# KIRTLAND AIR FORCE BASE
# ALBUQUERQUE, NEW MEXICO

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

**March 2014**

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

KIRTLAND AIR FORCE BASE
ALBUQUERQUE, NEW MEXICO

# RESOURCE CONSERVATION AND RECOVERY ACT FACILITY INVESTIGATION REPORT GROUNDWATER 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

***Prepared by***
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| REPORT DOCUMENTATION PAGE | Form Approved<br>OMB No. 0704-0188 |

|  |  |  |
|---|---|---|
| 1. AGENCY USE ONLY | 2. REPORT DATE<br>March 2014 | 3. REPORT TYPE AND DATES COVERED<br>RFI Report |

|  |  |
|---|---|
| 4. TITLE AND SUBTITLE<br>Resource Conservation and Recovery Act Facility Investigation Report<br>Groundwater Zone, Bulk Fuels Facility Spill<br>Solid Waste Management Units ST-106 and SS-111<br>Kirtland Air Force Base, Albuquerque, New Mexico | 5. FUNDING NUMBERS<br>USACE Contract No. W912DY-10-D-0014<br>Delivery Order 0002 |
| 6. AUTHOR<br>G. Hecox |  |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>CB&I Federal Services LLC<br>6380 South Fiddler’s Green Circle, Suite 300<br>Greenwood Village, Colorado 80111 | 8. PERFORMING ORGANIZATION REPORT NUMBER<br>KAFB-013-0008c |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br>USACE Albuquerque District<br>4101 Jefferson Plaza NE<br>Albuquerque, NM 87109-3435<br>Project Manager: John McBee | 10. SPONSORING/MONITORING AGENCY REPORT NUMBER |
| 11. SUPPLEMENTARY NOTES |  |
| 12a. DISTRIBUTION/AVAILABILITY STATEMENT | 12b. DISTRIBUTION CODE |

13. ABSTRACT (Maximum 200 words)

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 groundwater component Solid Waste Management Unit (SWMU) SS-111 and was conducted to fulfill RCRA permit requirements for the SWMU. The primary purpose of this Groundwater Zone RFI is to determine the nature and extent of contaminants of concern that may be present at SWMU SS-111, and to provide the necessary site characterization to evaluate and select the corrective measures required to address groundwater contamination, which will be performed during the Corrective Measures Evaluation phase.

|  |  |
|---|---|
| 14. SUBJECT TERMS<br>Bulk Fuels Facility Spill, NAPL, containment, characterization | 15. NUMBER OF PAGES<br>158 |
|  | 16. PRICE CODE |

|  |  |  |  |
|---|---|---|---|
| 17. SECURITY CLASSIFICATION OF REPORT<br>UNCLASSIFIED | 18. SECURITY CLASSIFICATION OF THIS PAGE<br>UNCLASSIFIED | 19. SECURITY CLASSIFICATION OF ABSTRACT<br>UNCLASSIFIED | 20. LIMITATION OF ABSTRACT |

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std 239-18 298-102

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# 40 CFR 270.11
# DOCUMENT CERTIFICATION
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Commander, 377th Air Base Wing

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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
Project Manager

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| % | percent |
| °F | degrees Fahrenheit |
| µg/L | microgram per liter |
| 1,2,4-TMB | 1,2,4-trimethylbenzene |
| | |
| AFB | Air Force Base |
| amsl | above mean sea level |
| API | American Petroleum Institute |
| AQTESOLV | Aquifer Test Solver |
| ARCH | air rotary casing hammer |
| ASTM | ASTM International |
| AvGas | aviation gasoline |
| | |
| BFF | Bulk Fuels Facility |
| bgs | below ground surface |
| BTEX | benzene, toluene, ethylbenzene, xylenes |
| | |
| CB&I | CB&I Federal Services LLC |
| cm | centimeter |
| CME | Corrective Measures Evaluation |
| $CO_2$ | carbon dioxide |
| COC | contaminant of concern |
| CSIA | Compound-Specific Isotope Analysis |
| CSS | Colorado silica sand |
| CY | calendar year |
| | |
| DO | dissolved oxygen |
| DOT | U.S. Department of Transportation |
| DRO | diesel range organic |
| | |
| EDB | 1,2-dibromoethane |
| EDC | 1,2-dichloroethane |
| EPA | U.S. Environmental Protection Agency |
| | |
| $ft^2$/day | square feet per day |
| feet/day | feet per day |
| feet/year | feet per year |
| FFOR | Former Fuel Off-Loading Rack |
| | |
| $g/cm^3$ | gram per cubic centimeter |
| GMS | Groundwater Modeling System |
| gpm | gallon per minute |
| GRO | gasoline range organic |
| GWM | groundwater monitoring |
| ID | identification |
| IDW | investigation-derived waste |
| | |
| JP-8 | jet propellant grade 8 |

# ACRONYMS AND ABBREVIATIONS (concluded)

| | |
|---|---|
| KAFB | Kirtland AFB |
| MCL | maximum contaminant level |
| mD | miliDarcies |
| mg/kg | milligram per kilogram |
| mg/L | milligram per liter |
| mL/g | mililiter per gram |
| mm | millimeter |
| mV | millivolt |
| NAPL | non-aqueous phase liquid |
| NMAC | New Mexico Administrative Code |
| NMED | New Mexico Environment Department |
| NOI | Notice of Intent |
| O.D. | outside diameter |
| $O_2$ | oxygen |
| ORP | oxidation-reduction potential |
| PAH | polynuclear aromatic hydrocarbons |
| PIANO | paraffins, isoparaffins, aromatics, naphthalenes, and olefins |
| PID | photoionization detector |
| psi | pound per square inch |
| PVC | polyvinyl chloride |
| QAPjP | Quality Assurance Project Plan |
| QC | quality control |
| RCI | reactivity cyanide and sulfide, corrosivity, and ignitibility |
| RCRA | Resource Conservation and Recovery Act |
| RFI | RCRA Facility Investigation |
| SSL | soil screening level |
| SVM | soil-vapor monitoring |
| SVOC | semivolatile organic compound |
| SWMU | Solid Waste Management Unit |
| TCLP | Toxicity Characteristic Leaching Procedure |
| TOC | total organic carbon |
| TPH | total petroleum hydrocarbons |
| USACE | United States Army Corps of Engineers |
| USAF | United States Air Force |
| USGS | United States Geological Survey |
| VA | Veterans Affairs |
| VOC | volatile organic compound |

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

The primary purpose of this Groundwater Zone RFI is to determine the nature and extent of contaminants of concern (COCs) that may be present at SWMU SS-111, and provide the necessary site characterization to evaluate and select the corrective measures required to address groundwater contamination. The corrective measures will be implemented during the Corrective Measures Evaluation (CME) phase. The key data and findings presented in this Groundwater 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 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**.** The first consistent groundwater contamination was discovered in 2004.

- Four internal combustion engine (ICE) soil vapor extraction (SVE) units were operational as an interim measure 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*

- A total of 116 GWM wells were installed between October 2000 and October 2013.

- 29 of the GWM wells were installed between October 2000 and December 2010 during previous investigations. At the time of installation, these wells were completed with screened intervals intersecting the water table.

- 87 of the GWM were installed between December 2010 and October 2013. Between December 2010 and August 2011, 78 GWM wells were installed at 28 locations with each location consisting of a cluster of three monitoring wells. Shallow zone wells were only installed at 22 of the 28 locations, as there were Shallow Zone wells already in existence at the remaining 6 locations.

- A cluster of three GWM wells spaced no more than 50 feet apart was installed at each location with 15 feet of submerged screen, one in each of the Shallow, Intermediate, and Deep Zones. The Shallow Zone is between the water table and 15 feet below the water table, the Intermediate Zone is from 15 to 30 feet below the water table, and the Deep Zone is between 40 and 130 feet below the water table. GWM wells were developed within 30 days of installation.

- Nine GWM wells were installed during the Third and Fourth Quarters CY 2012. The Shallow and Intermediate Zone wells had screened intervals consistent with the initial 28 clusters, while the Deep Zone well at each cluster was screened from a depth of 115 to 130 feet below the water level encountered during drilling.

- One well, KAFB-106041, was completed with the screened section above the water table based on an erroneous water-level measurements collected during drilling. As a result, this well is not used for liquid-level measurements and groundwater sampling, thus leaving 86 GWM wells with screened sections below the water table.

- Soil cuttings were lithologically logged during the drilling of each GWM well.

- The following samples were collected during the drilling of GWM wells:
    - Split-spoon soil samples were collected at four GWM wells located within the historical NAPL footprint and analyzed for total petroleum hydrocarbons as gasoline range organics (TPH-GRO), total petroleum hydrocarbons as diesel range organics (TPH-DRO), volatile organic compounds, semi-volatile organic compounds, and lead.
    - Representative bucket soil samples were collected across the screened interval of 69 GWM wells to determine physical properties of the soil in the screened interval, including porosity, hydraulic conductivity, permeability, grain-size distribution, and organic carbon content.
    - Continuous core samples were collected from six GWM wells located within the historical NAPL footprint to determine physical properties of the soil, air/water and water/NAPL capillary curve tests, and the calculation of van Genuchten parameters.
- NAPL samples were collected at two wells to characterize the physical parameters of the NAPL.
- Liquid levels, including NAPL thickness and the depth to groundwater, are measured quarterly in 121 GWM wells. This includes 29 GWM wells installed between October 2000 and December 2010, 86 GWM wells installed between December 2010 and October 2013 with screened sections below the water table, and an additional 6 nearby wells that were installed for unrelated projects.
- Quarterly groundwater sampling is conducted in 115 GWM and 4 nearby production wells. The wells include the 29 GWM wells installed between October 2000 and December 2010, and the 86 GWM wells installed between December 2010 and October 2013 with screened sections below the water table.
- Compound-Specific Isotope Analysis (CSIA) sampling and biological parameter sampling was conducted in 31 GWM wells during Third Quarter CY 2013 to determine the extent of microbial degradation of benzene and EDB at SWMU SS-111.
- Slug testing was conducted at 37 GWM wells to estimate hydraulic conductivity across SWMU SS-111.
- A contaminant fate and transport groundwater model was developed for use in simulating current and future migration of the EDB and benzene plumes at SWMU SS-111.

### *Investigation Results*

- Based on the detailed lithologic logs, there are two depositional units present at SWMU SS-111, 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 upper portion of the Santa Fe Group contains the primary aquifer for SWMU SS-111.
- 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.

- Analysis of bucket samples yielded an arithmetic mean porosity of approximately 30 percent within the screened interval of the 69 wells. The geometric mean of permeability was 4,700 miliDarcies (mD), and the geometric mean of hydraulic conductivity was 13 feet per day. The arithmetic mean of total organic carbon was 230 milligrams per kilogram, and the dominant grain size was medium sand with a median grain size of 0.23 to 10 millimeters.

- Continuous core analysis showed a median grain size of 0.43 to 1.8 millimeter. Results of the water/air capillary curve test yielded a water permeability of 3.2 to 11,283 mD and an air permeability of 24.3 to 16,350 mD. Results of the water/NAPL capillary curve test yielded a water permeability of 5.54 to 9,190 mD, and a NAPL permeability of 262 to 4,036 mD.

- Analysis of NAPL samples showed a low NAPL viscosity of 1.40 centipoises. The density and specific gravity of the two samples fell between the expected density and specific gravities of gasoline and diesel.

- Based on water-level measurements, groundwater flow direction is currently North 35° to 50° East, with a gradient of $5.7 \times 10^{-4}$ feet/foot. Between 1949 and 2009, the groundwater level fell approximately 140 feet. Since 2009, groundwater levels have risen between 7.5 and 10 feet.

- Measurements of NAPL thickness show that the NAPL interval has been flooded, with the majority now submerged below the water table. As groundwater levels have risen, measured NAPL thicknesses above the groundwater have progressively decreased. As of April 2013, only one well, KAFB-1065, had any measurable NAPL thickness (0.01 feet).

- There is no apparent vertical gradient within the upper 130 feet of the aquifer based on standard groundwater-level measurement methods.

- The following COCs have been identified in the groundwater at SWMU SS-111: 1,2,4-trimethylbenzene (1,2,4-TMB); EDB; 1,2-dichloroethane; 1,3,5-trimethylbenzene; 1-methylnaphthalene; 2-hexanone; 2-methylnaphthalene; acetone; acetophenone; benzene; bis (2-ethylhexyl) phthalate; ethylbenzene; iron; manganese; naphthalene; nitrate; nitrogen/nitrite; tetrachloroethene; toluene; o-xylene; and total xylenes. Although acetone was identified as a COC during the screening process, it is not a fuel-related contaminant and is attributed to laboratory contamination.

- Concentration contour maps were created for selected COCs with sufficient detections to warrant interpolation of contours. These are EDB, benzene, toluene, total xylenes, 1,2,4-TMB, and naphthalene. In addition, compound-specific dot and/or plume maps were prepared for TPH-GRO and TPH-DRO per New Mexico Environment Department direction.

- Slug testing at SWMU SS-111 showed a geometric mean hydraulic conductivity of 63 feet per day (feet/day) with a range of 12 to 129 feet/day. This hydraulic conductivity was used to estimate a groundwater velocity between 16 and 172 feet per year (feet/year) with a geometric mean of 95 feet/year.

- The contaminant fate and transport model used a hydraulic conductivity of 60 feet/day in the north-south direction. This hydraulic conductivity was used to estimate a groundwater velocity of 88 feet/year.

***Nature and Extent of Contamination***

- The majority of the observed contamination is located within the Shallow Zone, the upper 15 feet of the aquifer. Detections in the Intermediate Zone are of limited extent, as compared to the Shallow Zone, and the Deep Zone has only had detections of EDB in two groundwater monitoring wells.

- DRO, GRO, and EDB extend beyond the historical NAPL plume. The historical NAPL plume is approximately 2,300 feet long, 1,100 feet wide, and spans approximately 43 acres.

- As of Second Quarter CY 2013, the TPH-DRO Shallow Zone plume was approximately 4,800 feet long and 1,000 feet wide in the historical NAPL area, narrowing to 600 feet wide to the north. In the Intermediate Zone, the plume was 4,100 feet long by 800 feet wide with the highest concentrations in the historical NAPL area. In the Deep Zone, only two wells had detections of TPH-DRO, and were located within and immediately downgradient of the historical NAPL area.

- As of Second Quarter CY 2013, the TPH-GRO Shallow Zone plume was approximately 5,000 feet long and 1,600 feet wide in the historical NAPL area, narrowing to 1,000 feet wide to the north. In the Intermediate Zone, the plume was 4,200 feet long by 1,000 feet wide. In the Deep Zone, only one well had a detection of TPH-GRO, and was located within the historical NAPL area.

- EDB has migrated the farthest from the source. As of Second Quarter CY 2013, the Shallow Zone plume was 5,900 feet long and 1,000 feet wide, the Intermediate Zone plume was 4,100 feet long by 1,300 feet wide, and there were detections of EDB in two Deep Zone wells at the northern edge of the EDB plume.

- The benzene plume is contained almost entirely within the historical NAPL area. As of Second Quarter CY 2013, the Shallow Zone plume was 3,000 feet long by 1,300 feet wide, there were detections of benzene in two Intermediate Zone wells within the historical NAPL area, and there were no detections of benzene within the Deep Zone.

- Toluene and total xylene contamination has not migrated outside of the historical NAPL area. Shallow Zone detections were scattered throughout the historical NAPL area. Total xylenes were not detected in the Intermediate or Deep Zones. Toluene was detected in one Intermediate Zone well and zero Deep Zone wells during Second Quarter CY 2013.

- The naphthalene and 1,2,4-TMB plumes are contained almost entirely within the historical NAPL area. As of Second Quarter CY 2013, both Shallow Zone plumes were 2,000 feet long by 300 to 800 feet wide. In the Intermediate Zone, there were detections of 1,2,4-TMB above regulatory limits in three wells within and immediately downgradient of the historical NAPL area, and detections of naphthalene above regulatory limits were in two wells within the historical NAPL area. There were no detections of 1,2,4-TMB or naphthalene within the Deep Zone during Second Quarter CY 2013.

- Based on the NAPL density and the resulting buoyancy force, the NAPL, which has been flooded due to rising water levels, is unable to rise with the water table. 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.

