Colonel Eric H. Froehlich  
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2000 Wyoming Blvd SE  
Kirtland AFB NM 87117-5000

Mr. John Kieling, Bureau Chief  
Hazardous Waste Bureau (HWB)  
New Mexico Environment Department (NMED)  
2905 Rodeo Park Drive East, Building 1  
Santa Fe NM 87505-6303

Dear Mr. Kieling

Attached please find the Final WP-026, Base Sewage Lagoons and Golf Course Pond (SWMU WP-026) Interim Measures Work Plan, Kirtland Air Force Base, New Mexico, Revision 1, dated December 2016. The document was revised in response to the Notice of Disapproval (NMED, 18 April 2016, HWB-KAFB-15-002).

The attached work plan incorporates a remediation approach to address the proposed corrective actions regarding remediation design, aquifer properties and procedures for implementation, Section 4.

If you have any questions or concerns, please contact Mr. Scott Clark at (505) 846-9017 or at scott.clark@us.af.mil or Ms. Suzanne Devergie at (505) 853-7213 or at suzanne.devergie@us.af.mil.

Sincerely

ERIC H. FROEHLICH, Colonel, USAF  
Commander

Attachment:  
Final WP-026, Base Sewage Lagoons and Golf Course Pond (SWMU WP-026) Interim Measures Work Plan, Kirtland Air Force Base, New Mexico, Revision 1, dated December 2016; 1 Hard Copy/1 CD

cc:  
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KIRTLAND AIR FORCE BASE
ALBUQUERQUE, NEW MEXICO

FINAL WP-026 – BASE SEWAGE LAGOONS AND GOLF COURSE POND (SWMU WP-26) INTERIM MEASURES WORK PLAN, Rev. 1

December 2016

377 MSG/CEI
2050 Wyoming Blvd SE
Kirtland AFB, New Mexico 87117-5270
NOTICE

This Interim Measures Work Plan was prepared for the Air Force Civil Engineer Center by URS Group, Inc. in association with FPM Remediations, Inc. to aid in the implementation of a final remedial action plan under the Environmental Restoration Program. As the report relates to actual or possible releases of potentially hazardous substances, its release prior to an Air Force final decision on remedial action may be in the public’s interest. The limited objectives of this report and the ongoing nature of the Environmental Restoration Program, along with the evolving knowledge of site conditions and chemical effects on the environment and health, must be considered when evaluating this report, since subsequent facts may become known which may make this report premature or inaccurate.

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| 13. SUPPLEMENTARY NOTES                                | |

| 14. ABSTRACT                                           | This Interim Measures Work Plan specifies the activities that will be performed in support of the remediation of perched groundwater underlying the Base Sewage Lagoons at Kirkland Air Force Base located in Albuquerque, New Mexico. Sampling of soils and groundwater at the site has occurred over the years to identify the source of contamination. Trichloroethene impacted perched groundwater located beneath the former sewage lagoons. The purpose of this plan is to describe the interim measures that will be taken to address the contamination. Groundwater monitoring will be addressed in a separate long-term monitoring plan to support site closeout. To note, although the Golf Course Pond is associated with Site WP-026, the vadose zone underlying the pond is not negatively impacted; therefore, this plan addresses only the contamination associated with the vadose zone soils associated with the lagoons. |

| 15. SUBJECT TERMS                                      | Site WP-026, groundwater monitoring, trichloroethene, reductive dechlorination |

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<tr>
<td>19b. TELEPHONE NUMBER (Include area code)</td>
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ERIC H. FROEHlich, Colonel, USAF
Commander, 377th Air Base Wing

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KIRTLAND AIR FORCE BASE
377th Air Base Wing Public Affairs
This Interim Measures Work Plan addresses the activities that will be performed in support of remediation of trichloroethene impacted perched groundwater underlying the WP-026, Base Sewage Lagoons and Golf Course Pond, site at Kirtland Air Force Base, New Mexico. The primary activities that will be performed include injection of a nutrient-amended substrate solution with a microbial bioaugmentation culture into the perched groundwater to induce reductive dechlorination of trichloroethene dissolved in groundwater and sorbed to solids in the perched aquifer. A substrate solution consisting of potable water mixed with ethyl lactate amended with nutrients and pH buffer will be injected into up to three injection wells along with a dechlorinating microbial culture including *Dehalococcoides*. In situ bioremediation performance will be monitored at the injection wells and at nearby groundwater monitoring wells. An inert tracer will be included with the injection stream to help evaluate delivery and the effect of dilution from the injected potable water.

Because contaminant concentrations are initially very low (the maximum trichloroethene concentration is 15 µg/L found in well KAFB-2622 as of July 25, 2016), several lines of evidence will be evaluated to assess the effectiveness of in situ bioremediation including injection rate and volume, changes in dissolved oxygen and redox potential, establishment of a dechlorinating microbial population, contaminant and tracer concentrations, and production of degradation daughter products.

This work will be performed under the authority of the requirements of the Air Force Civil Engineer Center Contract No. FA8903-13-C-0008. This program is conducted under the Kirtland Air Force Base Environmental Restoration Section Chief, Mr. Ludie Bitner, and the Kirtland AFB Project Manager, Mr. Scott Clark. URS Group, Inc., as a subcontractor to FPM Remediations, Inc., has prepared this interim measures work plan as defined in the Performance-Based Remediation Contract for Cannon, Holloman, and Kirtland Air Force Bases located in New Mexico, and Luke Air Force Base located in Arizona. Mr. Richard Wells is the URS Group, Inc. Installation Manager for Environmental Restoration Project Sites at Kirtland Air Force Base.
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<td>µg/L</td>
<td>microgram per liter</td>
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<tr>
<td>AFB</td>
<td>Air Force Base</td>
</tr>
<tr>
<td>AFCEC</td>
<td>Air Force Civil Engineer Center</td>
</tr>
<tr>
<td>amsl</td>
<td>above mean sea level</td>
</tr>
<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
</tr>
<tr>
<td>bgs</td>
<td>below ground surface</td>
</tr>
<tr>
<td>CFR</td>
<td>Code of Federal Regulations</td>
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<tr>
<td>COPC</td>
<td>contaminant of potential concern</td>
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<td>Defense Technical Information Center</td>
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<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
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<tr>
<td>ft</td>
<td>feet</td>
</tr>
<tr>
<td>ft/day</td>
<td>feet per day</td>
</tr>
<tr>
<td>GAC</td>
<td>granular activated carbon</td>
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<tr>
<td>HASL</td>
<td>Health and Safety Laboratory</td>
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<td>HASP</td>
<td>Health and Safety Plan</td>
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<td>HHRA</td>
<td>Human Health Risk Assessment</td>
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<td>IDW</td>
<td>investigation-derived waste</td>
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<td>LTM</td>
<td>long-term monitoring</td>
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<tr>
<td>MCL</td>
<td>maximum contaminant level</td>
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<tr>
<td>NFA</td>
<td>no further action</td>
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<tr>
<td>PID</td>
<td>Photoionization Detector</td>
</tr>
<tr>
<td>ppbv</td>
<td>parts per billion by volume</td>
</tr>
<tr>
<td>PVC</td>
<td>polyvinyl chloride</td>
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<tr>
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<td>Quality Assurance Project Plan</td>
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<td>RCRA</td>
<td>Resource Conservation and Recovery Act</td>
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<tr>
<td>SLERA</td>
<td>Screening-Level Ecological Risk Assessment</td>
</tr>
<tr>
<td>SM</td>
<td>standard method</td>
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<tr>
<td>SNL</td>
<td>Sandia National Laboratories</td>
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<tr>
<td>SOP</td>
<td>standard operating procedure</td>
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<td>SVE</td>
<td>soil vapor extraction</td>
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<td>SWMU</td>
<td>solid waste management unit</td>
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<td>TCE</td>
<td>trichloroethene</td>
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<tr>
<td>URS</td>
<td>URS Group, Inc.</td>
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<td>USAF</td>
<td>U.S. Air Force</td>
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<td>USF</td>
<td>Santa Fe Group</td>
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<td>VOC</td>
<td>volatile organic compounds</td>
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1.0 INTRODUCTION

This Interim Measures Work Plan addresses the activities that will be performed for the WP-026 Base Sewage Lagoons and Golf Course Main Pond site at Kirtland Air Force Base (AFB), New Mexico, hereinafter referred to as the Site. The Site location is shown in Figure 1-1. This plan was prepared in accordance with the requirements of the Air Force Civil Engineering Center (AFCEC) Contract No. FA8903-13-C-0008. URS Group Inc. (URS), as a subcontractor to FPM Remediations, Inc. (FPM), has prepared this work plan in accordance with the Performance-Based Remediation Contract for Cannon, Holloman, and Kirtland AFBs located in New Mexico, and Luke AFB located in Arizona. Monitoring requirements are further delineated in the Final Long-Term Monitoring Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) (URS, 2016), which serves as a companion document to this Work Plan.

1.1 Purpose and Scope

The purpose of these interim measures is to facilitate a timely action that will mitigate the further migration of contaminants, as well as the actual or potential human and environmental exposure to contaminants. The purpose of this work plan is to outline the activities necessary to address volatile organic compound (VOC) impacts on the perched groundwater underlying the former sewage lagoons, most notably trichloroethene. The ultimate goal of this project is to bring the Site to corrective action complete status without controls.

1.2 Interim Measures Objectives

The primary objectives of the interim measures are to reduce trichloroethene (TCE) concentrations in perched groundwater near the former sewage lagoons to below maximum contaminant levels (MCLs). This objective will be achieved in part through the following field activities, which are described herein:

- Implement in situ bioremediation to address TCE-impacted perched groundwater.
  - Injection well installation and sample collection while drilling to provide additional vadose zone characterization.
  - Monitoring well installation to provide additional coverage of the perched groundwater zone. Soil samples will be collected while drilling to augment the data collected during the injection well installation.
  - Routine operation and maintenance to verify system performance
- Implement long-term monitoring (LTM) to evaluate the efficacy of measures taken to actively address site contamination, including monitoring groundwater data trends to ensure that the measures are reducing impacts on the groundwater to acceptable levels.
- Provide the necessary data to support a corrective action complete proposal to the New Mexico Environment Department (NMED) to delist the site from the Resource Conservation and Recovery Act (RCRA) Permit
- Site surveying.
- Site restoration following site closure.
1.3 Regulatory Setting

The interim measures described herein will be performed pursuant to the NMED Hazardous Waste Bureau regulations. The Site consists of two geographically distinct locations, the former sewage lagoons and the Golf Course Main Pond. As described in the Corrective Measures Study Report for Solid Waste Management Unit WP-26, Sewage Lagoons and Golf Course Main Pond (USAF, 2010), several investigations have been performed at both locations to define the nature and extent of contamination. Active remediation of the contaminated soils associated with the sewage lagoons was performed in January and February 2010. The primary media of concern for the Site is TCE-impacted perched groundwater underlying the former sewage lagoons.

The groundwater cleanup levels will be defined as the more conservative of those specified in either the New Mexico Water Quality Control Commission as protective of human health (New Mexico Annotated Code [NMAC], 20.6.2) or by the current U.S. Environmental Protection Agency’s (EPA’s) MCLs as found in 40 Code of Federal Regulations (CFR) 141 and 40 CFR 142. Soil cleanup levels will be based on NMED soil screening levels for residential soil (NMED, 2012).

1.4 Work Plan Organization

This work plan is divided into six sections including:

- Section 1.0 – Introduction, purpose, objectives, and regulatory setting
- Section 2.0 – Background and History
- Section 3.0 – Previous Investigations
- Section 4.0 – Procedures for Implementation
- Section 5.0 – Reporting
- Section 6.0 – Project Schedule
- Section 7.0 – References
Figure 1-1. WP-026 Site Location
2.0 BACKGROUND AND HISTORY

2.1 Installation Description

Kirtland AFB occupies approximately 51,558 acres in southeastern Albuquerque, New Mexico, nestled between the Sandia and Manzano mountain ranges. The base is located in Bernalillo County, in central New Mexico, southeast of and adjacent to the Albuquerque International Sunport (Figure 1-1). Kirtland AFB employs more than 23,000 people, including more than 4,200 active duty, 1,000 National Guard, and 3,200 part-time reservists. Kirtland AFB is home to the Air Force Nuclear Weapons Center and its subordinate wings, the 498th Armament Systems Wing and the 377th Air Base Wing. It is also home to the Defense Threat Reduction Agency Albuquerque office, Air Force Safety Center, the Air Force Inspection Agency, the Air Force Operational Test and Evaluation Center, the 58th Special Operations Wing, Space Development and Test Wing, the New Mexico Air National Guard 150th Fighter Wing, the Directed Energy and Space Vehicle Directorates of the Air Force Research Laboratory, the Department of Energy Albuquerque Office, the National Nuclear Security Administration, and Sandia National Laboratories (SNL) – New Mexico.

2.1.1 Regional Geology

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

In general, the near surface geology is characterized by recent deposits (i.e., mixtures of sandy silt and silty sand with minor amounts of clay and gravel); Ortiz gravel (i.e., alluvial piedmont sand and gravel deposits); and the Santa Fe Group (USF) (i.e., a mixture of sand, silt, clay, gravel, cobbles, and boulders). Generally, the northern and western portions of Kirtland AFB are dominated by unconsolidated geologic units; consolidated units predominate in the eastern half of the base.

Kirtland AFB lies within the eastern portion of the Albuquerque structural basin that 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 within most of the basin exceeds 3,000 ft, though the thickness varies considerably because of the significant amount of faulting in the basin.

Geologic materials of primary importance within the basin are the USF and piedmont slope deposits. The USF 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 deposited unconformably over the USF, 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 ft and thicken toward the mountains. The USF is further broken down into two depositional facies called the USF-1 and USF-2 (Hawley et al., 1995). USF-1 is present from ground surface to approximately 86 ft below ground surface (bgs), and then a transition occurs where USF-1 and USF-2 are interfingered to a depth of 144 ft bgs, underneath which USF-2 is present to a depth of greater than 500 ft bgs (CH2M Hill, 2008).
2.1.2 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 in thickness, most of which are referred to as the USF. The unit consists of unconsolidated sediments that thin toward the basin boundary. Edges of the basin are marked by normal faults. Overlying the USF are the Pliocene Ortiz gravel and Rio Grande fluvial deposits.

Generally, USF-2 contains the most productive portion of the regional aquifer that supplies groundwater to the City of Albuquerque 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 sand, silt, and clay with variable bed thickness.

Basin-fill deposits make up the aquifer in the Albuquerque Basin. Hydraulic conductivity values range from 0.25 to 130 feet per day (ft/day) due to large variations in the lithology of the basin-fill deposits. The average hydraulic conductivity is 70 ft/day with flow to the northeast. Clay layers have relatively low hydraulic conductivity, whereas gravel and cobble deposits exhibit relatively high hydraulic conductivity. Deposits of interbedded gravel, sand, silt, and clay have intermediate hydraulic conductivity.

This principal aquifer underlies Kirtland AFB, with the basin fill in this area consisting of unconsolidated and semi-consolidated sand, gravel, silt, and clay of the USF; 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 ft bgs at a location 5 miles southwest of the airfield (USAF, 2004). Depth to the regional aquifer in the vicinity of the former sewage lagoons ranged from 501.99 ft below the measuring point to 510.25 feet as measured in wells KAFB-0505, KAFB-2628, and KAFB-2629 in June 2012 (USAF, 2012).

Soil at Kirtland AFB ranges from wet to dry. The finer-grained upper soil is generally moist while the coarser-grained deeper soil could be moist or dry. Several minor perched water-bearing zones are present in the vadose zone above the regional water table. Some of these water-bearing zones below 400 ft bgs are likely remnants of the regional aquifer left behind as the water table has dropped.

2.1.3 Perched Aquifer Hydrogeology

Perched groundwater zones are also present at Kirtland AFB. The shallow groundwater system is defined as a zone of saturation above the regional aquifer and separated from the regional aquifer by an unsaturated interval. Correlation of lithologic information obtained from boreholes drilled during monitoring well installation at SNL and Kirtland AFB and water chemistry data indicate that the shallow system consists of multiple zones of discontinuous saturation up to 125 foot thick that dip to the southeast. The depth to perched groundwater ranges from 200 to 415 ft bgs. The direction of groundwater flow in the main perched zone appears to be to the east-southeast with a hydraulic gradient of between 0.01 and 0.02 foot per foot.

A thin and isolated groundwater unit referred to as the perched zone groundwater is present beneath the Solid Waste Management (SWMU) WP-26 sewage lagoons. This water-bearing unit is not suitable as a source of drinking water due to the lack of available water for pumping and the elevated salinity, as measured by total dissolved solids. This perched groundwater unit is distinct from the regional aquifer groundwater below and from other perched groundwater units located to the east of the site. The most likely source of this perched zone groundwater is infiltration of the former sewage lagoons effluent and accumulation above the silts and clays that form the perching layer. Since this supply of water has been
discontinued for more than 20 years, perched zone groundwater in the vicinity of the former sewage lagoons has begun to desiccate. This conclusion is supported by water quality data, lithologic information, and well gauging data. The sewage lagoons are now dry, and there is evidence, including results of perched-zone saturation modeling (SNL, 2002), that the volume of perched groundwater is currently shrinking beneath the former sewage lagoons. Depth to perched water underlying the former sewage lagoons as measured in June 2012 ranged from 167.74 feet below measuring point to 212.06 feet (USAF, 2012).

### 2.2 Site Characterization and Setting

The WP-026 Site consists of two geographically distinct locations, the former base sewage lagoons and the Golf Course Main Pond.

#### 2.2.1 Base Sewage Lagoons

As discussed in the Long-Term Groundwater Monitoring Summary Report, Fiscal Year 2011 (USAF, 2012), the former sewage lagoons are part of SWMU WP-26, which also includes the golf course main pond. The sewage lagoons site is located in the northwestern region of the Kirtland AFB, north of the Tijera Arroyo and 0.5 miles southeast of the main runway at the Albuquerque International Sunport (Figure 1-1). A detailed summary of the site’s background and history, results of previous investigation and corrective measures, is provided in the 2006 Resource Conservation and Recovery Act Facility Investigation Comprehensive Report for Solid Waste Management Unit WP-26, Sewage Lagoons and Golf Course Main Pond (USAF, 2007).

The sewage lagoons were constructed in 1962 of native soil and local fill and consisted of unlined north and south square cells separated by an earthen wall. Modifications to the lagoons occurred in 1970 and 1975, when the sides and slopes were reinforced with soil cement and capped with concrete to minimize erosion as described in the RCRA Facility Investigation (RFI), Stage 2A, Volume 1, Technical Report (USAF, 1993). Two pipes discharged raw sewage into the center of each lagoon from a splitter box located between and on the eastern boundary of the lagoons. Liquid levels in each lagoon were contained by an elevated soil berm surrounding the perimeter. The lagoons shared a common berm containing a pipe connecting the lagoons, which allowed liquids to pass freely between the north and south cells. Wastewater was transferred from the lagoons to the golf course main pond by way of a gravity-fed 15-inch sewage effluent line (SWMU ST-051).

The combined north and south lagoons covered an area of 14 acres and were generally filled to a depth of 6 ft during use, resulting in a storage capacity of approximately 84 acre-feet (27.4 million gallons). The sewage lagoons operated with a turnover rate of approximately 2 weeks, allowing approximately 330 million gallons of raw sewage to be handled from April through October each year. From November to March, base sewage was routed to the City of Albuquerque sanitary sewer system. Operations at the sewage lagoons ceased in October 1987. A locked, fenced enclosure limits access to the former lagoons area.

The waste stream discharged to the lagoons was comprised of municipal wastewater with commercial and light industrial components that received some pretreatment through sumps, catch basins, and oil-water separators. Residence time in the lagoons allowed for settling, oxidation, and digestion by facultative bacteria of the raw sewage. Because the lagoons were not lined, sewage effluent infiltrated into the subsurface beneath the lagoons. A perched groundwater mound developed during sewage lagoon operations. Based on the components of the waste stream, the contaminants of concern identified at the site consist of VOCs, principally TCE.
Groundwater underlying the former sewage lagoons site is present in a perched zone and in the regional aquifer. The regional aquifer is a source of drinking water for Kirtland AFB and the City of Albuquerque in areas downgradient of the former lagoons. The perched groundwater zone beneath the site is isolated and does not produce water of sufficient quality or quantity to supply municipal, industrial, or residential demands.

### 2.2.2 Golf Course Main Pond

As provided in the *RCRA Facility Investigation (RFI), Stage 2A, Volume 1, Technical Report* (USAF, 1993), the original Golf Course Main Pond was constructed by the USAF in 1962. The pond was constructed by excavating below the surrounding grade in a preexisting drainage, building an earthen dam on the west end of the excavated area, and lining the base of the pond with plastic, making the pond a surface-water catchment. The pond was originally used for storage of wastewater delivered via a pipeline from the sewage lagoons. As part of a water conservation program, the wastewater in the pond was mixed with surface water runoff and well water, and was pumped through a sprinkler system to irrigate the golf course. Depending upon irrigation needs, 40 to 100 percent of the untreated base sewage was routed through the sewage lagoons to the pond from 1962 through 1987, with the pond receiving water during April through October during those years. The pond last received effluent from the sewage lagoons in 1987 and reportedly evaporated to dryness in January 1989. The pond was left dry from 1989 to 1998.

By 1998, the pond liner material has weathered and disintegrated in most places and the pond bottom was revegetated with a number of native plants. As documented in the *Interim Corrective Measures Report for Site WP-26, Golf Course Main Pond (WP-26) and Areas of Concern SS-79, Building 381 Spill Site (SS-79), and WP-87, GRABS Site Waste Pile (WP-87), Kirtland Air Force Base, Albuquerque, New Mexico* (USAF, 1999), as part of the interim corrective measures, the pond was reconstructed in 1998 and 1999. Reconstruction activities included regrading and shaping the pond, and lining the pond with a 40-mil, high-density polyethylene liner. In 2006, repairs to the pond liner were made. These repairs included removing the vegetation growing on and through the upper portion of the existing liner, applying patches over the tears and holes exposed in the liner, and replacing the riprap over the repaired areas.

The Golf Course Main Pond remains an integral part of the Tijeras Arroyo Golf Course on Kirtland AFB. The pond receives water from recovery wells located near the pond as part of the interim corrective measure implemented in 1999 and from production well KAFB-7 located northwest of the former sewage lagoons. Water stored in the pond is used to irrigate the golf course with a pump house located at the pond serving as the control center for the automated golf course irrigation system.
3.0 PREVIOUS INVESTIGATIONS

Numerous investigations have been conducted for both the base sewage lagoons and the Golf Course Main Pond as discussed below. In addition, extensive groundwater monitoring has been conducted at the wells associated with both the lagoons and the pond of both the perched aquifer underlying the lagoons and the pond and the regional aquifer underlying the lagoons.

3.1 Base Sewage Lagoons

As documented in the Corrective Measures Study Report for Solid Waste Management Unit WP-26, Sewage Lagoons and Golf Course Main Pond (USAF, 2010), accelerated corrective measures were implemented at the sewage lagoons in January and February 2010 including waste characterization sampling, excavation of 1,946 cubic yards of dry sludge, transportation of the dry sludge to an off-site disposal facility for disposal, and collection of confirmation soil samples. Confirmation samples underwent analysis for the eight RCRA metals and hexavalent chromium. Although six metals (barium, cadmium, chromium, lead, mercury, and silver) were detected at concentrations that exceeded background concentrations, none exceeded NMED residential soil screening levels.

The Corrective Measures Study Report for Solid Waste Management Unit WP-26, Sewage Lagoons and Golf Course Main Pond (USAF, 2010b) discusses the numerous investigations that have occurred at the site since 1987. Constituents investigated at the former sewage lagoons have included metals, VOCs, semi-volatile organic compounds, pesticides, herbicides, petroleum hydrocarbons, dioxins, furans, polychlorinated biphenyls, cyanide, anions, gross alpha/beta radioactivity, radium-226 and radium-228. The site data indicate that the soil vapor in the vadose zone between the ground surface and the perched groundwater zone is contaminated with VOCs. Soil vapor concentrations tend to be highest on the west and northeast side of the former sewage lagoons and increase with depth towards the perched groundwater at 200 ft bgs. Contaminated soil vapor is not present in the vadose zone between the perched groundwater zone and the regional aquifer located approximately 500 ft bgs.

The VOCs detected in the vadose zone with elevated concentrations have included TCE (non-detect to 110 parts per billion volume [ppbv]), 1,1-dichloroethane (non-detect to 580 ppbv), and acetone (non-detect to 470 ppbv). Detected VOCs have included:

- Petroleum-related compounds: benzene, ethylbenzene, toluene, xylene, 1,2,4-trimethylbenzene, 2-hexanone, methyl tert-butyl ether
- Biodegradation products of petroleum hydrocarbons: acetone, 2-butanone, methyl ethyl ketone, and carbon disulfide
- Chlorinated VOCs: tetrachloroethene, 1,1-dichloroethene, cis-1,2-dichloroethene, chloroform, and methane chloride
- Chlorofluorocarbons: trichlorofluoromethane and Freon-12.

Groundwater in the perched zone is currently contaminated by VOCs with TCE concentrations exceeding the EPA MCL for drinking water of 5 micrograms per liter (µg/L) but below the New Mexico Water Quality Control Criterion standard for groundwater of 100 µg/L. Groundwater in the perched zone beneath the former sewage lagoons is isolated from the larger perched groundwater to the east, and is present in a relatively thin and discontinuous layer. Regional groundwater underlying the site is not contaminated with any constituents that exceed drinking water standards.
3.2 Golf Course Main Pond

The contaminants of potential concern (COPCs) investigated at the pond have included VOCs, semi-volatile organic compounds, metals, petroleum hydrocarbons, total dissolved solids, anions, ammonia, total Kjeldahl nitrogen, dioxins, furans, organochlorine pesticides, polychlorinated biphenyls, chlorinated herbicides, cyanide, gross alpha/beta radioactivity, radium-226 and radium-228. Previous investigations have eliminated all COPCs as posing an unacceptable risk to human health and the environment with the exception of nitrate. The nitrate contamination is being investigated under Site ST-105, TCE and Nitrate Contaminated Groundwater, which addresses a larger on-going concern with nitrate contamination in groundwater associated with the Kirtland AFB as part of a nitrate abatement program.

The results of previous investigations indicate that significant concentrations of contaminants are not present in the vadose zone underlying the original or current Golf Course Main Pond footprint. Therefore, it can be concluded that the vadose zone beneath the pond is not contributing nitrate contamination to the underlying aquifers. Several VOCs were detected in the 2006 RCRA Facility Investigation soil and soil-vapor samples; however, none of the VOCs detected in soils exceeded the NMED residential soil screening levels. VOC detections in groundwater sampled from the Golf Course Main Pond monitoring wells are sporadic and at concentrations below federal and state drinking water standards.

3.3 Recommendations

The Corrective Measures Study Report for Solid Waste Management Unit WP-26, Sewage Lagoons and Golf Course Main Pond (USAF, 2010) was developed and evaluated the corrective action alternatives and recommended a corrective measure to be taken for the Site.

3.3.1 Base Sewage Lagoons

Based on the data collected during the multiple site investigation, as well as the removal action conducted in 2010, a Screening-Level Ecological Risk Assessment (SLERA) was conducted. The objectives of the SLERA were to describe the potential for and magnitude of risk to ecological receptors in the sewage lagoons from current and future conditions. The medium of concern for the SLERA was soil vapor. Selected bird and mammal receptors included burrowing birds and mammals that have the potential to occur at the lagoons and included the burrowing owl and the coyote. Based on the results of the assessment, risk was determined to be negligible and additional investigation of the shallow soil vapor in regard to ecological exposures was not recommended.

The objectives of the Human Health Risk Assessment (HHRA) included (1) characterize the baseline risk to assess the need for remedial action; (2) provide a basis for determining levels of chemicals that can remain onsite and still be adequately protective of human health; and (3) provide a basis for comparing various remedial alternatives.

Based on current land use, no regular exposure to COPCs in soil vapor or groundwater was determined to exist. The most plausible, potential future exposure scenarios involved industrial workers. A residential scenario was also included for future risk management decision-making purposes. Two exposure scenarios were evaluated in the HHRA including (1) future industrial workers potentially exposed to soil vapor due to vapor intrusion into indoor air, and (2) future residents potentially exposure to groundwater and soil vapor.

