-36.

The SVMWs at depths 350-foot bgs and 150-foot bgs had the same ROI values as the three step-tests. The SVMWs at 350-foot bgs had an ROI of 300 to 350 feet, and the SVMWs at 150-foot bgs had an ROI of approximately 300 feet. The best fit line for the 350-foot bgs and 200-foot bgs PneuLog® wells had a poor fit to data, and was therefore not used to estimate an ROI. Data from the 350-foot bgs, 200-foot bgs, and 150-foot bgs PneuLog® and SVMWs were plotted on Figures 5-37 through 5-40.

5.3.3 Barometric Fluctuations

During ROI testing at SWMU ST-106, it was observed that barometric fluctuations had an influence on vacuum pressure in the vadose zone and mass recovery from the SVE system. These influences are discussed in the sections below.

5.3.3.1 Barometric Influence on Vacuum Pressure in the Vadose Zone

Using the methods described in Section 4.3.4, the vacuum response of the vadose zone to barometric fluctuations was quantified. For each well grouping, monitored vacuum pressure was plotted against the interpolated barometric pressure at the time of monitoring. A best-fit line was then matched to each set of data. The slope of the best fit line is the barometric efficiency calculated for each well grouping in inWC per inch of mercury (inHg), or the change in the vacuum pressure at a well per 1 inHg increase in barometric pressure. In addition, the correlation coefficient was calculated for each best-fit line, which determines the accuracy of the calculated barometric efficiency. The calculated barometric efficiency and correlation coefficient for each well grouping are summarized in Table 5-11.

Beginning with the 150-foot bgs SVMWs, there is a significant response to changes in barometric pressure. As barometric pressure increases, the vacuum pressure in a given well increases. The correlation coefficient for the 150-, 350-, and 450-foot bgs SVMW sets indicated an excellent positive correlation between the vacuum pressure in the vadose zone and barometric pressure during both rounds. The influence of barometric pressure increases with depth.

The barometric efficiency determined for a given well is the average barometric efficiency across the entire screened length. Each of the PneuLog® wells has approximately 150 feet of screen, while each of the SVMWs has approximately 10 feet of screen. This difference in screened length impacts each depth of the PneuLog® wells differently:

- The screened interval of the 484-foot bgs wells spans the depth from the 350-foot bgs SVMWs to 34 feet below the 450-foot bgs SVMWs. Barometric efficiencies are similar in all three well types, which indicates that the vadose zone response to barometric influences is consistent across this entire length.
- The screened interval of the 350-foot bgs PneuLog® wells spans the depth from the 350-foot bgs SVMWs to approximately 50 feet above the 250-foot bgs SVMWs. The barometric efficiency of the 350-foot bgs PneuLog® wells is less than the barometric efficiency of the 350-foot bgs SVMWs, but greater than the barometric efficiency of the 250-foot bgs SVMWs.
- The screened interval of the 200-foot bgs PneuLog® wells spans the depth from the 25-foot bgs SVMWs to 50 feet below the 150-foot bgs SVMWs. As discussed previously, there is no significant impact from barometric pressure in the SVMWs screened at depths less than 150 feet bgs. The barometric efficiency in the 200-foot bgs PneuLog® wells is therefore significantly less than the barometric efficiency in the 150-foot bgs SVMWs.

Using a known vacuum pressure from a well of a given type at a known barometric pressure, the range in vacuum pressures for each well type can be calculated. The calculated vacuum pressures are presented in Table 5-12. As indicated by the barometric efficiency, the total range in vacuum pressures increases with well depth for each type of well (SVM or PneuLog®). For all well types and depth, the minimum vacuum pressure is negative, and the maximum vacuum pressure is positive. This indicates that when the barometric pressure is high, the vacuum in the deep vadose zone will be positive, and wells screened within that zone will suck air in when they are uncapped as the vadose zone attempts to equilibrate with the atmosphere. Conversely, when the barometric pressure is low, the vacuum in the deep vadose zone will be negative, and wells screened within that zone will blow air out when they are uncapped as the vadose zone attempts to equilibrate with the atmosphere.

5.4 Site Contamination

This section describes the contaminants of concern (COCs), their concentrations, and their horizontal and vertical extent in the vadose zone at ST-106.

5.4.1 Detected Compounds and Contaminants of Concern

A COC screening analysis was performed on soil and soil vapor data to identify which compounds were the most frequently detected within the vadose zone. This COC analysis was performed to aid in characterization of the vadose zone. A separate risk assessment will be performed to identify potential hazards at ST-106 for evaluation of potential corrective measures. For the soil COC analysis, a compound was considered to be a COC if all of the following criteria were met:

- The total number of samples for a given parameter during the period between June 2006 and September 2013 was more than 20.
- More than 5 percent (%) of the analyses for a given parameter resulted in detections.
- As outlined the NMED *Risk Assessment Guidance for Site Investigations and Remediation* (NMED 2012): The maximum concentration was greater than the NMED SSLs. If no NMED SSL has been established for the parameter, then the EPA residential RSL (EPA, 2013) was used.
- NMED SSLs have not been promulgated for TPH-DRO and TPH-GRO. In the case of these contaminants, concentrations were compared to the NMED TPH Screening Guidelines for Residential Direct Exposure for kerosene and jet fuel (NMED, 2012). Although TPH is identified as a COC in this section, to more fully discuss the horizontal and vertical extent of contamination, the NMED TPH guidance states that the TPH guidelines are not designed to be protective of exposure to contaminants such as VOCs, SVOCs, and metals; therefore, they must be tested for and compared to their individual NMED SSLs.

The following COCs were identified for soil:

Parameter	CAS Number
1,2,4-trimethylbenzene	95-63-6
benz(a)anthracene	56-55-3
benzo(a)pyrene	50-32-8
benzo(b)fluoranthene	205-99-2
dibenz(a,h)anthracene	53-70-3
Ethylbenzene	100-41-4
indeno(1,2,3-cd)pyrene	193-39-5
Naphthalene	91-20-3
TPH-DRO	NA
TPH-GRO	NA

CAS	Chemical Abstract Service

Because there are no established cleanup levels for soil vapor, no COC evaluation was performed. The horizontal and vertical extent of soil vapor contamination will be discussed in terms of the benzene and total VOC plumes.

5.4.1.1 EDB in Soil Vapor

Based on the presence of EDB in AvGas, sporadic detections of EDB in soil vapor, the detections of EDB in groundwater and the physical properties of EDB, it is likely that an EDB vapor plume is present, likely contained within the extent of the vapor plume of the more volatile compounds (TPH constituents, BTEX). VOCs in soil vapor, including both BTEX and EDB (among others), were analyzed using EPA Method TO15 in accordance with EPA Method TO15 requirements, DoD QSM guidelines, and the approved Vadose Zone Investigation Work Plan (USACE, 2011a). . The detection limits of the method are impacted by the Total VOC concentrations. Due to elevated concentrations of aliphatic hydrocarbons and aromatic hydrocarbons in vapor samples, appropriate dilutions were performed in order to quantify these compounds within the instrument range, resulting in elevated individual detection limits. This resulted in “masking” of relatively lower EDB concentrations, with numerous non-detects for EDB in soil vapor each quarter and only a limited number of EDB detections. EDB data are presented in "dot maps" rather than contoured soil vapor plume maps.