### Contaminant Fate and Transport

- The various degradation indicator parameters lead to the same general conclusion that anaerobic degradation of organic compounds is occurring in the BFF groundwater plume.
- The dissolved iron plume has approximately the same footprint as the benzene plume, alkalinity is increased in the historical NAPL area, and dissolved oxygen is depleted in the historical NAPL area.
- Oxidation-reduction potential is low in the historical NAPL area and shows a gradual increase downgradient from the historical NAPL area, which is consistent with the footprint of the dissolved manganese plume.
- The microbial data indicate the presence of the bssA and PHE genes, which are involved in the degradation of benzene and other monoaromatic hydrocarbon compounds.
- The CSIA data indicate benzene, and by association, the other petroleum hydrocarbons, is effectively degraded within the groundwater associated with the NAPL plume or a short distance downgradient from the historical NAPL area. Conditions within this area of the plume appear to be optimal for benzene degradation. It is unlikely that the petroleum hydrocarbon contamination, excluding EDB, will reach any existing receptor well.
- The CSIA data indicate that EDB degradation is primarily occurring within and at the edge of the NAPL plume. Downgradient from the historical NAPL area, elevated manganese concentrations and anaerobic conditions (although with higher oxidation-reduction potentials than within the historical NAPL area) suggest that EDB degradation may be occurring at a slower rate in this area.
- Hydraulic parameters used in the contaminant fate and transport groundwater model include horizontal hydraulic conductivity of 60 feet/day, vertical hydraulic conductivity of 0.26 feet/day, and specific storage of 0.0035 feet$^{-1}$.
- Transport simulations in the groundwater model were able to reproduce the 2013 plume extents for EDB and benzene. Particle tracking using a simulated release to groundwater in 1980 yields the closest match to the 2013 plume extent.
- There have been no observed changes in the plume footprints of TPH-GRO, TPH-DRO, benzene or xylene between Second Quarter CY 2011 and Second Quarter CY 2013.
- There have been no observed changes in the plume footprint of EDB from Fourth Quarter CY 2012 when the plume was fully defined through Second Quarter CY 2013.
- The benzene plume has had an apparent increase in width from 1,100 feet to 1,600 feet between Second Quarter CY 2011 and Second Quarter CY 2013. The small apparent increase in length in length (from 2,700 feet to 2,900 feet) is most likely an artifact of contouring.

### Conclusions

- Based on the results of groundwater monitoring samples collected from the 115 GMWs, the nature and extent of contamination have been defined at SWMU SS-111. Additionally, the results of quarterly water-level measurements, bucket samples, continuous core samples, slug testing, and groundwater modeling have adequately defined aquifer characteristics to develop decisions for SS-111.

- A comprehensive screening analysis was performed on the groundwater data and used sample number, frequency of detection, screening levels to identify COCs at SWMU SS-111. The primary contaminants of concern at SWMU SS-111 are benzene, EDB, toluene, xylenes, 1,2,4-TMB, and naphthalene.

- Degradation of benzene and EDB is occurring in the anaerobic NAPL area. CSIA data indicate the degradation of EDB in the groundwater is occurring under anaerobic conditions. The CSIA data suggest that some degradation of EDB continues in the aerobic portion of the plume but it is not quantifiable.

- Based on groundwater fate and transport modeling, the fuel source reached the groundwater around 1980. 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 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. The NAPL initially floated on the groundwater table before becoming submerged as the result of the rising water table. The source of dissolved contaminants is a submerged volume of NAPL.

- The RFI data collected meet the quality requirements set forth in the project-specific Quality Assurance Project Plan (USACE, 2011c), as well as the applicable work plans and letters listed in Section 1, and are sufficient for determining future actions at SWMU SS-111. Analytical sampling, soil boring logs, CSIA and microbe analysis, slug testing, and groundwater modeling were the primary data sources for completing the RFI.

- The results of this investigation were used to develop a conceptual site model for SWMU SS-111.

- There are no remaining data gaps for SWMU SS-111 based on the results of the RFI.

### *Recommendations*

- Complete a Risk Assessment (to be submitted under separate cover).

- Continue quarterly monitoring of GWM wells for groundwater-level measurements, NAPL thickness measurements, and selected COC analyses, as well as continue monthly monitoring of nearby water supply wells. The frequency and scope of monitoring should be reviewed and revised to support the development of a CME.

- Complete a plume stability analysis.

- Complete a CME for SWMU SS-111 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.

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

## 1.1 Purpose and Objectives

The primary purpose of the Groundwater Zone RFI is to determine the nature and extent of contaminants of concern (COC) that may be present at SWMU SS-111. The primary purpose of this Groundwater 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 SS-111 (the groundwater zone).
- To provide the necessary site characterization to evaluate and select the corrective measures required to address groundwater contamination, which will be performed during the Corrective Measures Evaluation (CME) phase.

## 1.2 Regulatory History and Regulatory Criteria

This SWMU SS-111 Groundwater Zone RFI Report was prepared in accordance with 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 New Mexico Administrative Code (NMAC)
- RCRA Permit EPA ID No. NM9570024423/HWB-KAFB-10-004 for Kirtland AFB
- Base-Wide Plans for Investigation under the Environmental Restoration Program, Standard Operating Procedures
- Hazardous Waste Treatment Facility Operating Permit, EPA ID No. NM9570024423 dated July 2010
- Four directive letters from New Mexico Environment Department (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 Groundwater RFI Report was prepared in accordance to the following documents:

- Quality Assurance Project Plan Sampling and Analysis Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated October 2010
- Light Non-Aqueous Phase Liquid (LNAPL) Containment Interim Measures Work Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated November 2010
- 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
- Groundwater Investigation Work Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated March 2011
- Groundwater Investigation Work Plan Modification dated June 24, 2011

- Quality Assurance Project Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated August 2011
- Interim Measures Work Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated March 2011
- LNAPL Containment Interim Measure Work Plan Part 1 – Characterization Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated July 2011
- LNAPL Containment Well Location and Installation, LNAPL Containment Interim Measures Work Plan Part I – Characterization, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, Addendum November 2011
- LNAPL Containment Well Development, LNAPL Containment Interim Measures Work Plan Part I – Characterization, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, Addendum January 2012
- LNAPL Containment Interim Measure Work Plan Part I – Characterization Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated May 2012
- Additional Groundwater Monitoring Wells, Addendum to Groundwater Investigation Work Plan, March 2011, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated June 13, 2012
- In-Well Treatment Interim Measures Work Plan Part 1 – Data Gathering and Analysis Plan, Bulk Fuels Facility Spill, Solid Waste Management Units ST-106 and SS-111, dated December 2012
- 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

Groundwater screening levels were developed in accordance with Section 6.2.3.1 of the Hazardous Waste Facility Permit No. NM9570024423. Specifically, the screening levels are comprised of the most stringent of the following: 1) New Mexico Water Quality Control Commission water quality standards (20.6.2.3103 and 20.6.2.4103 NMAC) or 2) the drinking water maximum contaminant levels (MCLs) adopted by EPA under the Federal Safe Drinking Water Act (42 U.S.C. §§ 300f to 300j-26). If neither a New Mexico Water Quality Control Commission standard nor an MCL was established for a contaminant, then the EPA Regional Screening Level (EPA, 2013) for tap water was used. In order for a contaminant to be considered a COC, it must have an applicable screening level.

## 1.3 Report Organization

This Groundwater 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 SWMU SS-111 Groundwater Zone RFI 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<br>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 |
| Appendix B | Well Installation Forms |
| Appendix C | NAPL and Soil Hydraulic Property Laboratory Results |
| Appendix D | Field Sampling Data and Records |
| Appendix E | Geophysical Records |
| Appendix F | Historical Data Summaries |
| Appendix G | Time-Series Plots |
| Appendix H | Slug Test Results |
| Appendix I | NAPL Calculations |
| Appendix J | Waste Disposal Documentation |
| Appendix K | Bubble Sampling Results |
| Appendix L | Degradation Analysis |
| Appendix M | Groundwater Model Report and Data |
| Appendix N | Data Quality Evaluation Reports |
| Appendix O | Additional Cross Sections |

# 2. BACKGROUND INFORMATION

## 2.1 Site Description

Kirtland AFB is located in Bernalillo County in central New Mexico, southeast of the City of Albuquerque and adjacent to 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 groundwater characterization at SWMU SS-111.

### 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 a groundwater well (KAFB-1061). 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.

The first detection of 1,2-dibromoethane (EDB) in groundwater was in March 2001 at KAFB-1061 at a concentration of 0.21 microgram per liter (µg/L). There were no additional detections of EDB in this well from March 2001 until January 2004 when EDB was detected in the same well at a concentration of 0.049 µg/L. Since January 2004, with the exception of three quarters (Fourth Quarter calendar year [CY] 2004, First Quarter CY 2005, and First Quarter CY 2009), EDB has been consistently detected in this well.

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

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

- Former Wash Rack Drainfield
- 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 tasks:

- 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 Tank. There were no exceedances of the NMED residential soil screening levels (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 and 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 as diesel range organics (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 (SVM) points were installed in all direct-push boreholes and were 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.

### 2.3.3 Stage 2 Abatement Plan Completion Report for Groundwater Monitoring Well KAFB-1064 (CH2M HILL, 2006b)

Based on recommendations from the *Stage 2 Abatement Plan Summary and Performance Report for the Soil Vapor Extraction and Treatment System* (CH2M Hill, 2006c), monitoring well KAFB-1064 was constructed between existing well KAFB-1062 and the Veterans Affairs (VA) Medical Center production well; installation occurred between January 4 and January 10, 2006. KAFB-1064 serves as a sentinel monitoring well upgradient of the VA Medical Center production well. The new well has a total depth of 510 feet bgs with a screened interval of 484 to 509 feet bgs. TPH-DRO, total petroleum hydrocarbons as gasoline range organics (TPH-GRO), toluene, naphthalene, phenanthrene, nitrate, dissolved iron, and dissolved manganese were detected in a groundwater sample collected from KAFB-1064. Dissolved iron and manganese were the only contaminants that exceeded the EPA National Secondary Drinking Water Standards.

### 2.3.4 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, 2006c). 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 BFF 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.

## 2.4 Data Gaps

The following activities were completed as part of this SWMU SS-111 groundwater zone RFI to fill data gaps related to determining the nature and extent of fuel contamination resulting from past operational history at the BFF:

- Characterization of NAPL and dissolved-phase contaminants in the groundwater.
- Characterization of the vertical extent of the dissolved-phase contamination in the groundwater and the effects of vertical gradients.
- Characterization of the geology of the aquifer.
- Characterization of the leading edge and the eastern and western margins of the NAPL, benzene, and EDB plumes.
- Characterization of the groundwater immediately underneath the NAPL.
- Characterization of groundwater quality and distribution.
- Identification of groundwater flow direction and velocity, and aquifer hydraulic parameters such as hydraulic conductivity and porosity.
- Identification of COCs.

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# 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 semiarid, 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 in 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 SS-111 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

The majority of the City of Albuquerque production wells in the area of SWMU SS-111 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 thickness east of the Tijeras/Hubbell Spring/Sandia fault complex ranges from approximately 50 feet thick 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 SS-111. 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 Geology

### 4.1.1 Groundwater Monitoring Well Drilling

In total, the groundwater monitoring network at SWMU SS-111 consists of 116 groundwater monitoring (GWM) wells installed between October 2000 and October 2013. The majority of the wells, 87 GWM wells, were installed during the groundwater investigation conducted between December 2010 and October 2013. The remaining wells were installed by previous contractors between October 2000 and May 2010. During December 2010 and August 2011, 78 GWM wells were installed at 28 locations with each location consisting of a cluster of three monitoring wells. The 28 locations are listed in the Groundwater Investigation Work Plan (USACE, 2011a), with the exception of 4 well locations that were moved due to right-of-entry and safety issues. Shallow zone wells were only installed at 22 of the 28 locations, as there were Shallow Zone wells already in existence at the remaining 6 locations. These changes are described in the letter dated April 7, 2011 that requests the relocation of these well locations, which was approved by the NMED on April 14, 2011 (Appendix A). A cluster of three GWM wells spaced no more than 50 feet apart was installed at each location with screen depths at the locations listed in Table 4 of the NMED- Hazardous Waste Bureau August 6, 2010 letter (Appendix A), and in accordance with the approved Groundwater Investigation Work Plan (USACE, 2011a):

- **Shallow Zone—**Wells completed in the Shallow Zone were installed with screened intervals intersecting the water table measured during drilling. For the initial 18 Shallow Zone wells drilled, the entire screened interval was 20 feet, with approximately 5 feet of screen above the water table and 15 feet below the water table. The NMED approved a screen extension to a 30-foot screened interval in their June 24, 2011 letter (Appendix A), with the additional screen length above the water table, so that the screened interval would continue to intersect the water table in the Shallow Zone wells as the water table rose. For the 4 Shallow Zone wells completed following the screen-extension approval, the entire screened interval was 30 feet, with approximately 15 feet of screen above the water table and 15 feet below the water table. Shallow zone wells were only installed at 22 of the 28 locations, as there were Shallow Zone wells already in existence at the remaining 6 locations.

- **Intermediate Zone—**Wells completed in the Intermediate Zone were screened from a depth of 15 to 30 feet below the water level encountered during drilling.
- **Deep Zone—**Per NMED direction, 14 of the 28 locations, Deep Zone wells were screened from a depth of 40 to 55 feet below the water level encountered during drilling. At the remaining 14 locations, Deep Zone wells were screened from a depth of 85 to 100 feet below the water level encountered during drilling.

An additional nine GWM wells were installed during the Third and Fourth Quarters CY 2012 in accordance with the NMED approved Letter Addendum to the Groundwater Investigation Work Plan submitted on June 13, 2012 (Appendix A). The nine additional GWM wells were requested to address data gaps identified to complete delineation of the dissolved-phase groundwater plume. The Shallow and Intermediate Zone wells had screened intervals consistent with the initial 28 clusters, while the Deep Zone well at each cluster was screened from a depth of 115 to 130 feet below the water level encountered during drilling.

Before drilling, each borehole was 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 air rotary casing hammer (ARCH) drilling techniques. ARCH drilling uses steel-insulator casing, advanced with a drill bit or rod, to prevent borehole collapse and to seal off any contaminated zones to avoid cross-contamination of stratigraphic units. The boreholes for the GWM wells were drilled using an 11¾-inch outside diameter (O.D.) drive casing to a depth of approximately 200 feet bgs, and a 9⅝-inch O.D. casing was advanced to the total depth of the borehole. These drive-casing sizes effectively advance a 12-inch-diameter borehole to approximately 200 feet bgs, and a 10-inch-diameter borehole from approximately 200 feet bgs to the total depth of the borehole. The drive-casing sizes effectively advance a 14-inch-diameter borehole from approximately 250 feet bgs to the total depth of the borehole.

### 4.1.2 Geologic Logging During Drilling

During borehole advancement, drill cuttings were collected from the 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 International [ASTM] D2487-11 (2011). Color, moisture content, consistency, detailed lithology of individual gravel units, mineralogy, observed contamination, odor, changes in lithology, and depth to groundwater were also noted on the soil boring log. Soil classification logs for all 87 groundwater wells installed in 2011-2012 are included in Appendix B.

The cuttings were field-screened for volatile organic compounds (VOCs) using a photoionization detector (PID), as specified in 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.

### 4.1.3 Split-Spoon Soil Sampling

Soil samples were collected from the borehole using a split-spoon sampler during installation of four of the GWM wells.  Soil samples were collected from wells KAFB-106061, KAFB-106062, KAFB-106078, and KAFB-106081, which are located within the historic NAPL footprint of the groundwater contaminant plume. 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]).  The interval from 450 feet bgs and 510 feet bgs was continuously cored and samples were not collected at that interval. All soil samples were lithologically logged by a qualified geologist and field-screened for VOCs using a PID. 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

Split-spoon sample results are discussed in Section 5.1.2. The soil analytical data were validated for precision, accuracy, representativeness, comparability, and completeness in accordance with the Quality Assurance Project Plan (QAPjP) (USACE, 2011c), and appropriate data qualifiers are appended to the analytical data in the project database.