The two exposure scenarios were evaluated to estimate the cumulative soil vapor cancer risks. Only one of the 42 soil vapor samples evaluated had a cumulative cancer risk estimate for the future resident equal to $1 \times 10^{-5}$, which exceeded the NMED risk threshold. The cumulative potential cancer risk for the future...
resident for the other 41 soil vapor samples were below $1 \times 10^{-5}$. Non-cancer risk for the future resident for all vapor samples were less than 1.

The estimated cumulative groundwater cancer risks associated with exposure to perched groundwater exceeded the NMED target risk of $1 \times 10^{-5}$ at only two of the six sample locations (KAFB-2622 and KAFB-2624), with arsenic being the main risk driver at both locations. However, arsenic concentrations at KAFB-2622 (3.2 µg/L) and KAFB-2624 (2.7 µg/L) are less than the NMED-approved background concentration of 14 µg/L and below the MCL of 10 µg/L.

The cumulative potential cancer risk for the future resident was $4 \times 10^{-6}$ for regional groundwater at the Site. The cumulative potential cancer risks associated with exposure to groundwater in the regional aquifer did not exceed the NMED’s target risk of $1 \times 10^{-5}$. The cumulative potential hazard indices for non-cancerous effects were less than 1 for both perched and regional groundwater at the Site.

The interim measure objectives for WP-026 Sewage Lagoons are to reduce TCE concentrations in perched groundwater near the former sewage lagoons to below MCLs.

For the interim measures study, presumptive remedies and other remedial technologies were evaluated as part of the preliminary screening of technologies to determine their applicability to the site-specific conditions at the former sewage lagoons. Based on the preliminary screening, the following remedial technologies were retained for further evaluation:

1. No action (soil vapor and groundwater);
2. Soil vapor extraction (SVE, soil vapor and groundwater);
3. Monitored natural attenuation (groundwater);
4. Enhanced reductive dechlorination (groundwater); and
5. Groundwater extraction with ex-situ treatment.

A detailed evaluation of the alternatives was prepared to provide the relevant information necessary for decision makers to select an appropriate site remedy. Each of the developed remedial alternatives were assessed against the specified evaluation criteria, and compared in terms of how well they met those criteria. Detailed analysis of alternatives consisted of a detailed evaluation of each alternative against the first seven of the nine evaluation criteria and a comparative evaluation of the alternatives.

For soil remediation, the recommended interim measures alternative is the No Action Alternative. Because the COPCs in the soil do not exceed the NMED’s residential soil screening levels, the risk for exposure to the COPCs is acceptable.

For the perched groundwater, the recommended interim measures alternative was SVE. However, enhanced reductive dechlorination is a better overall approach to directly address the TCE-impacted groundwater underlying the former sewage lagoons due to low-concentrations of TCE. The maximum TCE concentration found in the perched groundwater is 15 µg/L associated with well KAFB-2622 as of 26 July 2016. Monitored natural attenuation will require an extended length of time to meet the remedial action objectives.

### 3.3.2 Golf Course Main Pond

A SLERA was conducted for the Golf Course Main Pond as part of the corrective measures study process. The objective of the SLERA was to describe the potential for and magnitude of risk to ecological
3.0 PREVIOUS INVESTIGATIONS

receptors in the pond from current and future conditions. The media of concern for the SLERA were soil, surface water, and soil vapor because they were the basis for receptor exposure. Receptors for evaluation include aquatic organisms, soil organisms, terrestrial plants, mourning doves, burrowing owls, deer mice, and coyotes. All analytes were determined to pose no or low risk. Based on the results of the SLERA, additional ecological investigation and evaluation was not recommended for the Golf Course Main Pond area.

An HHRA was also prepared as part the corrective measures study process. The objectives for the HHRA included (1) characterize the baseline risk to assess the need for remedial action; (2) provide a basis for determining levels of chemicals that can remain onsite and still be adequately protective of human health; and (3) provide a basis for comparing various remedial alternatives.

The HHRA evaluated four exposure scenarios including future onsite construction workers, hypothetical future residents, onsite recreationists, and onsite maintenance workers. The estimated cancer risk for each exposure scenario was less than the NMED’s $10^{-5}$ risk range. The estimated non-cancerous risks were less than 1 for each exposure scenario. Therefore, the Golf Course Main Pond meets the NMED risk standards.

The groundwater from the Golf Course Main Pond perched wells meets federal and state drinking water standards for all COPCs, except nitrate. This area is part of the Nitrate Abatement Program, under which the groundwater monitoring wells in the area are monitored on an annual basis. Because the known nitrate contamination has been characterized in accordance with current applicable state or federal regulation and is under an abatement plan, it poses an acceptable level of risk for current and projected future land use. Currently, this water is not being used for drinking water, and there are no plans to use the water as a potable water source. The nitrate-impacted groundwater is being addressed under site ST-105.

Based on the results of previous investigations and the risk assessments, the objective of the corrective measures study was to demonstrate that the Golf Course Main Pond requires no further action. The No Further Action (NFA) determination is based on the NMED No Further Action – Proposal Criteria NFA Criterion 5:

“The SWMU or AOC has been characterized or remediated in accordance with current applicable state or Federal regulations, and the available data indicate that contaminants pose an acceptable level of risk under current and projected future land use.”

The risk characterization for exposure of the future hypothetical onsite resident to soil and soil vapor indicate that the estimated cancer risks are below the NMED’s $10^{-5}$ risk range. The estimated risks for all exposure scenarios evaluated (residential, recreational, and construction) do not exceed the NMED risk thresholds.

In addition, it was recommended that the interim corrective measures implemented at the Golf Course Main Pond in 1999 be terminated.
4.0 PROCEDURES FOR IMPLEMENTATION

This section provides the general procedures for implementing the interim measures to be undertaken at WP-026. The following specific tasks will take place at the site subject to interim measures under this work plan:

- Pre-mobilization activities
- Mobilization/site setup
- Monitoring well installation
- Aquifer test described in Section 4.4
- Injection well installation
- Injection of substrate solution and bioaugmentation culture
- System operation and maintenance
- Management of investigation-derived waste (IDW)
- Site restoration
- Site surveying.

As shown in Figure 4-1, there are currently eight monitoring wells with only five from which viable analytical samples can be collected from the perched aquifer underlying the site of the former sewage lagoons. This is due to the decrease in the recharge of the perched aquifer resulting in other wells going dry. The first step in the implementation of interim measures to address the residual TCE impacts on the perched groundwater will be to install new monitoring wells to supplement the existing network and aid in further evaluation of the TCE impacts.

Following installation of the new monitoring wells, an aquifer test will be conducted to assess the groundwater flow within the perched aquifer to determine the efficacy of the implementation of enhanced reductive dechlorination to address the residual TCE. The current maximum TCE concentration is 15 μg/L as encountered in well KAFB-2622 located on the northeastern edge of the former sewage lagoons. Based on historic TCE concentrations encountered in this well, it is anticipated that concentrations would decline to less than the U.S. Environmental Protection Agency’s maximum contaminant level (MCL) of 5 μg/L within 20 years; however, it is desired to reduce the TCE concentrations to levels less than the MCL within five years. Therefore, the evaluation of groundwater flow will aid in determining the location and number of injection wells that would be necessary to reduce the TCE concentrations to below the 5 μg/L regulatory level within the five year timeframe.

Based on the aquifer test, the number of injection wells required will be determined as will the optimum locations of those wells. Initially, one injection well will be installed in close proximity to well KAFB-2622 which is the well with the current highest TCE concentration of 15 μg/L. A treatability phase will be conducted using the single well and evaluating results obtained for up to one year following the initial injection. The number and locations of future injection wells will be submitted in a technical letter report to the USAF and NMED for concurrence prior to proceeding with the installation. An appropriate permit for implementing the injections will be obtained from the New Mexico Environment Department - Ground Water Quality Bureau. It is anticipated that it will require up to 6 months from the date of application to obtain the permit.
Figure 4-1. WP-026 Sewage Lagoons Groundwater Monitoring Wells
Evaluation of the effectiveness of the employed interim measures will be done by conducting routine groundwater monitoring from the perched aquifer network. Monitoring of the underlying regional aquifer will be continued until determined to no longer be necessary to ensure that TCE in the perched aquifer does not adversely impact the regional aquifer. Monitoring will be conducted in accordance with the Final Long-Term Monitoring Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) (URS, 2016).

4.1 Pre-Mobilization Activities

Prior to mobilization of equipment, subcontracted services (e.g., drilling subcontractor, New Mexico licensed surveyor, and approved analytical laboratory) will be procured. All necessary permits (e.g., digging permits, drilling permits, etc.) will be initiated. All site activities will be coordinated with the appropriate Kirtland AFB personnel.

Prior to initiating intrusive activities, a completed and approved Air Force Form 332 will be obtained for authorization of construction work at Kirtland AFB. A request for locating underground utilities in the area will be submitted to the local one-call utility notification center, as applicable. Additionally, Air Force Form 103 will be submitted to request that the location of underground utilities be marked at the specific sites. Drilling and excavation locations will be identified with paint, flags, or stakes, as appropriate to the surface material. Utility clearance approvals will be completed by the appropriate Kirtland AFB utility office (e.g., telephone, sewer, water, natural gas, etc.). An appropriate permit will be obtained from the NMED Ground Water Quality Bureau for injection of the substrate required to support enhanced reductive dechlorination of the TCE in the perched aquifer.

In support of the activities to be performed at the WP-026 site, a project-specific groundwater monitoring plan and a basewide Health and Safety Plan (HASP) have been prepared.

4.2 Mobilization and Site Setup

Personnel, equipment, and resources necessary to implement the interim measures will be mobilized to the Site. Warning signs and safety fencing may be used, where necessary, to delineate the work zone and indicate the potential hazards. The work zone will be established so as to maintain the work area clear of obstructions and to provide clearly marked vehicle paths and parking areas. Setup will also include establishing a laydown area for material storage and other equipment staging as required.

4.3 Monitoring Well Installation

As indicated by the arrows in Figure 4-2, two new monitoring wells will be installed at WP-026 to supplement the current active monitoring network of the perched aquifer. The locations were selected to provide coverage of the area downgradient of KAFB-2622 which has had the highest TCE concentrations for the existing wells (see Figure 4-3). Prior to drilling, available engineering drawings will be reviewed, a utility location survey will be performed, and facility and security operations management will be involved throughout project planning activities. Figure 4-2 takes into account known access limitations, but final well locations will be determined in the field and modified as needed due to proximity of underground utilities and other obstructions encountered in the field. At this time, it is not anticipated that any such obstacles to installation will be encountered in the vicinity of WP-026.
Figure 4-2. Proposed Locations of New Monitoring Wells
4.0 PROCEDURES FOR IMPLEMENTATION

Kirtland AFB
Site WP-026

Figure 4-3. WP-026 Perched Aquifer Trichloroethene Concentrations
4.3.1 Well Survey

The new monitoring well will be surveyed relative to the North American Datum of 1983 (NAD 83) and elevations surveyed relative to North American Vertical Datum of 1988 (NAVD 88). Survey data will include northings, eastings, and elevations to the nearest hundredth of a foot. Survey elevations will be established at top-of-casing and ground surface, with a permanent marker indicating the point of survey. Well survey will be completed and certified by a licensed New Mexico professional surveyor.

4.3.2 Borehole Drilling

Based on local topography, recent groundwater level measurements at WP-026, and the lithology recorded during installation of the nearest groundwater monitoring wells, boreholes for the new monitoring well are anticipated to be drilled to approximately 230 feet below ground surface (bgs).

Boreholes for the new monitoring wells will be drilled using Air-Rotary Casing-Hammer (ARCH) drilling methods. It is anticipated that a telescoped borehole will be drilled and temporarily cased to reduce friction between the steel drive casing and borehole during drilling. The borehole will be advanced with 11.75-inch nominal diameter drive casing from ground surface to approximately 150 ft bgs and cased. The remaining borehole from 150 ft bgs to total depth will be advanced with a 9.625-inch nominal diameter drive casing and cased. The ARCH drilling method will use environmentally friendly lubricants and will be able to penetrate highly variable lithologies such as cobbles, boulders, gravel, sand, clay, and caliche. The borehole lithology will be logged by the URS field geologist during drilling. URS staff will retain cutting samples in chip boxes for three years after each well is installed. The depth of the first encounter with perched groundwater will be noted and recorded during drilling. Standby time will be used as needed for determining accurate water level.

Minimal water (but no other foams/liquids) in the form of mist may be introduced into the drive casing to aid in the removal of cuttings. Borehole cuttings and core will be stored within an area adjacent to the well. Water produced from the well during drilling or development will be contained in 55-gallon polypropylene drums, or other appropriate containers, and placed on spill control pallets or within appropriate confinement as secondary containment. Management and final disposition of cuttings, core, and water will be performed in accordance to applicable state and federal regulations.

4.3.3 Monitoring Well Design

The locations of the new groundwater monitoring wells are shown in Figure 4-2. The well screen and filter pack will either be 0.010-inch slot with #20/40 sand or 0.020-inch slot with #10/20 silica sand as the primary filter pack material depending on the degree of fines in the surrounding sediments. The well screen will be 20-ft long and extend 18 ft below and 2 ft above the static water level. If the bottom of the perched zone is less than 20-ft deep, the well screen length will be adjusted accordingly. Table 4-1 shows the anticipated design specifications. The configuration and construction of the monitoring well casing and screen will follow the same process as for the injection well described in Section 4.5.

Previously installed groundwater monitoring wells at WP-026 currently extend between being right at the water table to 17 ft below the water table. As shown in Figure 4-4, water levels have steadily been declining and are anticipated to continue to do so since sources that have been providing recharge to the perched aquifer are no longer in use. The final monitoring well construction design will be determined based on lithology and geophysics.
### Table 4-1. Monitoring Well Design Specifications

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Estimated Depth to Water (ft bgs)</th>
<th>Screen Interval (ft bgs)</th>
<th>Filter Pack Interval (ft bgs)</th>
<th>Total Casing Depth (ft bgs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KAFB-2633</td>
<td>204</td>
<td>202 – 222</td>
<td>192 – 228</td>
<td>227</td>
</tr>
<tr>
<td>KAFB-2634</td>
<td>205</td>
<td>203 – 223</td>
<td>193 – 228</td>
<td>228</td>
</tr>
<tr>
<td>KAFB-2635</td>
<td>206</td>
<td>204 – 224</td>
<td>194 – 229</td>
<td>229</td>
</tr>
</tbody>
</table>

The planned locations for the new groundwater monitoring wells at WP-026 are not in areas requiring at grade completion; therefore, the well casing will extend approximately 30 inches above ground surface with a water-tight cap. The borehole will be grouted to within 5 ft of the ground surface, allowed to cure, followed by placing another 2-foot lift of bentonite chips to serve as a firm base for the stovepipe. The wellhead will be protected with a steel stovepipe with locking hinged lid, set in a reinforced concrete pad and surrounded by three concrete-filled bollards. Each concrete pad will be affixed with a brass well identification plate.

#### 4.3.4 Well Development

Well development will begin after at least 48 hours following final grout placement. Development of groundwater monitoring wells will consist of bailing, surging, swabbing, and/or pumping techniques. During development, groundwater field parameters (pH, specific conductivity, temperature, and turbidity) will be continuously monitored, and development will continue until these parameters have stabilized. Development water will be contained in polyethylene drums and not allowed to discharge to the ground surface. All waste will be disposed of according to applicable state and federal regulations. The method of development, the volume of water added or removed, the parameters measured, the results of the measurements, and the time these activities take place will be document on field forms. If addition of water is necessary during development of a low yielding well, only potable water will be used.

During well development, a minimum of five well bore volumes of groundwater will be removed. One bore volume is calculated as the interior casing volume from static water level to the bottom of screen, plus the estimated porosity of the saturated filter pack. After the minimum volume has been removed, development will continue until representative groundwater is obtained. Representative water is assumed to be obtained when pH, specific conductivity, and temperature readings stabilize (less than 10 percent variability over three consecutive well bore volumes) and the water is visually clear of suspended solids with a target turbidity of less than 5 Nephelometric Turbidity Units (NTUs).

#### 4.4 Aquifer Test

Groundwater occurs above and within a fine-grained unit that forms a perched groundwater system above the regional aquifer. A perched groundwater system developed from sewage lagoons, artificial lakes, and major pipeline leaks, in addition to minor amounts of natural recharge. After closure of the sewage lagoons and pipeline leaks, groundwater elevations have decreased approximately 20 feet. TCE has been detected above the MCL in wells KAFB-2622 and KAFB-2625. The following describes a phased program to obtain data and design treatability study and long-term injection parameters for full-scale treatment of the TCE source-area hot-spots using gravity injection of the nutrient-amended substrate solution and a microbial bioaugmentation culture into perched groundwater.
Figure 4-4. KAFB Perched Groundwater Elevation.
NMED has requested evaluation of groundwater velocity and aquifer testing for the perched aquifer. Aquifer testing is necessary to provide estimates for aquifer hydraulic conductivity, which is used to calculate groundwater velocity and estimate groundwater level impacts from pumping or injection. Pumping tests are likely impractical in the perched system due to limited saturated thickness, dewatering, and unknown boundary conditions in the perched aquifer. Slug testing and injection testing are more feasible alternatives.

Slug testing is a method of testing wells to obtain estimates of hydraulic conductivity of the aquifer materials in the vicinity of the well. A length of pipe is filled with sand, capped, and lowered below the water level. After the water level has equilibrated to the pre-test level, the slug is rapidly removed and measurements of the water level recovery are recorded and analyzed to provide estimates of hydraulic conductivity. Slug testing has several advantages over pumping tests for this application. Slug tests do not produce large volumes of contaminated water that require management or disposal. Also, pumping tests would likely dewater the very limited saturated thickness of the aquifer, which is estimated to be less than 20 feet.

A review of the Balleau Groundwater, Inc. 2002 modeling report provided results of one aquifer test for well TJA-2 with horizontal hydraulic conductivity ranging from 17 to 50 feet per day. The conceptual model described the top of the fine-grained surface as a synclinal fold with a general north-south axis dipping to the south. In the westward direction, the fine-grained perching unit transitions to coarser materials a few hundred feet west of the former sewage lagoons that allow vertical flow to the regional aquifer without perching. The year 2000 observed groundwater elevation contour map indicates groundwater elevation near well KAFB-2624 was ~5,165 ft above mean sea level (amsl). The geologic structure contour map (estimated) indicates the top of the fine-grained unit at that location is ~5,147 ft amsl, indicating a saturated thickness of ~18 feet. The 2000 map indicates a relatively uniform surface across the site with groundwater flowing to the east.

The sewage lagoons were identified as a primary source of recharge. Since closure of the lagoons over 20 years ago, groundwater levels have dissipated. The 2015 groundwater elevation in well KAFB-2624 is 5,142 and in nearby well KAFB-0506, 260 feet south is 5,152. Based on estimated topography and the 2015 groundwater level, the indicated saturated thickness ranged from -5 to +5 feet in 2015. These data indicate groundwater level has declined more than 18 feet in approximately 15 years, and is likely at or near the estimated top of the fine-grained perching unit.

Six wells in the area of the sewage lagoons with sufficient saturated interval will be slug tested, including KAFB-2622 and KAFB-2625. Hydraulic conductivities from the slug tests will be used to refine the design of the injection treatability test for in situ bioremediation in well KAFB-2622. The hydraulic conductivity will be used to refine the parameters of the injection tests including injection rate, duration, groundwater mounding, and radius of influence. The estimates for radius of influence will be used to design and evaluate the location for a new injection well to be paired with the existing monitoring well, KAFB-2622.

The new injection well borehole will be drilled deep enough to identify the top of the perching unit and sampled to characterize the vertical extent of contamination. The treatability test injection well will be constructed with a screened interval designed to optimize the injection of reagents in the perched interval of saturation. During drilling, samples of soil core will be collected for laboratory analysis and bench testing to evaluate the effectiveness of at least two proposed reagents and cultures.

Results of the analysis of cross-sections, slug testing, and laboratory analysis and bench testing of cores will be used to design preliminary long-term injection parameters that will be tested during the treatability test. Results of the treatability study test will be used to refine the final long-term injection parameters and
equipment for long-term bioremediation with a goal of treating an area with a 60 foot radius of influence around each injection well, provided that the need for long-term treatment is determined to be necessary based on results of the treatability study test.

4.5 Injection Well Installation

As shown in Figure 4-5, an initial injection well will be installed in proximity to well KAFB-2622 which has historically had elevated concentrations of TCE. This injection well will be used for the treatability study phase of the interim measure. The injection well will be installed at a distance so that evidence of substrate delivery can be observed within the active injection period. The detailed derivation of the active injection period is presented in Appendix A. Placing the injection well in slightly closer proximity to the monitoring well accelerates the data collection timeframe and helps offset uncertainties regarding subsurface heterogeneity. However, the injection well cannot be placed too close to the monitoring well because well construction might damage the existing monitoring well due to gradual deviation of the drill stem during drilling or due to inaccurate/undesirable placement of grout in the borehole annulus during well construction. The location of additional injection wells, if needed, will be determined following completion of the treatability study phase with concurrence of the Air Force and NMED.

The initial injection well and any subsequent injection wells will be installed upgradient of their respective monitoring wells to the degree logistically possible. Prior to drilling, available engineering drawings will be reviewed, a utility location survey will be performed, and facility and security operations management will be involved throughout project planning activities. Figure 4-5 takes into account known access limitations, but final well locations will be determined in the field and modified as needed due to proximity of underground utilities and other obstructions encountered in the field. At this time, it is not anticipated that any such obstacles to installation will be encountered in the vicinity of WP-026. The groundwater gradient and flowrate will be evaluated during the aquifer test described in Section 4.4. It is anticipated that the groundwater gradient will be relatively low in the perched groundwater underlying the former sewage lagoons and will be overwhelmed by the temporary mounding effect induced during injection. Therefore, the relative lateral proximity to the neighboring monitoring well is more important than orientation with respect to the hydraulic gradient.

4.5.1 Well Survey

The new injection well(s) will be surveyed relative to the North American Datum of 1983 (NAD 83) and elevations surveyed relative to North American Vertical Datum of 1988 (NAVD 88). Survey data will include northings, eastings, and elevations to the nearest hundredth of a foot. Survey elevations will be established at top-of-casing and ground surface, with a permanent marker indicating the point of survey. Well survey will be completed and certified by a licensed New Mexico professional surveyor.

4.5.2 Borehole Drilling

Based on local topography, recent groundwater level measurements at WP-026, and the lithology recorded during installation of the nearest groundwater monitoring wells, boreholes for the new injection well(s) are anticipated to be drilled to approximately 230 feet below ground surface (bgs).

Boreholes for the new injection wells will be drilled using Air-Rotary Casing-Hammer (ARCH) drilling methods. It is anticipated that a telescoped borehole will be drilled and temporarily cased to reduce friction between the steel drive casing and borehole during drilling. The borehole will be advanced with 11.75-inch nominal diameter drive casing from ground surface to approximately 150 ft bgs and cased. The remaining borehole from 150 ft bgs to total depth will be advanced with a 9.625-inch nominal diameter drive casing and cased. The ARCH drilling method will use environmentally friendly lubricants.
Figure 4-5. Proposed Location of New Injection Well
and will be able to penetrate highly variable lithologies such as cobbles, boulders, gravel, sand, clay, and caliche. The borehole lithology will be logged by the URS field geologist during drilling. URS staff will retain cutting samples in chip boxes for three years after each well is installed. The depth of the first encounter with perched groundwater will be noted and recorded during drilling. Standby time will be used as needed for determining accurate water level.

Minimal water (but no other foams/liquids) in the form of mist may be introduced into the drive casing to aid in the removal of cuttings. Borehole cuttings and core will be stored within an area adjacent to the well. Water produced from the well during drilling or development will be contained in 55-gallon polypropylene drums, or other appropriate containers, and placed on spill control pallets or within appropriate confinement as secondary containment. Management and final disposition of cuttings, core, and water will be performed in accordance to applicable state and federal regulations.

4.5.3 Core Sampling at Injection Well Locations

To optimize the injection well construction design, continuous core will be collected from approximately 20 ft above the anticipated static water table to approximately 40 ft below the observed water table to allow detailed lithologic logging of the saturated zone and the overlying capillary fringe. Core will be obtained by advancing an acetate-lined inner diameter core barrel (or functional equivalent) ahead of the ARCH drill bit. The total depth of each borehole will be determined by the URS field geologist based on observed lithology and injection well design objectives. Lithology from coring will be used to refine the final well screen and filter pack placement to ensure injection wells are completed at the proper depth to optimize substrate delivery.

Unsaturated and saturated soil samples will be collected from the most permeable observed sediment layers within the core at a minimum of one per 10-ft interval. Soil samples will be analyzed by an approved laboratory for VOCs. If VOCs are not detected in any of the soil samples, the injection well screen completion interval will default to the injection well design detailed in Section 4.5.4. Because detected VOC concentrations have been historically very low at WP-026, lack of VOC detection in the soil samples does not preclude their presence at low concentrations in groundwater. The purposes of VOC analysis of soil samples are to confirm historical results of negligible contaminants in soil samples and to determine if significant concentrations are present in a deeper horizon than is monitored by the current perched groundwater monitoring network.

4.5.4 Well Construction

The new injection wells will be installed through the temporary steel drive casing and completed with flush-threaded, PVC Schedule-80 water well casing. No petroleum-based solvents, cleaners, or lubricants will be used for well construction. The casing and screen will be delivered pre-cleaned and bagged, or steam-cleaned on site prior to installation. To preserve the structural integrity of well materials, the casing and screen will be suspended in the drive casing while the primary filter pack, bentonite chips seal, and annular seal are installed. PVC centralizers might be placed at the bottom and top of the well screen, and at intervals not to exceed 100 ft along the well casing up to the ground surface.

4.5.5 Injection Well Design

Injection wells will consist of a 5-inch nominal diameter casing and screen as shown in Figure 4-6. The injection casing screen will be 20 ft long with its top placed approximately 5 ft below the water table to facilitate submerged placement of the injected solution. The casing will have a 5-ft long blank sump casing at the bottom to mitigate long-term silting up of the well.
4.0 PROCEDURES FOR IMPLEMENTATION

Figure 4-6. Injection Well Construction Diagram
4.0 PROCEDURES FOR IMPLEMENTATION

To enhance injection rate and lessen chance of biofouling, a relatively coarse-grained filter pack material, #8/12 sand or equivalent, will be used as the primary filter pack material extending from the bottom of the sump to at least 5 ft above the top of the screen. An additional 5 ft of #60 silica sand will be placed on top of the primary filter pack. Each filter pack interval will be tagged to verify the depth setting. Swabbing using a surge block will be performed to help settle the filter pack and reduce possible bridging of the sand.

An approximately 30-ft thick lift of 3/8-inch grade bentonite chips will be placed above the filter pack in 5-ft lifts. Each lift will be hydrated with 5 gallons of potable water and tagged prior to emplacement of the next lift. The first lift of bentonite chips will be allowed to hydrate for at least one hour to facilitate sufficient hydration.

The remaining annular space to ground surface will then be filled with bentonite grout. To prevent overloading, the first lift of bentonite grout will be approximately 100-ft thick and will be allowed to set for a minimum of 24 hours. Subsequently, the annulus will be filled continuously with grout to within 10 ft bgs. To prevent bridging within the annular space, during well construction the field crew will (1) tally the amount of emplaced materials to verify that the theoretical (planned) volume of each material corresponds to the actual volume installed, (2) pour the materials by hand at a slow rate into the annulus at the top of the drive casing, and (3) use a measuring tape at approximately 3-foot intervals to verify that the materials have fallen to the proper depths. Concrete will be used to complete the well installation.

Each injection well will require an at-grade completion. The PVC well casing for these wells will be cut off below grade, and fitted with a water-tight cap and a lock. The well casing and well cap will be protected by installing an 12-inch diameter traffic-rated steel vault centered over the PVC casing. The vault will be set in concrete, rebar-reinforced, constructed to surround the upper portion of each vault that slopes evenly away from the vault to meet the surrounding ground surface and direct water away from the top of the vault. A brass well identification marker will be fastened to each vault.

The initial injection well will be installed approximately 15 feet away from monitoring well KAFB-2622. The most recent depth to water at KAFB-2622 was 202.51 ft below the top of casing. Therefore, it is anticipated that the injection well will be screened from approximately 205 ft to 225 ft bgs. The filter pack interval will be from 200 ft to 230 ft bgs. The actual depths may be adjusted in the field depending on conditions encountered and actual depth of the perched aquifer in the area should the bottom of the perched zone be reached when drilling.

4.6 Enhanced Reductive Dechlorination

The approach for enhanced reductive dechlorination is based on an approach submitted by Sandia National Laboratories, New Mexico Environmental Restoration Operations and approved by the NMED in 2016. The approach is described in the Revised Treatability Study Work Plan for In-Situ Bioremediation at the Technical Area-V Groundwater Area of Concern (Sandia, 2016).