Due to the limited positive detections of EDB in soil vapor, an evaluation of EDB in soil vapor using an alternative analytical method with a lower detection limit is planned for later in 2014 and will be reported in the appropriate Quarterly Report.

5.4.2 Spatial Analysis of COCs

The spatial distribution of COCs in the vadose zone has been delineated based on soil and soil vapor sample results. Soil sample results (shallow and deep) are presented in the following subsections. In addition, compound-specific soil vapor plume footprint maps and cross-sections were prepared for total VOCs and benzene at 100-foot intervals, from 50 feet bgs to 450 feet bgs. FFOR soil sample and step-out locations exceeding NMED SSLs or EPA RSLs are detailed on plan view maps (Figures 5-1 through 5-5). Calculations based on NAPL concentrations in vadose zone soil, and soil vapor concentrations measured during Fourth Quarter 2011 (which generally had the highest soil vapor concentrations), indicate that approximately 48,000 gallons of NAPL were present in the vadose zone vapor, with approximately 630,000 gallons adsorbed to the vadose zone soil at ST-106. This is in addition to the calculated 5.2 million gallons in the historical NAPL plume at SS-111 for a combined total of 5.9 million gallons of NAPL. Calculations estimating NAPL mass in the vadose zone vapor, vadose zone soils and groundwater can be found in Appendix K.

5.4.2.1 Spatial Analysis of Soil Contamination Based on Shallow Sampling

Soil COCs are identified in Section 5.4.1. Shallow soil sample results from 2006 to 2013 were compared against NMED residential SSLs, or if no SSL exists at this time, samples were compared against EPA RSLs. In addition to historical shallow soil sampling, two shallow soil sampling tasks were completed during the RCRA Facility Investigation from 2011 to 2013: sampling along the former fuel pipelines and offloading rack (FFOR sampling), and sampling around the footprint of the former fuel tanks.

The analytical results of the shallow sampling locations completed between 2011 and 2013 indicate shallow soil contamination is delineated and is limited to an area no greater than 20 feet beyond the width of the former fuel lines, as confirmed by step-out sampling. The area of highest contamination is located northwest of the Pump House (Building 1033), where the former fuel line runs north and turns directly west. This western arm of the former fuel line contains an area of known leakages located approximately 18 feet, 150 feet, and 200 feet east of the FFOR. In accordance with the Interim Measures Work Plan (USACE, 2011c), additional boreholes were advanced in these known leak areas to more accurately delineate contamination. Figures 5-1 through 5-5 demonstrate that in general contamination is greater in the area of the previously identified leak locations.

The area of highest COC contamination is along the western arm of the former fuel line in the area of known leakages east of the FFOR. There are two general areas where contamination has been delineated: the first located at, and just west of, the 90° bend in the pipeline towards the FFOR (Figures 5-1 through 5-5). Although the locations exceeding screening levels in the surface and 5-foot samples are more dispersed, it becomes apparent in the 10-, 15-, and 20-foot samples that locations exceeding screening levels are grouped within 70 feet to the west and 30 feet to the south of the bend.

The second general area of contamination is located approximately 150 to 230 feet west of the 90° bend in the former pipeline. Again, the locations exceeding screening levels at the shallower sample depths are more disperse, but the contamination is more clearly delineated in the 15-foot and 20-foot locations exceeding screening levels.

South and southeast of the Pump House, smaller areas of contamination are noted south of Buildings 2404 and 2403, and northeast of Building 2422. The four rounds of soil sampling serve to delineate the area of soil contamination in exceedance of NMED SSLs along the former fuel lines, and fuel tanks for the FFOR and fuel tank shallow soil investigation.

Figure 4-1 denotes the soil sampling locations from the initial sampling event (Second and Third Quarters CY 2011) and all subsequent sampling events in 2012 and 2013. Figures 5-1 through 5-5 illustrate where sample analytical results exceed NMED SSLs or EPA RSLs. Table 5-1 presents a summary of the analytical results. Complete analytical results can be found in Appendix C-1.

5.4.2.2 Spatial Analysis of Deep Soil Contamination Based on Split-Spoon Sampling

Soil COCs are identified in Section 5.4.1. Deep soil sample results from 2006 to 2013 were compared against NMED residential SSLs, or if no SSL exists at this time, samples were compared against EPA RSLs. The following details deep soil contamination by COC:

- One split-spoon soil sample, representing the interval 400 to 450 ft bgs (collected at 447 to 448.5 bgs), was identified with a TPH-(GRO+DRO) concentration greater than the NMED TPH Screening Guideline of 1,000 mg/kg –at location KAFB-106120.
- No available soil sample analytical results from wells KAFB-1066 through KAFB-10610 collected between 2006 and 2011 exceeded regulatory criteria.

5.4.2.3 Spatial Analysis of Soil Vapor Contamination

Vapor plume maps for benzene and Total VOCs for the three most recent quarters available--Fourth Quarter 2012, First Quarter 2013 and Second Quarter 2013 are presented in Figures 5-41 through 5-46. Additional maps illustrating vapor plume maps for benzene and Total VOCs in Second Quarters 2011, and 2012 are presented in Figures 5-47 through 5-50 These figures depict both the aerial extent of the soil vapor footprints as well as the plume concentration distribution (in ppmv) for total VOC and benzene from 50 to 450 feet bgs (5300 feet to 4900 feet amsl) using soil vapor data. Because not all SVMWs were installed by Second Quarter 2011, a benzene vapor contour map is not available for this quarter.

As discussed in section 5.4.1, due to the analytical methods used during quarterly soil vapor sampling, EDB was not detected in the majority of soil vapor samples. Therefore a "dot" map of EDB concentrations is presented, rather than contoured plume maps. Figure 5-50 illustrates discrete EDB detections in soil vapor. These data do, however, show the maximum potential concentrations of EDB (e.g., if EDB is ND at 400 ppbv, we know that its concentration at that location would be less than 400 ppbv).

Total VOC and benzene cross sections for Second Quarter 2013 are depicted in Figures 5-51through 5-62. Apparent inconsistencies between soil vapor maps and cross sections are due to sample locations at non-standard depths. Although screened intervals are generally located at 25, 50, 150, 250, 350 and 450 feet bgs, they may be a few feet higher or lower. Additionally, screened intervals at wells installed prior to 2011 do not adhere to the standardized sample depths. Samples collected at non-standard sample depths may result in areas of high concentration that are shown on a cross section (where the sample depth falls between the standard depths for the plan view maps), but the data are not projected onto the plan view maps.

Total VOCs

50 Feet bgs

Figure 5-43, from the Second Quarter CY 2013 depicts a Total VOC vapor plume with the highest concentrations ranging from 1,100 to 10,000 ppmv directly beneath the FFOR. With the exception of this high concentration area, the majority of the of the vapor plume at 50 feet bgs has concentrations within the 10 to 100 ppmv range although four areas with concentrations from 100 to 1,000 ppmv are noted.