### 4.1.4 Bucket Sampling

Bucket samples were collected across the screened interval of 69 GWM wells during boring advancement (Table 4-1). The site geologist collected a representative 2.5-quart sample of sediment from the cyclone separator of the ARCH drill rig at the planned screened depth of the well. These samples were collected in plastic buckets for geotechnical testing, and were reconsolidated and tested by PTS Laboratories in Santa Fe Springs, California, for physical parameters, including total and effective porosity, hydraulic conductivity, effective permeability, grain-size distribution, total organic carbon (TOC), and fraction organic carbon. Results of the bucket sampling are discussed in Section 5.1.3.

### 4.1.5 Continuous Core Sampling

During the Second Quarter CY 2011, continuous core soil samples were collected from six boreholes (KAFB-106059, KAFB-106060, KAFB-106063, KAFB-106078, KAFB-106080, and KAFB-106081) for NAPL mobility testing (USACE, 2011b). The continuous core soil samples were collected by pushing a 4-inch-wide by 5-foot-long acetate sleeve into undisturbed soil; samples were sent to PTS Laboratories for geotechnical and NAPL testing. Table 4-1 presents the well locations, sample intervals, sample numbers, and Unified Soil Classification System symbols (ASTM, 2011) for the continuous core soil samples. Continuous core samples were obtained from 450 feet bgs (approximately 50 feet above the water table) to 510 feet bgs (approximately 10 feet below the water table).

Chemical and physical property tests were conducted on both NAPL and soil from the cores for two reasons: 1) to quantify key parameters important to future analysis and modeling of NAPL and groundwater migration and 2) to determine the overall contaminant source strength presented by the NAPL on or below the water table. Tests were conducted for average grain size, air/water and water/NAPL capillary curve tests, and calculation of van Genuchten parameters (alpha, n, and m).The results are discussed in Section 5.1.4. Laboratory reports are provided in Appendix C.

### 4.1.6 Groundwater Monitoring Well Construction

GWM wells were constructed in accordance with the NMED-approved Groundwater Investigation Work Plan (USACE, 2011a) and the Kirtland AFB RCRA permit (EPA ID No. NM9570024423). GWM wells were constructed using a 5-inch-diameter, Schedule 80 polyvinyl chloride (PVC) riser pipe and a 0.010-slot, Schedule 80 PVC well screen with a 5-foot blank Schedule 80 PVC sump. The Shallow Zone (water table) monitoring wells were installed with 20 or 30 feet of screen with no more than 15 feet of screen below the water level encountered during drilling. The Intermediate and Deep Zone monitoring wells were fitted with 15 feet of screen for wells completed below the water table in accordance with the NMED-approved Groundwater Investigation Work Plan (USACE, 2011a). Following placement of the well screen and riser pipe, a 10/20 Colorado silica sand (CSS) filter pack was tremied to approximately 2 feet above the top of the well screen followed by approximately 1 foot of fine-sand seal consisting of 20/40 CSS. A bentonite seal (approximately 30 to 40 feet) consisting of ⅜-inch bentonite chips was placed above the filter pack. The bentonite chip seal was hydrated in lifts using water obtained from a public system water hydrant. A high-solids bentonite grout was placed above the bentonite seal to near ground surface. A cement surface seal was placed above the bentonite grout to the ground surface.

The three wells at Cluster 5 (KAFB-106141, KAFB-106142, and KAFB-106143) were installed such that the tops of the screens were too shallow relative to the requirements specified in the Groundwater Investigation Work Plan (USACE, 2011a). As a result, the water well (KAFB-106041) is dry, and the Intermediate Zone well (KAFB-106042) and deep well (KAFB-106043) do not meet Work Plan requirements. The screens in all three wells were set based on an erroneous water-level measurement, thus causing the screen placements to be off by approximately 12 to 15 feet. The Field Work Variance for this cluster is included in Appendix A.  As a result, KAFB-106042 was designated as a shallow well as its screen intersected the water table at the time of installation. This designation replaces KAFB-106041 with KAFB-106042 as the Shallow Zone well, while still maintaining the previous designation of the Deep Zone well (KAFB-106043) at this cluster.

The groundwater extraction well KAFB-106157 was constructed in accordance with the Letter Addendum LNAPL Containment Interim Measures Work Plan dated November 18, 2011 (Shaw Environmental, Inc., 2011), which was partially approved by the NMED on December 1, 2011 (Appendix A).  KAFB-106157 was constructed using 8-inch-diameter, Schedule 40 carbon steel casing riser; a 10-foot blank stainless steel pump sleeve section placed approximately 30 feet below the current water table; and 0.030-slot, stainless steel-wire wrap well screen with a 5-foot blank sump. The well was installed with a 100-foot screen, with 60 feet of screen below the water table and 40 feet of screen above the water table to accommodate future water table rises. Following placement of the stainless steel, wire-wrapped screen and casing, a 10/20 CSS filter pack was tremied to approximately 11 feet above the top of the well screen. A 34-foot bentonite seal consisting of ⅜-inch bentonite chips was placed above the filter pack. The bentonite chip seal was hydrated in lifts using a clean water source. A high-solids bentonite grout was placed above the bentonite seal to near ground surface.

Table 4-2 presents the completion construction information for each GWM well and extraction well KAFB-106157, including surveyed elevations and coordinates, well casing material, and screen depths and elevations. Well installation reports for each well (Appendix B) consist of soil boring logs, well completion diagrams, and well development records.

### 4.1.7 Well Surveying

GWM wells and the groundwater extraction well were surveyed following well construction. At each GWM well, the elevation and coordinates were taken 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 PVC. The surveyed locations are shown on Figure 4-1, and survey plates are presented in Appendix D-3. The total number and types of wells installed and surveyed during the current groundwater investigation are as follows:

- 29 Shallow Zone wells installed prior to December 2010
- 3 Kirtland AFB supply wells (KAFB-3, KAFB-15, KAFB-16)
- 25 Shallow Zone wells installed since December 2010
- 31 Intermediate Zone wells installed since December 2010
- 31 Deep Zone wells installed since December 2010

### 4.1.8 Well Development

Groundwater monitoring wells were developed within 30 days of installation following the procedure outlined in the NMED-approved Groundwater Investigation Work Plan (USACE, 2011a). Initial development consisted of swabbing and bailing until the sediment load was reduced to the extent practicable. Following initial development, the well was continuously pumped using an electric submersible pump. Temperature, pH, specific conductivity, and turbidity were measured periodically. Development was considered complete when all of the following conditions were met:

- One well volume, including the filter pack, plus the volume of water introduced into the formation during drilling was removed.
- Extracted water was free of visible sediment, with a turbidity of less than 10 nephelometric turbidity units.
- pH, temperature, and specific conductance had stabilized within 10 percent (%).

### 4.1.9 NAPL Sampling

NAPL samples were collected from two wells, KAFB-1066 and KAFB-106076, to characterize the physical parameters of the NAPL at SWMU SS-111 in accordance with the procedure outlined in the LNAPL Containment Interim Measure Work Plan (Shaw Environmental, Inc., 2011).

Prior to sampling, the depth to NAPL and depth to water were measured with an interface probe to verify there was sufficient NAPL for sample collection; a minimum thickness of 6 inches of NAPL is needed for sampling. A bottom fill bailer was then lowered so that the bottom of the bailer was just below the NAPL-water interface. When the bailer was retrieved, NAPL was decanted from the bailer into sample jars.

Laboratory analyses were performed on the NAPL samples for density, viscosity at ambient groundwater temperature, interfacial tension, flashpoint, American Petroleum Institute (API) gravity, organic compound PIANO analysis (paraffins [P], isoparaffins [I], aromatics [A], naphthalene [N], and olefins [O]), EDB, 1,2-dichloroethane (EDC), and lead. The results of these analyses are presented in Section 5.1.5.

### 4.1.10 Geophysical Logging

Geophysical logging was conducted in accordance with the approved Groundwater 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 Groundwater Investigation Work Plan (USACE, 2011a). Logs for all boreholes that were geophysically logged are provided in Appendix E. The following wells were geophysically logged:

- 29 GWM wells installed prior to December 2010.
- 23 GWM wells installed since December 2010.
- 35 SVM wells installed since December 2010. Installation of SVM wells is discussed in the Vadose Zone RFI Report (submitted under separate cover) (USACE, 2014b).

Two geophysical subcontractors were employed to geophysically log boreholes. Colog Incorporated (Colog) initially logged the 29 GWM wells installed prior to December 2010, and Jet West Geophysical Services, LLC (Jet West) logged the 23 GWM and 35 SVM wells installed since December 2010. In addition, Jet West re-logged 8 of the wells initially logged by Colog: KAFB-1065, KAFB-1066, KAFB-1067, KAFB-1068, KAFB-10610, KAFB-10611, KAFB-10612, and KAFB-10617. These wells were selected because there was no nearby well with a Jet West geophysical log. Both Colog and Jet West geophysically logged KAFB-10624.

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). Information on quality control, field calibration, and logging activities can be found in Appendix E.

## 4.2 Hydrogeology

### 4.2.1 Liquid Levels

Liquid-level measurements include measurements of the distance from ground surface to the top of NAPL, and from ground surface to the top of groundwater.

Between the First and Fourth Quarters CY 2011, liquid levels were measured monthly; beginning with the First Quarter CY 2012, liquid levels were measured on a quarterly basis in accordance with the QAPjP (USACE, 2011c), which was accepted by the NMED letter dated 27 August 2012 (Appendix A). Liquid-levels were measured with either a Solinst Model 122 interface probe in wells that potentially contained NAPL, or a Solinst Model 101 water-level meter for wells that did not historically contain NAPL. All instruments were checked for proper operation and cable integrity before use and were decontaminated between mobilizations for each well. Liquid-level measurement data are maintained in the project database and the water level field forms are located in Appendix D-4.

During the quality control (QC) process, water levels are compared with historical water levels for each well. If the water level being measured differs by more than 2 feet from the previous quarter’s water level and is inconsistent with water-level changes in nearby wells, the water level is judged to be invalid. These data are posted as such on maps and are not used in the generation of water-level contours. All groundwater levels used to generate contour maps have been corrected for NAPL thickness using the density correction described by Mayer and Hassanizadeh (2005, Equation 4.5). The NAPL correction formula is automatically applied to all water levels.

Starting in the Fourth Quarter CY 2011, CB&I implemented an enhanced QC process for the liquid-level measurements. This level of QC was required because of the flat groundwater gradients and the effect that barometric pressure has on water levels within the aquifer at SWMU SS-111. CB&I followed the process described below to ensure that the liquid-level data met data quality requirements:

- Field technicians were provided with a standardized field form for liquid-level measurements.
- Field technicians recorded the serial number/identification of the water-level meter used to collect measurements on the field form.
- Field technicians measured liquid levels and field-checked to verify that measurements were within plus or minus 0.5 foot of previous quarterly measurements. If the difference was greater than plus or minus 0.5 foot, the field team then re-measured the liquid level in the well containing the discrepancy.
- All field measurements were submitted to the Field Sampling Coordinator for QC, who checked to ensure the measurements were within plus or minus 0.5 foot of previous quarterly measurements. This QC evaluation was documented on the liquid-level measurement field form.
- Additionally, the Field Sampling Coordinator compared the measurements against the measurements from the preceding quarter. If any measurements failed a plus or minus 1.0-foot check, they were marked and re-measured the following day. This QC evaluation was documented on the liquid-level measurement field form.
- The field team and Field Sampling Coordinator QC checks were conducted for all re-measurements of wells. Once the Field Sampling Coordinator verified that the data collected met the QC metrics, he/she signed the form and submitted it for entry into the database. The Field Sampling Coordinator redlined any measurements that should not have been entered into the database.
- Measurements (including re-measurements) were entered into the database along with associated flags noting that the QC checks were performed. The database entry form has an internal checking routine to flag any suspected data-entry mistakes.

Liquid-level measurements were conducted at the following GWM wells as part of the quarterly monitoring program (USACE, 2011d):

- Wells installed prior to 2011 that consist of KAFB-1061 through KAFB-10628; and KAFB-3411 (29 wells total).
- Wells installed during 2011 that consist of KAFB-106029 through KAFB-106055 with the exception of well KAFB-106041, which is dry, and KAFB-106057 through KAFB-106107 (77 wells total). There is no well KAFB-106056.
- Wells installed during 2012 that consist of KAFB-106201 through KAFB-106209 (9 wells total).

Though not sampled during quarterly events, liquid levels were also collected for the following wells:

- Liquid levels in KAFB-0118, KAFB-0119, KAFB-0121, KAFB-0510MW, KAFB-0524, and KAFB-3392 were collected beginning in September of 2011.
- Liquid levels in KAFB-0508 and KAFB-0624 were collected once each in the Second Quarter of 2011 in accordance with the NMED letter dated August 17, 2011 (Appendix A).

Historical liquid-level data are presented in Appendix F-2 and F-3. Liquid-level hydrographs and groundwater time-series graphs are presented in Appendix G-1 and G-3, respectively. Section 5.2.1 provides a discussion of time-series data analysis of groundwater and NAPL levels.

### 4.2.2 Quarterly Groundwater Sampling

Quarterly groundwater sampling is conducted in accordance with the approved Groundwater Investigation Work Plan (USACE, 2011a) and the NMED-approved QAPjP (USACE, 2011c).

Quarterly groundwater sampling was conducted at 115 GWM wells and 4 nearby production wells for field chemical parameters and off-site laboratory analysis. Groundwater monitoring well KAFB-106041 is dry and is not included in the quarterly sampling. The groundwater wells sampled between First Quarter CY 2011 to Second Quarter CY 2013 include the following:

- 29 wells installed prior to 2011 that consist of consecutively numbered GWM wells KAFB-1061 through KAFB-10628; and KAFB-3411, which was installed for an investigation of an adjacent site and provides a monitoring location upgradient of the FFOR.
- 77 GWM wells installed during 2011 that consist of consecutively numbered wells KAFB-106029 through KAFB-106040, KAFB-106042 through KAFB-106055, and KAFB-106057 through KAFB-106107. KAFB-106041 is dry (Section 4.1.6), and there is no well numbered KAFB-106056.
- 9 GWM wells installed during 2012 that consist of KAFB-106201 through KAFB-106209.

- KAFB-3, KAFB-15, and KAFB-16, which are Kirtland AFB drinking water production wells. KAFB-15 and KAFB-16 were not sampled during First and Second Quarters 2013 due to mechanical problems with well operation, and KAFB-16 continues to be out of service.
- VA-2 –VA Medical Center drinking water production well.

Groundwater sampling was performed using either dedicated Bennett sampling pumps or a portable Bennett pump sampling system. In accordance with the NMED-approved Groundwater Investigation Work Plan (USACE, 2011a), groundwater sampling included purging one well bore volume and monitoring field parameters for stabilization of temperature, pH, and specific conductance to within an estimated 10% prior to collecting water-quality measurements. Field parameters that were recorded prior to collecting groundwater samples for laboratory analysis were pH, conductivity, temperature, alkalinity, dissolved oxygen (DO), turbidity, oxidation-reduction potential (ORP), and alkalinity.

After collection of field water-quality measurements, the GWM wells were purged at an approximate rate of 1.0 liter per minute prior to sample collection. The Kirtland AFB production wells and the VA Medical Center groundwater production well were purged by flushing the dedicated sample line connected to each well, and then samples were collected. Samples were collected through non-chlorinated taps from the production wells. Groundwater samples collected were analyzed for the following list of parameters:

- VOCs by EPA Method SW-846 8260B
- EDB by EPA Method SW-846 8011
- SVOCs by EPA Method SW-846 8270D
- TPH-GRO and TPH-DRO by EPA Method SW-846 8015B
- Polycyclic aromatic hydrocarbons by EPA Method SW-846 8270D low-level method (VA-2 well only)
- Lead and major cations by EPA Method SW-846 6010B
- Dissolved iron and manganese by EPA Method SW-846 6010B
- Anions (chloride and sulfate) by EPA Method 300.0

- Nitrate/nitrite as nitrogen by EPA Method 353.2
- Ammonia nitrogen by EPA SM4500NH3BG
- Total sulfide by EPA Method SM4500 S-2CF
- Carbonate/bicarbonate alkalinity by EPA Method SM2320B

Field QC samples were collected in accordance with the QAPjP (USACE, 2011c) and included trip and ambient field blanks for VOCs, field duplicate samples, equipment rinse blank samples, and laboratory matrix spike and matrix spike duplicate QC measurement samples.