The injected substrate solution and bioaugmentation culture will include several components, each serving a specific purpose. The following sections discuss each of these components and the dosing and mixing ratio.
4.6.1 Components of Substrate Solution

Electron Donor

Ethyl lactate will be used as the electron donor or substrate for the interim measures to be performed at WP-026. Ethyl lactate has high water solubility, a low retardation factor, low viscosity, and lacks particulates, all of which ensure a high degree of transportability within the treatment area. Ethyl lactate has been shown to be very effective at stimulating microbial growth that produces conditions conducive to anaerobic degradation of contaminants such as TCE. It also has other favorable properties compared to other electron donors (Jayaraj et al, 2004). It is fully utilized by microbes, unlike substrates such as sodium lactate where the sodium is not utilized. Ethyl lactate yields the same hydrogen equivalent as dextrose (12:1) and is comprised of ester-linked carbons that break apart to form lactate and ethanol. The ethanol produced during dissolution acts as a co-solvent aiding in desorption of chlorinated solvents, such as TCE, from the aquifer matrix. The ethanol is also highly transportable, as is the lactate that is generated upon dissolution. Both of these components are then utilized by the bacteria, creating the desired anaerobic conditions.

From a practical standpoint, ethyl lactate is supplied in a liquid concentrate that will not spoil or freeze, providing a longer shelf life when compared with simple sugars such as glucose or dextrose. Because it is provided as a liquid, ethyl lactate can also be easily blended with other components in the tank prior to injection. To prevent oxidation, the ethyl lactate is supplied under a nitrogen or argon blanket. After opening the container, the product will be stored under inert conditions by purging the container head space with inert gas.

Nutrients

Diammonium phosphate and yeast extract will be added as nutrients to support microbial growth. They will be blended with the ethyl lactate at a weight ratio of approximately 80 percent ethyl lactate, 17 percent diammonium phosphate, and 3 percent yeast extract. This will provide a solution that is very similar to that used at wastewater treatment plants where for every 100 parts of carbon, 10 parts of nitrogen and 1 part of phosphorus are required for bacterial growth (Metcalf and Eddy, 1991). Without the addition of these nutrients, bacteria will enter nutrient-limited kinetic rates that are much more ineffective at reducing contaminant concentrations. The nitrogen and phosphorus will be mixed with the ethyl lactate before being injected into the subsurface to facilitate utilization by bacteria.

Ammonia and phosphate concentrations will increase as the solution is injected to the saturated zone. However, once the bacteria begin to grow on the substrate, they will rapidly utilize the nitrogen and phosphorus, reducing the ammonia and phosphate concentrations to background concentrations. The nitrogen and phosphorus are converted to microorganism biomass, and will not be a concern for downgradient migration.

pH Buffer

It is important to maintain a relatively neutral pH in the aquifer to support a robust microbial community that can fully dechlorinate TCE to ethene. Therefore, addition of a pH buffer is included to offset pH reduction that can occur as a result of volatile fatty acid production during fermentation of the electron donor. The diammonium phosphate added as a nutrient will also serve as the pH buffer; thereby eliminating the need to an additional component specific to buffering. *Dehalococcoides* optimally dechlorinates in a pH range between 6.9 and 7.5 (Loffler et al., April 2012), although keeping the pH between 6.0 and 8.5 is a common practice for bioremediation. Maintaining a neutral pH also mitigates the degree of metals and metalloid solubilization.
Tracer

Sodium bromide will be used as an inert tracer added to the substrate solution during the injections. During injections, bromide concentration date will be used to evaluate the degree of initial dilution caused at the injection location, the rate at which this dilution effect attenuated as a result of mixing with the surrounding groundwater, and delivery of the injected solution to nearby monitoring wells.

Background bromide concentrations in the perched groundwater average less than 2 mg/L. Assuming that the hydraulic conductivity at each injection well is comparable to that measured in nearby monitoring wells, a bromide concentration of approximately 20 mg/L would be a suitable tracer concentration. This translates to approximately 0.2 lbs of sodium bromide per 1,000 gallons of injected water. If significantly higher hydraulic conductivity is encountered at an injection well, the bromide concentration can be increased to as much as 200 mg/L to counter dilution effects from local groundwater advection.

Component Mixing

The substrate and other components will be mixed in aboveground tanks with water. Table 4-2 lists the components of the substrate solution, their respective roles, and mixing ratio. The estimated amount of sodium bromide tracer is also shown. The final mixing ratios may vary based on data acquired during more recent monitoring events. The Safety Data Sheet for each component is provided in Appendix A.

Each batch of mixed solution will be deoxygenated in the tank prior to gravity injection into the well to protect the anaerobic bioaugmentation culture that will be co-injected with the substrate solution. KB-1® Primer (slurry) will initially be used to accelerate the conversion from aerobic to anaerobic in the tank, typically within a few hours. Subsequent batches will rely on the ethyl lactate substrate to develop anaerobic conditions.

<table>
<thead>
<tr>
<th>Substrate Solution Component</th>
<th>Function</th>
<th>Mixing Ratio (by weight)</th>
<th>Weight per 1,000 gallons of Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethyl lactate</td>
<td>Electron donor (substrate)</td>
<td>80%</td>
<td>8.9 lbs</td>
</tr>
<tr>
<td>Diammonium phosphate</td>
<td>Nutrient and pH buffer</td>
<td>17%</td>
<td>1.9 lbs</td>
</tr>
<tr>
<td>Yeast extract</td>
<td>Nutrient</td>
<td>3%</td>
<td>0.3 lbs</td>
</tr>
<tr>
<td>Primary components per 1,000 gallons of water</td>
<td></td>
<td>100%</td>
<td>11.1 lbs</td>
</tr>
</tbody>
</table>

Table 4-2. Substrate Solution Components

<table>
<thead>
<tr>
<th>Additional Components Mixed with Substrate Solution</th>
<th>Function</th>
<th>Mixing Ratio (by weight)</th>
<th>Weight per 1,000 gallons of Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium bromide</td>
<td>Inert tracer (as bromide)</td>
<td>Not applicable</td>
<td>0.2 lbs</td>
</tr>
<tr>
<td></td>
<td>adjusted per field conditions</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial batch of Substrate Solution (to accelerate deoxygenation)</th>
<th>Function</th>
<th>Mixing Ratio (by weight)</th>
<th>Weight per 1,000 gallons of Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>KB-1® Primer</td>
<td>Substitute for ethyl lactate, diammonium phosphate, and yeast extract to accelerate deoxygenation during initial injection batches</td>
<td>100%</td>
<td>7.1 lbs</td>
</tr>
</tbody>
</table>
4.6.2 KB-1® Primer

KB-1® Primer is a proprietary mixture of amino acids, potassium bicarbonate, and sodium sulfite that is used to accelerate deoxygenation of water inorganically (sodium sulfite) while still providing an electron donor (amino acids) and buffer (potassium bicarbonate). It can therefore be used as a substitute for ethyl lactate, diammonium phosphate, and yeast extract, although it is significantly more costly and therefore not suitable for larger volumes if required. Treatment of the perched aquifer will occur in two phases, a treatability study phase and a full scale phase. The extent of the full scale phase will depend on the results of the treatability study phase. The groundwater used for the treatability study phase will be stored in approximately equal proportions in two tanks. One tank will be inoculated with a small amount of soil core/cuttings from an injection well screened interval and have KB-1® Primer added. The purposes of adding soil core/cuttings to the substrate solution are to (1) inoculate the solution with native microorganisms, (2) create a diverse microbial community that will more likely work synergistically with the bioaugmentation culture, and (3) reduce the lag time for initiating biostimulation associated with utilization of the substrate in the subsurface. If sufficient core/cuttings are not recovered during drilling, a commercial lyophilized bacterial septic tank amendment (e.g., Rid-X® Septic System Treatment or equivalent) may be substituted at a mass/volume based on manufacturer recommendations.

As water in the first tank turns anaerobic, water from the second tank will be transferred into the first tank and mixed with proportional amounts of the substrate solution components. Although addition of groundwater from the second tank is likely to increase the dissolved oxygen (DO) and oxidation-reduction potential (ORP) initially, the combined water volume is expected to return to sufficiently decreased DO and ORP within one to two days and ready for gravity injection into the injection well as one batch.

The full scale injection phase will follow a similar process. An additional pair of tanks may be employed if it is determined that the volumes required are sufficient to justify them. If just a single pair of tanks is employed, the same approach will be followed as outlined above for the treatability study phase. Following the two pairs of tanks scenario, both pairs of tanks will be filled halfway with potable water, inoculated, and have KB-1® Primer added. After turning anaerobic, the tanks will be filled with water and mixed with proportional amounts of the substrate solution components. As with the treatability study phase, the deoxygenation of the entire tank volume is expected within one to two days. Once anaerobic conditions are restored, half of the tank contents (from each pair) will be injected. Each pair of tanks will then be refilled with potable water and mixed with proportional amounts of the substrate solution components. Provided that approximately half a tank of the deoxygenated solution remains in each tank, this accelerated deoxygenation schedule is expected to continue without further use of KB-1® Primer during the remaining of the injection period. By alternating two pairs of tanks, injection would not be interrupted while waiting for the substrate solution to turn anaerobic.

4.6.3 KB-1® Dechlorinator

To expedite growth of a microbial population capable of fully dechlorinating TCE to ethene, a bioaugmentation culture, KB-1® Dechlorinator, will be injected in conjunction with the substrate solution. KB-1® Dechlorinator is a naturally occurring, non-hazardous, non-pathogenic, microbial culture that contains a consortium of anaerobic microorganisms that promote dechlorination of chlorinated solvents. It includes *Dehalococcoides* that has a strain possessing the gene capable of producing enzymes that reduce vinyl chloride to non-toxic ethene (vinyl chloride reductase). *Dehalococcoides* can be found naturally in the environment. However, these bacteria are not ubiquitous, and an aerobic environment, such as that present at WP-026 as evidenced by the sulfate and nitrate concentrations in the perched groundwater, is not favorable for establishing a population. With concentrations of TCE being very low at
the site, development of a robust *Dehalococcoides* population without bioaugmentation either may not be possible or would require a very long time if relying solely on an indigenous population.

Typical dosing of KB-1® Dechlorinator for site with TCE concentrations one or more orders of magnitude higher than that present at WP-026 is approximately 0.24 lbs per 1,000 gallons of water. The low concentrations of TCE present at WP-026 would result in a slower microbial population growth rate. Therefore, the KB-1® Dechlorinator will be doubled to 0.5 lbs per 1,000 gallons of water to facilitate population development within a reasonable timeframe.

To effectively deliver the KB-1® Dechlorinator to the treatment area, it will be injected simultaneously with the substrate solution. Waiting to deliver the bioaugmentation culture until after the initial injection of substrate solution alone would require additional injection volumes to reach the same treatment area and would have to be delayed long enough to ensure the groundwater had been deoxygenated.

KB-1® Dechlorinator is a liquid and is shipped by the supplier to the site in stainless steel containers. It has a shelf life of approximately two weeks, so shipments will be sized and delivered as needed to match the pace of injections without compromising the product shelf life. Injections will be performed in accordance with the supplier’s procedure and be mixed in-line with the substrate solution via a connection placed between the substrate solution mixing tank and the wellhead. The KB-1® Dechlorinator will be purged from its vessel into the aboveground injection line with inert gas (argon) under sufficient pressure to ensure proper mixing with the substrate solution injection stream. Concentrations of solubilized metals and metalloids and the pH in groundwater will also be evaluated prior to adding *Dehalococcoides* to determine if adjustments in buffering amendment are required over the course of the full-scale injection period.

4.7 Long-Term Groundwater Monitoring

The Final Long-Term Monitoring Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) (URS, 2016) has been developed to provide guidance for long-term groundwater monitoring at the Site. Annual groundwater monitoring and well gauging will be performed at the eight perched aquifer wells located at the sewage lagoons, three regional aquifer wells also located at the sewage lagoons, and the three perched aquifer wells located at the Golf Course Main Pond (see Figure 4-1). Samples will be collected and analyzed for the suite of analyses as provided in Table 1 of the monitoring plan. The sampling frequency will be increased to quarterly upon implementation of the interim measures described herein.

The objective of the LTM is to provide groundwater sample analytical data of sufficient quality and quantity to adequately characterize and monitor groundwater underlying the Site. The Final Long-Term Monitoring Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) (URS, 2016) provides the necessary procedures and requirements to ensure that the functional activities, organization, and quality assurance/quality control protocols are achieved in accordance with the project’s data quality objectives.

As additional monitoring data are collected, the analyte list, well list, and sampling frequency may be adjusted to focus on those constituents and wells of interest. A monitoring report will be prepared on an annual basis to evaluate the results and provide recommendations as to future monitoring requirements.
The change in monitoring scope or schedule will be documented in a revision to the *Long-Term Monitoring Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26)* (USAF, 2014a), as well as the *Uniform Federal Policy Quality Assurance Project Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26)* (USAF, 2014b), which will undergo review by the USAF and NMED prior to implementation.

### 4.8 Management of Investigation-Derived Waste

The IDW will be generated as a result of the activities conducted during this project. The types of waste expected to be generated include, but are not limited to, the following:

- Personal protective equipment
- Equipment decontamination liquid residue
- Purge water
- Plastic sheeting
- Unused/unaltered sample material
- Analytical residues
- Sample containers
- Hydraulic spills from mechanical equipment used during installation
- Miscellaneous waste

Waste could be hazardous. Waste will be managed in accordance with the *Environmental Restoration Program Investigation-Derived Waste Management Plan* (USAF, 2009). As the project continues, additional waste streams could be identified. All generated waste streams are required to have the waste identified and characterized as required by Resource Conservation and Recovery Act regulations (40 CFR 262.11, “Hazardous Waste Determination”). Hazardous waste determinations will be prepared for each waste stream in accordance with RCRA requirements. Wastes generated will be designated and characterized using process knowledge, historical analytical data, and/or analytical data generated during the course of the field activities. Hazardous waste determinations for all waste streams will be generated and maintained as part of the project file. Samples of IDW may be collected, if necessary, and submitted to the laboratory for analysis. The waste will be disposed of in accordance with applicable federal, state and local regulations. All drums will be labeled “Investigation Derived Waste, Awaiting Analysis” with contact information provided while being stored pending analysis.

Waste minimization techniques will be incorporated primarily through design, planning, and efficient operations. Specific waste minimization practices to be implemented during the project will include, but not be limited to, the following:

- Historic data evaluation to identify waste streams that may need to be segregated because of the potential of being hazardous
- Excluding materials that could become hazardous waste in the decontamination process (if any)
- Controlling transfer of materials and equipment between clean and contaminated areas
- Designing containment such that spread of contamination is minimized
- Deploying appropriate decontamination methods
Reuse and recycling opportunities also will be evaluated for waste, such as batteries, scrap metal, and equipment or materials that are no longer needed. Uncontaminated equipment that is determined to be excess will be evaluated for reused by other projects.

Wastes generated during the performance of LTM activities will be handled in accordance with the requirements provided in Section 5.0 of the Long-Term Monitoring Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) (USAF, 2016).

4.9 Site Restoration

Following delineation and remedial action activities at the former Site, site conditions will be restored to a similar state as initial conditions. It is not anticipated that any of the proposed actions will adversely impact the current topography of the former sewage lagoons requiring regrading. Any disturbances will be backfilled with clean fill to blend with surface topography and prevent ponding. Impacted areas will be reseeded with native vegetation.

Following regulatory approval of site closure, all existing monitoring wells will be abandoned according to the NMED Water Quality Bureau Monitoring Well Construction and Abandonment guidelines (NMED, 2011).

4.10 Site Surveying

Surveying of the locations (northing and easting) of new injection and monitoring well locations, and other pertinent site features will be conducted by a State of New Mexico-licensed surveyor. Elevation data for injection and monitoring wells will include the top of the PVC riser and ground surface elevation at the well locations. Surveying data will be provided in a spreadsheet format for import into the geographic information system, and the data will also be incorporated into the report figures.

Horizontal coordinates will be referenced to the New Mexico Central State Plane Coordinate System, and surveyed to an accuracy of ±1.0 foot. Vertical elevations will be referenced to North American Datum 1983 coordinate system to an accuracy of ±0.01 foot.

Geospatial information will also be submitted as a separate deliverable to the USAF. All applicable federal, U.S. Department of Defense, and USAF geospatial data standards will be followed. Spatial data will be compliant with the Spatial Data Standards for Facilities, Infrastructure, and Environment v2.6.

Each geospatial data set will be accompanied by metadata that conforms to the Spatial Data Facilities, Infrastructure, and Environment standards. The horizontal accuracy of any geospatial data created will be tested and reported in accordance with the National Standard for Spatial Data Accuracy, and the results will be recorded in the metadata.
5.0 TREATABILITY STUDY PHASE

The treatability study phase will be divided into two stages following installation of the initial injection well near KAFB-2622. The two stages consist of a push/pull test followed by a full-scale injection.

5.1 Push/Pull Test

A push/pull test will be performed on injection well WP26-INJ1. This is a small-scale proof of concept test designed to deliver substrate solution and the bioaugmentation culture laterally into the formation with a treatment area radius of approximately 5 ft. Performance monitoring will be conducted as outlined in Table 5-1. These analytical results, coupled with field measurements, will be used to assess if the injected bioaugmented substrate solution creates favorable conditions to support larger-scale biodegradation of the TCE and its daughter products. Additionally, data will be obtained regarding gravity-injection rates, which will impact planning for subsequent injections. Results of this test will be evaluated to determine whether to implement a full-scale injection at WP26-INJ1 and to refine procedures.

Table 5-1. Performance Monitoring Laboratory Analyses

<table>
<thead>
<tr>
<th>Analytical Group/Analyte</th>
<th>Analytical Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity (total, bicarbonate, and carbonate)</td>
<td>Standard Method 2320B</td>
</tr>
<tr>
<td>Ammonia, as nitrogen</td>
<td>EPA Method 350.1</td>
</tr>
<tr>
<td>Anions (bromide, chloride, fluoride, sulfate)</td>
<td>EPA Method 300.0</td>
</tr>
<tr>
<td>Nitrate/Nitrite, as nitrogen</td>
<td>EPA Method 353.2</td>
</tr>
<tr>
<td>Orthophosphate (as phosphorous)</td>
<td>EPA Method 300.0</td>
</tr>
<tr>
<td>Total organic carbon</td>
<td>SW-946 Method 9060</td>
</tr>
<tr>
<td>Sulfide</td>
<td>SW-846 Method 9034</td>
</tr>
<tr>
<td>Volatile organic compounds</td>
<td>SW-846 Method 8260B</td>
</tr>
<tr>
<td>Methane/ethane/ethene</td>
<td>RSK-175</td>
</tr>
<tr>
<td><em>Dehalococcoides</em> and three functional genes</td>
<td>CENSUS - Proprietary method of Microbial Insights, Inc. – quantitative polymerase chain reaction</td>
</tr>
</tbody>
</table>

The push/pull test includes the following sequential tasks:

- Extract and store groundwater from WP26-INJ1
- Prepare substrate solution in aboveground tanks
- Deoxygenate the injection well water column
- Reinject substrate solution and bioaugmentation culture
- Conduct post-injection performance monitoring.

Figure 5-1 shows a conceptual schematic of the gravity-injection system to be used as modified from the Revised Treatability Study Work Plan for In-Situ Bioremediation at the Technical Area-V Groundwater Area of Concern (Sandia, 2016).
Figure 5-1. Proposed Injection Layout – Extracted from Sandia Report
5.1.1 Groundwater Extraction from WP26-INJ1

The design of the push/pull test includes extracting the volume of groundwater necessary to be used for subsequent delivery of the substrate solution into saturated sediments to a radius of 5 ft from the injection well. It is estimated that approximately 3,000 gallons of groundwater will be sufficient. This volume is based on the design of a well screen set across the upper 20 ft of the saturated zone, and an estimated sediment porosity of 25 percent.

The groundwater will be extracted from WP26-INJ1 using an electrical submersible pump. The anticipated pumping rate would be less than 10 gallons per minute (gpm). Equal volumes of extracted groundwater will be stored onsite in two tanks, each storing approximately half the groundwater volume (1,500 gallons) and designated as Tank 1 and Tank 2.

5.1.2 Preparation of Substrate Solution in Aboveground Tanks

The initial Tank 1 solution will be:

- 1,500 gallons groundwater
- 4.8 kilograms (10.6 lbs) of KB-1® Primer
- 0.3 lbs sodium bromide (tracer)
- 8 lbs of WP26-INJ1 soil core/cutting from the well screen interval.

Tank 2 will hold the other 1,500 gallons of extracted groundwater until the solution in Tank 1 has been deoxygenated and has an ORP of less than negative 75 mV (the minimum required to sustain growth of KB-1® Dechlorinator). Tank 1 will then be filled with:

- 1,500 gallons of groundwater from Tank 2.
- 1.6 gallons of ethyl lactate (electron donor)
- 2.8 lbs of diammonium phosphate (nutrient and pH buffer)
- 0.5 lbs of yeast extract (nutrient)
- 0.3 lbs of sodium bromide (tracer).

After mixing the above contents in Tank 1, DO and ORP measurements will be taken of the substrate solution until deoxygenation and lowered ORP have been reestablished indicating it is ready for injection along with KB-1® dechlorinator. Deoxygenation may be accelerated by sparging the water with argon gas, if necessary.

Component ratios may be modified if analytical results from baseline sampling of the injection well are significantly different than currently detected in KAFB-2622.

5.1.3 Water Column Deoxygenation

Prior to injection, the aboveground injection line from the substrate solution mixing tanks will be connected to the injection casing at the wellhead (see Figure 5-1). The aboveground injection line and the injection casing in well WP26-INJ1 will be primed by draining a sufficient volume of deoxygenated substrate solution from the tank. A pre-injection of a sufficient amount of the substrate solution will be conducted to displace the water column in the injection well casing.
5.0 TREATABILITY STUDY PHASE

5.1.4 Reinject Substrate Solution and Bioaugmentation Culture into WP26-INJ1

Once the substrate solution has been deoxygenated and reducted to an ORP of less than negative 75 mv, it will be gravity-injected into the injection casing along with the KB-1® Dechlorinator (Figure 5-1). Injection will start with the substrate solution in the tank, quickly followed by mixing the KB-1® Dechlorinator. Argon will be used to displace the KB-1® Dechlorinator from its vessel for mixing during injection. Care will be taken to minimum turbulence during mixing and injection. A total of approximately 1.5 lbs of the KB-1® Dechlorinator will be needed for the 3,000 gallons of substrate solution.

A sample of the injected substrate solution will be collected as it is being injected and analyzed for the parameters listed in Table 5-1 and measured for field parameters (pH, specific conductivity, temperature, and turbidity). Depth to water measurements will be taken in all monitoring wells before, during, and after injection. Injection flow rate into the injection well will be routinely monitored. The injection rate will be reduced, if necessary, to ensure the water level in injection well W26-INJ1 does not exceed 150 feet above static water level to prevent damage to the well, as well as to preclude discharge to the ground surface. The injection rate of the push/pull test will be used to optimize procedures for subsequent injections.

5.1.5 Performance Monitoring of the Push/Pull Test

Performance monitoring of the push/pull test will commence after the target volume has been gravity-injected. The performance monitoring well network will consist of the nearby monitoring existing monitoring well, KAFB-2622; new monitoring wells KAFB-2633, KAFB-2634, and KAFB-2635; and existing monitoring well KAFB-2625. Post-injection performance monitoring will consist of weekly water level measurements, groundwater field parameter measurements, and groundwater sampling for analytical parameters for a period of eight weeks followed by monthly measurements and sampling for two months (a total of four months plus one month for final sample analysis and data validation). Table 5-1 lists the laboratory analyses that will be performed during each performance monitoring event.

Performance monitoring results will be evaluated to determine if the push/pull test is successful and that the Treatability Study should proceed to full-scale injection at WP26-INJ1. The evaluation criteria are listed below. Affirmative answers to these questions will support a decision to proceed to full-scale injection at WP26-INJ1. However, negative answers in and of themselves do not preclude further study, but would at least require re-evaluation of implementation procedures or the remedial approach before proceeding to full-scale injection.

1. Did the gravity-injection rate indicate that WP26-INJ1 could accommodate the planned rate for full-scale injection without exceeding the maximum pressure head in the monitoring casing?

   This will be determined by measuring the injection rate and water levels in the injection well.

2. Did groundwater conditions at well WP26-INJ1 become and remain conducive to dechlorinating TCE and its daughter products?

   Multiple lines of evidence that the injection is being effective at creating an environment that will stimulate in situ bioremediation include:

   a. Dissolved oxygen concentrations established and maintained well below 1 mg/L;
   b. Oxidation-reduction potential measurements established and maintained at or below -75 mv;
   c. Increases in orthophosphate concentrations;
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d. Decreases in nitrate and sulfate concentrations; and
e. Increases in iron, manganese, or arsenic concentrations.

3. Was a sufficient population of *Dehalococcoides* (with vinyl chloride reductase) established to facilitate complete dechlorination at WP26-INJ1?

4. Did TCE concentrations in well WP26-INJ1 demonstrate a decreasing trend that will reach MCLs within the anticipated time frame?

Concentration decreases indicate either in situ bioremediation is working or combined with the result of dilution, but support a decision to proceed with full-scale injection at WP26-INJ1.

5. Did bromide concentration initially increase and then attenuate during post-injection monitoring?

An initial increase in bromide concentration at a given location indicates that the substrate solution has been delivered to that point. Subsequent attenuation suggests advection of surrounding groundwater into the push/pull treatment area.

6. Were TCE dechlorination daughter products produced?

An increase followed by a decrease in TCE daughter products indicates dechlorination is occurring. Because concentrations of TCE are initially very low, it may be difficult to detect some or all daughter products. Inability to quantify dechlorination daughter products does not, in and of itself, indicate a lack of complete dechlorination.

Additionally, stability of pH and increases in iron, manganese, and arsenic concentrations will be monitored. Increases in dissolved iron, manganese, and arsenic can be expected within the anaerobic treatment area, but should re-precipitate as they migrate with groundwater back into aerobic environments.

Results from the push/pull test will be evaluated against the above criteria to determine whether full-scale injection should proceed and if changes in implementation procedures are necessary to optimize full-scale injection and performance monitoring. Results of the push/pull test and any associated revisions to procedures will be communicated to the Air Force and NMED at least 60 days prior to proceeding with full-scale injection at WP26-INJ1.

5.2 Full-Scale Injection at WP26-INJ1

The objective of full-scale injection is to deliver substrate solution and bioaugmentation culture to the treatment area thereby facilitating dechlorination of TCE and any daughter products in the perched aquifer underlying the former sewage lagoons to concentrations below MCLs.

5.2.1 Full-Scale Injection

Full-scale injection will involve mixing substrate solution components at prescribed ratios at prescribed ratios provides in Table 4-2 with potable water in two pairs of 5,000-gallon tanks (i.e., four 5,000-gallon tanks), deoxygenating the solution in the tanks and establishing an oxidation-reduction potential below -75 mV. As in the push/pull test, the initial injection batch will be deoxygenated with KB-1® Primer and inoculated with WP26-INJ1 soil core/cuttings. Once the first pair of tanks are deoxygenated, the aboveground injection line and the injection casing will be primed and the water column in the injection casing will be deoxygenated. The 5,000 gallons (2,500 gallons from each tank) will be injected into
5.0 TREATABILITY STUDY PHASE

WP26-INJ1 along with the bioaugmentation culture. The tanks will be refilled with potable water and commensurate amounts of ethyl lactate, diammonium phosphate, yeast extract, and sodium bromide.

During the anticipated one to two days for the first pair of tanks to re-establish anaerobic conditions and an oxidation-reduction potential less than -75 mv, 5,000 gallons of deoxygenated and low-oxidation-reduction potential substrate solution will be injected from the second pair of 5,000-gallon tanks along with the bioaugmentation culture. The second pair of tanks will then be refilled with potable water and the associated substrate solution components like the first pair of tanks. Injection can proceed to the first pair of tanks while the second pair of tanks are being refilled and deoxygenated. This process of alternating two pairs of tanks will continue for the duration of the injection provided in facilitates the most optimal injection schedule. By having two pairs of 5,000-gallon tanks onsite, the planned schedule assumes one 5,000-gallon batch can be injected per 8-hour work day by alternating deoxygenation and ready-to-inject pair of tanks each day.