As illustrated in Figures 5-41 through 5-43, 5-47 and 5-48, the total VOC footprint between 11 ppmv and 100 ppmv at 50 feet bgs (5300 feet amsl) increased from 38.3 acres in Second Quarter 2011 to 45.3 acres in Fourth Quarter 2012 to 80.3 acres in Second Quarter 2013. The footprint of VOC concentration between 110 ppmv and 1,000 ppmv decreased during this time from 36.2 acres in Second Quarter 2011 to 9 acres in Second Quarter 2013. The area of lower concentrations became larger while the area of higher concentrations became smaller, illustrating that concentrations decreased overall between Second Quarter 2011 and Second Quarter 2013. Some increase in size of the VOC footprint between 11 ppmv and 100 ppmv at 50 feet bgs from 2011 to 2012, may be due to the additional data points provided by wells installed near the former aboveground fuel tanks during that time. The installation of SVMWs was completed in Third Quarter 2011.

150 Feet bgs

At 150 ft bgs, Figure 5-43 depicts the highest concentration of Total VOCs (1,100-10,000 ppmv) as located directly below the FFOR, similar to the 50 foot bgs vapor contour. The extent of this area is similar in size to what was observed on the 50 foot bgs map.

As illustrated in Figures 5-41 through 5-43, 5-47 and 5-48, the total VOC footprint between 11 ppmv and 110 ppmv at 150 feet bgs (5200 feet amsl) increases from 42.5 acres in Second Quarter 2011 to 49.6 acres in Fourth Quarter 2012 to 55.4 acres in Second Quarter 2013. The area of VOC concentration between 100 ppmv and 1,000 ppmv also increased from 30.2 acres in Second Quarter 2011 to 45.5 acres in Fourth Quarter 2012, but then decreased to 9.1 acres in Second Quarter 2013. As at 150 feet bgs, the area of lower concentrations became larger while the area of higher concentrations became smaller, indicating that overall concentrations decreased between Second Quarter 2011 and Second Quarter 2013.

250 Feet bgs

At 250 ft bgs, Figure 5-43 depicts the highest concentration of Total VOCs (1,100-10,000 ppmv) east of the FFOR along the access road to the BFF. Unlike the 50 and 150 foot bgs maps there is no high concentration zone directly below the FFOR at this depth.

Figures 5-41 through 5-43, 5-47 and 5-48, indicate that the total VOC footprint between 11 ppmv and 110 ppmv at 250 feet bgs (5100 feet amsl) increases from 38.5 acres in Second Quarter 2011 to 53.3 acres in Fourth Quarter 2012 to 69.4 acres in Second Quarter 2013. The area of VOC concentration between 100 ppmv and 1,000 ppmv also increased from 34.6 acres in Second Quarter 2011 to 47.0 acres in Fourth Quarter 2012, but then decreased to 12.2 acres in Second Quarter 2013. As at 50 and 150 feet bgs, the area of lower concentrations became larger while the area of higher concentrations became smaller, indicating that overall concentrations decreased between Second Quarter 2011 and Second Quarter 2013.

350 Feet bgs

At 350 ft bgs, Figure 5-43 depicts that the highest concentration of Total VOCs does not exceed 1,000 ppmv compared with Second Quarter 2011 when 6.7 acres exceeded 1,000 ppmv. The area of the plume exceeding 100 ppmv is 19.9 acres and is located throughout the BFF.

Figures 5-41 through 5-43, 5-47 and 5-48 indicate that the total VOC footprint between 11 ppmv and 110 ppmv at 350 feet bgs (5000 feet amsl) decreases from 40.6 acres in Second Quarter 2011 to 34.8 acres in Fourth Quarter 2012, but then increases to 66.6 acres in Second Quarter 2013. The area of VOC concentration between 100 ppmv and 1,000 ppmv increased from 39.3 acres in Second Quarter 2011 to 70 acres in Fourth Quarter 2012, but then decreased to 19.9 acres in Second Quarter 2013, indicating that overall concentrations decreased between Second Quarter 2011 and Second Quarter 2013.

450 Feet bgs

At 450 feet bgs, Figure 5-43 depicts a plume area of Total VOCs with concentrations ranging from 11,000-18,000 ppmv in the vicinity of the easternmost former fuel tank. This depth has the highest concentration of total VOCs during Second Quarter 2013.

Figures 5-41 through 5-43, 5-47 and 5-48 indicate that the total VOC footprint between 11 ppmv and 110 ppmv at 450 feet bgs (4900 feet amsl) was approximately equal (27 acres) in Second Quarter to Fourth Quarter 2012 but increased to 52.6 acres in Second Quarter 2013. The area of VOC concentration between 100 ppmv and 1,000 ppmv increased from 46.8 acres in Second Quarter 2011 to 63.6 acres in Fourth Quarter 2012, but then decreased to 39.8 acres in Second Quarter 2013. As at 50 ft bgs, some increase in size of the VOC footprint between 100 ppmv and 1000 ppmv from 2011 to 2012, may be due to the additional data points provided by wells installed near the former aboveground fuel tanks during that time. The installation of SVMWs was completed in Third Quarter 2011; however, as at all other depths, the area of lower concentrations became larger while the area of higher concentrations became smaller, indicating that overall concentrations decreased between Second Quarter 2011 and Second Quarter 2013.

Cross Sections

The total VOC vapor cross sections for Second Quarter 2013 (Figures 5-51 through 5-56) confirm the results illustrated by the vapor plume maps. VOC vapor cross section G-G’ (Figure 5-52) illustrates an area of concentration greater than 1,000 ppmv approximately 500 feet wide between 50 feet bgs and 150 feet bgs directly beneath the FFOR. This zone of higher concentrations is also visible in the VOC vapor cross section I –I’ (Figure 5-54) and the vapor plume plan maps Cross Section H-H’ (Figure 5-53) and K-K’ (Figure 5-56) also show a second zone of concentrations greater than 1,000 ppmv from approximately 400 feet bgs to the top of the water table and approximately 600 to 700 ft wide.

Benzene

50 Feet bgs

As with the total VOC maps, Figure 5-46, from the Second Quarter CY 2013 depicts a benzene vapor plume at 50 ft bgs with the highest concentrations ranging from 11 to 100 ppmv directly beneath the FFOR. With the exception of this high concentration area, the majority of the vapor plume at 50 ft bgs has concentrations within the 1 to 10 ppmv range.

As illustrated in Figures 5-44 through 5-46, and 5-49, the total benzene footprint between 1 ppmv and 10 ppmv at 50 feet bgs (5300 feet amsl) increased from 35.3 acres in Second Quarter 2012 to 53.6 acres in Fourth Quarter 2012, and then decreased to 8.3 acres in Second Quarter 2013. The area of benzene concentration between 11 ppmv and 100 ppmv also decreased during this time from 6.9 acres in Second Quarter 2012 to 5 acres in Fourth Quarter 2012 to 0.8 acres in Second Quarter 2013. The footprints of both higher and lower benzene concentrations decreased during this time.