Groundwater purge logs and sample collection logs are presented in Appendix D-1 and D-2, respectively. Analytical data were validated for precision, accuracy, representativeness, comparability, and completeness in accordance with the QAPjP (USACE, 2011c), and appropriate data qualifiers are appended to the analytical data in the project database.

### 4.2.3 Sampling of Bubbles in Groundwater

During the purging and collection of groundwater samples, tiny effervescent-like bubbles were noted in the field. Based on discussions with the NMED, and in response to NMED letter correspondence (Appendix A), a Letter Work Plan (USACE, 2012) was developed for the sampling of gas bubbles. The objective of gas-bubble sampling was to determine whether or not the bubbles were the result of faulty sampling equipment.

Samples were collected during the Third Quarter CY 2013 to characterize the gas bubbles observed in some wells during quarterly groundwater sampling, as directed in the November 6, 2012, NMED letter (Appendix A), and pursuant to Parts 1.23.1 and 6.5.18.3.1 of the Hazardous Waste Treatment Facility Operating Permit (EPA ID No. NM9570024423). Sampling was conducted in accordance with the June 21, 2013 letter (Appendix A), which was approved by the NMED Hazardous Waste Bureau in the

July 26, 2013 approval and request for clarification letter (Appendix A), and in accordance with the IsoTech® Laboratories, Inc.-recommended sampling procedure. Sample locations were selected based upon well depth and the occurrence of bubbles during previous sampling events, and groundwater and groundwater gas samples were collected in accordance with the requirements set forth in the November 6, 2012 NMED letter (Appendix A):

- **KAFB-106205**—This well is one of the most recently installed GWM wells and had bubbles observed in the groundwater during sampling in November 2012. This well was sampled on July 15, 2013.
- **KAFB-106206**—This well is one of the most recently installed GWM wells and had bubbles observed in groundwater during sampling in November 2012. This well was sampled on July 15, 2013.
- **KAFB-106040**—This is a deep well located along the eastern edge of the plume that has had bubbles observed in six out of the past seven quarters. This well was sampled on August 6, 2013.
- **KAFB-106051**—This is a deep well that serves as a sentry well along the western edge of the plume, and it has had bubbles observed six out of the past seven quarters. This well was sampled on August 5, 2013.
- **KAFB-106071**—This is a deep well located along the western edge of the plume, and it has had bubbles observed six out of the past seven quarters. This well was sampled on August 7, 2013.
- **KAFB-106104**—This is a deep well located along the eastern edge of the plume, and it has had bubbles observed during the past seven quarters of sampling. This well was sampled on August 5, 2013.

One ambient air sample and two samples of the argon gas used to drive the down-hole pumps for groundwater and groundwater gas bubble samples were collected in accordance with the NMED-approved June 21, 2013 letter (Appendix A).

The ambient air sample was collected within 25 feet of well KAFB-106206 over a period of 60 minutes, during which time the groundwater gas sample from KAFB-106206 was collected. The ambient air sample was collected upwind of any exhaust-emitting equipment, and was collected in a cali-5 bond bag, provided by IsoTech ® Laboratories, Inc. in accordance with their recommended sampling procedure. The purpose of the ambient air sample was to use it as a laboratory QC and establish background content of carbon dioxide ($CO_2$), argon, methane, and other gases.

The argon samples were collected in a Tedlar bag connected directly to the argon gas source used to drive the down-hole pumps during groundwater and groundwater gas-bubble sampling. The purpose of these samples was to determine if the bubbles observed were introduced during sampling.

Gas samples were sent to IsoTech ® Laboratories, Inc. and analyzed for carbon monoxide, helium, hydrogen, argon, oxygen, nitrogen, $CO_2$, methane, ethane, ethylene, propane, propylene, iso-butane, n-butane, iso-pentane, n-pentane, and “hexane +” (the sum of hexane [$C_6H_{14}$] plus heavier hydrocarbons). After the results from the first two wells, KAFB-106205 and KAFB-106206, were received, validated, and evaluated to determine if any changes to the sampling procedure were needed, the remaining samples were collected. No changes to the sampling procedure were deemed necessary. Bubble-sampling results are discussed in Section 5.2.3 and Appendix K.

### 4.2.4 Compound-Specific Isotope Analysis and Biological Parameter Sampling

Groundwater samples were collected for compound-specific isotope analysis (CSIA) to determine the ratio of the stable isotopes Carbon-12 and Carbon-13 in EDB and benzene. These ratios change during microbial degradation of hydrocarbons. The following samples were collected:

- Samples for EDB CSIA were collected at 31 wells (Figure 4-2) with 4 field duplicate samples, for a total of 35 samples.
- Samples for benzene CSIA were collected at 14 of those 31 wells (Figure 4-2) with 2 field duplicate samples, for a total of 16 samples.

Samples were collected for biological parameters to determine whether aerobic or anaerobic microbes exist at each location, and whether the microbes present are capable of degrading benzene (EDB degrader gene analysis was not available). Biological parameter sampling occurred at the same 31 wells as EDB CSIA sampling (Figure 4-2) with 4 field duplicate samples, for a total of 35 samples. Biological parameter samples were analyzed for the following:

- Aerobic (heterotrophic) plate count
- Anaerobic plate count
- Benzene degrader genes

Results of the CSIA and biological parameter sampling are discussed in Section 5.2.4 and Appendix L.

### 4.2.5 Slug Testing

Slug tests were performed in accordance with industry standard practice (ASTM D4044-96) as documented in the May 5, 2011 letter (Appendix A) between Kirtland AFB and the NMED. The May 5, 2011 letter was issued in response to the NMED's Direction to Acquire Hydraulic Information letter from February 21, 2011 (Appendix A).

Slug tests were performed in 37 GWM wells (Table 4-4) at SWMU SS-111. The data can be used to obtain an estimate of the spatial variability of the hydraulic conductivity of the aquifer system at the site, and to assist in the refinement of the conceptual model and design of subsequent aquifer tests.

The test procedures, analytical methods, assumptions, and results are described below. A full report on slug testing is provided in Appendix H.

#### *4.2.5.1 Test Procedures*

Slug tests were performed in accordance with industry standard practice (ASTM D4044-96) by "instantaneously" displacing a known volume of water, and recording the water-level recovery. Two methods were used to accomplish this displacement: a mechanical slug and a pneumatic slug test. The procedures for the two methods are discussed below.

### *Mechanical Slug Tests*

Mechanical slug tests were performed in wells screened across the water table, wells where the pneumatic wellhead could not be mounted, and wells unable to hold the pressure required for pneumatic tests. A known volume was displaced within each tested well using a steel slug lowered into the well on the free line of a well-development rig. For the injection ("in") test, the slug was moved as rapidly as possible into the water until it was totally submerged. For the withdrawal ("out") test, the slug was pulled from the water as rapidly as possible until it was suspended totally above the water.

Following the rapid lowering or withdrawal of the slug, the water-level response in the well was monitored over time using pressure transducers and data loggers. Logging was ended when the water levels stabilized at pre-test levels.

Fifty-four injection or "in" or "out" mechanical slug tests were performed in 26 wells to obtain an estimate of aquifer hydraulic conductivity in the vicinity of the tested wells.

### *Pneumatic Slug Tests*

Pneumatic slug tests were performed in wells screened below the water table, where the well casing could maintain the pressure, and the pneumatic wellhead could be mounted. To conduct a pneumatic slug test, the wellhead is sealed, and air is pumped into the well. The increased air pressure lowers the water level in the well. When the water level is stabilized at the desired level (pressure), the pressure is released at the wellhead through a large-diameter valve. The rapid release of the air pressure represents a removal of a "slug" of water the size of the casing radius times the differential of the water levels before and after the well is pressurized. Pressure transducers and data loggers were used to record the water-level response, and were placed between 2.5 and 2.2 feet from the static water surface in accordance with industry standard practice (Butler and Zhan, 2004). Four tests were performed in each well: P1 with a pressure increase of 0.6 to 0.7 pounds per square inch (psi), P2 with an increase of 0.4 to 0.5 psi, P3 with an increase of 0.2 psi, and P4 with an increase of 0.7 to 0.8 psi.

Eighty-eight pneumatic slug tests were performed in 22 wells to obtain an estimate of aquifer hydraulic conductivity in the vicinity of the tested wells.

#### *4.2.5.2 Data analysis*

The slug test data were analyzed in the following iterative fashion:

1. Basic assumptions used in the Aquifer Test Solver (AQTESOLV) software were defined and tested (Duffield, 2007). AQTESOLV is advanced software for slug test data analysis that features the most comprehensive set of solution methods for over-damped and under-damped conditions in confined, unconfined, and fractured aquifers.
2. Multiple analyses were performed to determine the most appropriate analytical method for each test.
3. The data in Table 5-9 were summarized, and the results from all the tests were compared to determine the most appropriate hydraulic conductivity value for each well.
4. Tests were repeated on four wells to field-verify the consistency of test procedures.

A number of analytical methods was available for the interpretation of slug test data. The interpretations were implemented using the AQTESOLV groundwater modeling software package (Duffield, 2007). Multiple analyses were performed using differing methodologies. After a review of the results, one test was selected as the most representative test for each well. The tests performed are documented in the test sheets provided in Appendix H, and the results are discussed in Section 5.2.5. Each of the analytical methods used is described below.

***Bouwer and Rice***

The initial analysis of each test was performed using a straight-line matching approach (Bouwer and Rice, 1976). The Bouwer and Rice interpretation was performed as a first approximation of the hydraulic conductivity. Although it was originally developed for unconfined aquifers, this method has also been shown to be reliable for confined aquifer conditions. Because the analysis was universally performed and can be used to provide a relative comparison between all wells, the Bouwer and Rice interpretation is shown in Table 5-9 for all wells.

***Curve Matching Interpretations***

Once the straight line Bouwer and Rice interpretation was completed, various curve-matching interpretations were used, and the results of the curve-matching analysis with the best fit were added to the Table 5-9. The methods used were the Butler-Zhan intertial (test well) (Butler and Zhan, 2004), the Kansas Geological Society model with skin (Hyder et al., 1994), and the Springer-Gelhar intertial (Springer and Gelhar, 1991). The aquifer did not clearly respond as either confined or unconfined. Therefore, analyses for both conditions were performed and the final result selected from the best fit.

Complete slug test results are discussed in Section 5.2.5.

## 4.3 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, 2011c), 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 to meet data quality objectives 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 N.

Daily Quality Control Reports (DQCR), were completed in accordance with the approved Groundwater Investigation Work Plan (USACE, 2011a). Three field work variances were generated during field work activities and are located in Appendix A-1.

## 4.4 Investigation-Derived Waste

Investigation-derived waste (IDW) was characterized using data obtained from the analysis of environmental samples collected during the investigation as well as data from quarterly monitoring activity 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 (DOT) 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”

### 4.4.1 Soil IDW

GWM wells for SWMU SS-111 were drilled using ARCH, and the drill cuttings 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.

### 4.4.2 IDW Water from Well Installation and Development

Decontamination IDW water from well installation and well development IDW purge water were containerized in labeled polyurethane containers pending analysis. Wastewater samples were analyzed for SVOCs, TPH-GRO, TPH-DRO, and lead for the initial 78 GWM wells, and for VOCs, SVOCs, TPH-GRO, TPH-DRO, metals, EDB, anions, and nitrate-nitrite for the final 9 GWM wells that were installed. Based on the analytical results, IDW water was classified as hazardous, non-hazardous Notice of Intent (NOI), or non-hazardous clean, and then 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

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 United States Code 300
- NMED Standards for Groundwater 20 NMAC 6.2.3103

### 4.4.3 IDW Water from Quarterly Groundwater Sampling

Quarterly groundwater sampling at GWM wells generated IDW purge water. IDW water was stored at SWMU SS-111 in labeled, 55-gallon, polyethylene, open-top drums with sealable lids, or bulked and stored in large tanks pending groundwater sampling analyses and subsequent disposal determination. Following groundwater sampling analysis, the IDW water was classified as hazardous, non-hazardous NOI, or non-hazardous clean, and then 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

Results of the IDW testing are discussed in Section 5.3; hazardous waste manifests and waste disposal analytical data are presented in Appendix J.

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# 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 SS-111.

## 5.1 Geology

### 5.1.1 Geologic Logging Observations

Geologic cross-sections were created using the soil boring logs generated for each GWM well in accordance with the NMED Directive for Conducting Interim Measures and Notice of Disapproval dated August 6, 2010 (Appendix A). Cross-section transects, A-A’, B-B’, C-C’, D-D’, and E-E’, are shown on Figure 5-1, and the individual cross-sections are shown on Figures 5-2 through 5-6. 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

Unit A is approximately the top 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 5-5). Sand deposits within this unit consist of silty, well-graded, and poorly-graded sand intervals ranging in thickness from 0 to 60 feet.

Underlying the silty slope deposits 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 site. As presented 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 are up to 50 feet in thickness, particularly to the north of the site, and are of unknown lateral extent (Figures 5-3 and 5-4). Clay lenses are also observed heterogeneously within the Santa Fe Group, with the most notable lens shown in the A-A' cross-section (Figure 5-2). Within the screened zones of wells installed at the BFF Spill site, the geology is predominantly well-graded sand with varying percentages of gravel and fines.

Geologic logs for existing and newly installed monitoring wells and geophysical logging data indicate a considerable amount of variability within the two depositional units (Units A and B). Based on the lithologic logs and the five cross-sections, coarser materials, including gravel lenses, appear to be more concentrated in the central portion of the study area (Figures 5-3 and 5-4), while finer, silt-rich sediments appear to be more prevalent in the northern and southern portions of SWMU SS-111 (Figures 5-2, 5-5, and 5-6).

### 5.1.2 Split-Spoon Sample Results

Split-spoon samples at KAFB-106061, KAFB-106062, KAFB-106078, and KAFB-106081 were collected as described in Section 4.1.3, and analyzed for the following parameters:

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

Split-spoon soil data collected at SWMU SS-111 during the RFI indicate only one 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 (NMED, 2012). Sample KAFB-106078 representing the interval 400 to 450 ft bgs (collected at 447 to 448.5 bgs) had a TPH concentration of 1,332 mg/kg. No other analytes exceeded regulator screening levels. Sample results are provided in Appendix F-3.

Additional split-spoon samples were collected during the advancement and installation of SVM wells. The methods and results of these samples are discussed in the ST-106 Vadose Zone RFI Report (submitted under separate cover).

### 5.1.3 Bucket Sampling Results

Bucket samples were remolded in the laboratory and analyzed for porosity, hydraulic conductivity, TOC, and grain-size distribution. Results of all analyses are provided in Appendix C, and discussed below:

- The arithmetic mean total porosity value is 34.1% with a standard deviation of ± 4.85%. The arithmetic mean effective porosity value is 27.4% with a standard deviation of ± 4.87% (Table 5-1).
- The geometric mean permeability is 4,700 miliDarcies (mD) with a range in permeability values from 27 to 26,000 mD (Table 5-2). The geometric mean hydraulic conductivity is $4.6 \times 10^{-3}$ centimeters per second (13 feet/day) with a range in hydraulic conductivity values from $2.7 \times 10^{-5}$ to $2.6 \times 10^{-2}$ centimeters per second ($7.7 \times 10^{-2}$ to 7.4 feet per day) (Table 5-2).
- Overall, the TOC concentrations are low with an arithmetic mean concentration of 230 mg/kg and a standard deviation of ± 77.5 mg/kg (Table 5-3). The arithmetic mean fraction organic carbon concentration is $2.3 \times 10^{-4}$ gram/gram with a standard deviation of ± $7.75 \times 10^{-5}$ gram/gram (Table 5-3).
- The dominant grain size is medium sand with substantial samples of coarse sand and gravel (Table 5-4). The median grain size of the samples ranged from 0.23 to 10 millimeters (mm) with a fraction of medium sand ranging from 6.07 to 73.2% (Table 5-4).

A geometric mean is used where individual results vary across orders of magnitude, and an arithmetic mean is used where individual results fall within the same order of magnitude.