The total amount of substrate solution required for injection will be determined based on results of the push-pull test. If monitoring results at monitoring well KAFB-2622 indicate that the substrate solution has reached that well and created the desired reducing conditions, injection operations will be suspended to confirm that these conditions are stable. Injection will also be suspended if analytical results in other monitoring wells demonstrate unanticipated increases in concentrations of constituents of concern.

Prior to daily injection, the dissolved oxygen will be measured in the injection well water column to ensure it is sustaining anaerobic conditions. If not, it will be deoxygenated prior to injection. During injection, dissolved oxygen, oxidation-reduction potential, and pH will be monitored in injection well WP26-INJ1 using downhole electronic probes and a data logger. Water levels will also be frequently monitored immediately prior to injection and throughout each work day during injections. Additionally, wells KAFB-2622, KAFB-2625, KAFB-2633, KAFB-2634, and KAFB-2635 will be monitored monthly during injection for the analyses outlined in Table 5-1, as well as field parameters.

Each daily injection batch will be followed with approximately 100 gallons of chase water consisting of unamended potable water deoxygenated by sparging with argon gas. This is intended to push substrate solution away from the well screen and surrounding filter pack pore space and into the formation to mitigate localized biofouling.

5.2.2 Performance Monitoring of the Full-Scale Injection

Performance monitoring of the full-scale injection will commence after the target volume has been gravity-injected and within one month of the last sampling event conducted during injection. The performance monitoring well network will continue to consist of wells KAFB-2622, KAFB-2625, KAFB-2633, KAFB-2634, and KAFB-2635. Post-injection performance monitoring will be conducted for a total of 24 months at a monthly frequency for three months followed by quarterly monitoring for the remainder of the post-injection monitoring period. Table 5-1 lists the required analyses. Field parameters will be collected from each well during each monitoring event.

Within six months after the full-scale injection is completed, sufficient data should be available to determine if the full-scale injection at WP26-INJ1 is successful. This will also be the point at which a decision is reached as to whether additional injection wells are warranted. In brief, if data trends indicate that TCE concentrations within the WP-026 monitoring network are declining at a rate sufficient to drop below MCLs within a three year timeframe, monitored natural attenuation will continue and no additional injection wells will be installed. Conversely, if indications are that additional injection well(s) are needed to drive TCE concentrations to levels below the MCL within the 3 year timeframe, a technical memorandum will be submitted to the Air Force and NMED recommending the locations for the new
injection well(s). Upon concurrence with the recommended locations for the new injection well(s), the new wells will be installed and full scale injections at those locations will proceed following the same approach as described above for WP26-INJ1. Additional evaluation criteria include the following questions. As with the push-pull test, affirmative answers support proceeding to installation of additional injection wells. However, negative answers do not preclude further study, but would at least require re-evaluation of implementation procedures or the remedial approach prior to proceeding.

1. Was the planned full-scale injection volume injected within the anticipated time frame?

   Lower than anticipated full-scale injection volumes or longer time frames may render future injections impractical or require revision to procedures.

2. Did groundwater conditions in wells WP26-INJ1 and KAFB-2622 become and remain conducive to dechlorinating TCE and the daughter products?

   Multiple lines of evidence that the injection is being effective at creating an environment that will stimulate in situ bioremediation include:
   
   a. Dissolved oxygen concentrations established and maintained below 1 mg/L.
   b. Oxidation-reduction potential measurements established and maintained at or below -75 mv.
   c. Increase in orthophosphate concentration.
   d. Decreases in sulfate and nitrate concentrations.
   e. Increases in iron, manganese, or arsenic concentrations.

3. Was a sufficient population of *Dehalococcoides* (with vinyl chloride reductase) established to facilitate complete dechlorination both at WP26-INJ1 and at KAFB-2622?

   Over $10^7$ gene copies/liter indicates a high potential for complete dechlorination.

4. Did TCE concentrations in wells WP26-INJ1 and KAFB-2622 decrease below MCLs?

   Concentrations decreases indicate either in situ bioremediation is working or combined with the result of dilution, but support a decision to continue with full-scale injections at new injection wells if trends do not support monitored natural attenuation within the defined time frame.

5. Did bromide concentration initially increase and then attenuate during post-injection monitoring?

   An initial increase in bromide concentration at a given location indicates that the substrate solution has been delivered to that point. Subsequent attenuation suggests advection of surrounding native groundwater into the treatment area.

6. Were TCE dechlorination daughter products produced?

   An increase followed by a decrease in TCE daughter products indicates dechlorination is occurring. Because concentrations of TCE are initially very low, it may be difficult to detect some or all daughter products. Inability to quantify dechlorination daughter products does not, in and of itself, indicate a lack of complete dechlorination.

7. Did results from other monitoring wells support the conclusion that further injections will not adversely impact perched groundwater?
Increases in bromide concentrations and increased concentrations of TCE or associated daughter products in the monitoring network could indicate that further injection may adversely impact perched groundwater.

The monitoring data collected during the full-scale injection and during the six months after injection is completed will be evaluated against the above criteria to determine if the treatability study should proceed to the installation of additional injection wells. These interim performance results and any associated revisions to procedures will be communicated to the NMED along with the recommendation as to future actions.

5.3 Impact on Groundwater and Additional Monitoring

Biodegradation is intended to reduce TCE concentrations in the aquifer through reductive dechlorination. Reductive dechlorination occurs under anaerobic and reducing conditions in the perched aquifer. The process of developing strongly anaerobic redox conditions is likely to result in solubilization and mobilization of some naturally occurring oxidized metals and metalloids, most particularly iron, manganese, and arsenic, as a result of direction reduction and mineral dissolution. Increases in dissolved iron and manganese concentrations are indicators of biodegradation in an anaerobic and reducing environment. However, the solubilization of these metals is generally a transient phenomenon and is limited to the treatment zone. Solubilized metals and metalloids will precipitate into solid form once they leave the anaerobic treatment zone or after the aquifer returns to aerobic conditions in the treatment zone.

Concentrations of dissolved iron, manganese, and arsenic will be monitored within the treatability study treatment zone (refer to Table 5-1). In order to monitor the impact of substrate solution discharge on groundwater outside the treatment zone, wells KAFB-2622, KAFB-2625, KAFB-2633, KAFB-2634, and KAFB-2635 will be monitored for dissolved iron, manganese, and arsenic. These wells are chosen because of their proximity to the treatment zone as wells nearest to the in situ bioremediation injection. Dissolved iron, manganese, and arsenic will be monitored on a quarterly basis.
6.0 FIELD PROCEDURES

This section summarizes the procedures that will be followed in the field for collection of vadose zone soil samples during drilling, screening soil samples for VOCs using a photoionization detector (PID), collecting groundwater samples in support of the treatability study, and subsequent full-scale implementation (if necessary), collecting groundwater level measurements, performing the slug test, and decontaminating equipment.

6.1 Vadose Zone Soil Sampling

Vadose zone soil samples will be collected using split spoon samplers.

- Verify calibration checks on field monitoring equipment have been performed.
- Don personal protective equipment as specified in the health and safety plan.
- Determine the ambient VOC background levels in the immediate vicinity with a PID.
- Advance the split spoon sampler to the desired depth and retrieve the soil sample.
- Open the sampler taking care to minimize disturbance of the sample.
- Using the Munsell Soil Color Charts, visually describe the material and record observation on the soil sample field data sheet. Classify any pieces of gravel found as granitic, phyllitic, or calc-silicate, if possible.
- Obtain VOC and TPH-GRO samples directly from the sample material immediately upon opening to minimize loss due to volatilization. Sample material will be collected using samplers provided by the laboratory following the accompanying procedure specific to the sampler.
- Following collection of VOC and TPH-GRO samples, the remaining material will be transferred to a stainless steel mixing bowl and mixed to homogenize the soil.
- Soil samples for the remaining analyses will be collected in appropriate sample jars provided by the analytical laboratory.
- All equipment that has come in contact with soil will be decontaminated in accordance with the requirements outlined in Section 6.6.

6.2 Field Measurements

Soil samples will be screened for VOCs using a PID.

1. Prior to use, calibrate the PID using the isobutylene calibration gas.
2. Connect new, clean tubing from the valved sampling port to a new Tedlar® bag.
3. Connect new, clean tubing from the Tedlar® bag outlet to the pump.
4. Open the valve to the sampling port.
5. Turn on the pump and draw a minimum of three purge volumes from the sampling port.
6. Following the purge, fill the bag and close the bag valves.
7. Turn off the pump.
8. Disconnect the tubing between the Tedlar® bag and the sampling port.
9. Close the sampling port valve.
10. Attach the PID to the tubing connected to the Tedlar® bag.
11. Open the valve allowing the PID to draw the sample through the instrument.
12. Obtain a reading from the PID and record the reading in the field logbook.
13. Close the valve leading from the Tedlar® bag to the PID.
14. Disconnect the PID from the tubing connected to the Tedlar® bag.
15. Dispose of the Tedlar® bag and used tubing.

6.3 Groundwater Sampling

Groundwater samples will be collected in accordance with the requirements described below:

Before purging or sampling, pumps and hoses, water level measurement devices, and other sampling equipment that may come in contact with the sample will be decontaminated in accordance with procedures outlined in Section 3.6, with the exception of equipment still in the original packaging (for example, disposable bailers). While decontamination of the pump/hose assembly may generally be performed at a central decontamination area, mobile decontamination supplies will be available so that accessory equipment (e.g., electronic water level indicators) can be decontaminated in the field.

The purpose of well purging is to remove stagnant water from the well and obtain a representative sample from the geologic formation being sampled while minimizing disturbance of the water column during sample collection. A minimum of three pore volumes will be purged from the well prior to sample collection. The low-flow purge methodology will be followed as described below:

1. Inspect the well and surrounding area for security, damage, and evidence of tampering.
2. Establish the exclusion zone around the work area, using traffic cones and caution tape where necessary.
3. Don personal protective equipment as specified in the project-specific Health and Safety Plan or Safe Work Plan, as applicable.
4. Locate the well survey reference point. This is usually an indelible mark or V-notch cut in the top of the well casing. If this point is missing, make one on the north side of the well casing.
5. Measure the static water level in the well in accordance with Section 3.4.
6. Containerize wastewater until analytical data are available to determine the proper disposal process.
7. Install the pump to the depth prescribed in the sampling documentation. This depth should correspond to approximately the middle of the screened interval, five feet below the water table or in the instance where the well screen is submerged, 5 feet below the top of the screen.
8. Reinsert the water level meter to monitor water levels during purging.
9. Start the pump at a low flow rate until surface discharge occurs. Check the water level, if no drawdown occurs, gradually increase the pump rate until the flow is optimized with minimal drawdown. The maximum allowable drawdown is 0.3 feet.
10. Connect the pump discharge tubing directly to the flow-through-cell of the multi-parameter meter.
11. Using a stopwatch and appropriate volume measuring device (e.g., graduated cylinder), monitor and record water level and pumping rate every three to five minutes (or as appropriate) during purging.

12. During well purging, monitor selected indicator field parameters (e.g., turbidity, temperature, specific conductance, pH, oxidation-reduction potential, dissolved oxygen) every three to five minutes using the multiple parameter water quality meter.

13. When the field parameters have stabilized, disconnect the flow cell from the water path before collecting samples. Water samples for laboratory analyses must be collected before the water has passed through the cell to prevent cross-contamination or chemistry changes. Stabilization is achieved when three consecutive readings show the following:
   - Temperature – ± 1 degree Celsius
   - pH – ± 0.1 pH unit
   - Turbidity – ≤ 10 NTU or ± 10%
   - Conductivity – ± 5%
   - Dissolved Oxygen – ± 10%
   - Oxidation-Reduction Potential – ± 10 millivolts

Regardless of the purging methodology, samples for laboratory analyses will be collected immediately following purging. For wells that were purged dry, samples will be collected as soon as possible after a sufficient volume of groundwater is available in the well. The following sampling procedure will be used at each well:

1. Immediately following purging, the pump will be used to collect the groundwater sample. The pump should not be removed between purging and sampling.
2. Fill out identification labels for samples bottles for each well.
3. Fill containers until almost full. Samples will be preserved and managed in accordance with the analytical method.
4. Record the sampling information in the field logbook and/or the field data sheets.
5. After samples have been collected, immediately place the samples in a cooler with ice for transport to the analytical laboratory.
6. Complete all chain-of-custody information.

Remove the pump and equipment from the well, replace the well cap, and secure the lock.

6.4 Groundwater Level Measurements

Groundwater elevation measurements will be collected each time the well is sampled. This will be done before any water is withdrawn from the well and before any purging or sampling equipment enters the well. The following steps will be followed for obtaining the water level in the well:

1. Test the water level probe to ensure that it is working properly.
2. Decontaminate the water level indicator probe as described below in Section 3.6.
3. Unlock and open the well. If necessary, let the well vent any gases that may be present in the well casing. Also, this allows the water to equilibrate to barometric changes.

4. After opening the well cover, locate the water level measuring point. If a measuring point is not marked, the measurement should be taken from the north side of the well casing, if possible.

5. With the water level indicator switched on, slowly lower the probe until it contacts the water surface as indicated by the audible alarm.

6. Raise the probe out of the water until the alarm turns off. Three or more measurements will be taken at the well until two measurements agree to within +/- 0.01 feet.

7. Record the reading on the cable at the established reference point to the nearest 0.01 foot on the field data sheet. In addition, document the measuring point location. Compare the measurement with past measurements to verify that the measurement is reasonable before leaving the well. If the measurement does not seem reasonable, repeat the water level measurement.

8. If the water level indicator fails to activate and is operating properly, lower the water level probe to the bottom of the well to ensure that the well is dry. Document that the well is dry, and record the total depth of the well.

During the course of collecting water level measurements, observations of well condition will be collected and recorded. Water level measurements will be collected from the groundwater monitoring wells located at WP-026 during each groundwater sampling event. Static water levels and total well depth will be measured prior to purging activities.

6.5 Slug Testing

In a slug test, a known volume of water or solid slug is rapidly removed from or introduced into a well, after which the rate in the rise or fall of the water level in the well is measured. From these measurements, the hydraulic conductivity or transmissivity of the aquifer materials in the vicinity of the well can be estimated.

Slug testing is well suited for gaining a preliminary estimate of aquifer parameters in areas where no observation wells are available or hydraulic conductivities are too small to conduct a pumping test. In the case of WP-026, the saturated thickness of the perched aquifer is estimated to be less than 20 feet precluding an accurate performance of a pumping test making slug testing the preferred alternative.

6.5.1 Testing Equipment

The following equipment is required for conducting the slug tests:

1. Electronic water level measuring device (sounder) and back-up unit;
2. A “slug” (a solid volume that will fit easily into the well; a solid slug can be a sealed sand or water-filled length of clean polyvinyl chloride [pvc] pipe);
3. Low pounds per square inch pressure transducer with downhole logger, line, and hangers for suspending the unit in the well;
4. Laptop computer or device for communicating with the datalogger and communication cables;
5. Slug test data forms; and
6. Decontamination equipment for cleaning downhole equipment prior to installation in each well.
With the exception of Well KAFB-0506 which is 5-inch diameter, all other perched wells installed at the WP-026 sewage lagoons are 4-inch diameter. Table 6-1 provides the displacement calculations for a slug design.

### Table 6-1. Slug Design Displacement Calculations

<table>
<thead>
<tr>
<th>Well Nominal pipe diameter (inches)</th>
<th>Well Inside diameter sched 40 (inches)</th>
<th>Slug Nominal pipe diameter (inches)</th>
<th>Slug Outside diameter sched 40 (inches)</th>
<th>Annular Space (inches)</th>
<th>Well Volume (ft³/ft)</th>
<th>Slug Volume (ft³/ft)</th>
<th>Minimum length of Slug (feet)</th>
<th>Well Displacement (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3.998</td>
<td>3</td>
<td>3.500</td>
<td>0.249</td>
<td>0.087</td>
<td>0.067</td>
<td>4.5</td>
<td>3.45</td>
</tr>
<tr>
<td>5</td>
<td>5.016</td>
<td>4</td>
<td>4.500</td>
<td>0.258</td>
<td>0.137</td>
<td>0.110</td>
<td>4.0</td>
<td>3.21</td>
</tr>
</tbody>
</table>

**ft³** – cubic feet  
**ft³/ft** – cubic feet per foot

#### 6.5.2 Slug Construction

Slug construction will consist of the following:

1. For 4-inch diameter, Schedule 40 wells, use 4.5 feet of 3-inch diameter thin-wall PVC;
2. For 5-inch diameter, Schedule 40 wells, use 4.0 feet of 4-inch diameter thin-wall PVC;
3. Use flush mount, slip joint bushings;
4. Drill and mount eyebolt, seal with silicone caulk;
5. Attach bottom cap/plug with pop rivet or low-VOC glue;
6. Fill slug with sufficient sand to exceed the buoyancy of the PVC pipe;
7. Secure the top cap/plug with low VOC glue or pop rivet; and
8. Hang on enough sturdy rope to suspend below the water level in all wells.

#### 6.5.3 Slug Test Performance

Follow the procedures below to conduct the slug testing:

1. Conduct slug testing only during stable weather conditions (steady barometric pressure) when the threat of sudden storms or barometric pressure changes are minimal. Document atmospheric conductions in the logbook and on the field data forms.
2. Use weather service data to check for possible barometric effects on the data.
3. Establish the work zone as directed in the project health and safety plan.
4. Decontaminate all equipment that will enter the well in accordance with Section 6.6.
5. Measure the depth to static water with the water level indicator and record the reading in the field logbook and on the field data forms.
6. Use a transducer and downhole logger with the lowest possible pressure rating requiring minimum submergence appropriate for the estimated hanging position and required submergence. Set the record time at the shortest interval. Short measurement intervals will ultimately result in better data. Test the transducer calibration and programming in a bucket of water or PVC pipe by...
raising or lowering the transducer and comparing the known change with the change indicated by
the pressure transducer.

7. Please the pressure transducer inside the well casing, ensuring that the height of the water column
above the transducer is sufficient for it to remain under water and function efficiently even at
maximum drawdown. Hang the transducer 10 feet above the point of maximum submergence for
the pressure rating of the transducer, or 1 foot above the top of fill in the well, whichever is the
smaller depth that is still deeper than the bottom of the slug when submerged below static water
level. Throughout the test, the slug should always be above the transducer in the well casing.
Hang the transducer such that is cannot slip. Mark the transducer suspension line so that any
slippage or lack thereof can be documented. Start the data logger and collect a minimum of 10
minutes of background data to document the water level is stable.

8. Set up the slug rope with two hanging points (rope knotted loops); #1 for hanging the slug with
the bottom one foot above the static water level (pre-test), and #2 for hanging the slug with the
top one foot below the static water level (testing position).

9. Hang the sounder one foot above the top of the slug at #1 position.

**Slug Introduction Test**

Slug data from slug removal is preferable to slug introduction, but both will be collected. Slug
introduction data are influenced by the larger saturated column with the part above static water level
being variably saturated, but may still be useful for comparison.

1. Lower the slug as quickly as possible and hang in position #2.
2. Collect manual sounder measurements as quickly as possible at first. Use a stop watch to record
time of measurements, with lap mode to record time as accurately as possible. If the transducer
fails, this manual data may be used.
3. Collect data until the water level has returned to the pre-test static water level. As the rate of
water level change slows, the measurement interval can be spaced out appropriately.
4. Collect a minimum of 10 minutes of data after reaching the pre-test static water level to document
that the level is stable.

**Slug Removal Test**

Remove sounder from well. Remove slug from well as rapidly as possible. Lower the sounder and take
manual measurements as rapidly as possible, recording measurement time.

1. Conduct manual measurements until the water level recovers to at least 90 percent of the static
water level allowing the well to full recover, if possible, before removing the pressure transducer.
Enter manual measurements into the field forms.
2. Remove the transducer, download the data, and compare to manual measurements.
3. Conduct the slug test on relatively undisturbed wells. If a slug test is conducted on a well that has
recently been purged for sample collection, the water level must be within 0.10 feet of the pre-
purge water level before initiating the slug test. The measurement of water levels over several
days will indicate when equilibrium is achieved and slug testing can be conducted.
4. If possible, plot well recovery curves in the field to evaluate the success of the test. The use of electronic data loggers and laptop computers allows field evaluation to be completed relatively quickly. If the data are too irregular to fit curves or straight lines, the field personnel will determine whether retesting is necessary.

5. Any water added to the well will be from a known uncontaminated source that has undergone laboratory analysis. Properly containerize any water removed for disposal according to procedures outlined in the groundwater monitoring plan.

Slug test data will be documented in the field logbook and on field data forms.

### 6.6 Decontamination

Non-dedicated sampling equipment will be decontaminated following the procedures described below:

Procedures for decontamination of sampling equipment apply to:

- Reusable equipment that will and has come in contact with a sample medium
- Wash and rinse tubs/buckets
- Water levels probes
- Sample bottles and coolers.

Disposable items such as disposable filters and tubing that are certified clean by the manufacturer are not subject to decontamination requirements. Decontamination of sampling equipment will in general be performed at individual sample locations. However, any pre-rinsing or decontamination of reusable equipment prior to sampling can be performed at other specified locations suitably established for such activities.

1. Don appropriate PPE as specified in the project-specific HASP. To note, new latex gloves shall be worn when performing equipment decontamination.
2. Scrape off gross contamination from equipment at the sampling site and place in containers specified for investigation-derived waste (IDW).
3. Place the equipment in a wash tub containing detergent solution or spray the equipment with a detergent solution contained within a water sprayer. Scrub the equipment with a bristle brush or similar utensil (if possible).
4. Triple rinse the equipment with deionized or distilled water from a water sprayer or wash bottles catching the rinsate in a second wash tub or bucket.
5. In a third wash tub or bucket, rinse equipment with a 10% nitric acid solution or reagent grade methanol, as applicable. A nitric acid rinse will be used when samples are collected for metals analysis with a methanol rinse used for collecting semi-volatile organic compounds.
6. Re-rinse the equipment with deionized or distilled water (note that if time allows for air drying after performing a methanol rinse, this step shall be omitted.
7. Allow equipment to gravity drain or air dry.
7.0 REPORTING

Reporting will be comprised of a Interim Measures Report and annual LTM reports.

7.1 Interim Measures Report

Documentation of the project will include field notes and forms, photographs (if allowed), and analytical data. The Interim Measures Report will be prepared following completion of the interim measures detailing the activities conducted to address contamination at the Site. The report will be submitted for USAF and NMED review. The Interim Measures Report will include, at a minimum, the following elements:

- A description of the interim measures implemented
- As-built drawings showing the injection well and monitoring well construction diagrams including the well installation details
- Summaries of LTM analytical results
- Summaries of problems encountered and deviations from the planned work scope
- Summaries of accomplishments and/or effectiveness of the interim measures
- Recommendations for disposition of the site.

The Interim Measures Report will include VLEACH vapor modeling and an evaluation of risk associated with any residual constituents that remain in the vadose zone and groundwater underlying the site. VLEACH is a one-dimensional, finite difference model used to make preliminary assessments of the effects on groundwater from the leaching of volatile, sorbed constituents through the vadose zone. The program models four main processes including liquid-phase advection, solid-phase sorption, vapor-phase diffusion, and three-phase equilibration. The software is available on-line at the following EPA web address: http://www.epa.gov/ada/csmos/models/vleach.html

7.2 Long-Term Monitoring Reports

Annual LTM reports will be prepared to document the results of the groundwater sampling and well gauging activities completed during the fiscal year. The annual monitoring reports will provide evaluation of the data and associated trends and provide recommendations as to future monitoring requirements and optimization actions. Concentration versus time trend analysis for key constituents will be performed using appropriate statistical analysis software such as the Monitoring and Remediation Optimization System, which was developed by GSI Environmental Inc. of Houston, Texas and the University of Houston for the Air Force Center for Environmental Excellence in accordance with the organization’s Long-Term Monitoring Optimization guide. Other appropriate statistical methods may be employed with approval of the USAF.

In addition to the above reports, analytical data will be exported for upload to AFCEC’s Environmental Restoration Program Information Management System database within 90 days of sample collection.
8.0 PROJECT SCHEDULE

An integrated master schedule has been prepared for the overall anticipated sequence of activities to be performed in support of the interim measures at the Site. The schedule is depended on many independent factors including, but not limited to, USAF and NMED review and comment, subcontractor availability, weather, and site conditions. The USAF and NMED will be notified 30 days prior to the implementation of interim measure field activities. Additionally, during implementation of the interim measures, monthly status reports will be submitted to Kirtland AFB ERP personnel by electronic mail. These reports will summarize the previous week’s activities, the planned activities for the following week, and any other pertinent information.

The interim measures implementation schedule will allow for evaluation of screening level data during field work to allow for timely response to changing conditions. Post-interim measures groundwater monitoring will be conducted to monitor effectiveness of the interim measures implemented, to augment the implemented interim measures with additional actions if determined to be necessary in order to achieve the project objectives, and to demonstrate that the interim measures have successfully addressed contamination at the site based on mitigation of contaminant impacts on groundwater underlying the site thereby supporting a corrective action completion without controls determination.

The Interim Measures Report will be submitted for review and approval by USAF and NMED personnel.
9.0 REFERENCES


APPENDIX A

ELECTRON DONOR DEMAND AND MASS CALCULATIONS
ELECTRON DONOR DEMAND AND MASS CALCULATIONS

The following spreadsheets present the calculations to estimate the mass of ethyl lactate needed to meet electron donor demand in groundwater within the projected treatment area for each full-scale injection to be implemented during the treatability study.

The spreadsheet first presents the dimensions of the treatment area for one injection location. Subsequent injection locations, if needed, are assumed to have the same treatment zone dimensions and effective porosity. Electron donor demand also used electron acceptor concentrations from monitoring well KAFB-2622 where constituent concentrations are highest. Electron donor demand calculations will be performed on a location-specific basis based on initial sampling results from injection wells once they are installed and these results will be used to refine substrate solution constituent ratios prior to injection.

Electron donor demand was divided into two categories that calculate demand based on a stoichiometric ratio:

- Electron donor demand for competing terminal electron acceptors (TEAs)
- Electron donor demand for dissolved volatile organic compounds (VOCs)

Based on work previously performed by Sandia National Laboratory as presented in Appendix A of the Revised Treatability Study Work Plan for In-Situ Bioremediation at the Technical Area-V Groundwater Area of Concern (Sandia, 2016), electron donor demand for VOCs sorbed to saturated soil is negligible; therefore, the calculation was not performed for this category.

As discussed in the Sandia work plan, experience from projects at similar sites shows that the theoretical stoichiometric value is often not sufficient to create the desired conditions. Research has shown that only 30 percent of the electron donor is utilized for dechlorination (referred to as the ‘McCarty’ factor). The McCarty factor was applied to calculate electron donor demand based on stoichiometry. A safety factor of 10 was then applied based on Sandia’s field experience and to account for low permeability of the saturated sediments at the site.

Estimated delivery timeframe per full-scale injection is also presented based on the assumption that 5,000 gallons per day of potable water mixed with the electron donor, amendments, and bioaugmentation culture could be gravity-injected each work day, plus an additional three weeks to allow for system setup and optimization.