150 Feet bgs

At 150 ft bgs, Figure 5-46 depicts the highest concentration benzene (11-100 ppmv) as located directly below the FFOR, similar to the 50 foot bgs vapor contour. The extent of this area is similar in size to what was observed at 50 foot bgs.

As illustrated in Figures 5-44 through 5-46, and 5-49 the total benzene footprint between 1 ppmv and 10 ppmv at 150 feet bgs (5200 feet amsl) increased from 36.8 acres in Second Quarter 2012 to 55.2 acres in Fourth Quarter 2012 and then decreased to 10.4 acres in Second Quarter 2013. The area of benzene concentration between 11 ppmv and 100 ppmv also decreased during this time from 9.8 acres in Second Quarter 2012 to 5.3 acres in Fourth Quarter 2012 to 0.6 acres in Second Quarter 2013. As at 50 feet bgs, the footprints of both higher and lower benzene concentrations decreased during this time.

250 Feet bgs

At 250 ft bgs, Figure 5-46 depicts the highest concentration of benzene (11-100 ppmv) east of the FFOR along the access road to the BFF. Unlike the 50 and 150 foot bgs data there is no high concentration zone directly below the FFOR at this depth.

As illustrated in Figures 5-44 through 5-46, and 5-49, the total benzene footprint between 1 ppmv and 10 ppmv at 250 feet bgs (5100 feet amsl) increased from 32.8 acres in Second Quarter 2012 to 48.5 acres in Fourth Quarter 2012 and then decreased to 12.9 acres in Second Quarter 2013. The area of benzene concentration between 11 ppmv and 100 ppmv also decreased overall during this time from 10.5 acres in Second Quarter 2012 to 12.5 acres in Fourth Quarter 2012 to 2.8 acres in Second Quarter 2013. The footprints of both higher and lower benzene concentrations decreased during this time.

350 Feet bgs

At 350 ft bgs, Figure 5-46 depicts three zones of concentrations exceeding 11 ppmv east of the FFOR and north of the former fuel tanks. The remainder of the plume is between 1 and 10 ppmv.

As illustrated in Figures 5-44 through 5-46, and 5-49, the total benzene footprint between 1 ppmv and 10 ppmv at 350 feet bgs (5000 feet amsl) increased from 43.8 acres in Second Quarter 2012 to 62.4 acres in Fourth Quarter 2012 and then decreased to 16.6 acres in Second Quarter 2013. The area of benzene concentration between 11 ppmv and 100 ppmv also decreased during this time from 11.8 acres in Second Quarter 2012 to 8.3 acres in Fourth Quarter 2012 to 0.3 acres in Second Quarter 2013. The footprints of both higher and lower benzene concentrations decreased during this time.

450 Feet bgs

At 450 ft bgs, Figure 5-46 depicts two zones of concentrations exceeding 11 ppmv south and east of the FFOR and west of the former fuel tanks. The remainder of the plume is between 1 and 10 ppmv.

As illustrated in Figures 5-44 through 5-46, and 5-49, the total benzene footprint between 1 ppmv and 10 ppmv at 450 feet bgs (4900 feet amsl) increased from 50 acres in Second Quarter 2012 to 69 acres in Fourth Quarter 2012 and then decreased to 39 acres in Second Quarter 2013. The area of benzene concentration between 11 ppmv and 100 ppmv also decreased during this time from 15.7 acres in Second Quarter 2012 to 14.6 acres in Fourth Quarter 2012 to 0.4 acres in Second Quarter 2013. As at all other depths, the footprints of both higher and lower benzene concentrations decreased during this time.

Cross Sections

Figures 5-57 through 5-62 illustrate benzene vapor cross sections for Second Quarter 2013. Benzene vapor cross section G-G' illustrates an area of concentration greater than 10 ppmv approximately 500 feet wide between about 50 feet bgs and 150 feet bgs. This zone of higher concentrations is also visible to a smaller extent in the benzene vapor cross section I –I'.

The benzene cross sections H-H' and K-K' from Second Quarter 2013 are similar to the VOC cross sections, but do not show a second zone of elevated concentrations at the water table. Together, the cross sections and the plan view maps indicate that benzene contamination originated in the northwestern part of the BFF beneath the FFOR and migrated downward. At 200 to 250 ft bgs it began to move to the south and east, until it reached the water table in an area somewhere between the former fuel tanks, and the FFOR.

Summary of Soil Vapor Spatial Analysis

Both the total VOC and benzene plan maps (Figures 5-41 through 5-49) along with the total VOC and benzene vapor and lithology cross sections from Second Quarter 2013 (Figures 5-51 through 5-62; cross sections from previous quarters can be found in Appendix L) indicate a vapor zone of higher concentrations originating beneath the FFOR (SVEW-01 through SVEW-09) and terminating at the water table to the southeast. The highest benzene and total VOC concentrations at the 50 and 150 foot depths are located directly below the FFOR, and the area of the known spill locations. At 200 to 250 ft bgs contamination began to move to the south and east, until it reached the water table in an area between the former fuel tanks and the FFOR. The maximum concentrations of benzene and total VOCs in samples collected at 350 and 450 feet bgs are located to the south and east of the FFOR, indicating movement of contaminants in a southeasterly direction in addition to downward migration toward the water table. The results of vapor profiles collected during PneuLog® testing support the Quarterly Soil Vapor Sampling results (Section 5.2.2). As the NAPL travels through the vadose zone, COCs are detected at various depths from the NAPL source. Once the COC is volatilized from the NAPL body, it is free to move as a vapor phase. The plume maps that illustrate the different spatial distributions of total VOCs and benzene offer an example of the aforementioned processes. In these figures, the total VOCs have vapor hotspots that do not directly correspond with the benzene hotspots. This suggests that COCs are moving out of the NAPL body and migrating through the vadose zone at different rates. Possible explanations for this contaminant migration are discussed in Section 6.2, Contaminant Migration.

5.5 IDW Results

Appendix J provides waste disposal analytical data and hazardous waste manifests. The summary of the analysis and disposal of each type of IDW is discussed below.

5.5.1 Soil IDW

Table 5-14 details the sampling and disposal of each roll-off generated from January 2011 to June 2013.

5.5.1.1 Disposal of Hazardous Soil IDW

No roll-off containers of soil IDW were classified as hazardous as defined by 40 CFR 261.24.

5.5.1.2 Disposal of Non-Hazardous Special Waste Soil IDW

Two roll-off containers of soil IDW (from the drilling of PneuLog® well KAFB-106150 and installation of shallow soil borings during the first round of sampling at FFOR) were classified as non-hazardous as defined by 40 CFR 261.24, but classified as Special Waste as defined by 20 NMAC Chapter 9. Soil from this roll-off container was transported by a subcontractor for disposal off-site at the Valencia Regional Landfill and Recycling Facility, a facility permitted to handle special wastes. Special Waste was manifested in accordance with NMAC 20.9.8.19.