### 5.1.4 Continuous Core Sampling Results

Table 5-5 presents the air/water and the water/NAPL capillary test results and calculated van Genuchten parameters (alpha, n, and m) from the continuous core sampling at the six wells: KAFB-106059, KAFB-106060, KAFB-106063, KAFB-106078, KAFB-106080, and KAFB-106081. The median grain size of the samples ranged from 0.43 to 1.8 mm with a fraction of medium sand ranging from 39 to 64%.

For the water/air test, the water permeability of the samples ranged from 3.2 to 11,283 mD, and the air permeability ranged from 24.3 to 16,350 mD. The van Genuchten alpha parameter ranged from 0.0019 to 0.032 centimeter (cm)$^{-1}$ (0.059 to 0.97 foot$^{-1}$) with an average value of 0.023 cm$^{-1}$ (0.69 foot$^{-1}$). The values for van Genuchten parameter "n" ranged from 1.7 to 2.3 with an average of 2.1. The values for van Genuchten parameter "m" ranged from 0.42 to 0.57 with an average of 0.52.

For the water/NAPL test, the water permeability of the samples ranged from 5.54 to 9,190 mD, and the NAPL permeability ranged from 262 to 4,036 mD. Alpha ranged from 0.036 to 0.15 cm$^{-1}$ (1.1 to 4.6 feet$^{-1}$) with an average value of 0.093 cm$^{-1}$ (2.8 feet$^{-1}$). The values for "n" ranged from 1.4 to 2.6 with an average of 2.0. The values for "m" ranged from 0.26 to 0.61 with an average of 0.47.

### 5.1.5 NAPL Sampling Results

During Third Quarter CY 2011, physical and chemical tests were conducted on the NAPL collected at two wells (KAFB-1066 and KAFB-106076), including density, viscosity, interfacial tension, and chemical PIANO, plus specific tests for EDB, EDC, and lead. The results presented are included in Appendix C and are summarized below:

- The NAPL viscosity is low, at around 1.40 centipoises. The NAPL-air and NAPL-water interfacial tension values are 25.3 and 13.1 dynes/cm, respectively.
- The NAPL density values of 0.77 grams per cubic centimeter (g/cm$^3$) and 0.80 g/cm$^3$ fall between the expected values for a mixture of gasoline (approximate density of 0.73 g/cm$^3$) and diesel (approximate density of 0.88 g/cm$^3$).
- The sample from KAFB-1066 yielded the API specific gravity of 51.6 and flashpoint of less than 70°F, which is closer to the gravity of gasoline (approximately 58 API) than that of diesel (approximately 30 API). The sample from KAFB-106076 yielded an API gravity of 44.7 with a flashpoint of 94°F, which is closer to diesel.
- Chromatograms for both samples are provided in Appendix C.
- The PIANO results yielded aromatic percentages of 18 and 29% for the two samples.

NAPL and Soil Hydraulic Property Results are listed in Appendix C.

### 5.1.6 Geophysical Logging Results

Geophysical logs were compared against and correlated with soil boring logs used in the cross-sections (Figures 5-1 through 5-6). Soil boring logs are discussed in Section 5.1.1. Geophysical Logs, Calibration Data, and QC Forms are located in Appendix E.

## 5.2 Hydrogeology

### 5.2.1 Groundwater Levels

The April 2013 groundwater-level contour maps for the Shallow, Intermediate, and Deep Zones are presented in Table 5-6 and on Figures 5-7, 5-8, and 5-9, respectively. Figure 5-10 displays comprehensive groundwater levels for April 2013, including the wells currently included in the monitoring program for SWMU SS-111. Figure 5-11 depicts NAPL thickness in shallow GWM wells in April 2013.

Based on the groundwater levels from April of 2013, the groundwater-flow direction is approximately North 35° to 50° East . At the northern edge of the monitoring well network, the groundwater-flow direction turns almost due east. This is most likely a result of pumping at the Kirtland AFB water supply well KAFB-3, which is located approximately 100 feet to the east of the KAFB-106201 well cluster. Groundwater gradients in Second Quarter CY 2013 were 5.7 by $10^{-4}$ feet per foot.

Over the past 60 years, water levels have declined at SWMU SS-111 based on water-level data from KAFB-3, which is provided in Appendix F. Between 1949 and 2009, the water level in KAFB-3 declined from 4,953 feet to 4,811 feet in elevation, thus lowering the water table at this location by more than 140 feet. Since 2009, groundwater levels have risen between 7.5 and 10 feet based on the analysis of the time-series hydrographs (Appendix G) for each GWM well.

These rising water levels have resulted in flooded screens in a number of Shallow Zone wells with the top of the screen below the current water table. Figure 5-7 illustrates the wells in which the screens are now below the water table. As of April 2013, 15 Shallow Zone wells have flooded screens, 14 wells have their tops of screen within 2 feet of the water table, and 20 wells have their tops of screens more than 2 feet above the water table. Table 5-7 offers a comparison of screen and water levels for the Shallow Groundwater Zone.

### *5.2.1.1 NAPL Occurrence*

NAPL was first identified at SWMU SS-111 in well KAFB-1065 in 2007 at a thickness of 1.44 feet. The NAPL "footprint" was defined by 6 wells with measurable NAPL thicknesses in July 2009. The thickest NAPL intervals were measured in wells KAFB-1065 (4.03 ft) and KAFB-1068 (2.83 ft) in 2010. The historical NAPL plume is approximately 2,300 feet long, 1,100 feet wide, and spans approximately 43 acres.

Based on the analysis of NAPL thickness data (measured in feet) over time (Appendix G-2), it is apparent that the NAPL thickness observed in wells since 2009 has markedly declined as groundwater levels have risen. Figures 5-12 and 5-13 show the measured NAPL thickness over time in each GWM well where NAPL has historically been observed. The 7.5- to 10-foot rise in groundwater levels and concurrent reduction of NAPL thickness in Shallow Zone wells indicate that the NAPL interval is now flooded, with most of the NAPL being submerged below the water table. Based on the NAPL data discussed in Section 5.1.5, the difference in density between the NAPL and groundwater is approximately 0.23 g/cm$^3$. If the resulting buoyancy force is less than the displacement pressure (i.e., the capillary pressure required for NAPL to migrate into a soil pore space and displace the water), then the NAPL cannot rise when the water table rises.

#### *5.2.1.2 Vertical Gradients*

Vertical gradients within the upper 100 feet of the aquifer are less than can be quantified from standard groundwater-level measurements. Groundwater-level data were compiled to determine if any vertical gradients were apparent. No consistent gradients were observed across SWMU SS-111 (Figures 5-14 through 5-16).

### 5.2.2 Quarterly Groundwater Sampling

The results of the analyses of quarterly groundwater samples are provided in Appendix F, and summarized in the discussion below.

#### *5.2.2.1 Selection of Groundwater Contaminants of Concern*

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

1. The total number of samples for a given parameter during the period between January 2009 and June 2013 was more than 20.
2. More than 5% of the analytical results were detections for a given parameter. (Meaning that no more than 95% of the samples were nondetects).
3. The maximum detected concentration exceeded the lowest regulatory screening level for each parameter. As outlined in Section 6.2.3.1 of the RCRA Permit (EPA ID No. NM9570024423), the lowest screening level was chosen based on a comparison between the EPA MCLs (EPA, 2013) and NMED Groundwater Standards (20.6.4 NMAC). The EPA regional screening level for tap water was used where there was no MCL or NMED Groundwater Standard established for a given parameter.

The groundwater COCs for the Shallow Zone are the following:

| Parameter | CAS Number |
|---|---|
| 1,2,4-trimethylbenzene | 95-63-6 |
| 1,2-dibromoethane (EDB) | 106-93-4 |

| Parameter | CAS Number |
|---|---|
| 1,2-dichloroethane (EDC) | 107-06-2 |
| 1,3,5-trimethylbenzene | 108-67-8 |
| 1-methylnaphthalene | 90-12-0 |
| 2-hexanone | 591-78-6 |
| 2-methylnaphthalene | 91-57-6 |
| * Acetone | 67-64-1 |
| Acetophenone | 98-86-2 |
| Benzene | 71-43-2 |
| bis (2-ethylhexyl) phthalate | 117-81-7 |
| Ethylbenzene | 100-41-4 |
| Iron | 7439-89-6D |
| Manganese | 7439-96-5D |
| Naphthalene | 91-20-3 |
| Nitrate (as N) | 39018 |
| Nitrogen, Nitrite | 7727-37-9 |
| Tetrachloroethene | 127-18-4 |
| Toluene | 108-88-3 |
| Xylene, o- | 95-47-6 |
| Xylenes, total | 1330-20-7 |

CAS Chemical Abstract Service

* Although acetone was identified as a COC during the screening process, it is not a fuel-related contaminant and is attributed to laboratory contamination. Therefore, it will not be discussed as a COC in this RFI report.

The groundwater COCs for the Intermediate Zone are the following:

| Parameter | CAS Number |
|---|---|
| 1,2,4-trimethylbenzene | 95-63-6 |
| 1,2-dibromoethane (EDB) | 106-93-4 |
| 1-methylnaphthalene | 90-12-0 |
| Benzene | 71-43-2 |
| Ethylbenzene | 100-41-4 |
| Manganese | 7439-96-5D |
| Naphthalene | 91-20-3 |
| Toluene | 108-88-3 |
| Xylene, o- | 95-47-6 |

CAS Chemical Abstract Service

The groundwater COCs for the Deep Zone are the following:

| Parameter | CAS Number |
|---|---|
| 1,2-dibromoethane (EDB) | 106-93-4 |
| Manganese | 7439-96-5D |
| Nitrate (as N) | 39018 |

CAS Chemical Abstract Service

#### 5.2.2.2 *Spatial Analysis of COCs*

Concentration contour maps for spatial analysis were prepared for selected COCs with sufficient detections to warrant interpolation of contours. Of the primary COCs that the NMED specified in the letter dated August 17, 2011 (Appendix A), with comments on the First Quarter CY 2011, concentration contour maps were created for all COCs with a detection rate of at least 20% in any of the Shallow, Intermediate, or Deep Zones.

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 I.

Compound-specific dot and/or plume maps (Figures 5-17 through 5-40) were prepared for TPH-GRO; TPH-DRO; EDB; benzene; toluene; total xylenes; 1,2,4-TMB; and naphthalene. Although not regulated under RCRA or defined as COCs, plume maps for TPH-GRO and TPH-DRO are included per NMED direction in their August 6, 2010 letter (Appendix A), requesting that TPH-GRO and TPH-DRO be included in plume characterization evaluation. The analytical data indicate that the majority of the groundwater contamination is concentrated in the Shallow Zone, but some COCs are present in the Intermediate and Deep Zones as described in this section.

### *TPH-GRO*

The TPH-GRO plume extent was fully delineated in First Quarter CY 2012 and confirmed in each following quarter (Figures 5-17 through 5-19). The TPH-GRO Shallow Zone plume is approximately 5,000 feet long, and the approximate width of the plume in the historical NAPL area is 1,600 feet with the plume narrowing to the north to a width of 1,000 feet. The highest Shallow Zone TPH-GRO concentrations are in the historical NAPL area (Figures 5-17 through 5-19). The historical maximum observed concentration of TPH-GRO was 72,000 µg/L in Second Quarter CY 2012).

In the Intermediate Zone, the TPH-GRO plume is approximately 4,200 feet long and 1,000 feet wide. The highest measured concentration of TPH-GRO in the Intermediate Zone was 27,000 µg/L during the Third Quarter CY 2012. Only a single well in the Deep Zone (KAFB-10681) has had a detection of TPH-GRO, and this well is located in the center of the historical NAPL area; the detected concentration of TPH-GRO at this well was 320 µg/L in Fourth Quarter CY 2011.

In Second Quarter CY 2013, a total of 14 Shallow Zone wells, 3 Intermediate Zone wells, and no Deep Zone wells exceeded the NMED TPH screening guideline for kerosene and jet fuel of 550 µg/L for potable groundwater (NMED, 2012).

### *TPH-DRO*

The TPH-DRO plume extent was fully delineated in First Quarter CY 2012 and confirmed in each following quarter (Figures 5-20 through 5-22). The TPH-DRO Shallow Zone plume is approximately 4,800 feet long, and the approximate width in the historical NAPL area is 1,000 feet with the plume narrowing to the north to a width of 600 feet. The highest Shallow Zone TPH-DRO concentrations are in the historical NAPL area with a historical maximum observed concentration of 240,000 µg/L in Second Quarter CY 2013.

In the Intermediate Zone, the TPH-DRO plume is approximately 4,100 feet long and 800 feet wide. The highest Intermediate Zone TPH-DRO concentrations are in the historical NAPL area with a maximum observed concentration of 22,000 µg/L in Fourth Quarter CY 2011. Only two wells in the Deep Zone have had detections of TPH-DRO: KAFB-106084 (immediately downgradient of the historical NAPL area) had a detection of 510 µg/L in Third Quarter CY 2013, and KAFB-106098 (within the historical NAPL area) had a detection of 3,800 µg/L in Fourth Quarter CY 2012.

In Second Quarter CY 2013, a total of 19 Shallow Zone wells, 6 Intermediate Zone wells, and no Deep Zone wells exceeded the NMED TPH screening guideline for kerosene and jet fuel of 550 µg/L for potable groundwater (NMED, 2012).

### *EDB*

The EDB plume extent was fully delineated in Fourth Quarter CY 2012 and confirmed in each following quarter (Figures 5-23 through 5-25). The EDB Shallow Zone plume is approximately 5,900 feet long and approximately 1,000 feet wide along the entire length. The highest Shallow Zone EDB concentrations are in the historical NAPL area with a historical maximum observed concentration of 370 µg/L in Third Quarter CY 2011.

In the Intermediate Zone, the EDB plume is approximately 4,100 feet long and 1,300 feet wide. The highest Intermediate Zone EDB concentrations are downgradient of the historical NAPL area with a maximum observed concentration of 1.4 µg/L in First Quarter CY 2012.

In the Deep Zone, only two wells have had consistent detections of EDB, KAFB-106058 and KAFB-106037, which are downgradient of the historical NAPL area. The maximum observed concentration of EDB in the Deep Zone was 0.71 µg/L in Third Quarter CY 2011.

During Second Quarter CY 2013, 30 Shallow Zone wells, 8 Intermediate Zone wells, and 2 Deep Zone wells had EDB concentrations exceeding the regulatory limit of 0.05 µg/L (EPA, 2013).

***Benzene***

The benzene plume extent was fully delineated in Third Quarter CY 2011 and confirmed in each following quarter (Figures 5-26 through 5-28). The benzene Shallow Zone plume is approximately 3,000 feet long and 1,300 feet wide, and is almost entirely within the historical NAPL area. The historical maximum observed Shallow Zone concentration was 16,000 µg/L in Third Quarter CY 2012.

In the Intermediate Zone, there have only been detections above the MCL of 5 µg/L (EPA, 2013) in two wells. There have consistently been detections in KAFB-106080, and there were two detections in KAFB-106065: one of 1,200 µg/L in Fourth Quarter CY 2011, and one of 16 µg/L in Second Quarter CY 2013. Both wells are within the historical NAPL area. Benzene has not been detected above the MCL of 5 µg/L (EPA, 2013) in any Deep Zone wells.

During Second Quarter CY 2013, there were 13 Shallow Zone wells and 2 Intermediate Zone wells with benzene concentrations above the MCL of 5 µg/L (EPA, 2013).

### *Toluene*

The toluene extent was fully delineated in Second Quarter CY 2011 and confirmed in each following quarter (Figures 5-29 through 5-31). Toluene in the Shallow Zone is almost entirely within the historical NAPL area with a historical maximum observed concentration of 19,000 µg/L in Third Quarter CY 2011.

In the Intermediate Zone, only one well has had consistent detections of toluene, KAFB-106080, which is in the Intermediate Zone. Only one detection has been above the NMED groundwater standard of 750 µg/L (20.6.4 NMAC). This was a detection of 1,300 µg/L in Second Quarter CY 2012. In the Deep Zone, toluene has not been detected above the NMED groundwater standard of 750 µg/L (20.6.4 NMAC).

During Second Quarter CY 2013, 7 wells in the Shallow Zone and zero wells in the Intermediate and Deep Zones had concentrations above the NMED groundwater standard of 750 µg/L (20.6.4 NMAC).