Due to very low concentrations of VOCs, the electron donor demand is almost completely governed by concentrations of competing terminal electron acceptors in groundwater (dissolved oxygen, nitrate, iron, manganese, and sulfate). The bulk of electron donor will be adjusted in-situ for reductive dechlorination to take place.
Electron Donor (Ethyl Lactate) Demand and Mass Calculations

<table>
<thead>
<tr>
<th>Dimensions of Treatment Area (one injection well)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivery Radius (ft)</td>
</tr>
<tr>
<td>Area (ft²)</td>
</tr>
<tr>
<td>Thickness (ft)</td>
</tr>
<tr>
<td>Total Target Volume (ft³)</td>
</tr>
<tr>
<td>Total Target Volume (CY)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electron Donor Demand for Competing Terminal Electron Acceptors (TEAs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal Electron Acceptor</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
</tr>
<tr>
<td>Nitrate</td>
</tr>
<tr>
<td>Iron</td>
</tr>
<tr>
<td>Manganese</td>
</tr>
<tr>
<td>Sulfate</td>
</tr>
<tr>
<td>Electron Donor: Ethyl Lactate</td>
</tr>
<tr>
<td>Total electron donor demand (mg/L)</td>
</tr>
<tr>
<td>Treatment area pore volume (L)</td>
</tr>
<tr>
<td>Total electron donor demand (mg)</td>
</tr>
<tr>
<td>Total electron donor demand for competing TEAs (lbs) - rounded to nearest 0.1 lb</td>
</tr>
</tbody>
</table>
## Electron Donor Demand for Dissolved Volatile Organic Compounds

<table>
<thead>
<tr>
<th>Volatile Organic Compound</th>
<th>Concentration (µg/L)</th>
<th>Molecular Weight (g/mol)</th>
<th>Molar Ratio (mol electron donor/ mol VOC)</th>
<th>Electron Donor Demand (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetrachloroethene</td>
<td>0</td>
<td>165.8</td>
<td>1/3</td>
<td>0.0000</td>
</tr>
<tr>
<td>Trichloroethene</td>
<td>15</td>
<td>131.4</td>
<td>1/4</td>
<td>3.3704</td>
</tr>
<tr>
<td>cis-1,2-Dichloroethene</td>
<td>3.5</td>
<td>96.9</td>
<td>1/6</td>
<td>0.7110</td>
</tr>
<tr>
<td>Vinyl Chloride</td>
<td>0</td>
<td>62.5</td>
<td>1/12</td>
<td>0.0000</td>
</tr>
<tr>
<td>Electron Donor: Ethyl Lactate</td>
<td></td>
<td></td>
<td></td>
<td>118.1</td>
</tr>
</tbody>
</table>

Subtotal electron donor demand (µg/L) (based on ethyl lactate) 4.081

Treatment area pore volume (L) 1,601,280

Total electron donor demand (mg) 6,535,449

Total electron donor demand for competing TEAs (lbs) - rounded to nearest 0.1 lb 0.014

### Mass of Electron Donor to be Injected

- Total electron donor demand for competing terminal electron acceptors (lbs) 178.2
- Total electron donor demand for dissolved volatile organic compounds (lbs) 0.014
- Total electron donor demand as ethyl lactate (lbs) 178.2
- Adjusted total accounting for the McCarty Factor (30% efficiency) (lbs) 594
- Safety factor for Low K sediment 10
- Total electron donor to be injected in one pore volume (lbs) 5,940
- Total electron donor to be injected per 1,000 gallons of water (lbs) 8.9
## Injection Timeframe

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Volume (gal)</td>
<td>423,013</td>
</tr>
<tr>
<td>Number of injection wells</td>
<td>1</td>
</tr>
<tr>
<td>Total injection volume (gal)</td>
<td>423,013</td>
</tr>
<tr>
<td>Batch volume (gal)</td>
<td>5,000</td>
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<tr>
<td>Batches per day</td>
<td>1</td>
</tr>
<tr>
<td>Estimated injection rate (gal per day)</td>
<td>5,000</td>
</tr>
<tr>
<td>Total injection batches for one pore volume (rounded up to the nearest whole batch)</td>
<td>85</td>
</tr>
<tr>
<td>Total injection timeframe (days)</td>
<td>85</td>
</tr>
<tr>
<td>Total injection timeframe (weeks) - assumes 5 days per week plus 3 weeks for system set-up, optimization, and demobilization.</td>
<td>20</td>
</tr>
</tbody>
</table>

CY – cubic yard  
ft – feet  
ft² – square feet  
ft³ – cubic feet  
gal – gallon  
g/mol – grams per mole  
L - liter  
lbs – pounds  
mol - mole  
TEA – terminal electron acceptor  
µg/L – micrograms per liter  
VOC – volatile organic compound
**Dimensions of Treatment Area (one injection well)**

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Delivery Radius (ft)</td>
<td>60</td>
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<tr>
<td>Area (ft$^2$)</td>
<td>11,310</td>
</tr>
<tr>
<td>Thickness (ft)</td>
<td>20</td>
</tr>
<tr>
<td>Total Target Volume (ft$^3$)</td>
<td>226,195</td>
</tr>
<tr>
<td>Total Target Volume (CY)</td>
<td>8,378</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
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<tbody>
<tr>
<td>Effective Porosity</td>
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<tr>
<td>Volume of Soil Matrix (CY)</td>
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<tr>
<td>Pore Volume (ft$^3$)</td>
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</tr>
<tr>
<td>Pore Volume (L)</td>
<td>1,601,280</td>
</tr>
<tr>
<td>Pore Volume (gal)</td>
<td>423,013</td>
</tr>
</tbody>
</table>

**Electron Donor Demand for Competing Terminal Electron Acceptors (TEAs)**

<table>
<thead>
<tr>
<th>Terminal Electron Acceptor</th>
<th>Concentration (mg/L)</th>
<th>Molecular Weight (g/mol)</th>
<th>Molar Ratio (mol electron donor/mol TEA)</th>
<th>Electron Donor Demand (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved Oxygen</td>
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<td>3.7152</td>
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<tr>
<td>Nitrate</td>
<td>3.8</td>
<td>62</td>
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</tr>
<tr>
<td>Iron</td>
<td>0</td>
<td>55.9</td>
<td>1/24</td>
<td>0.0000</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.7</td>
<td>54.9</td>
<td>1/12</td>
<td>0.1255</td>
</tr>
<tr>
<td>Sulfate</td>
<td>110</td>
<td>96</td>
<td>1/3</td>
<td>45.1076</td>
</tr>
<tr>
<td>Electron Donor: Ethyl Lactate</td>
<td></td>
<td></td>
<td></td>
<td>118.1</td>
</tr>
</tbody>
</table>

| Total electron donor demand (mg/L) | 50.456 |
| Treatment area pore volume (L)    | 1,601,280 |
| Total electron donor demand (mg)  | 80,794,753 |
| Total electron donor demand for competing TEAs (lbs) - rounded to nearest 0.1 lb | 178.2 |
## Electron Donor Demand for Dissolved Volatile Organic Compounds

<table>
<thead>
<tr>
<th>Volatile Organic Compound</th>
<th>Concentration (µg/L)</th>
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<td>62.5</td>
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<td>0.0000</td>
</tr>
</tbody>
</table>

Electron Donor: Ethyl Lactate 118.1

Subtotal electron donor demand (µg/L) (based on ethyl lactate) 4.081

Treatment area pore volume (L) 1,601,280

Total electron donor demand (mg) 6,535,449

Total electron donor demand for competing TEAs (lbs) - rounded to nearest 0.1 lb 0.014

### Mass of Electron Donor to be Injected

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<tr>
<td>Number of injection wells</td>
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</tr>
<tr>
<td>Batch volume (gal)</td>
<td>5,000</td>
</tr>
<tr>
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</tr>
<tr>
<td>Estimated injection rate (gallons per day)</td>
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<tr>
<td>Total injection batches for one pore volume (rounded up)</td>
<td>85</td>
</tr>
<tr>
<td>Total injection timeframe (days)</td>
<td>85</td>
</tr>
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<td>20</td>
</tr>
</tbody>
</table>
KIRTLAND AIR FORCE BASE
ALBUQUERQUE, NEW MEXICO

FINAL WP-026 – BASE SEWAGE LAGOONS
AND GOLF COURSE POND (SWMU WP-26)
INTERIM MEASURES WORK PLAN, Rev. 1

December 2015
November 2016

377 MSG/CEI
2050 Wyoming Blvd SE
Kirtland AFB, New Mexico 87117-5270
KIRTLAND AIR FORCE BASE
ALBUQUERQUE, NEW MEXICO

WP-026 – BASE SEWAGE LAGOONS AND GOLF COURSE POND
(SWMU WP-26)

INTERIM MEASURES WORK PLAN

Revision 1

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Air Force Civil Engineer Center
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Joint Base San Antonio Lackland, Texas 78226-2018

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**ABSTRACT**
This Interim Measures Work Plan specifies the activities that will be performed in support of the remediation of trichloroethene-impacted groundwater underlying the Base Sewage Lagoons at Kirtland Air Force Base located in Albuquerque, New Mexico. Sampling of soils and groundwater at the site has occurred over the years to identify the source of contamination. Contamination that had been in the vadose zone soils impacted perched groundwater located beneath the former sewage lagoons. Subsequent vapor sampling of the vadose zone has demonstrated that residual contamination remaining the vadose zone no longer impacts the groundwater. The purpose of this plan is to describe the corrective measures that will be taken to address the trichloroethene in the perched groundwater. Groundwater monitoring has been addressed in a separate long-term monitoring plan to support site closure.

**SUBJECT TERMS**
Site WP-026, groundwater monitoring, vadose zone, soil vapor extraction

**CLASSIFICATION OF REPORT**
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Commander, 377th Air Base Wing

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KIRTLAND AIR FORCE BASE
377th Air Base Wing Public Affairs
This Interim Measures Work Plan addresses the activities that will be performed in support of remediation of trichloroethene impacted contamination associated with the perched groundwater underlying the WP-026, Base Sewage Lagoons and Golf Course Pond, site at Kirtland Air Force Base, New Mexico. The primary activities that will be performed include injection of a nutrient-amended substrate solution with a microbial bioaugmentation culture into the perched groundwater to induce reductive dechlorination of trichloroethene dissolved in groundwater and sorbed to solids in the perched aquifer and soil vapor extraction to remove contamination existing in the vadose zone underlying the former sewage lagoons and continued groundwater monitoring of existing wells to assess the impacts of contamination and the efficacy of the cleanup actions. A substrate solution consisting of potable water mixed with ethyl lactate amended with nutrients and pH buffer will be injected into up to three injection wells along with a dechlorinating microbial culture including *Dehalococcoides*. In situ bioremediation performance will be monitored at the injection wells and at nearby groundwater monitoring wells. An inert tracer will be included with the injection stream to help evaluate delivery and the effect of dilution from the injected potable water.

Because contaminant concentrations are initially very low (the maximum trichloroethene concentration is 15 µg/L found in well KAFB-2622 as of July 25, 2016), several lines of evidence will be evaluated to assess the effectiveness of in situ bioremediation including injection rate and volume, changes in dissolved oxygen and redox potential, establishment of a dechlorinating microbial population, contaminant and tracer concentrations, and production of degradation daughter products.

This work will be performed under the authority of the requirements of the Air Force Civil Engineer Center Contract No. FA8903-13-C-0008. This program is conducted under the Kirtland Air Force Base Environmental Restoration Section Chief, Mr. Ludie Bitner, and the Kirtland AFB Project Manager, Mr. Cole Crossgrove, Scott Clark, URS Group, Inc., as a subcontractor to FPM Remediations, Inc., has prepared this interim measures work plan as defined in the Performance-Based Remediation Contract for Cannon, Holloman, and Kirtland Air Force Bases located in New Mexico, and Luke Air Force Base located in Arizona. Mr. Richard Wells is the URS Group, Inc. Installation Manager for Environmental Restoration Project Sites at Kirtland Air Force Base.
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<table>
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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>µg/L</td>
<td>microgram per liter</td>
</tr>
<tr>
<td>AFB</td>
<td>Air Force Base</td>
</tr>
<tr>
<td>AFCEC</td>
<td>Air Force Civil Engineer Center</td>
</tr>
<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
</tr>
<tr>
<td>bgs</td>
<td>below ground surface</td>
</tr>
<tr>
<td>CFR</td>
<td>Code of Federal Regulations</td>
</tr>
<tr>
<td>COPC</td>
<td>contaminant of potential concern</td>
</tr>
<tr>
<td>DTIC</td>
<td>Defense Technical Information Center</td>
</tr>
<tr>
<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
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<tr>
<td>ERP</td>
<td>Environmental Restoration Program</td>
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<tr>
<td>FPM</td>
<td>FPM Remediations, Inc.</td>
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<tr>
<td>ft</td>
<td>feet</td>
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<tr>
<td>ft/day</td>
<td>feet per day</td>
</tr>
<tr>
<td>GAC</td>
<td>granular activated carbon</td>
</tr>
<tr>
<td>HASL</td>
<td>Health and Safety Laboratory</td>
</tr>
<tr>
<td>HASP</td>
<td>Health and Safety Plan</td>
</tr>
<tr>
<td>HHRA</td>
<td>Human Health Risk Assessment</td>
</tr>
<tr>
<td>IDW</td>
<td>investigation-derived waste</td>
</tr>
<tr>
<td>LTM</td>
<td>long-term monitoring</td>
</tr>
<tr>
<td>MCL</td>
<td>maximum contaminant level</td>
</tr>
<tr>
<td>NFA</td>
<td>no further action</td>
</tr>
<tr>
<td>NMAC</td>
<td>New Mexico Annotated Code</td>
</tr>
<tr>
<td>NMED</td>
<td>New Mexico Environment Department</td>
</tr>
<tr>
<td>PID</td>
<td>Photoionization Detector</td>
</tr>
<tr>
<td>ppbv</td>
<td>parts per billion by volume</td>
</tr>
<tr>
<td>PVC</td>
<td>polyvinyl chloride</td>
</tr>
<tr>
<td>QAPP</td>
<td>Quality Assurance Project Plan</td>
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<tr>
<td>RCRA</td>
<td>Resource Conservation and Recovery Act</td>
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<tr>
<td>SLERA</td>
<td>Screening-Level Ecological Risk Assessment</td>
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<tr>
<td>SM</td>
<td>standard method</td>
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<tr>
<td>SNL</td>
<td>Sandia National Laboratories</td>
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<tr>
<td>SOP</td>
<td>standard operating procedure</td>
</tr>
<tr>
<td>SVE</td>
<td>soil vapor extraction</td>
</tr>
<tr>
<td>SWMU</td>
<td>solid waste management unit</td>
</tr>
<tr>
<td>TCE</td>
<td>trichloroethene</td>
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<tr>
<td>URS</td>
<td>URS Group, Inc.</td>
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<tr>
<td>USAF</td>
<td>U.S. Air Force</td>
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<tr>
<td>USF</td>
<td>Santa Fe Group</td>
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<tr>
<td>VOC</td>
<td>volatile organic compounds</td>
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1.0 INTRODUCTION

This Interim Measures Work Plan addresses the activities that will be performed for the WP-026 Base Sewage Lagoons and Golf Course Main Pond site at Kirtland Air Force Base (AFB), New Mexico, hereinafter referred to as the Site. The Site location is shown in Figure 1-1. This plan was prepared in accordance with the requirements of the Air Force Civil Engineering Center (AFCEC) Contract No. FA8903-13-C-0008. URS Group Inc. (URS), as a subcontractor to FPM Remediations, Inc. (FPM), has prepared this work plan in accordance with the Performance-Based Remediation Contract for Cannon, Holloman, and Kirtland AFBs located in New Mexico, and Luke AFB located in Arizona. Monitoring requirements are further delineated in the Final Long-Term Monitoring Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) (URS, 2014a) and the Uniform Federal Policy Quality Assurance Project Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) (USAF, 2014b), which serves as a companion document to this Work Plan.

1.1 Purpose and Scope

The purpose of these interim measures is to facilitate a timely action that will mitigate the further migration of contaminants, as well as the actual or potential human and environmental exposure to contaminants. The purpose of this work plan is to outline the activities necessary to address volatile organic compound (VOC) impacts on contamination in the vadose zone that is impacting the perched groundwater underlying the former sewage lagoons, most notably trichloroethene. The ultimate goal of this project is to bring the Site to corrective action complete status without controls.

1.2 Interim Measures Objectives

As provided in the Corrective Measures Study Report for Solid Waste Management Unit WP-26, Sewage Lagoons and Golf Course Main Pond (USAF, 2010), the primary objectives of the interim measures are to:

1. Reduce trichloroethene (TCE) concentrations in perched groundwater near the former sewage lagoons to below maximum contaminant levels (MCLs), and
2. Induce pneumatic control of contaminated soil vapor to reduce contaminants in the perched groundwater.

These objectives will be achieved in part through the following field activities, which are described herein:

- Implement SVE to address VOCs in situ bioremediation to address TCE-impacted perched groundwater contamination remaining in the vadose zone.
  - Injection Extraction well installation and sample collection while drilling to provide additional vadose zone characterization.
  - Monitoring well installation to provide additional coverage of the perched groundwater zone. Installation of an SVE unit to address remaining vadose zone contamination. Soil samples will be collected while drilling to augment the data collected during the injection well installation.
  - Routine operation and maintenance to verify system performance
1.0 INTRODUCTION

- Implement long-term monitoring (LTM) to evaluate the efficacy of measures taken to actively address site contamination, including monitoring groundwater data trends to ensure that the measures are reducing impacts on the groundwater to acceptable levels.
- Provide the necessary data to support a corrective action complete proposal to the New Mexico Environment Department (NMED) to delist the site from the Resource Conservation and Recovery Act (RCRA) Permit
- Site surveying.
- Site restoration following site closure.

1.3 Regulatory Setting

The interim measures described herein will be performed pursuant to the NMED Hazardous Waste Bureau regulations. The Site consists of two geographically distinct locations, the former sewage lagoons and the Golf Course Main Pond. As described in the Corrective Measures Study Report for Solid Waste Management Unit WP-26, Sewage Lagoons and Golf Course Main Pond (USAF, 2010), several investigations have been performed at both locations to define the nature and extent of contamination. Active remediation of the contaminated soils associated with the sewage lagoons was performed in January and February 2010. The primary media of concern for the Site is TCE-impacted perched groundwater underlying groundwater the former sewage lagoons.

The groundwater cleanup levels will be defined as the more conservative of those specified in either the New Mexico Water Quality Control Commission as protective of human health (New Mexico Annotated Code [NMAC], 20.6.2) or by the current U.S. Environmental Protection Agency’s (EPAs) MCLs as found in 40 Code of Federal Regulations (CFR) 141 and 40 CFR 142. Soil cleanup levels will be based on NMED soil screening levels for residential soil (NMED, 2012).

1.4 Work Plan Organization

This work plan is divided into six sections including:
- Section 1.0 – Introduction, purpose, objectives, and regulatory setting
- Section 2.0 – Background and History
- Section 3.0 – Previous Investigations
- Section 4.0 – Procedures for Implementation
- Section 5.0 – Reporting
- Section 6.0 – Project Schedule
- Section 7.0 – References
2.0 BACKGROUND AND HISTORY

2.1 Installation Description

Kirtland AFB occupies approximately 51,558 acres in southeastern Albuquerque, New Mexico, nestled between the Sandia and Manzano mountain ranges. The base is located in Bernalillo County, in central New Mexico, southeast of and adjacent to the Albuquerque International Sunport (Figure 1-1). Kirtland AFB employs more than 23,000 people, including more than 4,200 active duty, 1,000 National Guard, and 3,200 part-time reservists. Kirtland AFB is home to the Air Force Nuclear Weapons Center and its subordinate wings, the 498th Armament Systems Wing and the 377th Air Base Wing. It is also home to the Defense Threat Reduction Agency Albuquerque office, Air Force Safety Center, the Air Force Inspection Agency, the Air Force Operational Test and Evaluation Center, the 58th Special Operations Wing, Space Development and Test Wing, the New Mexico Air National Guard 150th Fighter Wing, the Directed Energy and Space Vehicle Directorates of the Air Force Research Laboratory, the Department of Energy Albuquerque Office, the National Nuclear Security Administration, and Sandia National Laboratories (SNL) – New Mexico.

2.1.1 Regional Geology

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

In general, the near surface geology is characterized by recent deposits (i.e., mixtures of sandy silt and silty sand with minor amounts of clay and gravel); Ortiz gravel (i.e., alluvial piedmont sand and gravel deposits); and the Santa Fe Group (USF) (i.e., a mixture of sand, silt, clay, gravel, cobbles, and boulders). Generally, the northern and western portions of Kirtland AFB are dominated by unconsolidated geologic units; consolidated units predominate in the eastern half of the base.

Kirtland AFB lies within the eastern portion of the Albuquerque structural basin that 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 within most of the basin exceeds 3,000 ft, though the thickness varies considerably because of the significant amount of faulting in the basin.

Geologic materials of primary importance within the basin are the USF and piedmont slope deposits. The USF 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 deposited unconformably over the USF, 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 ft and thicken toward the mountains. The USF is further broken down into two depositional facies called the USF-1 and USF-2 (Hawley et al., 1995). USF-1 is present from ground surface to approximately 86 ft below ground surface (bgs), and then a transition occurs where USF-1 and USF-2 are interfingered to a depth of 144 ft bgs, underneath which USF-2 is present to a depth of greater than 500 ft bgs (CH2M Hill, 2008).
2.1.2 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 in thickness, most of which are referred to as the USF. The unit consists of unconsolidated sediments that thin toward the basin boundary. Edges of the basin are marked by normal faults. Overlying the USF are the Pliocene Ortiz gravel and Rio Grande fluvial deposits.

Generally, USF-2 contains the most productive portion of the regional aquifer that supplies groundwater to the City of Albuquerque 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 sand, silt, and clay with variable bed thickness.

Basin-fill deposits make up the aquifer in the Albuquerque Basin. Hydraulic conductivity values range from 0.25 to 130 feet per day (ft/day) due to large variations in the lithology of the basin-fill deposits. The average hydraulic conductivity is 70 ft/day with flow to the northeast. Clay layers have relatively low hydraulic conductivity, whereas gravel and cobble deposits exhibit relatively high hydraulic conductivity. Deposits of interbedded gravel, sand, silt, and clay have intermediate hydraulic conductivity.

This principal aquifer underlies Kirtland AFB, with the basin fill in this area consisting of unconsolidated and semi-consolidated sand, gravel, silt, and clay of the USF; 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 ft bgs at a location 5 miles southwest of the airfield (USAF, 2004). Depth to the regional aquifer in the vicinity of the former sewage lagoons ranged from 501.99 ft below the measuring point to 510.25 feet as measured in wells KAFB-0505, KAFB-2628, and KAFB-2629 in June 2012 (USAF, 2012).

Soil at Kirtland AFB ranges from wet to dry. The finer-grained upper soil is generally moist while the coarser-grained deeper soil could be moist or dry. Several minor perched water-bearing zones are present in the vadose zone above the regional water table. Some of these water-bearing zones below 400 ft bgs are likely remnants of the regional aquifer left behind as the water table has dropped.

2.1.3 Perched Aquifer Hydrogeology

Perched groundwater zones are also present at Kirtland AFB. The shallow groundwater system is defined as a zone of saturation above the regional aquifer and separated from the regional aquifer by an unsaturated interval. Correlation of lithologic information obtained from boreholes drilled during monitoring well installation at SNL and Kirtland AFB and water chemistry data indicate that the shallow system consists of multiple zones of discontinuous saturation up to 125 foot thick that dip to the southeast. The depth to perched groundwater ranges from 200 to 415 ft bgs. The direction of groundwater flow in the main perched zone appears to be to the east-southeast with a hydraulic gradient of between 0.01 and 0.02 foot per foot.

A thin and isolated groundwater unit referred to as the perched zone groundwater is present beneath the Solid Waste Management (SWMU) WP-26 sewage lagoons. This water-bearing unit is not suitable as a source of drinking water due to the lack of available water for pumping and the elevated salinity, as measured by total dissolved solids. This perched groundwater unit is distinct from the regional aquifer groundwater below and from other perched groundwater units located to the east of the site. The most likely source of this perched zone groundwater is infiltration of the former sewage lagoons effluent and accumulation above the silts and clays that form the perching layer. Since this supply of water has been
2.0 BACKGROUND AND HISTORY

discontinued for more than 20 years, perched zone groundwater in the vicinity of the former sewage lagoons has begun to desiccate. This conclusion is supported by water quality data, lithologic information, and well gauging data. The sewage lagoons are now dry, and there is evidence, including results of perched-zone saturation modeling (SNL, 2002), that the volume of perched groundwater is currently shrinking beneath the former sewage lagoons. Depth to perched water underlying the former sewage lagoons as measured in June 2012 ranged from 167.74 feet below measuring point to 212.06 feet (USAF, 2012).

2.2 Site Characterization and Setting

The WP-026 Site consists of two geographically distinct locations, the former base sewage lagoons and the Golf Course Main Pond.

2.2.1 Base Sewage Lagoons

As discussed in the Long-Term Groundwater Monitoring Summary Report, Fiscal Year 2011 (USAF, 2012), the former sewage lagoons are part of SWMU WP-26, which also includes the golf course main pond. The sewage lagoons site is located in the northwestern region of the Kirtland AFB, north of the Tijera Arroyo and 0.5 miles southeast of the main runway at the Albuquerque International Sunport (Figure 1-1). A detailed summary of the site’s background and history, results of previous investigation and corrective measures, is provided in the 2006 Resource Conservation and Recovery Act Facility Investigation Comprehensive Report for Solid Waste Management Unit WP-26, Sewage Lagoons and Golf Course Main Pond (USAF, 2007).

The sewage lagoons were constructed in 1962 of native soil and local fill and consisted of unlined north and south square cells separated by an earthen wall. Modifications to the lagoons occurred in 1970 and 1975, when the sides and slopes were reinforced with soil cement and capped with concrete to minimize erosion as described in the RCRA Facility Investigation (RFI), Stage 2A, Volume I, Technical Report (USAF, 1993). Two pipes discharged raw sewage into the center of each lagoon from a splitter box located between and on the eastern boundary of the lagoons. Liquid levels in each lagoon were contained by an elevated soil berm surrounding the perimeter. The lagoons shared a common berm containing a pipe connecting the lagoons, which allowed liquids to pass freely between the north and south cells. Wastewater was transferred from the lagoons to the golf course main pond by way of a gravity-fed 15-inch sewage effluent line (SWMU ST-051).

The combined north and south lagoons covered an area of 14 acres and were generally filled to a depth of 6 ft during use, resulting in a storage capacity of approximately 84 acre-feet (27.4 million gallons). The sewage lagoons operated with a turnover rate of approximately 2 weeks, allowing approximately 330 million gallons of raw sewage to be handled from April through October each year. From November to March, base sewage was routed to the City of Albuquerque sanitary sewer system. Operations at the sewage lagoons ceased in October 1987. A locked, fenced enclosure limits access to the former lagoons area.

The waste stream discharged to the lagoons was comprised of municipal wastewater with commercial and light industrial components that received some pretreatment through sumps, catch basins, and oil-water separators. Residence time in the lagoons allowed for settling, oxidation, and digestion by facultative bacteria of the raw sewage. Because the lagoons were not lined, sewage effluent infiltrated into the subsurface beneath the lagoons. A perched groundwater mound developed during sewage lagoon operations. Based on the components of the waste stream, the contaminants of concern identified at the site consist of VOCs, principally TCE.
Groundwater underlying the former sewage lagoons site is present in a perched zone and in the regional aquifer. The regional aquifer is a source of drinking water for Kirtland AFB and the City of Albuquerque in areas downgradient of the former lagoons. The perched groundwater zone beneath the site is isolated and does not produce water of sufficient quality or quantity to supply municipal, industrial, or residential demands.

2.2.2 Golf Course Main Pond

As provided in the RCRA Facility Investigation (RFI), Stage 2A, Volume 1, Technical Report (USAF, 1993), the original Golf Course Main Pond was constructed by the USAF in 1962. The pond was constructed by excavating below the surrounding grade in a preexisting drainage, building an earthen dam on the west end of the excavated area, and lining the base of the pond with plastic, making the pond a surface-water catchment. The pond was originally used for storage of wastewater delivered via a pipeline from the sewage lagoons. As part of a water conservation program, the wastewater in the pond was mixed with surface water runoff and well water, and was pumped through a sprinkler system to irrigate the golf course. Depending upon irrigation needs, 40 to 100 percent of the untreated base sewage was routed through the sewage lagoons to the pond from 1962 through 1987, with the pond receiving water during April through October during those years. The pond last received effluent from the sewage lagoons in 1987 and reportedly evaporated to dryness in January 1989. The pond was left dry from 1989 to 1998.

By 1998, the pond liner material has weathered and disintegrated in most places and the pond bottom was revegetated with a number of native plants. As documented in the Interim Corrective Measures Report for Site WP-26, Golf Course Main Pond (WP-26) and Areas of Concern SS-79, Building 381 Spill Site (SS-79), and WP-87, GRABS Site Waste Pile (WP-87), Kirtland Air Force Base, Albuquerque, New Mexico (USAF, 1999), as part of the interim corrective measures, the pond was reconstructed in 1998 and 1999. Reconstruction activities included regrading and shaping the pond, and lining the pond with a 40-mil, high-density polyethylene liner. In 2006, repairs to the pond liner were made. These repairs included removing the vegetation growing on and through the upper portion of the existing liner, applying patches over the tears and holes exposed in the liner, and replacing the riprap over the repaired areas.

The Golf Course Main Pond remains an integral part of the Tijeras Arroyo Golf Course on Kirtland AFB. The pond receives water from recovery wells located near the pond as part of the interim corrective measure implemented in 1999 and from production well KAFB-7 located northwest of the former sewage lagoons. Water stored in the pond is used to irrigate the golf course with a pump house located at the pond serving as the control center for the automated golf course irrigation system.
3.0 PREVIOUS INVESTIGATIONS

Numerous investigations have been conducted for both the base sewage lagoons and the Golf Course Main Pond as discussed below. In addition, extensive groundwater monitoring has been conducted at the wells associated with both the lagoons and the pond of both the perched aquifer underlying the lagoons and the pond and the regional aquifer underlying the lagoons.