5.5.1.3 Disposal of Non-Hazardous Clean Soil IDW

The remaining 98 roll-off containers of soil IDW were determined to be non-hazardous as defined by 40 CFR 261.24 and did not exceed Special Waste criteria (20 NMAC, Chapter 9). Soil from these roll-off containers was accepted by the Kirtland AFB Construction and Demolition Landfill for disposal.

5.5.2 IDW Water from Decontamination of Drilling Equipment

Table 4-8 details the sampling and disposal of each wastewater container from January 2011 to June 2013. Appendix J provides hazardous waste manifests and waste disposal analytical data.

5.5.2.1 Disposal of Hazardous IDW Water from Decontamination of Drilling Equipment

Decontamination IDW water from one well, KAFB-106129, was classified as hazardous, as defined by 40 CFR 261.24. The IDW water from this well was containerized in 55-gallon, closed-topped, polyethylene, U.S. Department of Transportation -approved shipping drums and then manifested as hazardous waste and transported by a subcontractor to US Ecology in Beatty, NV, a facility that is permitted to handle hazardous IDW water. Hazardous waste manifests are provided in Appendix J.

5.5.2.2 Disposal of Non-Hazardous IDW Water from Decontamination of Drilling Equipment

The remaining IDW water was characterized as non-hazardous by 44 samples, each pertaining to decontamination IDW water generated during installation of a given well. This water was discharged to the ground surface ensuring that IDW water did not enter a watercourse for surface water with Notice of Intent approval where necessary.

6. CONTAMINANT FATE AND TRANSPORT

This section describes the fate of contaminants in the environment and potential transport mechanisms. Contaminant fate refers to the expected final state that an element, compound, or group of compounds will achieve following release into the environment. Contaminant transport refers to migration mechanisms away from the source area.

Once a contaminant enters an environmental medium, the fate and transport are dependent on a wide variety of factors. Migration pathways often include air, water, soil, and the interfaces between the phases of the contaminant (i.e., solid, liquid, or gas). The fate and transport of contaminants occur in all three environmental media: terrestrial, aquatic, and atmospheric. Terrestrial environments are comprised of soil and groundwater, aquatic environments are comprised of surface water and sediment, and air is the only component of the atmospheric environment. At SWMU ST-106, the environments present are limited to terrestrial and atmospheric; there is no surface water body present at the site.

The physical and chemical properties of the impacted media (soil and soil vapor at ST-106) can affect the fate and persistence of the contaminants. This, in turn, governs the contaminant distribution and behavior in environmental media. For example, DeVaull et al. (1997) reported that oxygen concentrations above 4% in the vadose zone are adequate for substantial biodegradation of BTEX contaminants. Depending upon the specific chemical and soil conditions, contaminants may be transferred from surface soil to subsurface soil, to stream/wetland sediments or surface water, and from other media to the air. The propensity of a contaminant to react in a way that moves it toward equilibrium conditions in the environment as well as transfer between media is an important factor in determining its mobility.

In the terrestrial environment, if the contaminant is released to soil, the contaminant may volatilize, adhere to the soil by sorption, leach into the groundwater, or degrade because of chemical (abiotic) or biological (biotic) processes. If the contaminant is volatilized, it may be released to the atmosphere. Contaminants that are dissolved eventually may be transported to an aquatic environment (e.g., groundwater).

In the atmospheric environment, contaminants may exist as vapors or as particulate matter. The transport of contaminants relies mostly on wind currents and continues until the contaminants are returned to the earth by wet or dry deposition. Degradation of organic compounds in the atmosphere can occur due to direct photolysis, reaction with other chemicals, or reaction with photochemically generated hydroxyl radicals.

6.1 Contaminant Properties and Persistence

This section presents a discussion of each of the COCs in soil (shallow and deep) at SWMU ST-106. Because there are no established cleanup levels for soil vapor, no COC evaluation was performed. The soil COCs identified in Section 5.4 for SWMU ST-106 is as follows:

Parameter	CAS Number
1,2,4-trimethylbenzene	95-63-6
benz(a)anthracene	56-55-3
benzo(a)pyrene	50-32-8
benzo(b)fluoranthene	205-99-2
dibenz(a,h)anthracene	53-70-3
Ethylbenzene	100-41-4
indeno(1,2,3-cd)pyrene	193-39-5
Naphthalene	91-20-3
TPH-DRO	NA
TPH-GRO	NA

CAS Chemical Abstract Service

As discussed in Section 5.4.4.1, EDB is not considered a COC at ST-106 as defined by the COC analysis, however; an evaluation of EDB in soil vapor using an alternative analytical method with a lower detection limit is planned for later in 2014 and will be reported in the appropriate Quarterly Report. Table 6-1 presents a summary of the physical and chemical properties of each COC. An overview of these properties as they relate to contaminant migration is presented below:

Specific Gravity—The ratio of the density of a substance to that of a standard substance. The usual standard of comparison for solids and liquids is water at 4°Celsius (39.2°F), which has a density of 1.000 kilograms per liter (62.4 pounds per cubic foot). Gases are commonly compared to dry air, which has a density of 1.29 grams per liter under so-called "standard conditions" (0°Celsius and 1 atmosphere pressure).

Solubility—The solubility expresses the mass of a substance that will dissolve completely in a given volume of water and is temperature-dependent. Generally, substances with a high aqueous solubility will tend to partition to the water phase and have lower octanol-water and air-water (Henry's Law) partition coefficients.

Vapor Pressure—Vapor pressure is defined as "a measure of the tendency of a substance to pass from a solid or a liquid to a vapor state. It is the pressure of the gas in equilibrium with the liquid or the solid at a given temperature. The greater the vapor pressure, the more volatile the substance" (Fetter 1993).

Henry's Law—Henry's Law states "there is a linear relationship between the partial pressure of a gas above a liquid and the mole fraction of the gas dissolved in the liquid" (Fetter 1993). The partitioning between the water and air phases aids in understanding the fate and transport behavior of compounds, because it relates to subsurface behavior (volatilization from groundwater into soil air) as well as behavior at the surface (volatilization into air in the boundary layer). Chemicals with low Henry's Law constants will tend to stay in solution rather than move into the vapor phase; those with high Henry's Law constants will readily move from the aqueous to vapor phase.

Octanol-water Partition Coefficient (K_{ow})— The octanol-water partition coefficient (K_{ow}) has been defined as "a measure of the degree to which an organic substance will preferentially dissolve in water or an organic solvent" (Fetter, 1993). A higher K_{ow} value indicates a more non-polar compound, one that does not readily dissolve in water. Log K_{ow} is also used as a relative indicator of the tendency of an organic compound to adsorb to soil and is used to evaluate solubility of organic compounds. Log K_{ow} values are generally inversely related to aqueous solubility and directly proportional to molecular weight (EPA, 2009).