### *Total Xylenes*

The total xylenes extent was fully delineated in Fourth Quarter CY 2011 and confirmed in each following quarter (Figures 5-32 through 5-34). Total xylene detections in the Shallow Zone are almost entirely contained within the historical NAPL area with a historical maximum concentration of 4,600 µg/L detected in Fourth Quarter CY 2012.

In the Intermediate and Deep Zones, total xylenes have not been detected above the NMED groundwater standard of 620 µg/L (20.6.4 NMAC).

During Second Quarter 2013, 7 Shallow Zone wells and zero Intermediate and Deep Zone wells had total xylenes detections above the NMED groundwater standard of 620 µg/L.

### *1,2,4-TMB*

The 1,2,4-TMB plume extent was fully delineated in Second Quarter CY 2011 and confirmed in each following quarter (Figures 5-35 through 5-37). The 1,2,4-TMB Shallow Zone plume is approximately 2,000 feet long; the approximate width of the plume in the center of the historical NAPL area is 800 feet with the plume narrowing to the north and south to 300 feet wide. The 1,2,4-TMB Shallow Zone plume is within the historical NAPL area, with a historical maximum detected concentration of 640 µg/L in Third Quarter CY 2011.

In the Intermediate Zone, three wells have had detections of 1,2,4-TMB greater than the EPA tap water limit of 15 µg/L (EPA, 2013). These are KAFB-106080 and KAFB-106065, which are within the historical NAPL area, and KAFB-106083, which is immediately downgradient of the historical NAPL area. The maximum detected concentration of 1,2,4-TMB in the Intermediate Zone was 140 µg/L in Second Quarter CY 2012. In the Deep Zone, 1,2,4-TMB has not been detected above the EPA tap water limit of 15 µg/L (EPA, 2013).

During Second Quarter CY 2013, 10 Shallow Zone wells, 1 Intermediate Zone well, and zero Deep Zone wells had detections of 1,2,4-TMB above the EPA tap water limit of 15 µg/L.

### *Naphthalene*

The naphthalene plume extent was fully delineated in Third Quarter CY 2011 and confirmed in each following quarter (Figures 5-38 through 5-40). The naphthalene Shallow Zone plume is approximately 2,000 feet long; the approximate width of the plume at the center of the historical NAPL area is 800 feet with the plume narrowing to the north and south to a width of 300 feet. The Shallow Zone naphthalene plume is contained within the historical NAPL area, with a historical maximum observed concentration of 470 µg/L (J+ qualified result) in Third Quarter CY 2011.

In the Intermediate Zone, two wells have historically had detections of naphthalene, KAFB-106080 and KAFB-106065, which are both within the historical NAPL area. The maximum observed concentration in the Intermediate Zone was 120 µg/L in Third Quarter CY 2011. In the Deep Zone, naphthalene has not been detected above the EPA MCL of 30 µg/L.

During Second Quarter CY 2013, 9 Shallow Zone wells, 1 Intermediate Zone well, and zero Deep Zone wells had detections of naphthalene above the EPA MCL of 30 µg/L.

### 5.2.3 Bubble Sampling Results

Detectable amounts of argon (Ar), oxygen ($O_2$), carbon dioxide ($CO_2$), nitrogen ($N_2$), methane ($CH_4$), ethane ($C_2H_6$), and “hexane +” (the sum of hexane [$C_6H_{14}$] plus heavier hydrocarbons) were found in one or more of the six groundwater gas samples that were collected in Third Quarter CY 2013. Ethylene, propane, propylene, iso-butane, normal-butane, iso-pentane, and normal-pentane were analyzed for, but were nondetectable in the samples.

Analytical results are summarized in Table 5-8 for the six groundwater gas samples, an ambient air sample, and two argon drive gas samples in units of mole percent (approximately equivalent to partial pressure or volume percent). Also provided in Table 5-8 are calculated “enrichment factors,” which are the ratios of the composition of the analytes in the groundwater gas samples divided by the compositions of the analytes in the ambient air sample. Factors greater than 1.0 indicate a higher proportion of that component relative to the ambient air sample, and factors less than 1.0 indicate a lower proportion of that component relative to the ambient air sample. A complete discussion of the results of sampling can be found in Appendix K

The analyses of the six samples show that the dissolved gases in the six groundwater samples closely match the composition of air, modified by an increase of approximately 2.5 percent $CO_2$, an increase of less than 0.005 percent methane, and a decrease of approximately 4 percent $N_2$. The slight enrichment of $O_2$ and Ar in the groundwater samples could be explained by the higher solubility of $N_2$, which allows the $N_2$ to remain in solution rather than exsolving when the water sample is brought to the surface.

The analyses of the six groundwater gas samples show that there is no significant leakage of argon drive gas in the samples, which demonstrates that the bubbles observed during groundwater sampling are not produced by the sampling procedure. The bubbles closely match the composition of ambient air, and small amounts of naturally occurring $CO_2$ and smaller amounts of methane may continue to exsolve from the samples.

Using Henry's Law and an initial EDB groundwater concentration of 1.0 µg/L, the equilibrium concentrations in an air bubble and in the water sample in a volatile organic analysis vial were calculated based on varying temperatures (Appendix K). After calculating Henry's Law concentrations for EDB in groundwater with varying initial groundwater concentrations, temperatures, and air volumes, it was determined that over 99.6% of EDB will remain in water under the potential range of sample temperatures, initial EDB concentrations, and bubble volumes in the vial.

### 5.2.4 Compound-specific Isotope Analysis and Biological Parameter Sampling

Figures 5-41 through 5-47 show the results of the CSIA and biological sampling conducted as part of the RFI for SWMU SS-111. The following spatial patterns are observed on these figures:

- Benzene $\delta^{13}C$ ratios are the lowest in the historical NAPL area, where benzene concentrations are the highest. Benzene $\delta^{13}C$ ratios generally increase as concentrations decrease further downgradient.

- The lowest EDB $\delta^{13}C$ ratios are in the historical NAPL area, where EDB concentrations are the highest. In the downgradient portion of the EDB plume, $\delta^{13}C$ are higher, with no apparent spatial pattern.
- Anaerobic bacteria counts are the highest in the historical NAPL area, and decrease to the north in the downgradient portion of the plume.
- Heterotrophic bacteria counts do not show a strong spatial pattern.
- Benzene degrador genes bSSA and PHE are generally more abundant in the historical NAPL area, and decrease overall to the north in the downgradient portion of the plume.

These results were used in a degradation analysis, which is discussed in detail in Appendix L.

### 5.2.5 NAPL Slug Test Results

A complete report on slug testing, including all data and solution methods, is provided in Appendix H.

Results are presented in Table 5-9. A summary of the conclusions and observations is below:

- The aquifer in the vicinity of the Kirtland AFB wells has a mean hydraulic conductivity of 63 feet/day with a minimum of 12 feet/day and a maximum of 129 feet/day.
- Results of the slug tests were within the ranges expected for units ranging in grain size from silty sand to gravel.
- The results of the slug tests were internally consistent within each well.
- Slug tests were performed consistently, and slug test types yielded results consistent with one another.
- Some component of vertical anisotropy was observed in all the tests.
- Results indicative of boundary conditions were not observed.

## 5.3 IDW Results

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

### 5.3.1 Soil IDW

Table 5-10 details the sampling and disposal of each roll-off container generated from January 2011 to June 2013.

#### *5.3.1.1 Disposal of Hazardous Soil IDW*

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

#### *5.3.1.2 Disposal of Non-Hazardous Special Waste Soil IDW*

One roll-off container of soil IDW (from the drilling of KAFB-106083) was 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.

#### *5.3.1.3 Disposal of Non-Hazardous Clean Soil IDW*

The remaining 282 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.

### 5.3.2 IDW Water from Well Installation and Development

Table 5-11 details the sampling and disposal of each wastewater container from January 2011 to June 2013. Appendix J contains the hazardous waste manifests and waste disposal analytical data.

#### *5.3.2.1 Disposal of Hazardous IDW Water from Well Installation and Development*

Investigation-derived waste water from six wells (KAFB-106059, 106061, KAFB-106063, KAFB-106076, KAFB-106080, and KAFB-106101) was classified as hazardous, as defined by 40 CFR

261.24. The IDW water from these wells was containerized in 55-gallon, closed-topped, polyethylene, DOT-approved shipping drums, and then manifested as hazardous waste and transported by a subcontractor to US Ecology in Beatty, Nevada, a facility that is permitted to handle hazardous IDW water. Hazardous waste manifests are provided in Appendix J.

#### *5.3.2.2 Disposal of Non-Hazardous NOI IDW Water from Well Installation and Development*

IDW from 13 wells (Table 5-11) was classified as non-hazardous as defined by 40 CFR 261.24, but required NOI approval prior to discharge. For this IDW water, NOIs were prepared in accordance with Subsection A of 20.6.2 NMAC. Once the NOI was approved by the Ground Water Quality Bureau (NMED), the water was discharged to the ground surface, in a location where IDW water could not enter a watercourse for surface water.

#### *5.3.2.3 Disposal of Non-Hazardous Clean IDW Water from Well Installation and Development*

The remaining IDW water was classified by 70 samples as non-hazardous as defined by 40 CFR 261.24, and did not require NOI approval (20.6.2 NMAC) prior to discharge. This IDW water was discharged to the ground surface in a location where IDW water could not enter a watercourse for surface water.

### 5.3.3 IDW Water from Quarterly Groundwater Sampling

Table 5-12 details the volume of purge water generated from January 2011 to June 2013 from each monitoring well and the storage location of purge water. Appendix J provides hazardous waste manifests and waste disposal analytical data.

#### *5.3.3.1 Disposal of Hazardous IDW Water from Quarterly Groundwater Sampling*

From January 2011 to June 2013, 4,769 gallons of IDW water from quarterly groundwater sampling was classified as hazardous as defined by 40 CFR 261.24. This IDW water was containerized in 55-gallon, close-topped, polyethylene, DOT-approved shipping drums, and then manifested as hazardous waste and transported by a subcontractor to US Ecology in Beatty, Nevada, a facility that is permitted to handle hazardous IDW water. Hazardous waste manifests are provided in Appendix J.

#### *5.3.3.2 Disposal of Non-Hazardous NOI IDW Water from Quarterly Groundwater Sampling*

From January 2011 to June 2013, 25,066 gallons of IDW water from quarterly groundwater sampling were classified as non-hazardous as defined by 40 CFR 261.24, but required NOI approval prior to discharge. For this IDW water, NOIs were prepared in accordance with Subsection A of 20.6.2 NMAC. Once the NOI was approved by the Ground Water Quality Bureau (NMED), the water was discharged to the ground surface, in a location where IDW water could not enter a watercourse for surface water.

#### *5.3.3.3 Disposal of Non-Hazardous Clean IDW Water from Quarterly Groundwater Sampling*

From January 2011 to June 2013, 28,539 gallons of IDW water from quarterly groundwater sampling were classified as non-hazardous as defined by 40 CFR 261.24, and did not require NOI approval (20.6.2 NMAC) prior to discharge. This IDW water was discharged to the ground surface in a location where IDW water could not enter a watercourse for surface water.

# 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 SS-111, 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 (groundwater at SWMU SS-111) can affect the fate and persistence of the contaminants; this, in turn, governs the contaminant distribution and behavior in environmental media. Depending upon the specific chemical and soil conditions, contaminants may be transferred from surface soil to subsurface soil, to groundwater, 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 and transfers it between media is an important factor 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 the environmental media at SWMU SS-111. A summary of the COCs identified (Section 5.2.2.1) in the groundwater is as follows:

| Parameter | CAS Number |
|---|---|
| 1,2,4-trimethylbenzene | 95-63-6 |
| 1,2-dibromoethane (EDB) | 106-93-4 |
| 1,2-dichloroethane (EDC) | 107-06-2 |
| 1,3,5-trimethylbenzene | 108-67-8 |
| 1-methylnaphthalene | 90-12-0 |
| 2-hexanone | 591-78-6 |
| 2-methylnaphthalene | 91-57-6 |
| Acetophenone | 98-86-2 |
| Benzene | 71-43-2 |
| bis (2-ethylhexyl) phthalate | 117-81-7 |
| Ethylbenzene | 100-41-4 |
| Iron | 7439-89-6D |
| Manganese | 7439-96-5D |
| Naphthalene | 91-20-3 |
| Nitrate (as N) | 39018 |
| Nitrogen, Nitrite | 7727-37-9 |
| Tetrachloroethene | 127-18-4 |

| Parameter | CAS Number |
|---|---|
| Toluene | 108-88-3 |
| Xylene, o- | 95-47-6 |
| Xylenes, total | 1330-20-7 |

CAS Chemical Abstract Service

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**—Specific gravity is 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 degrees Celsius (39.2°F), which has a density of 1.000 kg 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 degree 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**— he 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.

Additional detail on chemical source, persistence, and properties are discussed below for select compounds. These compounds were selected for additional discussion since they have been consistently detected over multiple quarters of monitoring and have plume maps for the three groundwater zones (Shallow, Intermediate, and Deep).

### 6.1.1 Inorganics

Since most metals are indigenous to the earth, they are usually found at varying concentration levels in most environmental media. Some metals concentrate in animal tissue (for example, zinc accumulation in fish), while some metals accumulate in plants (for example, vanadium). In soil, metal contaminants are dissolved in the soil pore water, adsorbed or ion-exchanged on the surfaces of inorganic soil contaminants, complexed with soluble soil organic matter, and precipitated as pure or mixed solids. Metals dissolved in the soil pore water are subject to movement with water and may be transported through the vadose zone to groundwater to remain in the aquifer or be taken up by plants. Unlike organic contaminants, metals cannot be degraded; however, the mobility and toxicity of some metals (i.e., arsenic, chromium, and mercury) can be altered due to changes in oxidation states. The fate and transport of the metals identified as COCs at SWMU SS-111 are as follows:

- **Iron**—The oxidation-reduction state of the environment has the greatest influence on the fate and transport of iron. Iron naturally occurs in the environment in two oxidation states: ferrous iron ($Fe^{+2}$) and ferric iron ($Fe^{+3}$). Ferric iron is commonly present in oxic soil as iron oxides and hydroxides, which are present as discrete minerals or as coatings on the surfaces of other minerals (Kabata-Pendias, 2001). Iron oxides are relatively insoluble in oxic soil under circum-neutral pH conditions, and are soluble only under very low pH (below about 4) or high pH (above about 11) (Langmuir et al., 2004). The physical transport of ferric iron occurs mostly due to the erosion of soil material and sediments with the deposition of the minerals occurring at a downgradient point. Under reducing conditions (low oxidation-reduction conditions), ferric iron is reduced to ferrous iron. Free ferrous iron is very soluble and is easily transported under reducing conditions. Precipitation of ferrous iron is possible under strongly reducing conditions in the presence of sulfide ($S^{-2}$). The precipitation of iron sulfide minerals limits the mobility of ferrous iron; however, if conditions become oxidizing, the precipitated ferrous iron is released to solution and may be subject to re-precipitation (as ferric iron oxides or hydroxides) if oxic conditions are encountered (Kabata-Pendias, 2001).

- **Manganese**—Manganese is a naturally occurring element that is present in most soil. Manganese can be present in soil in the +2, +3, or +4 valence state, depending on the local oxidation-reduction conditions. The solubilities, sorption behavior, and mobilities of manganese in theses valence states are quite different. In oxidizing environments that are typical of surface soil, manganese is in the +4 valence state, where it forms oxide minerals such as $MnO_2$ that have very low solubilities. These minerals are quite stable and limit the mobility of manganese as long as oxidation-reduction conditions remain oxidizing. Under reducing conditions, manganese reduces to the +2 valence state. This form of manganese can be soluble up to tens of mg/L. Despite the high solubility, manganese in the +2 state is subject to adsorption and ion exchange on mineral surfaces, and may also precipitate as $MnCO_3$ if carbonate is present and the pH is above neutral (Electric Power Research Institute, 1984). The release of organic contaminants can create local reducing conditions in the soil as oxygen is depleted by microbial degradation of the organic contaminants. The naturally occurring manganese oxides within the local reducing zone can be reduced and dissolve, thus potentially impacting underlying groundwater. These reactions are, however, fully reversible, so a return to an oxidizing condition will cause fairly rapid precipitation and immobilization of manganese.