3.1 Base Sewage Lagoons

As documented in the Corrective Measures Study Report for Solid Waste Management Unit WP-26, Sewage Lagoons and Golf Course Main Pond (USAF, 2010), accelerated corrective measures were implemented at the sewage lagoons in January and February 2010 including waste characterization sampling, excavation of 1,946 cubic yards of dry sludge, transportation of the dry sludge to an off-site disposal facility for disposal, and collection of confirmation soil samples. Confirmation samples underwent analysis for the eight RCRA metals and hexavalent chromium. Although six metals (barium, cadmium, chromium, lead, mercury, and silver) were detected at concentrations that exceeded background concentrations, none exceeded NMED residential soil screening levels.

The Corrective Measures Study Report for Solid Waste Management Unit WP-26, Sewage Lagoons and Golf Course Main Pond (USAF, 2010b) discusses the numerous investigations that have occurred at the site since 1987. Constituents investigated at the former sewage lagoons have included metals, VOCs, semi-volatile organic compounds, pesticides, herbicides, petroleum hydrocarbons, dioxins, furans, polychlorinated biphenyls, cyanide, anions, gross alpha/beta radioactivity, radium-226 and radium-228. The site data indicate that the soil vapor in the vadose zone between the ground surface and the perched groundwater zone is contaminated with VOCs. Soil vapor concentrations tend to be highest on the west and northeast side of the former sewage lagoons and increase with depth towards the perched groundwater at 200 ft bgs. Contaminated soil vapor is not present in the vadose zone between the perched groundwater zone and the regional aquifer located approximately 500 ft bgs.

The VOCs detected in the vadose zone with elevated concentrations have included TCE (non-detect to 110 parts per billion volume [ppbv]), 1,1-dichloroethane (non-detect to 580 ppbv), and acetone (non-detect to 470 ppbv). Detected VOCs have included:

- Petroleum-related compounds: benzene, ethylbenzene, toluene, xylene, xylenes, 1,2,4-trimethylbenzene, 2-hexanone, methyl tert-butyl ether
- Biodegradation products of petroleum hydrocarbons: acetone, 2-butanone, methyl ethyl ketone, and carbon disulfide
- Chlorinated VOCs: tetrachloroethene, 1,1-dichloroethene, cis-1,2-dichloroethene, chloroform, and methylene chloride
- Chlorofluorocarbons: trichlorofluoromethane and Freon-12.

Groundwater in the perched zone is currently contaminated by VOCs with TCE concentrations exceeding the EPA MCL for drinking water of 5 micrograms per liter (µg/L) but below the New Mexico Water Quality Control Criterion standard for groundwater of 100 µg/L. Groundwater in the perched zone beneath the former sewage lagoons is isolated from the larger perched groundwater to the east, and is present in a relatively thin and discontinuous layer. Regional groundwater underlying the site is not contaminated with any constituents that exceed drinking water standards.
3.0 PREVIOUS INVESTIGATIONS

3.2 Golf Course Main Pond

The contaminants of potential concern (COPCs) investigated at the pond have included VOCs, semi-volatile organic compounds, metals, petroleum hydrocarbons, total dissolved solids, anions, ammonia, total Kjeldahl nitrogen, dioxins, furans, organochlorine pesticides, polychlorinated biphenyls, chlorinated herbicides, cyanide, gross alpha/beta radioactivity, radium-226 and radium-228. Previous investigations have eliminated all COPCs as posing an unacceptable risk to human health and the environment with the exception of nitrate. The nitrate contamination is being investigated under Site ST-105, TCE and Nitrate Contaminated Groundwater, which addresses a larger on-going concern with nitrate contamination in groundwater associated with the Kirtland AFB as part of a nitrate abatement program.

The results of previous investigations indicate that significant concentrations of contaminants are not present in the vadose zone underlying the original or current Golf Course Main Pond footprint. Therefore, it can be concluded that the vadose zone beneath the pond is not contributing nitrate contamination to the underlying aquifers. Several VOCs were detected in the 2006 RCRA Facility Investigation soil and soil vapor samples; however, none of the VOCs detected in soils exceeded the NMED residential soil screening levels. VOC detections in groundwater sampled from the Golf Course Main Pond monitoring wells are sporadic and at concentrations below federal and state drinking water standards.

3.3 Recommendations

The Corrective Measures Study Report for Solid Waste Management Unit WP-26, Sewage Lagoons and Golf Course Main Pond (USAF, 2010) was developed and evaluated the corrective action alternatives and recommended the corrective measure to be taken for the Site.

3.3.1 Base Sewage Lagoons

Based on the data collected during the multiple site investigation, as well as the removal action conducted in 2010, a Screening-Level Ecological Risk Assessment (SLERA) was conducted. The objectives of the SLERA were to describe the potential for and magnitude of risk to ecological receptors in the sewage lagoons from current and future conditions. The medium of concern for the SLERA was soil vapor. Selected bird and mammal receptors included burrowing birds and mammals that have the potential to occur at the lagoons and included the burrowing owl and the coyote. Based on the results of the assessment, risk was determined to be negligible and additional investigation of the shallow soil vapor in regard to ecological exposures was not recommended.

The objectives of the Human Health Risk Assessment (HHRA) included (1) characterize the baseline risk to assess the need for remedial action; (2) provide a basis for determining levels of chemicals that can remain onsite and still be adequately protective of human health; and (3) provide a basis for comparing various remedial alternatives.

Based on current land use, no regular exposure to COPCs in soil vapor or groundwater was determined to exist. The most plausible, potential future exposure scenarios involved industrial workers. A residential scenario was also included for future risk management decision-making purposes. Two exposure scenarios were evaluated in the HHRA including (1) future industrial workers potentially exposed to soil vapor due to vapor intrusion into indoor air, and (2) future residents potentially exposure to groundwater and soil vapor.

The two exposure scenarios were evaluated to estimate the cumulative soil vapor cancer risks. Only one of the 42 soil vapor samples evaluated had a cumulative cancer risk estimate for the future resident equal to $1 \times 10^{-5}$, which exceeded the NMED risk threshold. The cumulative potential cancer risk for the future
3.0 PREVIOUS INVESTIGATIONS

resident for the other 41 soil vapor samples were below $1 \times 10^{-5}$. Non-cancer risk for the future resident for all vapor samples were less than 1.

The estimated cumulative groundwater cancer risks associated with exposure to perched groundwater exceeded the NMED target risk of $1 \times 10^{-5}$ at only two of the six sample locations (KAFB-2622 and KAFB-2624), with arsenic being the main risk driver at both locations. However, arsenic concentrations at KAFB-2622 (3.2 µg/L) and KAFB-2624 (2.7 µg/L) are less than the NMED-approved background concentration of 14 µg/L and below the MCL of 10 µg/L.

The cumulative potential cancer risk for the future resident was $4 \times 10^{-6}$ for regional groundwater at the Site. The cumulative potential cancer risks associated with exposure to groundwater in the regional aquifer did not exceed the NMED’s target risk of $1 \times 10^{-5}$. The cumulative potential hazard indices for non-cancerous effects were less than 1 for both perched and regional groundwater at the Site.

The interim measure objectives for WP-026 Sewage Lagoons are (1) reduce TCE concentrations in perched groundwater near the former sewage lagoons to below MCLs; and (2) induce pneumatic control of contaminated soil vapor to reduce contaminants in the perched groundwater.

For the interim measures study, presumptive remedies and other remedial technologies were evaluated as part of the preliminary screening of technologies to determine their applicability to the site-specific conditions at the former sewage lagoons. Based on the preliminary screening, the following remedial technologies were retained for further evaluation:

1. No action (soil vapor and groundwater);
2. Soil vapor extraction (SVE, soil vapor and groundwater);
3. Monitored natural attenuation (groundwater);
4. Enhanced reductive dechlorination (groundwater); and
5. Groundwater extraction with ex-situ treatment.

A detailed evaluation of the alternatives was prepared to provide the relevant information necessary for decision makers to select an appropriate site remedy. Each of the developed remedial alternatives were assessed against the specified evaluation criteria, and compared in terms of how well they met those criteria. Detailed analysis of alternatives consisted of a detailed evaluation of each alternative against the first seven of the nine evaluation criteria and a comparative evaluation of the alternatives.

For soil remediation, the recommended interim measures alternative is the No Action Alternative. Because the COPCs in the soil do not exceed the NMED’s residential soil screening levels, the risk for exposure to the COPCs is acceptable.

For the perched groundwater, the recommended interim measures alternative was SVE. However, enhanced reductive dechlorination is a better overall approach to directly address the TCE-impacted groundwater underlying the former sewage lagoons due to low concentrations of TCE. The maximum TCE concentration found in the perched groundwater is 15 µg/L associated with well KAFB-2622 as of 26 July 2016. Monitored natural attenuation will require an extended length of time to meet the remedial action objectives. Groundwater extraction with ex-situ treatment is not technically feasible due to the difficulty in extracting the perched groundwater from the Site. Enhanced reductive dechlorination is technically feasible, however SVE is a better overall approach based on all criteria evaluated.
3.3.2 Golf Course Main Pond

A SLERA was conducted for the Golf Course Main Pond as part of the corrective measures study process. The objective of the SLERA was to describe the potential for and magnitude of risk to ecological receptors in the pond from current and future conditions. The media of concern for the SLERA were soil, surface water, and sol vapor because they were the basis for receptor exposure. Receptors for evaluation include aquatic organisms, soil organisms, terrestrial plants, mourning doves, burrowing owls, deer mice, and coyotes. All analytes were determined to pose no or low risk. Based on the results of the SLERA, additional ecological investigation and evaluation was not recommended for the Golf Course Main Pond area.

An HHRA was also prepared as part of the corrective measures study process. The objectives for the HHRA included (1) characterize the baseline risk to assess the need for remedial action; (2) provide a basis for determining levels of chemicals that can remain onsite and still be adequately protective of human health; and (3) provide a basis for comparing various remedial alternatives.

The HHRA evaluated four exposure scenarios including future onsite construction workers, hypothetical future residents, onsite recreationists, and onsite maintenance workers. The estimated cancer risk for each exposure scenario was less than the NMED’s $10^{-5}$ risk range. The estimated non-cancerous risks were less than 1 for each exposure scenario. Therefore, the Golf Course Main Pond meets the NMED risk standards.

The groundwater from the Golf Course Main Pond perched wells meets federal and state drinking water standards for all COPCs, except nitrate. This area is part of the Nitrate Abatement Program, under which the groundwater monitoring wells in the area are monitored on an annual basis. Because the known nitrate contamination has been characterized in accordance with current applicable state or federal regulation and is under an abatement plan, it poses an acceptable level of risk for current and projected future land use. Currently, this water is not being used for drinking water, and there are no plans to use the water as a potable water source. The nitrate-impacted groundwater is being addressed under site ST-105.

Based on the results of previous investigations and the risk assessments, the objective of the corrective measures study was to demonstrate that the Golf Course Main Pond requires no further action. The No Further Action (NFA) determination is based on the NMED No Further Action – Proposal Criteria NFA Criterion 5:

“The SWMU or AOC has been characterized or remediated in accordance with current applicable state or Federal regulations, and the available data indicate that contaminants pose an acceptable level of risk under current and projected future land use.”

The risk characterization for exposure of the future hypothetical onsite resident to soil and soil vapor indicate that the estimated cancer risks are below the NMED’s $10^{-5}$ risk range. The estimated risks for all exposure scenarios evaluated (residential, recreational, and construction) do not exceed the NMED risk thresholds.

In addition, it was recommended that the interim corrective measures implemented at the Golf Course Main Pond in 1999 be terminated. The measures currently include pumping groundwater from monitoring wells KAFB-0602, KAFB-0609, KAFB-0160, and the golf course production well, RG-1598-S-4.
4.0 PROCEDURES FOR IMPLEMENTATION

This section provides the general procedures for implementing the interim measures to be undertaken at WP-026. As recommended in the Corrective Measures Study Report for Solid Waste Management Unit WP-26, Sewage Lagoons and Golf Course Main Pond (USAF, 2010), SVE will be implemented to address the remaining contamination in the vadose zone in an effort to mitigate impacts that the contaminants are having on the perched aquifer, as well as any potential impacts on the regional aquifer. Figure 4-1 provides a conceptual layout for the SVE system installation as presented in the corrective measures study report, including the proposed locations of the extraction wells. As discussed in the report, the presumed radius of influence for WP-026 using SVE wells connected to a 500 standard cubic feet per minute blower was approximately 600 feet based on previous experience with the technology being employed in soil types similar to those present at the WP-026 site.

Based on evaluation of the lithology of the site, a more realistic radius of influence for the vadose zone underly ing the former sewage lagoons is 70 feet. One perched groundwater well (KAFB-2622) had a TCE concentration of 15 µg/L based on the most recent sampling event conducted for that well in July 2015. The TCE concentrations for all of the other perched groundwater monitoring wells associated with the former sewage lagoon site are below the 5 µg/L regulatory level. Based on the historic data, the remediation efforts described herein will be concentrated in the vicinity of monitoring well KAFB-2622 to remove the residual contamination in the vadose zone that is impacting the underlying perched groundwater and air sparging to address the low concentrations of TCE in the perched groundwater itself. The actual layout and final installation locations of the wells are discussed below. The following specific tasks will take place at the site subject to interim measures under this work plan:

- Pre-mobilization activities
- Mobilization/site setup
- Extraction/Monitoring well installation
  - Air Sparging and SVE (AS/SVE) system
  - Aquifer test described in Section 4.4
- Injection well installation
- Injection of substrate solution and bioaugmentation culture
- Long-term groundwater monitoring
- System operation and maintenance
- Management of investigation-derived waste (IDW)
- Site restoration
- Site surveying.

As shown in Figure 4-1, there are currently eight monitoring wells with only five from which viable analytical samples can be collected from the perched aquifer underlying the site of the former sewage lagoons. This is due to the decrease in the recharge of the perched aquifer resulting in other wells going dry. The first step in the implementation of interim measures to address the residual TCE impacts on the perched groundwater will be to install new monitoring wells to supplement the existing network and aid in further evaluation of the TCE impacts.

Following installation of the new monitoring wells, an aquifer test will be conducted to assess the groundwater flow within the perched aquifer to determine the efficacy of the implementation of enhanced
4.0 PROCEDURES FOR IMPLEMENTATION

Kirtland AFB
Site WP-026

Interim Measures Work Plan

December 2015
November 2016

Figure 4-1. WP-026 Sewage Lagoons Groundwater Monitoring Wells
reductive dechlorination to address the residual TCE. The current maximum TCE concentration is 15 µg/L as encountered in well KAFB-2622 located on the northeastern edge of the former sewage lagoons. Based on historic TCE concentrations encountered in this well, it is anticipated that concentrations would decline to less than the U.S. Environmental Protection Agency’s maximum contaminant level (MCL) of 5 µg/L within 20 years; however, it is desired to reduce the TCE concentrations to levels less than the MCL within five years. Therefore, the evaluation of groundwater flow will aid in determining the location and number of injection wells that would be necessary to reduce the TCE concentrations to below the 5 µg/L regulatory level within the five year timeframe.

Based on the aquifer test, the number of injection wells required will be determined as will the optimum locations of those wells. Initially, one injection well will be installed in close proximity to well KAFB-2622 which is the well with the current highest TCE concentration of 15 µg/L. A treatability phase will be conducted using the single well and evaluating results obtained for up to one year following the initial injection. The number and locations of future injection wells will be submitted in a technical letter report to the USAF and NMED for concurrence prior to proceeding with the installation. An appropriate permit for implementing the injections will be obtained from the New Mexico Environment Department - Ground Water Quality Bureau. It is anticipated that it will require up to 6 months from the date of application to obtain the permit.

Evaluation of the effectiveness of the employed interim measures will be done by conducting routine groundwater monitoring from the perched aquifer network. Monitoring of the underlying regional aquifer will be continued until determined to no longer be necessary to ensure that TCE in the perched aquifer does not adversely impact the regional aquifer. Monitoring will be conducted in accordance with the Final Long-Term Monitoring Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) (URS, 2016).

4.1 Pre-Mobilization Activities

Prior to mobilization of equipment, subcontracted services (e.g., drilling subcontractor, New Mexico licensed surveyor, and approved analytical laboratory) will be procured. All necessary permits (e.g., digging permits, drilling permits, etc.) will be initiated. All site activities will be coordinated with the appropriate Kirtland AFB personnel.

Prior to initiating intrusive activities, a completed and approved Air Force Form 332 will be obtained for authorization of construction work at Kirtland AFB. A request for locating underground utilities in the area will be submitted to the local one-call utility notification center, as applicable. Additionally, Air Force Form 103 will be submitted to request that the location of underground utilities be marked at the specific sites. Drilling and excavation locations will be identified with paint, flags, or stakes, as
Figure 4.1. Air Sparge/SVE System Conceptual Design Layout
appropriate to the surface material. Utility clearance approvals will be completed by the appropriate Kirtland AFB utility office (e.g., telephone, sewer, water, natural gas, etc.). An appropriate permit will be obtained from the NMED Ground Water Quality Bureau for injection of the substrate required to support enhanced reductive dechlorination of the TCE in the perched aquifer.

In support of the activities to be performed at the WP-026 site, a project-specific Quality Assurance Project Plan (QAPP) groundwater monitoring plan and a basewide Health and Safety Plan (HASP) have been prepared.

4.1.1—Quality Assurance Project Plan

The Final Uniform Federal Policy Quality Assurance Project Plan, WP-026—Base Sewage Lagoons and Golf Course Pond (SWMU WP 26) (USAF, 2014b) provides the direction necessary for the collection of data required for assessment of the groundwater underlying the Site, vadose zone soils collected during extraction well installation, and operation and maintenance of the AS/SVE system. The plan was written in accordance with the QAPP requirements and elements set forth in the Intergovernmental Data Quality Task Force Uniform Policy for QAPPs by the EPA, dated March 2005, which was adopted by the AFCEC. QAPPs written in the Uniform Federal Policy format integrate the technical and quality aspects of a project, including planning, implementation, and assessment and include all the elements of a Sampling and Analysis Plan. Groundwater sampling requirements will also follow URS Standard Operating Procedures (SOP) 15 Groundwater Purging and Sampling (Appendix A of the QAPP).

As outlined in the QAPP, quality assurance objectives are specified to ensure that data produced are of a known and sufficient quality for determining whether a risk to human health or the environment exists. Minimum precision, accuracy, and completeness measurements and minimum detection limits are quantitative objectives specified in the QAPP. Representativeness and comparability are qualitative objectives. During the sampling discussed in the QAPP, field quality control samples will be collected and analyzed to evaluate the achievement of the precision and accuracy objectives specified in the QAPP. Overall, both field and laboratory precision will be evaluated through the results of duplicate groundwater samples, equipment rinsates, and field blanks. The duplicate samples, equipment rinsates, and field blanks will be analyzed for the same suite of analytes as the regular groundwater samples. Trip blanks to be analyzed for VOCs will be included in each cooler containing VOC samples shipped to the laboratory.

Environmental analyses are critical, because decision making based on inaccurate measurements or data of unknown quality can have significant economic and health consequences. Data verification and validation will be performed as specified in the QAPP to ensure data meet the project requirements. Method data validation is the process whereby analytical data are reviewed against set criteria to ensure that the results conform to the requirements of the analytical method and any other specified requirements. All laboratory-generated data will be validated in accordance with the requirements of the QAPP. The field-generated data will not be validated, but the quality of the field-generated data will be ensured through adherence to established operating procedures and use of equipment calibration and standardization, as appropriate.

4.1.2—Health and Safety Plan

The Health and Safety Plan—Basewide (USAF, 2014c) has been prepared and addresses the tasks and conditions to be encountered during this project. The HASP presents the health and safety requirements and guidelines for field operations addressed under the Environmental Restoration Program (ERP) at Kirtland AFB, specifically for the 12 sites being administered by URS under terms of the AFCEC Contract No. FA8903-13-C-0008. The purpose of the HASP is to identify and educate personnel of the potential hazards associated with field activities at Kirtland AFB. Subcontractors working for URS at task
slopes will be responsible to provide their own HASPs and provide documentation to URS that describes their plan for addressing applicable health and safety requirements for activities that are unique to their scope of services. The HASP is a living document and may be updated as conditions dictate. The HASP covers the following items:

- Project team organization and responsibilities
- Training and medical monitoring requirements
- Site hazard analysis
- Emergency response plan
- Personal protective equipment and medical screening
- Frequencies and types of air monitoring
- Site control measures and safe work practices
- Decontamination procedures
- Site inspections
- Recordkeeping

The Health and Safety Plan—Basewide (USAF, 2014c) is augmented by the URS Health and Safety Program’s relevant Safety Management Standards that were developed under the company’s Health and Safety Management System and are required to be available on-site during all activities.

4.2 Mobilization and Site Setup

Personnel, equipment, and resources necessary to implement the interim measures will be mobilized to the Site. Warning signs and safety fencing may be used, where necessary, to delineate the work zone and indicate the potential hazards. The work zone will be established so as to maintain the work area clear of obstructions and to provide clearly marked vehicle paths and parking areas. Setup will also include establishing a laydown area for material storage and other equipment staging as required.

4.3 Monitoring Well Installation

As indicated by the arrows in Figure 4-2, two new monitoring wells will be installed at WP-026 to supplement the current active monitoring network of the perched aquifer. The locations were selected to provide coverage of the area downgradient of KAFB-2622 which has had the highest TCE concentrations for the existing wells (see Figure 4-3). Prior to drilling, available engineering drawings will be reviewed, a utility location survey will be performed, and facility and security operations management will be involved throughout project planning activities. Figure 4-2 takes into account known access limitations, but final well locations will be determined in the field and modified as needed due to proximity of underground utilities and other obstructions encountered in the field. At this time, it is not anticipated that any such obstacles to installation will be encountered in the vicinity of WP-026.

4.3.1 Well Survey

The new monitoring well will be surveyed relative to the North American Datum of 1983 (NAD 83) and elevations surveyed relative to North American Vertical Datum of 1988 (NAVD 88). Survey data will include northings, eastings, and elevations to the nearest hundredth of a foot. Survey elevations will be
Figure 4-2. Proposed Locations of New Monitoring Wells
Figure 4-3. WP-026 Perched Aquifer Trichloroethene Concentrations
established at top-of-casing and ground surface, with a permanent marker indicating the point of survey. Well survey will be completed and certified by a licensed New Mexico professional surveyor.

### 4.3.2 Borehole Drilling

Based on local topography, recent groundwater level measurements at WP-026, and the lithology recorded during installation of the nearest groundwater monitoring wells, boreholes for the new monitoring well are anticipated to be drilled to approximately 230 feet below ground surface (bgs).

Boreholes for the new monitoring wells will be drilled using Air-Rotary Casing-Hammer (ARCH) drilling methods. It is anticipated that a telescoped borehole will be drilled and temporarily cased to reduce friction between the steel drive casing and borehole during drilling. The borehole will be advanced with 11.75-inch nominal diameter drive casing from ground surface to approximately 150 ft bgs and cased. The remaining borehole from 150 ft bgs to total depth will be advanced with a 9.625-inch nominal diameter drive casing and cased. The ARCH drilling method will use environmentally friendly lubricants and will be able to penetrate highly variable lithologies such as cobbles, boulders, gravel, sand, clay, and caliche. The borehole lithology will be logged by the URS field geologist during drilling. URS staff will retain cutting samples in chip boxes for three years after each well is installed. The depth of the first encounter with perched groundwater will be noted and recorded during drilling. Standby time will be used as needed for determining accurate water level.

Minimal water (but no other foams/liquids) in the form of mist may be introduced into the drive casing to aid in the removal of cuttings. Borehole cuttings and core will be stored within an area adjacent to the well. Water produced from the well during drilling or development will be contained in 55-gallon polypropylene drums, or other appropriate containers, and placed on spill control pallets or within appropriate confinement as secondary containment. Management and final disposition of cuttings, core, and water will be performed in accordance to applicable state and federal regulations.

### 4.3.3 Monitoring Well Design

The locations of the new groundwater monitoring wells are shown in Figure 4-2. The well screen and filter pack will either be 0.010-inch slot with #20/40 sand or 0.020-inch slot with #10/20 silica sand as the primary filter pack material depending on the degree of fines in the surrounding sediments. The well screen will be 20-ft long and extend 18 ft below and 2 ft above the static water level. If the bottom of the perched zone is less than 20-ft deep, the well screen length will be adjusted accordingly. Table 4-1 shows the anticipated design specifications. The configuration and construction of the monitoring well casing and screen will follow the same process as for the injection well described in Section 4.5.

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Estimated Depth to Water (ft bgs)</th>
<th>Screen Interval (ft bgs)</th>
<th>Filter Pack Interval (ft bgs)</th>
<th>Total Casing Depth (ft bgs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KAFB-2633</td>
<td>204</td>
<td>202 – 222</td>
<td>192 – 228</td>
<td>227</td>
</tr>
<tr>
<td>KAFB-2634</td>
<td>205</td>
<td>203 – 223</td>
<td>193 – 228</td>
<td>228</td>
</tr>
<tr>
<td>KAFB-2635</td>
<td>206</td>
<td>204 – 224</td>
<td>194 – 229</td>
<td>229</td>
</tr>
</tbody>
</table>

Previously installed groundwater monitoring wells at WP-026 currently extend between being right at the water table to 17 ft below the water table. As shown in Figure 4-4, water levels have steadily been declining and are anticipated to continue to do so since sources that have been providing recharge to the
The perched aquifer are no longer in use. The final monitoring well construction design will be determined based on lithology and geophysics.
4.0 PROCEDURES FOR IMPLEMENTATION

Kirtland AFB Site WP-026
Interim Measures Work Plan

Figure 4.4. KAFB Perched Groundwater Elevation.
The planned locations for the new groundwater monitoring wells at WP-026 are not in areas requiring at-grade completion; therefore, the well casing will extend approximately 30 inches above ground surface with a water-tight cap. The borehole will be grouted to within 5 ft of the ground surface, allowed to cure, followed by placing another 2-foot lift of bentonite chips to serve as a firm base for the stovepipe. The wellhead will be protected with a steel stovepipe with locking hinged lid, set in a reinforced concrete pad and surrounded by three concrete-filled bollards. Each concrete pad will be affixed with a brass well identification plate.

4.3.4 Well Development

Well development will begin after at least 48 hours following final grout placement. Development of groundwater monitoring wells will consist of bailing, surging, swabbing, and/or pumping techniques. During development, groundwater field parameters (pH, specific conductivity, temperature, and turbidity) will be continuously monitored, and development will continue until these parameters have stabilized. Development water will be contained in polyethylene drums and not allowed to discharge to the ground surface. All waste will be disposed of according to applicable state and federal regulations. The method of development, the volume of water added or removed, the parameters measured, the results of the measurements, and the time these activities take place will be documented on field forms. If addition of water is necessary during development of a low yielding well, only potable water will be used.

During well development, a minimum of five well bore volumes of groundwater will be removed. One bore volume is calculated as the interior casing volume from static water level to the bottom of screen, plus the estimated porosity of the saturated filter pack. After the minimum volume has been removed, development will continue until representative groundwater is obtained. Representative water is assumed to be obtained when pH, specific conductivity, and temperature readings stabilize (less than 10 percent variability over three consecutive well bore volumes) and the water is visually clear of suspended solids with a target turbidity of less than 5 Nephelometric Turbidity Units (NTUs).

4.4 Aquifer Test

Groundwater occurs above and within a fine-grained unit that forms a perched groundwater system above the regional aquifer. A perched groundwater system developed from sewage lagoons, artificial lakes, and major pipeline leaks, in addition to minor amounts of natural recharge. After closure of the sewage lagoons and pipeline leaks, groundwater elevations have decreased approximately 20 feet. TCE has been detected above the MCL in wells KAFB-2622 and KAFB-2625. The following describes a phased program to obtain data and design treatability study and long-term injection parameters for full-scale treatment of the TCE source-area hot-spots using gravity injection of the nutrient-amended substrate solution and a microbial bioaugmentation culture into perched groundwater.

NMED has requested evaluation of groundwater velocity and aquifer testing for the perched aquifer. Aquifer testing is necessary to provide estimates for aquifer hydraulic conductivity, which is used to calculate groundwater velocity and estimate groundwater level impacts from pumping or injection. Pumping tests are likely impractical in the perched system due to limited saturated thickness, dewatering, and unknown boundary conditions in the perched aquifer. Slug testing and injection testing are more feasible alternatives.