Vapor Density— Vapor density is the weight of a unit volume of gas or vapor compared to the weight of an equal volume of air. Substances lighter than air (such as acetylene and methane) are said to have vapor densities less than 1.0 and substances heavier than air (such as butane, chlorine, and ethane) are said to have vapor densities higher than 1.0. Whereas all gases and vapors mix with air, the lighter substances tend to rise and dissipate, and the heavier substances tend to concentrate in low places along floors, sewers, and trenches.

Organic Carbon Partition Coefficient—The organic carbon partition coefficient (K_{oc}) expresses the tendency of a compound to be adsorbed onto the organic carbon within the soil, i.e., the partitioning of the solute between soil water and organic carbon. K_{oc} values are useful in predicting the mobility of organic soil contaminants; higher K_{oc} values correlate to less mobile organic chemicals, while lower K_{oc} values correlate to more mobile organic chemicals.

The physical and chemical properties, potential release mechanisms, and routes of migration for the COC are discussed in Sections 6.1.1 through 6.1.3.

6.1.1 VOCs

Three VOCs (ethylbenzene; naphthalene; and 1,2,4-trimethylbenzene) were identified as COCs at SWMU ST-106. The fate and transport of these VOCs is as follows:

- **BTEX**—While only ethylbenzene was identified as a COC, the four "BTEX" compounds have similar properties and are discussed as a group. They are classified as "monoaromatic" hydrocarbons because they all contain one benzene ring with or without alkyl groups. These compounds have the lowest molecular weights of the fuel contaminants. Their low molecular weights impart higher aqueous solubilities, higher volatilities, and lower partition to soil or organics relative to the other fuel contaminants. Benzene is the most water soluble of the BTEX compounds and is 10 times more soluble than ethylbenzene or xylenes. BTEX compounds also are the most volatile of the aromatic compounds and have the lowest soil organic carbon sorption coefficients (K_{oc}) of the common hydrocarbon fuel contaminants (Table 6-1). Benzene (K_{oc} of 59 milliliter per gram [mL/g]) is considered to be highly mobile in soil, toluene (K_{oc} of 182 mL/g) is considered to be moderate to highly mobile in soil, xylene isomers (K_{oc} of 363 to 407 mL/g) are considered to be moderately mobile in soil, and ethylbenzene (K_{oc} of 446 mL/g) is considered to be moderately mobile in soil (EPA, 1995). These compounds will degrade under both aerobic and anaerobic conditions. After oxygen is depleted, anaerobic degradation can continue until the compounds are completely degraded.

- **Naphthalene**—Naphthalene is both a PAH and a VOC; however, for purposes of this RFI, it will be discussed as a VOC. Naphthalene in the atmosphere is subject to a number of degradation processes, including reaction with photochemically produced hydroxyl radicals. Naphthalene has a short half-life in most natural waters and soil because of its tendency to volatilize and biodegrade. Naphthalene is easily volatilized from aerated soil and is adsorbed to a moderate extent (10%). The extent of sorption depends on the organic carbon content of the soil, with rapid movement expected through sandy soil; however, because it adsorbs to aquifer material, naphthalene's passage through groundwater will still be somewhat retarded (ASTDR, 2011). Levels of naphthalene in water, sediments, and soil tend to be low, except in the immediate vicinity of point sources of release.

- **1,2,4-TMB**—This compound is a volatile aromatic hydrocarbon liquid that is less dense than water and typically insoluble in water. 1,2,4-trimethylbenzene volatilizes rapidly from surface waters as predicted by a Henry's Law constant of 6.16 x 10-3 atm-cu m/mole and a vapor pressure of 2.1 millimeter Hg (EPA, 1987). In addition, volatilization from moist and dry soil surfaces is expected to occur based on the Henry's Law constant and the vapor pressure of this compound. Vapor-phase 1,2,4-trimethylbenzene is degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals and nitrate radicals with half-lives of about 12 hours and 7 to 28 days, respectively. 1,2,4-trimethylbenzene is not susceptible to direct photolysis by sunlight. If released to soil, a measured K_{oc} value of 614 mL/g suggests that 1,2,4-trimethylbenzene will have low mobility. Non-volatilized 1,2,4-trimethylbenzene may be subject to biodegradation under aerobic conditions. If released to water, 1,2,4-trimethylbenzene is expected to adsorb to sediment or particulate matter based on its K_{oc} value.

6.1.2 SVOCS

A total of five SVOCs (benz(a)anthracene, benzo(b)fluoranthene, indeno(1,2,3-cd)pyrene, benzo(a)pyrene, and dibenzo(a,h)anthracene) were identified as COCs at SWMU ST-106, all of which are PAHs. The fate and transport of these SVOCs in soil is as follows:

- **PAHs**—Benzo(a)anthracene, benzo(b)fluoranthene, indeno(1,2,3-cd)pyrene, benzo(a)pyrene, and dibenzo(a,h)anthracene were identified as COCs in the deep soil at SWMU ST-106. PAHs are a group of more than 100 organic compounds consisting of two or more fused aromatic rings. As a general rule, PAH compounds with higher molecular weights have lower solubility in water, lower volatility, higher solubility in fat tissues, and higher melting and boiling points. Given the high K_{oc} value of these PAHs, they are not expected to be mobile in soil. If released to the soil, these PAHs will be expected to adsorb very strongly and will not be expected to leach to the groundwater. Evaporation from soil and surfaces is not expected to be significant. Biodegradation tests in soil have resulted in a wide range of reported half-lives. Based on the range in values and the apparent lack of a significant competing fate process, biodegradation may be an important process in soil. The PAHs have low vapor pressures, which is an indication that volatilization is not expected to be an important factor in transport.

6.2 Contamination Migration

When released to the terrestrial environment, NAPL will generally migrate downward through the unsaturated zone under the force of gravity, with some NAPL retained in the soil pore space. Small releases of NAPL may be entirely adsorbed within the vadose zone. Larger releases will continue downward migration until the NAPL encounters physical barriers (such as a zone of low permeability) or reaches the capillary fringe just above the water table. At this point the NAPL may spread laterally as a continuous, free-phase layer along the upper boundary of the water-saturated zone. Migration is influenced by the variability of subsurface media and may be complex. For example, NAPL may migrate laterally through more permeable pathways or accumulate and migrate along low permeability layers above the water table. NAPL can also move through man-made pathways such as trenches containing distribution piping or utilities. Areas backfilled with coarse-grained material (such as utility trenches) can provide a horizontal pathway for NAPL migration.

6.2.1 Impact of Water-Level Fluctuations

Water-table changes have had a profound impact on the distribution and migration of vadose zone contamination at ST-106. Based on analysis of historical water-table elevations, water levels have declined approximately 140 feet since 1949 with the majority of the water-level decline (over 100 feet) since 1975. The PneuLog® data indicate that the water table beneath SWMU ST-106 was at approximately 350 feet bgs when the NAPL reached the water table. As the water table declined due to regional groundwater extraction, the NAPL followed the water table downward. Over time, this had the effect of creating a residual NAPL smear zone from nominal depths of 400 to 500 feet bgs providing an ongoing source for groundwater contamination.