### 6.1.2 VOCs

A total of 11 VOCs were identified as COCs at SWMU SS-111: 1,2,4-TMB, EDB, 1,2-dichloroethane, 1,3,5-trimethylbenzene, 2-hexanone, acetophenone, tetrachloroethene, and BTEX (benzene, ethylbenzene, toluene, and xylenes). BTEX compounds are grouped below due to their similar properties and signature for fuel-related contamination. The discussion below focuses on compounds with measurable plumes at SWMU SS-111.

- **BTEX—**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.

- **EDB—**EDB is a synthetic compound with the formula $C_2H_4Br_2$. It was added to aviation fuel as a lead scavenger. The fairly low molecular weight results in a high solubility of greater than 1,000 mg/L and a low $K_{oc}$ of 40 mL/g. The high solubility and low $K_{oc}$ indicate that the compound will be fairly mobile in most aquifer environments. The compound is known to slowly biodegrade under aerobic and anaerobic conditions, but biodegradation under anaerobic conditions is faster. EDB will also degrade abiotically under anaerobic conditions, catalyzed by the presence of iron sulfide (FeS).

The most rapid degradation of EDB was observed under strongly reducing conditions in the presence of sulfide and methane (EPA, 2006).

- **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-TMB volatilizes rapidly from surface waters as predicted by Henry's Law constant of 5.18 x $10^{-3}$ atm-cu m/mole and a vapor pressure of 2.1 mm mercury (EPA 1987). In addition, volatilization from moist and dry soil surfaces is expected to occur based on Henry's Law constant and the vapor pressure of this compound, respectively. Vapor-phase 1,2,4-TMB 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-TMB is not susceptible to direct photolysis by sunlight. If released to soil, a measured Koc value of 472 mL/g suggests that 1,2,4-TMB will have low mobility in soil. Non-volatilized 1,2,4-TMB may be subject to biodegradation under aerobic conditions. If released to water, 1,2,4-TMB is expected to adsorb to sediment or particulate matter based on its $K_{oc}$ value.

### 6.1.3 SVOCS

A total of four SVOCs was (2-methylnaphthalene, bis (2-ethylhexyl) phthalate, 1-methylnaphthalene, and naphthalene) identified as COCs at the SWMU SS-111, of which two were polynuclear aromatic hydrocarbons (PAHs) (1-methylnaphthalene and naphthalene). The PAH, naphthalene, is the only compound with a contoured plume in the groundwater at SWMU SS-111 and is the focus of this discussion. The fate and transport of PAHs, primarily naphthalene, are as follows:

- **PAHs—**PAHs were identified as COCs in the groundwater at the SWMU SS-111. PAHs are a group of more than 100 organic compounds consisting of two or more fused aromatic rings. As a general rule, when PAH compounds grow in molecular weight, their solubility in water decreases, solubility in fat tissues increases, their melting and boiling points increase, and their volatilities decrease. The vapor pressures and Henry's Law constants of the PAHs present indicate that these compounds do not readily volatilize into the atmosphere. The $K_{oc}$ values for the PAHs detected indicate these PAHs have high sorption potentials and will not tend to leach into water. This is further supported by the octanol/water partition coefficient ($K_{ow}$), which is an indication of whether a compound will dissolve in n-octanol and by analogy, in water. The PAHs detected are nonpolar and hydrophobic and, as mentioned above, will tend to sorb to surface soil rather than partition into the polar water phase (Environment Canada, 1998).

## 6.2 Degradation Analysis

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

Microorganisms + Electron donors + Electron acceptor + Nutrients →
Metabolic by products + Energy + Additional microorganisms

Degradation indicators can be analyzed to determine if biodegradation may be occurring (Table 6-2). Dot maps were prepared for selected degradation indicators: DO, ORP, alkalinity, iron, manganese, nitrogen, and sulfate. Only dissolved (filtered) iron data were available; however, as ferric iron is relatively insoluble in water, the majority of the dissolved iron is assumed to be ferrous iron. For this Groundwater Zone RFI Report, dot maps of ammonia and sulfide were not prepared because these two compounds were not detected in a sufficient number of wells to allow meaningful map analysis.

If microbial degradation is occurring, the following data trends should be observed in site-specific data:

- Decreased DO concentrations.
- Decreased ORP values.
- Lowering of pH as a result of increased alkalinity because of elevated $CO_2$ concentrations. Decreased pH will then result in an increased rate in mineral dissolution.
- Increased iron concentrations as mineral dissolution reactions occur.
- Increased manganese concentrations.
- Decreases in nitrate/nitrite concentrations.
- Decreased sulfate concentrations

### 6.2.1 ORP and Dissolved Oxygen

Concentrations of these degradation indicators for the three aquifer zones from Second Quarter CY 2013 are presented on Figures 6-1 through 6-6. Both ORP and DO have the same basic pattern with regard to anaerobic and aerobic areas in the aquifer.

- Outside of the NAPL area, both ORP and DO show that the aquifer is aerobic.
- In the Shallow Zone within the NAPL area and immediately downgradient from the NAPL, the groundwater is strongly anaerobic with 0 mg/L DO values and ORP values less than -100 millivolt (mV). As distance from the NAPL increases, the ORP and DO increase until at nominal distances of 200 feet laterally and 1,000 feet downgradient, the shallow system is aerobic with DO values in the 2- to 10-mg/L range, and ORP greater than 50 mV. It is noted that ORP is less than 0 mV in the EDB plume downgradient from the NAPL as far as Gibson Street (Figure 6-4).
- The Intermediate Zone is largely aerobic except in an area immediately downgradient from the BFF in the vicinity of wells KAFB-106065 and KAFB-106080 (north of Randolph Street). This is also the area where EDB is detectable in this zone downgradient from the NAPL.
- The Deep Zone is aerobic across the entire site with DO concentrations greater than 2 mg/L and ORP greater than 50 mV.

### 6.2.2 Alkalinity and Nitrogen

As presented in Section 3.0 of Appendix L, nitrate is a nutrient for bacteria, and alkalinity reflects the generation of carbon dioxide from microbial degradation of the fuel contaminants. The nitrate and alkalinity point-pattern results are presented on Figures 6-7 through 6-12.

- Nitrate is largely non-detect in the Shallow, Intermediate, and Deep Zones within the NAPL area and the downgradient EDB plume area. Several low concentration detections of nitrate were observed outside of the EDB plume in all three zones on the northwest side of the plume.
- Other remediation sites in areas of Kirtland AFB upgradient from the BFF have elevated nitrate concentrations (ST-105, for example); however, upgradient monitoring wells within the BFF plume are non-detect for nitrate. Background groundwater nitrate concentrations in the aquifer in the vicinity of the BFF have not been determined at this time.
- Within the NAPL plume area, the alkalinity is elevated in the Shallow and Intermediate Zones. As discussed in Section 3.0 of Appendix L, the increase in alkalinity in the NAPL area is attributed to microbial degradation of petroleum hydrocarbons in this area. This is consistent with the concentration-distance plots discussed in Section 5.2 of Appendix L. Downgradient from the NAPL area and in the Deep Zone, the alkalinity is less than 200 mg/L.

### 6.2.3 Dissolved Iron and Manganese

As shown on Figures 6-13 through 6-18, the highest dissolved iron and manganese concentrations are observed in the NAPL plume, but a manganese plume extends approximately 2,000 feet downgradient from the NAPL area.

- Outside of the EDB plume and NAPL area, both iron and manganese results are nondetect.
- Dissolved iron detections are largely located in the Shallow Zone in the NAPL area. Only three Intermediate Zone wells have detectable dissolved iron: KAFB-106065, KAFB-106080, and KAFB-106083. No dissolved iron is detected in the Deep Zone wells.
- In the Shallow and Intermediate Zones, manganese is detected across the majority of the EDB plume footprint with the manganese plume extending approximately 2,000 feet from the downgradient front of the NAPL plume

One Deep Zone well, KAFB-106066 north of Randolph Street, has low but detectable manganese concentrations.

The elevated manganese downgradient of the NAPL plume is attributed to the reduction of manganese (IV) to the more soluble Mn (II) form as a result of the microbial degradation of the NAPL constituents (TPH-DRO and TPH-GRO). This reaction occurs at a much higher ORP than denitrification or iron reduction (Section 3 of Appendix L).  EDB degradation may also be occurring in this area of the plume with EDB being the electron donor, and manganese being the electron acceptor. It is apparent in comparing Figures 6-1, 6-4, and 6-16 that manganese reduction is occurring, which indicates a depression in oxidation-reduction conditions.

### 6.2.4 Sulfate

Concentrations of this degradation indicator are presented on Figures 6-19 through 6-21.

Microbial degradation can use sulfate as an electron donor, leading to decreases in sulfate concentrations (Table 6-2). No obvious pattern is apparent in the Shallow, Intermediate, and Deep Zone sulfate results, and none has been observed since monitoring began in First Quarter CY 2011. No sulfate samples exceed the secondary MCL of 250 mg/L.

## 6.3 CSIA Degradation Analysis

Appendix L is the full, detailed report on the CSIA degradation analysis for the SWMU SS-111 site. The results of the analysis demonstrate that benzene is definitely degrading in the SWMU SS-111 site plume:

- The various degradation indicator parameters all lead to the same general conclusion that anaerobic degradation of organic compounds is occurring in the BFF groundwater plume.
  - The dissolved iron plume has approximately the same footprint as the benzene plume, alkalinity is increased in the NAPL area, and dissolved oxygen is depleted in the NAPL area.
  - ORP is low in the NAPL area and shows a gradual increase downgradient from the NAPL area, which is consistent with the dissolved manganese plume that extends beyond the NAPL area.
- The microbial data indicate the presence of the bssA and PHE genes, which are involved in the degradation of benzene and other monoaromatic hydrocarbon compounds.
- The CSIA data indicate benzene degradation with isotope ratios increasing from -34‰ in the NAPL area to -27‰ immediately downgradient from the NAPL area. This shift in ratios corresponds to a minimum degraded mass fraction of 20%. The actual mass fraction of benzene that has degraded is likely higher.
- Benzene, and by association the other petroleum hydrocarbons, is effectively degraded within the groundwater associated with the NAPL plume or a short distance downgradient from the NAPL area. Conditions within this area of the plume appear to be optimal for benzene degradation. It is unlikely that the petroleum hydrocarbon contamination, excluding EDB, will reach any existing receptor well.

The degradation of EDB is dependent on anaerobic versus aerobic conditions in the plume:

- The $\delta^{13}C$ ($^{13}C/^{12}C$ isotope ratio expressed in $\delta$ notation) results for EDB show an increase from -35‰ in the NAPL area to -27‰ at the downgradient edge of the NAPL plume, and have a statistically significant $\delta^{13}C$ versus distance regression result. This shift in ratios corresponds to a minimum degraded mass fraction of 23%. The actual mass fraction of EDB that has degraded is likely higher.
- The $\delta^{13}C$ versus distance trend shows that the majority of the isotope change occurs at the distal edge of the NAPL plume, and further increases in the EDB $\delta^{13}C$ isotope ratios downgradient are less apparent. These results to-date indicate that the majority of EDB degradation, like benzene, is occurring within or at the edge of the NAPL plume.
- There is an area of negative ORP measurements downgradient from the NAPL that is attributed to degradation of fuel contaminants. Detections of TPH (DRO and GRO) and elevated manganese concentrations indicate anaerobic conditions exist in this area, although the ORP values are somewhat higher than ORP measured in the NAPL area. Decreasing concentrations of EDB in this area suggest that degradation of EDB may continue downgradient of the NAPL, but additional monitoring is needed to confirm this trend.

## 6.4 Groundwater Fate and Transport Modeling

A contaminant fate and transport model, based on MODFLOW, MODPATH, and MT3DMS model codes, has been developed for the BFF at Kirtland AFB (Appendix M). The objective of this modeling is to develop a local groundwater flow and transport model for use in simulating current and future migration of the EDB and benzene plumes from the BFF, which are associated with the large, submerged area of NAPL. Below is a summary of the groundwater modeling fate and transport; details on the model can be found in Appendix M.

In order to meet the objective of the groundwater fate and transport modeling, the modeling effort was completed in three phases:

- **Phase 1**—The 2002 United States Geological Survey (USGS) Middle Rio Grande Basin groundwater flow model (USGS regional model) from 1900 to 2000 (McAda and Barroll, 2002; Figure 1-1) was imported into the Groundwater Modeling System (GMS) software (Aquaveo, LLC, 2013). This phase entailed using MODFLOW-2000 (McDonald and Harbaugh, 2003) to update, run, and check the calibration of the imported USGS regional model. Once the model files were imported into the GMS, the calibration was checked against the original model calibration and found to be an acceptable match.
- **Phase 2**—The USGS regional model was extended for the time period from 2000 to 2013 using the recent pumping data from the water supply wells across the model area. The remaining boundary conditions, including recharge due to precipitation, evapotranspiration, mountain front recharge, and canal recharge, were held constant to the year 2000-simulated wet/dry season values. This model was used to define the boundary-condition values for the local model used in transport simulations.
- **Phase 3—**Using the regional model results to define boundary conditions, a local groundwater flow and solute (contaminant) transport model was developed to simulate EDB and benzene migration from the BFF. This phase included refinement of the extended USGS regional model into a local model (Figure 6-22). The local model was defined by transient specified heads on each side of the local model extent. The flow fields were populated by transient head values interpolated from the USGS regional model. Pumping wells specific to the local model were next incorporated into MODFLOW-2000 using GMS.

### 6.4.1 USGS Regional Model

The Middle Rio Grande Basin model (McAda and Barroll, 2002) is represented by nine model layers extending from the water table to the pre-Santa Fe Group basement rocks, as deep as 9,000 feet bgs, within the Middle Rio Grande Basin. The horizontal grid contains 156 rows and 80 columns, each spaced 3,281 feet (1 kilometer) apart. The model simulates pre-development, steady-state conditions and historical transient conditions from 1900 to March 2000. The model simulates mountain-front, tributary, and subsurface recharge; canal, irrigation, and septic-field seepage; and groundwater withdrawal as specified flow boundaries. The model simulates the Rio Grande, riverside drains, Jemez River, Jemez Canyon Reservoir, Cochiti Lake, riparian evapotranspiration, and interior drains as head-dependent flow boundaries (McAda and Barroll, 2002).

Hydrologic properties representing the Santa Fe Group aquifer system in the regional model are horizontal hydraulic conductivity, vertical hydraulic conductivity, specific storage, and specific yield. Variable horizontal anisotropy is applied to the model so that hydraulic conductivity in the north-south direction is greater than hydraulic conductivity in the east-west direction over much of the model. This pattern of horizontal anisotropy was simulated to reflect the general north-south orientation of faulting. Horizontal hydraulic conductivities ranged from 0.05 to 60 feet per day. Vertical hydraulic conductivity is specified in the model as a horizontal-to-vertical anisotropy ratio (calculated to be 150:1 in the model) multiplied by the horizontal hydraulic conductivity along rows. Specific storage was estimated to be 0.000002 feet$^{-1}$. Specific yield was estimated to be 0.2 and is dimensionless (McAda and Barroll, 2002).

The nine model layers used to represent the Santa Fe Group aquifer system include layers of constant and variable thickness. The variable thickness layers were used to help model the interaction with the Rio Grande. In contrast, the constant thickness layers were used to simulate the deeper portions of the Santa Fe Group.

The top of layer 1 is defined as the water table from the steady-state simulated head. The bottom of layer 5 is 800 feet below the Rio Grande. Layers 1 through 5 vary in thickness, depending on the water table elevation relative to the bottom of layer 5. The thicknesses of layers 1, 2, 3, 4, and 5 are 5 feet, 30 feet, 50 feet, 100 feet, 220 feet, and 400 feet, respectively, below the Rio Grande. Layer 1 is relatively thin to simulate the groundwater-to-surface water interaction. Layers 6 and 7 are a constant 600 feet and 1,000 feet thick, respectively. The thicknesses of layers 8 and 9 are one-third and two-thirds, respectively, of the Santa Fe Group thickness below layer 7. Cells in model layers 8 and 9 are active only where their combined thickness is at least 1,200 feet (McAda and Barroll, 2002).