Slug testing is a method of testing wells to obtain estimates of hydraulic conductivity of the aquifer materials in the vicinity of the well. A length of pipe is filled with sand, capped, and lowered below the water level. After the water level has equilibrated to the pre-test level, the slug is rapidly removed and measurements of the water level recovery are recorded and analyzed to provide estimates of hydraulic conductivity. Slug testing has several advantages over pumping tests for this application. Slug tests do not
produce large volumes of contaminated water that require management or disposal. Also, pumping tests would likely dewater the very limited saturated thickness of the aquifer, which is estimated to be less than 20 feet.

A review of the Balleau Groundwater, Inc. 2002 modeling report provided results of one aquifer test for well TJA-2 with horizontal hydraulic conductivity ranging from 17 to 50 feet per day. The conceptual model described the top of the fine-grained surface as a synclinal fold with a general north-south axis dipping to the south. In the westward direction, the fine-grained perching unit transitions to coarser, materials a few hundred feet west of the former sewage lagoons that allow vertical flow to the regional aquifer without perching. The year 2000 observed groundwater elevation contour map indicates groundwater elevation near well KAFB-2624 was ~5.165 ft-amsl. The geologic structure contour map (estimated) indicates the top of the fine-grained unit at that location is ~5.147 ft-amsl, indicating a saturated thickness of ~18 feet. The 2000 map indicates a relatively uniform surface across the site with groundwater flowing to the east.

The sewage lagoons were identified as a primary source of recharge. Since closure of the lagoons over 20 years ago, groundwater levels have dissipated. The 2015 groundwater elevation in well KAFB-2624 is 5.142 and in nearby well KAFB-0506, 260 feet south is 5.152. Based on estimated topography and the 2015 groundwater level, the indicated saturated thickness ranged from -5 to +5 feet in 2015. These data indicate groundwater level has declined more than 18 feet in approximately 15 years, and is likely at or near the estimated top of the fine-grained perching unit.

Six wells in the area of the sewage lagoons with sufficient saturated interval will be slug tested, including KAFB-2622 and KAFB-2625. Hydraulic conductivities from the slug tests will be used to refine the design of the injection treatability test for in situ bioremediation in well KAFB-2622. The hydraulic conductivity will be used to refine the parameters of the injection tests including injection rate, duration, groundwater mounding, and radius of influence. The estimates for radius of influence will be used to design and evaluate the location for a new injection well to be paired with the existing monitoring well, KAFB-2622.

The new injection well borehole will be drilled deep enough to identify the top of the perching unit and sampled to characterize the vertical extent of contamination. The treatability test injection well will be constructed with a screened interval designed to optimize the injection of reagents in the perched interval of saturation. During drilling, samples of soil core will be collected for laboratory analysis and bench testing to evaluate the effectiveness of at least two proposed reagents and cultures.

Results of the analysis of cross-sections, slug testing, and laboratory analysis and bench testing of cores will be used to design preliminary long-term injection parameters that will be tested during the treatability test. Results of the treatability study test will be used to refine the final long-term injection parameters and equipment for long-term bioremediation with a goal of treating an area with a 60 foot radius of influence around each injection well, provided that the need for long-term treatment is determined to be necessary based on results of the treatability study test.

4.5 Injection Well Installation

As shown in Figure 4-5, an initial injection well will be installed in proximity to well KAFB-2622 which has historically had elevated concentrations of TCE. This injection well will be used for the treatability study phase of the interim measure. The injection well will be installed at a distance so that evidence of substrate delivery can be observed within the active injection period. The detailed derivation of the active injection period is presented in Appendix A. Placing the injection well in slightly closer proximity to the monitoring well accelerates the data collection timeframe and helps offset uncertainties regarding
Figure 4-5. Proposed Location of New Injection Well
subsurface heterogeneity. However, the injection well cannot be placed too close to the monitoring well because well construction might damage the existing monitoring well due to gradual deviation of the drill stem during drilling or due to inaccurate/undesirable placement of grout in the borehole annulus during well construction. The location of additional injection wells, if needed, will be determined following completion of the treatability study phase with concurrence of the Air Force and NMED.

The initial injection well and any subsequent injection wells will be installed upgradient of their respective monitoring wells to the degree logistically possible. Prior to drilling, available engineering drawings will be reviewed, a utility location survey will be performed, and facility and security operations management will be involved throughout project planning activities. Figure 4-5 takes into account known access limitations, but final well locations will be determined in the field and modified as needed due to proximity of underground utilities and other obstructions encountered in the field. At this time, it is not anticipated that any such obstacles to installation will be encountered in the vicinity of WP-026. The groundwater gradient and flowrate will be evaluated during the aquifer test described in Section 4.4. It is anticipated that the groundwater gradient will be relatively low in the perched groundwater underlying the former sewage lagoons and will be overwhelmed by the temporary mounding effect induced during injection. Therefore, the relative lateral proximity to the neighboring monitoring well is more important than orientation with respect to the hydraulic gradient.

4.5.1 Well Survey

The new injection well(s) will be surveyed relative to the North American Datum of 1983 (NAD 83) and elevations surveyed relative to North American Vertical Datum of 1988 (NAVD 88). Survey data will include northings, eastings, and elevations to the nearest hundredth of a foot. Survey elevations will be established at top-of-casing and ground surface, with a permanent marker indicating the point of survey. Well survey will be completed and certified by a licensed New Mexico professional surveyor.

4.5.2 Borehole Drilling

Based on local topography, recent groundwater level measurements at WP-026, and the lithology recorded during installation of the nearest groundwater monitoring wells, boreholes for the new injection well(s) are anticipated to be drilled to approximately 230 feet below ground surface (bgs).

Boreholes for the new injection wells will be drilled using Air-Rotary Casing-Hammer (ARCH) drilling methods. It is anticipated that a telescoped borehole will be drilled and temporarily cased to reduce friction between the steel drive casing and borehole during drilling. The borehole will be advanced with 11.75-inch nominal diameter drive casing from ground surface to approximately 150 ft bgs and cased. The remaining borehole from 150 ft bgs to total depth will be advanced with a 9.625-inch nominal diameter drive casing and cased. The ARCH drilling method will use environmentally friendly lubricants and will be able to penetrate highly variable lithologies such as cobbles, boulders, gravel, sand, clay, and caliche. The borehole lithology will be logged by the URS field geologist during drilling. URS staff will retain cutting samples in chip boxes for three years after each well is installed. The depth of the first encounter with perched groundwater will be noted and recorded during drilling. Standby time will be used as needed for determining accurate water level.

Minimal water (but no other foams/liquids) in the form of mist may be introduced into the drive casing to aid in the removal of cuttings. Borehole cuttings and core will be stored within an area adjacent to the well. Water produced from the well during drilling or development will be contained in 55-gallon polypropylene drums, or other appropriate containers, and placed on spill control pallets or within appropriate confinement as secondary containment. Management and final disposition of cuttings, core, and water will be performed in accordance to applicable state and federal regulations.
4.5.3 Core Sampling at Injection Well Locations

To optimize the injection well construction design, continuous core will be collected from approximately 20 ft above the anticipated static water table to approximately 40 ft below the observed water table to allow detailed lithologic logging of the saturated zone and the overlying capillary fringe. Core will be obtained by advancing an acetate-lined inner diameter core barrel (or functional equivalent) ahead of the ARCH drill bit. The total depth of each borehole will be determined by the URS field geologist based on observed lithology and injection well design objectives. Lithology from coring will be used to refine the final well screen and filter pack placement to ensure injection wells are completed at the proper depth to optimize substrate delivery.

Unsaturated and saturated soil samples will be collected from the most permeable observed sediment layers within the core at a minimum of one per 10-ft interval. Soil samples will be analyzed by an approved laboratory for VOCs. If VOCs are not detected in any of the soil samples, the injection well screen completion interval will default to the injection well design detailed in Section 4.5.4. Because detected VOC concentrations have been historically very low at WP-026, lack of VOC detection in the soil samples does not preclude their presence at low concentrations in groundwater. The purposes of VOC analysis of soil samples are to confirm historical results of negligible contaminants in soil samples and to determine if significant concentrations are present in a deeper horizon than is monitored by the current perched groundwater monitoring network.

4.5.4 Well Construction

The new injection wells will be installed through the temporary steel drive casing and completed with flush-threaded, PVC Schedule-80 water well casing. No petroleum-based solvents, cleaners, or lubricants will be used for well construction. The casing and screen will be delivered pre-cleaned and bagged, or steam-cleaned on site prior to installation. To preserve the structural integrity of well materials, the casing and screen will be suspended in the drive casing while the primary filter pack, bentonite chips seal, and annular seal are installed. PVC centralizers might be placed at the bottom and top of the well screen, and at intervals not to exceed 100 ft along the well casing up to the ground surface.

4.5.5 Injection Well Design

Injection wells will consist of a 5-inch nominal diameter casing and screen as shown in Figure 4-6. The injection casing screen will be 20 ft long with its top placed approximately 5 ft below the water table to facilitate submerged placement of the injected solution. The casing will have a 5-ft long blank sump casing at the bottom to mitigate long-term silting up of the well.

To enhance injection rate and lessen chance of biofouling, a relatively coarse-grained filter pack material, #8/12 sand or equivalent, will be used as the primary filter pack material extending from the bottom of the sump to at least 5 ft above the top of the screen. An additional 5 ft of #60 silica sand will be placed on top of the primary filter pack. Each filter pack interval will be tagged to verify the depth setting. Swabbing using a surge block will be performed to help settle the filter pack and reduce possible bridging of the sand.

An approximately 30-ft thick lift of 3/8-inch grade bentonite chips will be placed above the filter pack in 5-ft lifts. Each lift will be hydrated with 5 gallons of potable water and tagged prior to emplacement of the next lift. The first lift of bentonite chips will be allowed to hydrate for at least one hour to facilitate sufficient hydration.
4.0 PROCEDURES FOR IMPLEMENTATION

Figure 4-6. Injection Well Construction Diagram

Injection Well Construction Diagram
Kirtland Air Force Base
Sewage Lagoons and Golf Course (WP-026)
Albuquerque, New Mexico

Figure 4.6
The remaining annular space to ground surface will then be filled with bentonite grout. To prevent overloading, the first lift of bentonite grout will be approximately 100-ft thick and will be allowed to set for a minimum of 24 hours. Subsequently, the annulus will be filled continuously with grout to within 10 ft bgs. To prevent bridging within the annular space, during well construction the field crew will (1) tally the amount of emplaced materials to verify that the theoretical (planned) volume of each material corresponds to the actual volume installed, (2) pour the materials by hand at a slow rate into the annulus at the top of the drive casing, and (3) use a measuring tape at approximately 3-foot intervals to verify that the materials have fallen to the proper depths. Concrete will be used to complete the well installation.

Each injection well will require an at-grade completion. The PVC well casing for these wells will be cut off below grade, and fitted with a water-tight cap and a lock. The well casing and well cap will be protected by installing an 12-inch diameter traffic-rated steel vault centered over the PVC casing. The vault will be set in concrete, rebar-reinforced, constructed to surround the upper portion of each vault that slopes evenly away from the vault to meet the surrounding ground surface and direct water away from the top of the vault. A brass well identification marker will be fastened to each vault.

The initial injection well will be installed approximately 15 feet away from monitoring well KAFB-2622. The most recent depth to water at KAFB-2622 was 202.51 ft below the top of casing. Therefore, it is anticipated that the injection well will be screened from approximately 205 ft to 225 ft bgs. The filter pack interval will be from 200 ft to 230 ft bgs. The actual depths may be adjusted in the field depending on conditions encountered and actual depth of the perched aquifer in the area should the bottom of the perched zone be reached when drilling.

### 4.6 Enhanced Reductive Dechlorination

The approach for enhanced reductive dechlorination is based on an approach submitted by Sandia National Laboratories, New Mexico Environmental Restoration Operations and approved by the NMED in 2016. The approach is described in the Revised Treatability Study Work Plan for In-Situ Bioremediation at the Technical Area-V Groundwater Area of Concern (Sandia, 2016).

The injected substrate solution and bioaugmentation culture will include several components, each serving a specific purpose. The following sections discuss each of these components and the dosing and mixing ratio.

#### 4.6.1 Components of Substrate Solution

**Electron Donor**

Ethyl lactate will be used as the electron donor or substrate for the interim measures to be performed at WP-026. Ethyl lactate has high water solubility, a low retardation factor, low viscosity, and lacks particulates, all of which ensure a high degree of transportability within the treatment area. Ethyl lactate has been shown to be very effective at stimulating microbial growth that produces conditions conducive to anaerobic degradation of contaminants such as TCE. It also has other favorable properties compared to other electron donors (Jayaraj et al, 2004). It is fully utilized by microbes, unlike substrates such as sodium lactate where the sodium is not utilized. Ethyl lactate yields the same hydrogen equivalent as dextrose (12:1) and is comprised of ester-linked carbons that break apart to form lactate and ethanol. The ethanol produced during dissolution acts as a co-solvent aiding in desorption of chlorinated solvents, such as TCE, from the aquifer matrix. The ethanol is also highly transportable, as is the lactate that is generated upon dissolution. Both of these components are then utilized by the bacteria, creating the desired anaerobic conditions.
From a practical standpoint, ethyl lactate is supplied in a liquid concentrate that will not spoil or freeze, providing a longer shelf life when compared with simple sugars such as glucose or dextrose. Because it is provided as a liquid, ethyl lactate can also be easily blended with other components in the tank prior to injection. To prevent oxidation, the ethyl lactate is supplied under a nitrogen or argon blanket. After opening the container, the product will be stored under inert conditions by purging the container head space with inert gas.

Nutrients

Diammonium phosphate and yeast extract will be added as nutrients to support microbial growth. They will be blended with the ethyl lactate at a weight ratio of approximately 80 percent ethyl lactate, 17 percent diammomium phosphate, and 3 percent yeast extract. This will provide a solution that is very similar to that used at wastewater treatment plants where for every 100 parts of carbon, 10 parts of nitrogen and 1 part of phosphorus are required for bacterial growth (Metcalf and Eddy, 1991). Without the addition of these nutrients, bacteria will enter nutrient-limited kinetic rates that are much more ineffective at reducing contaminant concentrations. The nitrogen and phosphorus will be mixed with the ethyl lactate before being injected into the subsurface to facilitate utilization by bacteria.

Ammonia and phosphate concentrations will increase as the solution is injected to the saturated zone. However, once the bacteria begin to grow on the substrate, they will rapidly utilize the nitrogen and phosphorus, reducing the ammonia and phosphate concentrations to background concentrations. The nitrogen and phosphorus are converted to microorganism biomass, and will not be a concern for downgradient migration.

pH Buffer

It is important to maintain a relatively neutral pH in the aquifer to support a robust microbial community that can fully dechlorinate TCE to ethene. Therefore, addition of a pH buffer is included to offset pH reduction that can occur as a result of volatile fatty acid production during fermentation of the electron donor. The diammomium phosphate added as a nutrient will also serve as the pH buffer; thereby eliminating the need to an additional component specific to buffering. Dehalococcoides optimally dechlorinates in a pH range between 6.9 and 7.5 (Loffler et al., April 2012), although keeping the pH between 6.0 and 8.5 is a common practice for bioremediation. Maintaining a neutral pH also mitigates the degree of metals and metalloid solubilization.

Tracer

Sodium bromide will be used as an inert tracer added to the substrate solution during the injections. During injections, bromide concentration date will be used to evaluate the degree of initial dilution caused at the injection location, the rate at which this dilution effect attenuated as a result of mixing with the surrounding groundwater, and delivery of the injected solution to nearby monitoring wells.

Background bromide concentrations in the perched groundwater average less than 2 mg/L. Assuming that the hydraulic conductivity at each injection well is comparable to that measured in nearby monitoring wells, a bromide concentration of approximately 20 mg/L would be a suitable tracer concentration. This translates to approximately 0.2 lbs of sodium bromide per 1,000 gallons of injected water. If significantly higher hydraulic conductivity is encountered at an injection well, the bromide concentration can be increased to as much as 200 mg/L to counter dilution effects from local groundwater advection.

Component Mixing
The substrate and other components will be mixed in aboveground tanks with water. Table 4-2 lists the components of the substrate solution, their respective roles, and mixing ratio. The estimated amount of sodium bromide tracer is also shown. The final mixing ratios may vary based on data acquired during more recent monitoring events. The Safety Data Sheet for each component is provided in Appendix A.

Each batch of mixed solution will be deoxygenated in the tank prior to gravity injection into the well to protect the anaerobic bioaugmentation culture that will be co-injected with the substrate solution. KB-1® Primer (slurry) will initially be used to accelerate the conversion from aerobic to anaerobic in the tank.

<table>
<thead>
<tr>
<th>Substrate Solution Component</th>
<th>Function</th>
<th>Mixing Ratio (by weight)</th>
<th>Weight per 1,000 gallons of Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Components</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethyl lactate</td>
<td>Electron donor (substrate)</td>
<td>80%</td>
<td>8.9 lbs</td>
</tr>
<tr>
<td>Diammonium phosphate</td>
<td>Nutrient and pH buffer</td>
<td>17%</td>
<td>1.9 lbs</td>
</tr>
<tr>
<td>Yeast extract</td>
<td>Nutrient</td>
<td>3%</td>
<td>0.3 lbs</td>
</tr>
<tr>
<td>Primary components per 1,000 gal water</td>
<td></td>
<td>100%</td>
<td>11.1 lbs</td>
</tr>
<tr>
<td>Additional Components Mixed with Substrate Solution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium bromide</td>
<td>Inert tracer (as bromide)</td>
<td>Not applicable</td>
<td>0.2 lbs</td>
</tr>
<tr>
<td>KB-1® Primer</td>
<td>Substitute for ethyl lactate, diammonium phosphate, and yeast extract to accelerate deoxygenation during initial injection batches</td>
<td>100%</td>
<td>7.1 lbs</td>
</tr>
</tbody>
</table>

Typically within a few hours. Subsequent batches will rely on the ethyl lactate substrate to develop anaerobic conditions.

### 4.6.2 KB-1® Primer

KB-1® Primer is a proprietary mixture of amino acids, potassium bicarbonate, and sodium sulfite that is used to accelerate deoxygenation of water inorganically (sodium sulfite) while still providing an electron donor (amino acids) and buffer (potassium bicarbonate). It can therefore be used as a substitute for ethyl lactate, diammonium phosphate, and yeast extract, although it is significantly more costly and therefore, not suitable for larger volumes if required. Treatment of the perched aquifer will occur in two phases, a treatability study phase and a full scale phase. The extent of the full scale phase will depend on the results of the treatability study phase. The groundwater used for the treatability study phase will be stored in approximately equal proportions in two tanks. One tank will be inoculated with a small amount of soil core/cuttings from an injection well screened interval and have KB-1® Primer added. The purposes of adding soil core/cuttings to the substrate solution are to (1) inoculate the solution with native microorganisms, (2) create a diverse microbial community that will more likely work synergistically with the bioaugmentation culture, and (3) reduce the lag time for initiating biostimulation associated with utilization of the substrate in the subsurface. If sufficient core/cuttings are not recovered during drilling, a
4.0 PROCEDURES FOR IMPLEMENTATION

commercial lyophilized bacterial septic tank amendment (e.g., Rid-X® Septic System Treatment or equivalent) may be substituted at a mass/volume based on manufacturer recommendations.

As water in the first tank turns anaerobic, water from the second tank will be transferred into the first tank and mixed with proportional amounts of the substrate solution components. Although addition of groundwater from the second tank is likely to increase the dissolved oxygen (DO) and oxidation-reduction potential (ORP) initially, the combined water volume is expected to return to sufficiently decreased DO and ORP within one to two days and ready for gravity injection into the injection well as one batch.

The full scale injection phase will follow a similar process. An additional pair of tanks may be employed if it is determined that the volumes required are sufficient to justify them. If just a single pair of tanks is employed, the same approach will be followed as outlined above for the treatability study phase. Following the two pairs of tanks scenario, both pairs of tanks will be filled halfway with potable water, inoculated, and have KB-1® Primer added. After turning anaerobic, the tanks will be filled with water and mixed with proportional amounts of the substrate solution components. As with the treatability study phase, the deoxygenation of the entire tank volume is expected within one to two days. Once anaerobic conditions are restored, half of the tank contents (from each pair) will be injected. Each pair of tanks will then be refilled with potable water and mixed with proportional amounts of the substrate solution components. Provided that approximately half a tank of the deoxygenated solution remains in each tank, this accelerated deoxygenation schedule is expected to continue without further use of KB-1® Primer during the remainder of the injection period. By alternating two pairs of tanks, injection would not be interrupted while waiting for the substrate solution to turn anaerobic.

4.6.3 KB-1® Dechlorinator

To expedite growth of a microbial population capable of fully dechlorinating TCE to ethene, a bioaugmentation culture, KB-1® Dechlorinator, will be injected in conjunction with the substrate solution. KB-1® Dechlorinator is a naturally occurring, non-hazardous, non-pathogenic, microbial culture that contains a consortium of anaerobic microorganisms that promote dechlorination of chlorinated solvents. In includes Dehalococcoides that has a strain possessing the gene capable of producing enzymes that reduce vinyl chloride to non-toxic ethene (vinyl chloride reductase). Dehalococcoides can be found naturally in the environment. However, these bacteria are not ubiquitous, and an aerobic environment, such as that present at WP-026 as evidenced by the sulfate and nitrate concentrations in the perched groundwater, is not favorable for establishing a population. With concentrations of TCE being very low at the site, development of a robust Dehalococcoides population without bioaugmentation either may not be possible or would require a very long time if relying solely on an indigenous population.

Typical dosing of KB-1® Dechlorinator for site with TCE concentrations one or more orders of magnitude higher than that present at WP-026 is approximately 0.24 lbs per 1,000 gallons of water. The low concentrations of TCE present at WP-026 would result in a slower microbial population growth rate. Therefore, the KB-1® Dechlorinator will be doubled to 0.5 lbs per 1,000 gallons of water to facilitate population development within a reasonable timeframe.

To effectively deliver the KB-1® Dechlorinator to the treatment area, it will be injected simultaneously with the substrate solution. Waiting to deliver the bioaugmentation culture until after the initial injection of substrate solution alone would require additional injection volumes to reach the same treatment area and would have to be delayed long enough to ensure the groundwater had been deoxygenated.

KB-1® Dechlorinator is a liquid and is shipped by the supplier to the site in stainless steel containers. It has a shelf life of approximately two weeks, so shipments will be sized and delivered as needed to match
the pace of injections without compromising the product shelf life. Injections will be performed in
accordance with the supplier’s procedure and be mixed in-line with the substrate solution via a connection
placed between the substrate solution mixing tank and the wellhead. The KB-1® Dechlorinator will be
purged from its vessel into the aboveground injection line with inert gas (argon) under sufficient pressure
to ensure proper mixing with the substrate solution injection stream. Concentrations of solubilized metals
and metalloids and the pH in groundwater will also be evaluated prior to adding *Dehalococcoides* to
determine if adjustments in buffering amendment are required over the course of the full-scale injection
period.

### 4.3 SVE and AS/SVE Well Installation

The three new SVE wells (nested triplets) and single AS/SVE well (nested pair) will be installed at the
Site with conveyance piping run to the location of the new AS/SVE system. Conceptual well schematics
for the SVE and AS/SVE wells are provided as Figures 4.2 and 4.3. The actual screen intervals of the
wells are subject to change from those shown in the well schematics based on field characteristics
encountered while drilling (i.e., examination of soil lithology and screening soil samples with a
photionization detector [PID]). Well drilling activities will be performed by a drilling company licensed
by the State of New Mexico. The wells will be installed in accordance with NMED Ground Water
Quality Bureau Monitoring Well Construction and Abandonment Guidelines (NMED, 2011). The
boreholes will be advanced such that the borehole diameter will be at least 4 inches larger than the outer
diameter of the nested wells to allow for proper placement of the well piping, filter pack(s), and sealant.

During drilling, a geologist will document the following information for each boring:

- Well identification (this identification will be unique, and ensure it has not been used previously
  at the Base);
- Purpose of the boring (e.g., extraction well);
- Location in relation to an easily identifiable landmark;
- Names of drilling subcontractor and logger;
- Start and finish dates and times;
- Drilling method;
- Diameters of surface casing, casing type, and methods of installation;
- Lithologic descriptions and depths of lithologic boundaries (section 5.3);
- Sampling interval depths;
- Potential PID readings indicating concentrations of VOCs in sample headspace (section 4.3.1);
- Other pertinent field observations.

Well installation equipment will be decontaminated according to the specifications of the URS SOP-20
Decontamination provided in the Appendix A of the project QAPP.
4.0 PROCEDURES FOR IMPLEMENTATION

4.3.1 Well Construction and Vadose Zone Sampling

Each of the three SVE well boreholes will be advanced to a depth just above the perched aquifer estimated to range in depth from 20 to 215 feet bgs, based on water level measurements collected from monitoring well KAFB-2622 during the July 2015 monitoring event. As the boreholes are being drilled, soil samples will be collected from split spoons during the advancement at 10-foot intervals. PID measurements will be collected at each sample interval in accordance with URS SOP-033 Organic Vapor Measurement provided in Appendix A of the QAPP. PID measurements will be recorded on the sample collection logs. Results of the PID measurements will be used to determine the optimum locations for the extraction zones for each of up to three nested wells to be constructed in each borehole. The decision as to placement of the extraction intervals will be based on a combination of higher VOC concentrations and lithology taking into account the soils that are most amenable (higher permeability) to vacuum extraction. Similar to the boreholes drilled for the nested SVE wells, soil samples from the boring drilled for the AS/SVE well will be collected at 10-foot intervals in the vadose zone for lithologic characterization and PID screening. However, after the perched water table is encountered, the sample interval will be adjusted to five foot intervals for enhanced characterization of the aquifer material, and a sample of groundwater will be collected from a depth of approximately 207 feet (the anticipated mid-point of the perched aquifer thickness) using a Simulprobe® or equivalent sampling technique. The soil and groundwater samples will be submitted to an approved laboratory for VOCs, polynuclear aromatic hydrocarbons, metals, anions, and total petroleum hydrocarbon-gasoline range organic analyses.

The nested SVE wells will be screened with 2-inch diameter American National Standards Institute (ANSI) Schedule 40 polyvinyl chloride (PVC) piping. Each well will be screened with a 2-inch diameter ANSI Schedule 40 PVC 0.1-inch slotted well screen at depths determined from the field PID measurements. Annular materials will be installed during nested well installation as the drill casing is removed from the borehole. Silica sand (10-20) will be used to form the filter pack around the slotted casings. The filter pack will be installed to a depth of 2 to 3 feet above the top of each screen to allow for settling. A bentonite seal of 2 to 3 feet will be placed in the interval between well screens. Following placement of the bentonite pellets, the material will be allowed to hydrate for at least 2 hours prior to proceeding with additional placement of annular materials. The remaining annulus will be sealed from the shallowest bentonite seal to the surface using cement-bentonite grout (5% bentonite). The tops of the nested well casing will be finished with slip caps pending connection to the SVE conveyance piping and final wellhead completion. Figure 4-2 provides a conceptual design of the typical SVE extraction well.
4.0 PROCEDURES FOR IMPLEMENTATION

Figure 4-2. Nested Vapor Extraction Well Schematic
A conceptual design of the nested AS/SVE well is provided as Figure 4-3. The SVE well within the nest will be comprised of 3-inch diameter Schedule 40 PVC and 0.010-inch slot screen. The well is anticipated to have a screened interval extending from approximately 153 to 192 ft above the perched water table. Assuming this screened interval, number 8-12 sand pack would be placed around the SVE well screen from 150 to 195 ft bgs, and five ft thick bentonite seals would be constructed above and below the screen/sand pack. The AS well within the nest would be comprised of a 1-1/2 inch black steel pipe above the water table, transitioning to a 1-1/2 inch galvanized steel pipe that extends into the aquifer material. A dielectric union will connect the black steel to galvanized steel pipe to mitigate corrosion of the dissimilar materials. A two ft long, 1-1/4 inch diameter, 0.010 slot, stainless steel sparge point would be installed at the terminal end of the pipe to a total anticipated depth of approximately 213 ft bgs. A dielectric union would also be used to connect the galvanized steel pipe to the stainless steel sparge point. Number 8-12 size sand pack would be placed around the sparge point to extend from 211 to 214 ft bgs, and a 5 ft thick bentonite seal would be constructed above the sand pack.