Groundwater levels below SWMU ST-106 have risen between 7.5 and 10 feet since 2009 due to water conservation practices implemented by the City of Albuquerque and the San Juan-Chama Diversion Project completed in December 2008. As the water table started rising, the NAPL that could flow into monitoring wells (i.e., NAPL floating on the water table) became trapped below the water table. This is because the NAPL buoyancy force, resulting from a density difference of approximately 0.2 gram per cubic centimeter, is not sufficient to overcome the entry pressures and generate the upward buoyancy required for the NAPL to rise along with the rising water table. Although the remaining NAPL is currently trapped below the water table, the NAPL “body” can act as a potential source of secondary impacts to adjacent soil and soil vapor if groundwater levels fluctuate.

6.2.2 Volatilization and Diffusion

Some NAPL within the vadose zone is subject to redistribution as soil gas due to volatilization of hydrocarbon contaminants. Volatilization is the process of converting a chemical substance from a liquid or solid state to a gaseous or vapor state. Volatile contaminants move from areas of higher concentration to areas of lower concentration. As SVE is applied to the vadose zone, NAPL adsorbed to the soil (Appendix K) may volatilize and become available for extraction. COCs with higher vapor pressure, such as ethylbenzene, are more volatile and move more rapidly into a vapor state. Vapors can migrate through the vadose zone soil by diffusive and advective processes. In the subsurface, vapors preferentially migrate from subsurface contaminant source areas towards the ground surface.

Diffusion is usually the dominant mechanism for vapor-phase transport in unsaturated, porous media under most natural conditions, and is a function of the contaminant’s concentration gradient in the vadose zone and air diffusion coefficient, and the air-filled porosity of the soil. Diffusion and vapor migration are faster in soil with more air-filled, effective porosity such as sand with low moisture content (Rockhold et al., 2004). Advection is the movement of bulk soil vapor and is driven by pressure gradients; the vapor moves from areas of higher pressure to areas of lower pressure. Thin soil layers with different soil properties (e.g., a layer of silty soil in medium-grained sand) can have a significant effect on the transport of vapors through unsaturated soil (DeVaull et al., 2002).

Due to the varying physical and chemical properties of each contaminant, as the NAPL travels through the vadose zone, COCs are detected at various depths from the NAPL source. Once the COC is volatilized from the NAPL body, it is free to move as a vapor phase. The plume maps that illustrate the different spatial distributions of total VOCs and benzene offer an example of the aforementioned processes. In these figures, the total VOCs have vapor hotspots that do not directly correspond with the benzene hotspots. This suggests that COCs are moving out of the NAPL body and migrating through the vadose zone at different rates.

The equilibrium vapor concentration of a volatile compound adjacent to NAPL can be determined by using its vapor pressure. This is found using Raoult’s Law (Stephens, 1996):

$$P = X_c P_T$$

Where:

P = vapor pressure of the compound immediately adjacent to the NAPL mixture
Xc = mole fraction of the compound in the NAPL
P_T = total vapor pressure

Using the vapor pressure value determined above, the equilibrium soil gas concentration of the compound in question can be calculated using the formula below (Stephens, 1996):

$$C_g = \frac{MX_cP}{RT}$$

Where:

Cg = equilibrium vapor concentration of the compound
M = molecular weight (g/mol)
Xc = mole fraction of the compound in the NAPL
P = vapor pressure of the compound immediately adjacent to the NAPL mixture
R = ideal gas constant (8.2×10^{-5} atm-m^3/mol-k)

This equilibrium concentration is the maximum concentration of a compound that can exist in the vadose zone. These maximum vapor phase concentrations are expected to exist in close proximity to the NAPL.

Once a compound vaporizes from the NAPL, vapor migration through the vadose zone is primarily driven by diffusion along a concentration gradient, which will be in all directions away from the NAPL source. The rate of diffusion is governed by the gas's chemical diffusion coefficient, the gas's concentration gradient, the overall composition of the gas, and temperature. In a simple system with one compound diffusing through air, Fick's Law determines the mass flux of a compound that will diffuse due to a gradient in the gas's concentration (Stephens, 1996):

$$q_m = D_g \nabla C_g$$

Where:

q_m = mass flux of the compound
D_g = gas chemical diffusion coefficient
∇C_g = gradient of the gas concentration

In a complex system with multiple diffusing compounds, like SWMU ST-106, mass flux is more accurately predicted by a coupled system of linear equations for the diffusing gases, known as the Stefan-Maxwell equation. In both cases, diffusion rates of individual compounds are proportional to their diffusion coefficients. These diffusion coefficients are, in turn, a function of the size and molecular weight of the compounds with smaller low molecular weight compounds, such as benzene, diffusing faster than the larger and higher molecular weight fuel contaminants. In addition, low molecular weight compounds have higher vapor pressures, so it is possible to establish higher concentration gradients for these compounds that drive diffusion. These processes result in much higher diffusion rates for the lower molecular weight compounds relative to the larger and heavier fuel contaminants.

6.2.3 Sorption

Sorption is the removal of a compound from solution to a solid phase. The soil through which contaminants move can sorb the contaminant molecules onto the particle surfaces, and hold bulk liquids in the pores in and between the particles, thereby slowing or stopping the movement of the contaminants. This process can reduce the likelihood that the contaminants will reach a distal location (such as a drinking water well). Some of the COCs, such as PAHs, 1,2,4-trimethylebenze, and naphthalene, have low to moderately low mobility and a higher tendency for sorption into soil; these are more likely to be found near the source area.

6.2.4 Biodegradation

Biodegradation is the microbially-mediated breakdown of contaminants into simpler compounds. Many petroleum hydrocarbons, such as BTEX and lighter PAHs, can be biodegraded under proper environmental conditions. Generally speaking, the petroleum hydrocarbons that are most mobile in the environment are also readily biodegraded. Biodegradation can occur aerobically (in the presence of oxygen); however, anaerobic biodegradation will also occur in the presence of other electron acceptors such as nitrate and sulfate.

Since First Quarter CY 2011, the amount of biodegradation occurring at the BFF has been estimated using the Air Force Civil Engineer Center – Environmental Center of Excellence published guidance to account for the attenuation of petroleum hydrocarbons by bioventing (Leeson and Hinchee, 1996a and 1996b). Bioventing is a process of stimulating the natural biodegradation of contaminants in soil by providing air or oxygen to existing soil microorganisms. The mass of petroleum hydrocarbons biodegraded can be calculated using the following equation:

$$HC_{Bio} = (C_{V,bkgd} - C_{V,O2})/100 \text{ x } Q \text{ x } C \text{ x } \rho_{O2} \text{ x } MW_{O2} \text{ x } (\text{kg}/1{,}000\text{g}) \text{ x } (1{,}440 \text{ min/day})$$

Where:

HC_{Bio} = Mass of hydrocarbons biodegraded (kilograms per day)
$C_{V,bkgd}$ = Concentration of oxygen in background, uncontaminated area (%)
$C_{V,O2}$ = Concentration of oxygen in extracted off-gas (%)
Q = Flowrate (cubic feet per minute)
C = Mass ratio of hydrocarbon to oxygen degraded based on stoichiometry[2] (1/3.5)
ρ_{O2} = density of oxygen (moles/liter)
MW_{O2} = Molecular weight of oxygen (grams/mole)

Based on this equation and an average oxygen deficit in the influent vapor, the amount of biodegradation occurring at the BFF is estimated each quarter. The calculated biodegradation mass applies to the entire vadose zone volume of impacted soil, and the reported mass removal (in pounds) is from the area treated by the SVE system. The calculated quarterly biodegradation from January 2011 through Second Quarter CY 2013 is presented in Table 6-2.