## 6.4.2 Kirtland AFB Local Model

Upon calibration check of the USGS regional model and extension of the model time period from 2000 to 2013 potentiometric heads, the local model was developed as summarized in Section 3.1. The local model represents a subset of the USGS regional model using the transient head boundaries for the north, west, south and east local model boundaries. The local model build and input parameters are included in Table 6-3.

### *6.4.2.1 Grid and Layer Designations*

The local model boundary is provided on Figure 6-23 and Figure 6-24. Grid dimensions are discussed in more detail in Section 3.1 of Appendix M. The local model is represented by 8 layers; see Section 3.3.1 of Appendix M for a description of each of the 8 layers.

## 6.4.3 Boundary Conditions

The local model boundary conditions are largely governed by the USGS regional model. This includes specified flow fields at the local model extents, production well pumping rates, and precipitation-based recharge. Transient heads were interpolated from the regional flow model to the north, west, south, and east of local model boundaries. Precipitation-based recharge used the values established in the updated USGS regional model. Details on how pumping rates were assigned can be found in Section 3.1 of Appendix M.

### 6.4.4 Parameter Values

Parameter values in the local model were initially held constant to those used in the regional model. However, during the local model calibration process, several key parameter values were revised to better align the simulated hydrogeologic flow and transport with observed conditions. The revised parameters included hydraulic conductivity and specific storage.

#### *6.4.4.1 Hydraulic Conductivity*

The horizontal hydraulic conductivity for local model layers 1 through 4 was revised from the regional model value of 15 feet per day (ft/d) to 60 ft/d. This change reflected slug test results from SWMU SS-111 monitoring wells (Table 5-9) and was necessary to calibrate flow velocities and EDB plume transport. A hydraulic conductivity of 60 ft/d was applied universally in the local model for layers 1 through 4 as there exists minimal data outside the BFF site to suggest differing hydrogeologic conditions. The existing regional model vertical hydraulic conductivity for model layers 1 through 4 was increased from 0.1 ft/d to 0.26 ft/d.

#### *6.4.4.2 Specific Storage*

The storage coefficient or storativity within the MODFLOW code is estimated through the use of the specific yield and specific storage parameters. In unconfined systems specific yield represent the storage coefficient within the aquifer. In confined systems, however, the storage coefficient represents the volume of water released from storage, per unit area of aquifer, per unit change in head (Dunne and Leopold, 1996). Similarly, for use with the flow modeling, specific storage is defined as the volume of water released by the aquifer, per volume of aquifer, per unit decline in head (Freeze and Cherry, 1979). Therefore the difference between the storage coefficient and specific storage is that specific storage is calculated on a volumetric basis and not a unit area basis.

Specific storage in the regional model is a constant 0.000002/foot for each of the model layers. This value was maintained initially within the local model. However, upon evaluation of local model hydrographs, it was apparent that the model-simulated aquifer was not responding quickly enough to boundary condition variations (i.e., changes in the well pumping rates and corresponding drawdown). Therefore, the specific storage was incrementally edited to determine a value that allowed the simulated aquifer to respond appropriately to boundary-condition changes. A final value of 0.0035/foot provided the best fit to the data .

The variation in specific storage between the regional and local model is attributable to differences in scale and level of calibration. On a regional scale a generalized specific storage value was appropriate, even though specific storage likely varies by location. For the local model, however, a refinement of the generalized specific storage value was necessary during model calibration.

Simulated and field observed heads in the USGS regional model were believed well matched if the differences (residuals) were less than 20 feet within the Albuquerque area (McAda and Barroll, 2002). At the local level, however, simulated heads were calibrated to a range of 0 to 5 feet of the observed heads. The refined calibration included significant drawdown and recovery associated with the Burton, Love, Charles and Ridgecrest well fields. To simulate the drawdown and recovery of the water table within the correct time period (observed local data from 2001 through 2013) the specific storage parameter was adjusted so that the drawdown data available for specific wells could be matched with the model. This adjustment during model calibration resulted in an increase in the specific storage value. The increased specific storage provided more water within the modeled aquifer for extraction by the pumping wells. In essence this increased water availability within the model reduced the over-stressing (drawdown) of the simulated aquifer due to pumping. The calibrated specific storage value of 0.0035/ft (or storativity of 0.35 divided by 100 ft of aquifer) is representative of a leaky confined aquifer. This value is also similar to storativity values reported for gravelly alluvium (0.05) and alluvial fan deposits (0.06) as reported by Dunne and Leopold (1996).

### 6.4.5 Model Calibration

Numerically simulated heads generated in the USGS regional models (through years 2000 and 2013) and the local model were evaluated against field-observed data. For the original USGS regional, model-simulated heads were compared to field observations from 1900 to 2000. The extended USGS regional model (through year 2013) incorporated head-observation data from the USGS Middle Rio Grande piezometers (http://nm.water.usgs.gov/projects/piezometers/piezometers.city.new/, 11/23/2013). The majority of the Middle Rio Grande piezometers used for model calibration are presented on Figure 6-25.

The local model used the array of Kirtland AFB monitoring wells to evaluate not only simulated versus observed heads in layers 1 and 3, but also calculated groundwater flow directions, gradients, and velocities. Transport calibrations for EDB and benzene compounds were also completed through a comparison to the Second Quarter CY 2013 groundwater sampling results.

Calibration statistics for each of the three models are included in Appendix M.

### 6.4.6 Transport Calibration

Transport calibration was conducted by comparing simulated EDB and benzene concentrations for model layers 1, 2, and 3 against actual EDB and benzene analytical results. Due to the model layer thicknesses, both EDB and benzene results were averaged over the Shallow and Intermediate Zones. Local model layer 1 extends to 4,800 feet amsl, which is below the screen interval for the Shallow and Intermediate Zone wells. Deep Zone EDB concentrations were compared to local model layer 3 simulations. To derive observed plume concentration maps that were consistent with the construction of the local model, the geometric mean Shallow and Intermediate Zone monitoring well concentration data were used to develop EDB and benzene concentration target plumes (Appendix M).

Overall, transport simulations for both EDB and benzene were able to reproduce the actual 2013 respective plume extents.

### 6.4.7 Particle-Tracking Analysis

MODPATH particle tracking was used within the local model to estimate the groundwater source term, release location, and release time. Due to the heterogeneous nature and varying depth of the vadose zone, the contaminant source term to groundwater could not be assumed to be directly beneath the surface release area. Additionally, the contaminant travel time through the vadose zone to groundwater was unknown. To better estimate the source term (source-term is defined as the NAPL soil/groundwater interface area) location and time period, iterative particle tracking runs were completed. Initial particle tracks were started in 1970 from the toe portion of the historic NAPL extent (as defined in 2009). Similar particle track runs were started in 1980, 1990, and 2000. Particle-tracking results are provided on Figure 6-26.

As presented on Figure 6-26, particles initiated in 1970 have a strong initial southwest flow component and then rotate counter-clockwise toward the north, then northeast. If contamination had been released to groundwater in 1970, one would expect to see a remnant plume southwest and west of the current plume extent. Particles released in 1980 and later, however, better match the known EDB plume boundary. Furthermore, it is interesting to see that the 1990 particle tracks did not move outside of the defined EDB plume. This indicates that ongoing releases from the source term were likely occurring and corresponds well to the site conceptual model.

### 6.4.8 Transport-Model Evaluation

Simulated transport evaluations were completed for both EDB and benzene. Each of the modeled simulations assessed groundwater plume migration from plume inception to present day. In both cases, contaminant concentrations were held constant at each of the respective source term locations. This approach was taken because it best represented contaminant dissolution from the existing subsurface NAPL. Transport parameter values used for EDB and benzene are provided in Table 6-4 and a detailed discussion of transport model evaluation is in Section 6 of Appendix M.

### 6.4.9 Model Uncertainty

A thorough discussion of model uncertainties is in Section 7 of Appendix M. The following text provides a summary of the model uncertainties.

A number of uncertainties in the flow and transport model will be addressed when the model is updated with additional benzene and EDB degradation data collected during future sampling rounds. The major uncertainties in the current local model are listed as follows:

- The steep gradients in the local model from 1990 through 2005, resulting from the regional flow fields, were used to define the northern and eastern boundaries of the local model. At present, it is uncertain if these steep gradients and associated water budgets are realistic, or an artifact of how the regional model simulated the aquifer northeast of the BFF.
- The value for specific storage in the local model is high and needs to be evaluated further.
- There is uncertainty about the timing of the release of AvGas from the surface into the environment, and when it reached the water table. As shown by modeling, the most reasonable EDB plume calibration is based on an assumption that EDB reached the water table in 1980, and that NAPL functions as a constant source term through present day. There is anecdotal data indicating that Kirtland AFB stopped using AvGas, which contains EDB, as a lead scavenger in 1975.
- The largest uncertainty for use of the local model in future-scenario predictions is the assumed pumping rates for the municipal and local (KAFB, VA) water supply wells. As shown in the regional model results, pumping of the Ridgecrest, Lomas, and Love wells fields was sufficient to change the groundwater flow direction by 180 degrees from southwest to northeast, and the pumping of the Ridgecrest well field may have caused the gradient from 1990 to 2005 to be five times steeper than is presently observed.

## 6.5 Plume-Map Analysis

Figures 6-27 through 6-44 illustrate plume extent over time for TPH-GRO, TPH-DRO, EDB, benzene, toluene, and xylenes. A complete plume stability analysis requires larger datasets that allow for statistical and qualitative evaluation of COC concentrations over time in order to make a determination of whether or not COC plumes are stable. The plume extents were defined through the installation of additional GWM wells between December 2010 and October 2012. While the plume extents are currently defined for the COCs at SWMU SS-111, the limited time span of data collection (eight quarterly sampling events) allows only the following general observations to be made from Figures 6-27 through 6-44:

### 6.5.1 TPH-GRO and TPH-DRO

- The extent of TPH-GRO detected in the Shallow Zone GWM wells has not changed between Second Quarter CY 2012 and Second Quarter CY 2013 (Figure 6-27). The shallow TPH-GRO plume is approximately 4,900 feet in length and 1,350 feet wide. The zone of highest concentration is within the historic NAPL footprint.

- The number of wells with detections of TPH-GRO in the Intermediate Zone (Figure 6-28) has varied between Second Quarter CY 2012 and Second Quarter CY 2013. The northern extent of the plume has not moved, with the northernmost detection just north of Gibson Street.

- Detections of TPH-GRO have been sporadic in the Deep Zone (Figure 6-29).

### 6.5.2 EDB

- The full plume extent for EDB was not defined until Fourth Quarter CY 2012; therefore, the apparent variability in the plume extents on Figures 6-33 through 6-35 is the result of installation and sampling of additional GWM wells, and not movement of the EDB plume. Between Fourth Quarter CY 2012 and Second Quarter CY 2013 (Figure 5-21), there has been no apparent change in the EDB plume extent in the Shallow Zone.

- In the Intermediate Zone, the EDB plume length ranges from 5,400 feet in Fourth Quarter CY 2012 to 4,500 feet in Second Quarter CY 2013 (Figure 5-22).

- EDB has been consistently detected in two deep wells over the past three consecutive quarters, as shown on Figure 5-23.

### 6.5.3 Benzene

- There is a slight change in plume extent for benzene in the Shallow Zone between the three quarters shown on Figure 6-36. The total length of the benzene plume ranges from 2,700 feet in Second Quarter CY 2011 to 2,900 feet in Second Quarter CY 2013; the difference in plume length is most likely the result of slightly different contouring of quarterly monitoring data and not an actual change in the physical plume extent. Likewise, the width of the plume ranges from 1,100 feet in Second Quarter CY 2011 to 1,600 feet in Second Quarter CY 2013.

- Benzene has been detected in three to four wells in the Intermediate Zone (Figure 6-37). Two wells had detections in Second Quarter CY 2011 in the Deep Zone but no deep well detections in Second Quarter CY 2012 or Second Quarter CY 2013.

### 6.5.4 Toluene

- A change in plume footprint in the Shallow Zone is observed between Second Quarter CY 2011 and Second Quarter CY 2013 (Figure 6-39). The total plume length has not changed from approximately 2,250 feet. The width of the plume is approximately 900 feet in the three quarters shown on Figure 6-39.

- Detections of toluene in the Intermediate and Deep Zones have been sporadic between Second Quarter CY 2011 and Second Quarter 2013 (Figures 6-40 and 6-41).

### 6.5.5 Xylenes

- Dot maps for xylenes in the Shallow Zone are shown on Figure 6-42. In general, well detections have been limited to the historic NAPL area, with two to three detections in wells immediately adjacent to the historic NAPL area. Second Quarter CY 2012 has the northernmost detection, just north of Gibson Street.

- Detections of xylenes in the Intermediate and Deep Zones have been sporadic between Second Quarter CY 2011 and Second Quarter 2013 (Figures 6-43 and 6-44).

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# 7. CONCLUSIONS AND RECOMMENDATIONS

The information and results collected for the groundwater investigation are used to develop a comprehensive overview of the geology, hydrology, and contamination at SWMU SS-111. The following conclusions are based on the results of the RFI performed at SWMU SS-111:

- The results of up to eight quarterly rounds of groundwater monitoring samples collected from the 115 groundwater monitoring wells define the nature and extent of contamination at SWMU SS-111. Additionally, the results of quarterly water level measurements, bucket samples, continuous core samples, and slug testing have adequately defined aquifer characteristics to inform decisions for SS-111.
- A comprehensive screening analysis was performed on the groundwater data and used sample number, frequency of detection, screening levels to identify COCs at SWMU SS-111. The primary COCs at SWMU SS-111 are benzene, EDB, toluene, xylenes, 1,2,4-TMB, and naphthalene.
- Degradation of benzene and EDB is occurring in the anaerobic NAPL area. CSIA data indicate the degradation of EDB in the groundwater is occurring under anaerobic conditions. The CSIA data suggest that some degradation of EDB continues in the aerobic portion of the plume but it is not quantifiable.
- Based on groundwater fate and transport modeling, the fuel source reached the groundwater around 1980. The NAPL initially floated on the groundwater table before becoming submerged as a result of the rising water table. The source of dissolved contaminants is a submerged volume of NAPL.
- The RFI data collected meets the quality requirements set forth in the QAPjP (USACE, 2011c) as well as the applicable work plans and letters listed in Section 1 and is sufficient for informing future actions at SWMU SS-111. Analytical sampling, soil boring logs, CSIA and microbe analysis, slug testing, and groundwater modeling were the primary data sources for completing the RFI.
- Figure 7-1 details the conceptual site model for SS-111 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 groundwater zone contamination.
- There are no remaining data gaps for SWMU SS-111, based on the results of the RFI.

Recommendations for SWMU SS-111 include:

- Completion of a Risk Assessment (to be submitted under separate cover);
- Continued quarterly monitoring of GWM wells for groundwater level measurements, NAPL thickness measurements, selected COC analyses, and continued monthly monitoring of nearby water

supply wells. Review and revise frequency and scope of monitoring to support development of a Corrective Measures Evaluation;

- Complete a plume stability analysis; and
- Complete a Corrective Measures Evaluation for SWMU SS-111 to define cleanup criteria, determine remedy evaluation criteria, and propose a selected remedy to address contamination that pose a risk to human health and the environment.

A Risk Assessment Report will be submitted under separate cover, which 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.

This 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 outstanding data gaps. Together with the risk assessment, submitted under separate cover, this groundwater investigation provides robust and sufficient data to fully characterize the nature and extent of groundwater contamination at SWMU SS-111. The findings of this investigation will be used to inform the CME for the Kirtland AFB BFF Spill SWMUs ST-106 and SS-111.

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# APPENDIX A

## Correspondence

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# APPENDIX B

## Well Installation Forms

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## NAPL and Soil Hydraulic Property Laboratory Results

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# APPENDIX D

## Field Sampling Data and Records

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# APPENDIX E

## Geophysical Records

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# APPENDIX F

## Historical Data Summaries

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## Time-Series Plots

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# APPENDIX H

## Slug Test Results

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# APPENDIX I

## NAPL Calculations

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# APPENDIX J

## Waste Disposal Documentation

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# APPENDIX K

## Bubble Sampling Results

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# APPENDIX L

## Degradation Analysis

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# APPENDIX M

## Groundwater Model Report and Data

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# APPENDIX N

## Data Quality Evaluation Reports

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# APPENDIX O

## Additional Cross Sections

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