6.2.5 Barometric Fluctuations

Barometric fluctuations are not seen as a significant factor in COC migration. Pressure measurements from May 2013 to November 2013 ranged from 26.9 to 30.5 inches of Hg. The daily fluctuations were on average much less. In addition, barometric pressure studies indicate that the influence does not extend more than a few meters below ground surface (Stephens, 1996). Additionally, the SVM wells are capped with an air-tight test plug, except when they are sampled four times a year. Therefore, the amount of time the well is open to the atmosphere, thus allowing air pressure to influence vadose zone contaminants, is minimal.

7. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are based on the results of the Vadose Zone RFI performed at SWMU ST-106:

- Based on the results of analytical samples for soil and soil vapor, soil boring logs, PneuLog® testing, and ROI testing, the nature and extent of contamination at have been adequately defined at SWMU ST-106, with the exception of quantitation of EDB in soil vapor.

- Stage 1 Abatement Plan activities were conducted in 2000 and included collection of surface (defined in the report as less than 40 bgs) and subsurface soil samples, completion of a soil gas screening survey, and the installation of groundwater well (KAFB-106-1). TPH was identified in the surface and subsurface soil samples collected during the investigation. Surface soil samples collected near the FFOR had maximum TPH concentrations ranging from 34,000 mg/kg to 51,000 mg/kg. The maximum concentration detected in the subsurface was from boring SB-26, which was 114,000 parts per million of TPH in the sample from 270 feet bgs.

- Shallow soil contamination (to a depth of 20 feet bgs) was delineated during the FFOR sampling task. The majority of shallow soil contamination is located along the former pipeline from Building 1033 to the FFOR. These locations roughly correspond to known spill locations. The delineation of hydrocarbon contamination in shallow soil, in conjunction with the soil vapor analytical data, confirms the pipeline near the FFOR as a source of contamination at ST-106.

- A total of 10 COCs has been identified in soil at SWMU ST-106; these are compounds with detections greater than their applicable screening levels. The primary COCs in soil at SWMU ST106 are 1,2,4 trimethylbenzene; PAHs; and TPH based on results of shallow and deep soil sampling between 2006 and 2013.

- No screening levels exist for soil vapor, and therefore, no soil vapor COCs have been identified for ST-106 as part of the Vadose Zone RFI.

- Soil vapor contour maps of benzene and total VOCs between 2011 and 2013 indicate that overall concentrations of soil vapor have decreased during this time.

- Quarterly soil vapor analytical data, FFOR soil sampling data, and PneuLog testing data indicate a vapor zone of higher concentrations originating beneath the FFOR (SVEW-01 through SVEW-09) and terminating at the water table to the southeast.

- The highest benzene and total VOC soil vapor concentrations at the 50 and 150 foot depths are located directly below the FFOR, and the area of the known spill locations. The maximum concentrations of benzene and total VOCs in samples collected at 350 and 450 feet bgs are located to the south and east of the FFOR, indicating movement of contaminants in a southeasterly direction in addition to downward migration toward the water table. As the NAPL has migrated downward, vapor emanates into the vadose zone pore space. This migration pathway is likely due to a combination of lithologic constraints and changing water table elevations.

- Due to the varying physical and chemical properties of each contaminant, as the NAPL travels through the vadose zone, COCs are detected at various depths from the NAPL source. Total VOCs have vapor hotspots that do not directly correspond with the benzene hotspots. This suggests that

COCs are moving out of the NAPL body at different rates governed by their physiochemical properties.

- The RFI data collected meet the quality requirements set forth in QAPjP (USACE, 2011d) as well as the applicable work plans and letters listed in Section 1, and are sufficient for informing future actions at SWMU ST-106. Geophysical logging was conducted in accordance with the Vadose Zone Investigation Work Plan (USACE, 2011a) but was not critical in completing the characterization of subsurface geology and hydrology for the site. Analytical soil and soil vapor sampling, soil boring logs, PneuLog® testing, and ROI testing were the primary data sources for completing the RFI.
- Figure 7-1 details the conceptual site model for ST-106 based on the results of this investigation. The Figure represents the linkages among contaminant sources, release mechanisms, exposure pathways and routes, and receptors to summarize the current understanding of the vadose zone contamination.

Recommendations for SWMU ST-106 include the following:

- Complete a risk assessment (to be submitted under separate cover).
- Conduct one quarter of soil vapor sampling for EDB using the CARB422Mod analysis. Due to the analytical methods used in quarterly soil vapor sampling (USACE, 2011a), quantitative evaluation of EDB in soil vapor remains a data gap for ST-106.
- Complete a CME for SWMU ST-106 to identify applicable cleanup standards, to determine remedy evaluation criteria, and to propose a selected remedy to address the contamination that poses a risk to human health and the environment.

This RFI report presents a preliminary conceptual site model (Figure 7-1) that will require further definition and refinement as part of the CME. This investigation has acquired sufficient data to close the outstanding data gaps listed in the Vadose Zone Investigation Work Plan (USACE, 2011a) with the exception of quantitative assessment of EDB in soil vapor. Together with the risk assessment (submitted under separate cover) and additional sampling for EDB in soil vapor, this vadose zone investigation provides robust and sufficient data to fully characterize the nature and extent of soil contamination at SWMU ST-106. The findings of this investigation will be used to determine the CME for the Kirtland AFB BFF Spill SWMUs ST-106 and SS-111.

A Risk Assessment Report, which will be submitted under separate cover, will evaluate data collected at both SWMUs, SS-111 and ST-106. A CME will be completed in accordance with Section 6.2.2.2 of the Kirtland AFB RCRA permit, and will be documented in a CME Report, as outlined in Section 6.2.4.7 of the Kirtland AFB RCRA Permit.

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APPENDIX A

Correspondence Letters

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APPENDIX B

Well Installation Forms

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APPENDIX C

Historical Data Summaries

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APPENDIX D

PneuLog® Evaluation Report

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APPENDIX E

Field Sampling Data and Records

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APPENDIX F

Geophysical Records

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APPENDIX G

Radius of Influence Test Results

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APPENDIX H

Data Quality Evaluation Reports and Data Packages

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APPENDIX I

Time Series Plots

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APPENDIX J

Waste Disposal Documentation

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APPENDIX K

NAPL Calculations

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APPENDIX L

Cross-Sections

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