4.3.2 SVE Well Head Completion

Each nested well will be connected to dedicated PVC ball valves and the well capped with threaded PVC caps. The threaded caps topping the wells will have ¼ inch brass ball valves and sampling ports. Each sampling interval will be equipped with its own sampling port and vacuum gauge. Both the sampling port and the vacuum gauge will be located on the well side of the ball valves. The vacuum gauges will have a measurement range of 0 to 30 inches of water.

The SVE wells will be completed to surface grade in a 2-foot by 2-foot traffic-rated locking vault. The concrete completion for the well vault will extend at least 6 inches around the vault, and the concrete will be a minimum of 8 inches deep. Figures 4-4 and 4-5 present the top and side views of the conceptual design of the SVE well heads.

4.3.3 AS/SVE Well Head Completion

It is anticipated that the nested AS/SVE well will be completed by installing a pre-cast concrete vault with a spring-assisted, single torsion door (i.e. hatch) over the wellhead. A 1-1/2 inch air supply line derived from the sparge compressor will connect to the AS wellhead using a Tee fitting. A ball valve, mechanical flow meter, and pressure gauge will be equipped on the air supply line immediately upstream of the Tee fitting within the vault. Union fittings will be installed on each side of the flow meter to facilitate maintenance or replacement of the meter. A Schedule 40 PVC elbow will be used to connect the SVE wellhead to a 3-inch diameter vapor extraction line. The line segment within the wellhead vault will be equipped with a butterfly valve and a vacuum gauge to control the vapor extraction rate and monitor the applied well vacuum, respectively.
4.0 PROCEDURES FOR IMPLEMENTATION

Figure 4-3. Nested Air Sparge/SVE Well Schematic
Figure 4-4. Typical SVE Well Head – Top View

Figure 4-5. Typical SVE Well Head – Side View
4.4 Air Sparge and Soil Vapor Extraction System Installation

This section provides an overview of the design elements for the proposed AS/SVE system. The final design details will be determined during execution of this Work Plan. The SVE system is proposed to consist of the following elements:

- Either a rotary vane or rotary claw air sparge compressor with a capacity to deliver up to 15 standard cubic feet per minute (scfm) of air at an injection pressure of up to 12 pounds per square inch (psi) to the sparge point.
- An SVE blower with a capacity of approximately 500 scfm at an applied vacuum of up to 100 inches of water column (7.3 inches of mercury).
- The SVE blower and AS compressor motors will be totally enclosed-fan cooled, 240 volt, 3-phase models.
- The SVE blower will be enclosed in a sound enclosure to reduce noise levels approximately 10 decibels from the baseline at 3 ft from the blower. The sound enclosure will include any necessary cooling/heating to operate year round.
- An air-to-air heat exchanger will be installed to cool the discharge of the blower before entering the granular activated carbon (GAC) vessels.
- A vapor/liquid separator (knock-out pot) equipped with an automatic drain pump and associated liquid level controls will function to remove condensate from the vapor stream and transfer it from the knock-out pot to a secondary condensate storage vessel. The vessel will consist of a high-density polyethylene tote or storage tank to be staged within approximately 15 ft of the SVE system skid. The vapor/liquid separator will incorporate a high liquid level shutdown interlock to turn off the AS/SVE system in order to protect against damage to the blower if the automatic drain pump fails to operate. To prevent the potential overflow of condensate from the secondary storage vessel, the vessel will also be equipped with a high liquid level shutdown interlock to shut off the AS/SVE system.
- The air sparge compressor will be used to deliver ambient air to the sparge point that terminates in the bottom portion of the perched aquifer (Figure 4.4). The flow rate will be determined using both a mechanical rotameter and a flow meter installed on the sparge line at the equipment compound and within the AS/SVE wellhead vault (Figure 4.6), respectively.
- A combination of black steel and galvanized steel piping will be used to convey compressed air to the sparge point. The use of steel pipe will alleviate concerns of pipe failure associated with high temperature air typically produced from the heat of compression.
- The SVE blower will be used to concurrently extract vapor from the newly constructed extraction wells described above. Flow rates will be determined following installation of the system and optimized to achieve maximum contaminant mass removal.
- Conveyance piping will connect the extraction wells to the SVE blower assembly using either Schedule 40 or 80 PVC piping that is buried in a piping trench. The piping schedule, diameter, lengths and fitting types will be determined during execution of the Work Plan.
Figure 4.6. Well and Wellhead Connection Details—Air Sparging/Soil Vapor Extraction System
4.0 PROCEEDURES FOR IMPLEMENTATION

- Vapor abatement of the extracted vapor is proposed to consist of two 3,000-pound GAC vessels containing either virgin or reactivated coconut shell carbon. If contaminants are determined to be present that are not readily adsorbed to carbon (e.g., vinyl chloride), a “polishing” vessel containing 500-pounds of permanganate-impregnated zeolite beads will be included in the treatment train.

- The AS/SVE system will include a discharge stack that vents treated vapor to the atmosphere.

Final design is considered to be a component of execution of this Work Plan. The final as-built design will be presented in the interim measures report. Design activities to be conducted prior to installation will include the following:

- Final sizing and specification of the air sparge compressor and vacuum blower to be used for the AS/SVE system.
- Sizing and specification of the moisture knockout vessel.
- Evaluation of the requirement for and specification for controls for the AS/SVE system.
- Evaluation and specification of the electrical supply required for the AS/SVE system and verification that the availability and suitability of electrical power for the temporary operation of the AS compressor and SVE blower. A New Mexico license electrical engineer will be subcontracted as needed to design the electrical supply for the AS/SVE system and associated controls and to prepare electrical drawings suitable for submittal to the Kirtland AFB for review and approval.

It is not anticipated that formal construction drawings will be required for this installation. Diagrams will consist of a process flow diagram, a site plan indicating the location of AS/SVE equipment, the location of piping runs, and the location and distribution of the electrical supply to power the AS/SVE system. Wellhead construction drawings (e.g., final versions of Figures 4-1, 4-2, and 4-6) indicating the underground piping connections to the AS and SVE wells along with trench details indicating pipe sizes and backfill requirements will be prepared to guide field personnel in the installation of the system.

4.54.7 Long-Term Groundwater Monitoring

The Final Long-Term Monitoring Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) (URSSAF, 2016a) has been developed to provide guidance for long-term groundwater monitoring at the Site. Annual groundwater monitoring and well gauging will be performed at the eight perched aquifer wells located at the sewage lagoons, three regional aquifer wells also located at the sewage lagoons, and the three perched aquifer wells located at the Golf Course Main Pond (see Figure 4-1). Samples will be collected and analyzed for the suite of analyses as provided in Table 1 of the monitoring plan. The sampling frequency will be increased to quarterly upon implementation of the interim measures described herein.

The objective of the LTM is to provide groundwater sample analytical data of sufficient quality and quantity to adequately characterize and monitor groundwater underlying the Site. The Final Long-Term Monitoring Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) (URSSAF, 2016a) is used in conjunction with the Uniform Federal Policy Quality Assurance Project Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) (USAF, 2014) to provide the necessary procedures and requirements to ensure that the functional activities, organization, and quality assurance/quality control protocols are achieved in accordance with the project’s data quality objectives.
As additional monitoring data are collected, the analyte list, well list, and sampling frequency may be adjusted to focus on those constituents and wells of interest. A monitoring report will be prepared on an annual basis to evaluate the results and provide recommendations as to future monitoring requirements.
Figure 4-44-7. Groundwater Monitoring Well Locations
The change in monitoring scope or schedule will be documented in a revision to the Long Term Monitoring Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) (USAF, 2014a), as well as the Uniform Federal Policy Quality Assurance Project Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) (USAF, 2014b), which will undergo review by the USAF and NMED prior to implementation.

4.6 System Operation and Maintenance

The SVE system will be installed in accordance with the developed process flow diagram, Site plan, and wellhead construction diagram(s). A conceptual site plan is provided in Figure 4-8 with Figure 4-9 providing the conceptual process flow diagram. A subcontractor will place the skid-mounted SVE system, moisture knockout vessel, and treatment train at their designated locations and construct the piping runs and connections. Licensed subcontractors will be used as needed to make necessary connections to wellheads and the electrical supply.

4.6.1 System Start-Up

The system will be started and initial system monitoring and sampling of the vapor influent and effluent streams will be conducted. The system will be shut down following this initial sampling pending receipt of the analytical results. Following confirmation that the analytical results demonstrate that the system is operating as designed, the system will be started for continuous operation. The sampling frequency during system start-up will be on a semi-weekly basis for the first week followed by weekly sampling for three additional weeks. Samples will undergo analyses for VOCs via EPA Method TO-15 as specified in the project QAPP.

Initial system monitoring consisting of PID measurements, vacuum measurements, and mechanical system checks will be conducted daily for the first week (Monday through Friday) of continuous operation, semi-weekly for three additional weeks, and monthly thereafter. A visual inspection of the wellhead connections and above-ground piping will also be performed on a weekly basis during this initial startup phase.

4.6.2 System Monitoring

SVE system vapor samples will be collected from the influent, mid-carbon, and effluent sampling ports installed in the SVE system. The influent sampling port will be located in between the extraction well manifold and the flow meter prior to the SVE blower motor. The mid-carbon sampling port will be located between the two GAC filters. The effluent sampling port will be located prior to the final flow meter just before the system exhaust. Monthly samples from the three monitoring ports will undergo VOC analysis using a PID and fixed gases using an air monitoring meter. Quarterly samples will be collected and submitted for laboratory analysis of VOCs in accordance with EPA Method TO-15 in accordance with the project QAPP.

In addition to the AS/SVE system monitoring, soil vapor samples will be collected from each of the sampling ports installed in the extraction wells. A sampling port is associated with each depth interval within an extraction well; therefore, the samples will be collected from each discrete interval from which vapor is being extracted. If the SVE system is not currently extracting vapor from an interval, a sample will not be collected from the port associated with that interval. The soil vapor samples will undergo monthly analysis for VOCs and fixed gases using the PID and air monitoring meter with quarterly sampling being collected and submitted for off-site laboratory analysis of VOCs and fixed gases as per the project QAPP.
Figure 4.8: SVE System Layout
Figure 4.9 - Treatment Compound Site Plan and Details
4.0 PROCEDURES FOR IMPLEMENTATION

4.6.3 System Condensate

Condensate from the SVE system is expected to be generated, especially during the winter operating months. The condensate will be removed from each of the moisture separators and pumped to a 275-gallon tote. The condensate will be periodically sampled and analyzed to evaluate contaminant concentrations and to ensure that the condensate is not hazardous. If analytical results demonstrate that the condensate may be hazardous, the quantity of condensate collected will be limited to less than 55 gallons prior to disposal. As the tote becomes full, the contents will be evaluated for disposal in accordance with the requirements specified in Section 4.7.

4.6.4 Granular Activated Carbon

The GAC performance will be monitored as part of the routine AS/SVE system monitoring with collection of samples from the influent, mid-carbon, and effluent sample ports. When breakthrough of the lead GAC vessel occurs, the spent GAC will be replaced with fresh GAC and the vessel will be moved into the lag vessel position. The vessel previously in the lag vessel position will become the lead vessel. The movement of vessels from lead to lag will be achieved using a valve manifold. A mechanical design drawing will be prepared providing the specifications for the GAC system.

4.6.5 Permanganate-Impregnated Zeolite Beads

If used, status of the permanganate impregnated zeolite beads will be monitored using PID readings, effluent analytical results, and visual confirmation, as the bead color changes from purple to brown when the permanganate reacts with any VOCs that may not be adsorbed in the GAC vessels. The bed will be replaced prior to the color change progressing throughout the entire length of the bed.

4.6.6 System Shutdown and Rebound Testing

Once SVE concentrations have reached an asymptotic level for a period of three consecutive months, the SVE system will be shut down and rebound testing will commence. Rebound testing will consist of collection of soil vapor samples from each of the extraction well sampling ports as discussed in Section 4.6.2. Samples will be collected on a weekly basis and analyzed for VOCs using the PID. The results will be compared to results obtained prior to the rebound test to evaluate whether or not the VOC concentrations rebound to levels observed at the conclusion of the SVE system operation. Such rebound may indicate volatilization of VOCs from a low-permeability zone in soil into soil vapor or volatilization of VOCs from perched groundwater underlying the former sewage lagoons into soil vapor. If soil vapor concentrations rebound, the continued long-term operation of the AS/SVE system will be considered.

4.7.4.8 Management of Investigation-Derived Waste

The IDW will be generated as a result of the activities conducted during this project. The types of waste expected to be generated include, but are not limited to, the following:

- Personal protective equipment
- Equipment decontamination liquid residue
- Purge water
  - Condensate water
  - Blower filters
4.0 PROCEDURES FOR IMPLEMENTATION

- Granular activated carbon (will be regenerated and recycled as appropriate)
- Permanganate impregnated zeolite beads
- Plastic sheeting
- Unused/unaltered sample material
- Analytical residues
- Sample containers
- Hydraulic spills from mechanical equipment used during installation
- Miscellaneous waste

Waste could be hazardous. Waste will be managed in accordance with the Environmental Restoration Program Investigation-Derived Waste Management Plan (USAF, 2009). As the project continues, additional waste streams could be identified. All generated waste streams are required to have the waste identified and characterized as required by Resource Conservation and Recovery Act regulations (40 CFR 262.11, “Hazardous Waste Determination”). Hazardous waste determinations will be prepared for each waste stream in accordance with RCRA requirements. URS SOP-49 (Appendix A of the Uniform Federal Policy Quality Assurance Project Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) [USAF, 2014b]). Wastes generated will be designated and characterized using process knowledge, historical analytical data, and/or analytical data generated during the course of the field activities. Hazardous waste determinations for all waste streams will be generated and maintained as part of the project file. Samples of IDW may be collected, if necessary, and submitted to the laboratory for analysis. The waste will be disposed of in accordance with applicable federal, state and local regulations. All drums will be labeled “Investigation Derived Waste, Awaiting Analysis” with contact information provided while being stored pending analysis.

Waste minimization techniques will be incorporated primarily through design, planning, and efficient operations. Specific waste minimization practices to be implemented during the project will include, but not be limited to, the following:

- Historic data evaluation to identify waste streams that may need to be segregated because of the potential of being hazardous
- Excluding materials that could become hazardous waste in the decontamination process (if any)
- Controlling transfer of materials and equipment between clean and contaminated areas
- Designing containment such that spread of contamination is minimized
- Deploying appropriate decontamination methods

Reuse and recycling opportunities also will be evaluated for waste, such as batteries, scrap metal, and equipment or materials that are no longer needed. Uncontaminated equipment that is determined to be excess will be evaluated for reused by other projects.

Wastes generated during the performance of LTM activities will be handled in accordance with the requirements provided in Section 5.0 of the Long-Term Monitoring Plan, WP-026 – Base Sewage Lagoons and Golf Course Pond (SWMU WP-26) (USAF, 2016d), and URS SOP-49 Investigative Derived Waste (Appendix A of the project QAPP).
4.94.9 Site Restoration

Following delineation and remedial action activities at the former Site, site conditions will be restored to a similar state as initial conditions. *It is not anticipated that any of the proposed actions will adversely impact the current topography of the former sewage lagoons requiring regrading. Any disturbances will be backfilled with clean fill to blend with surface topography and prevent ponding. Impacted areas will be reseeded with native vegetation. Excavations will be backfilled with clean fill and compacted with a vibratory compactor, backhoe, or other appropriate methods. The area will be graded to maintain positive drainage to conform to site conditions. The ground covering will then be restored to surrounding site conditions or other covering as directed by Kirtland AFB.*

Following regulatory approval of site closure, all existing monitoring wells will be abandoned according to the *NMED Water Quality Bureau Monitoring Well Construction and Abandonment guidelines* (NMED, 2011). The SVE system will be dismantled and recycled and all piping will be removed and disposed of at the Kirtland AFB landfill. The electrical service will be decommissioned. The Site will be graded to match the existing topography, if necessary.

4.94.10 Site Surveying

Surveying of the locations (northing and easting) of new extraction, injection, and monitoring well locations, and other pertinent site features will be conducted by a State of New Mexico-licensed surveyor. Elevation data for extraction, injection, and monitoring wells will include the top of the PVC riser and ground surface elevation at the well locations. Surveying data will be provided in a spreadsheet format for import into the geographic information system, and the data will also be incorporated into the report figures.

Horizontal coordinates will be referenced to the New Mexico Central State Plane Coordinate System, and surveyed to an accuracy of ±1.0 foot. Vertical elevations will be referenced to North American Datum 1983 coordinate system to an accuracy of ±0.01 foot.

Geospatial information will also be submitted as a separate deliverable to the USAF. All applicable federal, U.S. Department of Defense, and USAF geospatial data standards will be followed. Spatial data will be compliant with the Spatial Data Standards for Facilities, Infrastructure, and Environment v2.6.

Each geospatial data set will be accompanied by metadata that conforms to the Spatial Data Facilities, Infrastructure, and Environment standards. The horizontal accuracy of any geospatial data created will be tested and reported in accordance with the National Standard for Spatial Data Accuracy, and the results will be recorded in the metadata.
5.0 TREATABILITY STUDY PHASE

The treatability study phase will be divided into two stages following installation of the initial injection well near KAFB-2622. The two stages consist of a push/pull test followed by a full-scale injection.

5.1 Push/Pull Test

A push/pull test will be performed on injection well WP26-INJ1. This is a small-scale proof of concept test designed to deliver substrate solution and the bioaugmentation culture laterally into the formation with a treatment area radius of approximately 5 ft. Performance monitoring will be conducted as outlined in Table 5-1. These analytical results, coupled with field measurements, will be used to assess if the injected bioaugmented substrate solution creates favorable conditions to support larger-scale biodegradation of the TCE and its daughter products. Additionally, data will be obtained regarding gravity-injection rates, which will impact planning for subsequent injections. Results of this test will be evaluated to determine whether to implement a full-scale injection at WP26-INJ1 and to refine procedures.

The push/pull test includes the following sequential tasks:

- Extract and store groundwater from WP26-INJ1
- Prepare substrate solution in aboveground tanks
- Deoxygenate the injection well water column
- Reinject substrate solution and bioaugmentation culture
- Conduct post-injection performance monitoring.

Figure 5-1 shows a conceptual schematic of the gravity-injection system to be used as modified from the Revised Treatability Study Work Plan for In-Situ Bioremediation at the Technical Area-V Groundwater Area of Concern (Sandia, 2016).

5.1.1 Groundwater Extraction from WP26-INJ1

The design of the push/pull test includes extracting the volume of groundwater necessary to be used for subsequent delivery of the substrate solution into saturated sediments to a radius of 5 ft from the injection well. It is estimated that approximately 3,000 gallons of groundwater will be sufficient. This volume is based on the design of a well screen set across the upper 20 ft of the saturated zone, and an estimated sediment porosity of 25 percent.

The groundwater will be extracted from WP26-INJ1 using an electrical submersible pump. The anticipated pumping rate would be less than 10 gallons per minute (gpm). Equal volumes of extracted groundwater will be stored onsite in two tanks, each storing approximately half the groundwater volume (1,500 gallons) and designated as Tank 1 and Tank 2.

5.1.2 Preparation of Substrate Solution in Aboveground Tanks

The initial Tank 1 solution will be:

- 1,500 gallons groundwater
- 4.8 kilograms (10.6 lbs) of KB-1® Primer
Figure 5-1. Proposed Injection Layout – Extracted from Sandia Report
5.0 TREATABILITY STUDY PHASE REPORTING

- 0.3 lbs sodium bromide (tracer)
- 8 lbs of WP26-INJ1 soil core/cutting from the well screen interval.

Tank 2 will hold the other 1,500 gallons of extracted groundwater until the solution in Tank 1 has been deoxygenated and has an ORP of less than negative 75 mV (the minimum required to sustain growth of KB-1® Dechlorinator). Tank 1 will then be filled with:

- 1,500 gallons of groundwater from Tank 2.
- 1.6 gallons of ethyl lactate (electron donor)
- 2.8 lbs of diammonium phosphate (nutrient and pH buffer)
- 0.5 lbs of yeast extract (nutrient)
- 0.3 lbs of sodium bromide (tracer).

After mixing the above contents in Tank 1, DO and ORP measurements will be taken of the substrate solution until deoxygenation and lowered ORP have been reestablished indicating it is ready for injection along with KB-1® Dechlorinator. Deoxygenation may be accelerated by sparging the water with argon gas, if necessary.

Component ratios may be modified if analytical results from baseline sampling of the injection well are significantly different than currently detected in KAFB-2622.

5.1.3 Water Column Deoxygenation

Prior to injection, the aboveground injection line from the substrate solution mixing tanks will be connected to the injection casing at the wellhead (see Figure 5-1). The aboveground injection line and the injection casing in well WP26-INJ1 will be primed by draining a sufficient volume of deoxygenated substrate solution from the tank. A pre-injection of a sufficient amount of the substrate solution will be conducted to displace the water column in the injection well casing.

5.1.4 Reinject Substrate Solution and Bioaugmentation Culture into WP26-INJ1

Once the substrate solution has been deoxygenated and reduced to an ORP of less than negative 75 mv, it will be gravity-injected into the injection casing along with the KB-1® Dechlorinator (Figure 5-1). Injection will start with the substrate solution in the tank, quickly followed by mixing the KB-1® Dechlorinator. Argon will be used to displace the KB-1® Dechlorinator from its vessel for mixing during injection. Care will be taken to minimum turbulence during mixing and injection. A total of approximately 1.5 lbs of the KB-1® Dechlorinator will be needed for the 3,000 gallons of substrate solution.

A sample of the injected substrate solution will be collected as it is being injected and analyzed for the parameters listed in Table 5-1 and measured for field parameters (pH, specific conductivity, temperature, and turbidity). Depth to water measurements will be taken in all monitoring wells before, during, and after injection. Injection flow rate into the injection well will be routinely monitored. The injection rate will be reduced, if necessary, to ensure the water level in injection well W26-INJ1 does not exceed 150 feet above static water level to prevent damage to the well, as well as to preclude discharge to the ground surface. The injection rate of the push/pull test will be used to optimize procedures for subsequent injections.
5.1.5 Performance Monitoring of the Push/Pull Test

Performance monitoring of the push/pull test will commence after the target volume has been gravity-injected. The performance monitoring well network will consist of the nearby monitoring existing monitoring well KAFB-2622; new monitoring wells KAFB-2633, KAFB-2634, and KAFB-2635; and existing monitoring well KAFB-2625. Post-injection performance monitoring will consist of weekly water level measurements, groundwater field parameter measurements, and groundwater sampling for analytical parameters for a period of eight weeks followed by monthly measurements and sampling for two months (a total of four months plus one month for final sample analysis and data validation). Table 5-1 lists the laboratory analyses that will be performed during each performance monitoring event.

Table 5-1. Performance Monitoring Laboratory Analyses

<table>
<thead>
<tr>
<th>Analytical Group/Analyte</th>
<th>Analytical Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity (total, bicarbonate, and carbonate)</td>
<td>Standard Method 2320B</td>
</tr>
<tr>
<td>Ammonia as nitrogen</td>
<td>EPA Method 350.1</td>
</tr>
<tr>
<td>Anions (bromide, chloride, fluoride, sulfate)</td>
<td>EPA Method 300.0</td>
</tr>
<tr>
<td>Nitrate/Nitrite as nitrogen</td>
<td>EPA Method 353.2</td>
</tr>
<tr>
<td>Orthophosphate (as phosphorous)</td>
<td>EPA Method 300.0</td>
</tr>
<tr>
<td>Total organic carbon</td>
<td>SW-946 Method 9060</td>
</tr>
<tr>
<td>Sulfide</td>
<td>SW-846 Method 9034</td>
</tr>
<tr>
<td>Volatile organic compounds</td>
<td>SW-846 Method 8260B</td>
</tr>
<tr>
<td>Methane/ethane/ethene</td>
<td>RSK-175</td>
</tr>
<tr>
<td><em>Dehalococcoides</em> and three functional genes</td>
<td>CENSUS - Proprietary method of Microbial Insights, Inc. – quantitative polymerase chain reaction</td>
</tr>
</tbody>
</table>

Performance monitoring results will be evaluated to determine if the push/pull test is successful and that the Treatability Study should proceed to full-scale injection at WP26-INJ1. The evaluation criteria are listed below. Affirmative answers to these questions will support a decision to proceed to the Treatability Study should proceed to full-scale injection at WP26-INJ1. However, negative answers in and of themselves do not preclude further study, but would at least require re-evaluation of implementation procedures or the remedial approach before proceeding to full-scale injection.

1. Did the gravity-injection rate indicate that WP26-INJ1 could accommodate the planned rate for full-scale injection without exceeding the maximum pressure head in the monitoring casing?

   This will be determined by measuring the injection rate and water levels in the injection well.

2. Did groundwater conditions at well WP26-INJ1 become and remain conducive to dechlorinating TCE and its daughter products?

   Multiple lines of evidence that the injection is being effective at creating an environment that will stimulate in situ bioremediation include:

   a. Dissolved oxygen concentrations established and maintained well below 1 mg/L;
   b. Oxidation-reduction potential measurements established and maintained at or below -75 mv;
   c. Increases in orthophosphate concentrations;
3. Was a sufficient population of *Dehalococcoides* (with vinyl chloride reductase) established to facilitate complete dechlorination at WP26-INJ1?

4. Did TCE concentrations in well WP26-INJ1 demonstrate a decreasing trend that will reach MCLs within the anticipated time frame?

   Concentration decreases indicate either in situ bioremediation is working or combined with the result of dilution, but support a decision to proceed with full-scale injection at WP26-INJ1.

5. Did bromide concentration initially increase and then attenuate during post-injection monitoring?

   An initial increase in bromide concentration at a given location indicates that the substrate solution has been delivered to that point. Subsequent attenuation suggests advection of surrounding groundwater into the push/pull treatment area.

6. Were TCE dechlorination daughter products produced?

   An increase followed by a decrease in TCE daughter products indicates dechlorination is occurring. Because concentrations of TCE are initially very low, it may be difficult to detect some or all daughter products. Inability to quantify dechlorination daughter products does not, in and of itself, indicate a lack of complete dechlorination.

Additionally, stability of pH and increases in iron, manganese, and arsenic concentrations will be monitored. Increases in dissolved iron, manganese, and arsenic can be expected within the anaerobic treatment area, but should re-precipitate as they migrate with groundwater back into aerobic environments.

Results from the push/pull test will be evaluated against the above criteria to determine whether full-scale injection should proceed and if changes in implementation procedures are necessary to optimize full-scale injection and performance monitoring. Results of the push/pull test and any associated revisions to procedures will be communicated to the Air Force and NMED at least 60 days prior to proceeding with full-scale injection at WP26-INJ1.

### 5.2 Full-Scale Injection at WP26-INJ1

The objective of full-scale injection is to deliver substrate solution and bioaugmentation culture to the treatment area thereby facilitating dechlorination of TCE and any daughter products in the perched aquifer underlying the former sewage lagoons to concentrations below MCLs.

#### 5.2.1 Full-Scale Injection

Full-scale injection will involve mixing substrate solution components at prescribed ratios at prescribed ratios provides in Table 4-2 with potable water in two pairs of 5,000-gallon tanks (i.e., four 5,000-gallon tanks), deoxygenating the solution in the tanks and establishing an oxidation-reduction potential below -75 mV. As in the push/pull test, the initial injection batch will be deoxygenated with KB-1® Primer and inoculated with WP26-INJ1 soil core/cuttings. Once the first pair of tanks are deoxygenated, the aboveground injection line and the injection casing will be primed and the water column in the injection casing will be deoxygenated. The 5,000 gallons (2,500 gallons from each tank) will be injected into
WP26-INJ1 along with the bioaugmentation culture. The tanks will be refilled with potable water and commensurate amounts of ethyl lactate, diammonium phosphate, yeast extract, and sodium bromide.

During the anticipated one to two days for the first pair of tanks to re-establish anaerobic conditions and an oxidation-reduction potential less than -75 mv, 5,000 gallons of deoxygenated and low-oxidation-reduction potential substrate solution will be injected from the second pair of 5,000-gallon tanks along with the bioaugmentation culture. The second pair of tanks will then be refilled with potable water and the associated substrate solution components like the first pair of tanks. Injection can proceed to the first pair of tanks while the second pair of tanks are being refilled and deoxygenated. This process of alternating two pairs of tanks will continue for the duration of the injection provided in facilitates the most optimal injection schedule. By having two pairs of 5,000-gallon tanks onsite, the planned schedule assumes one 5,000-gallon batch can be injected per 8-hour work day by alternating deoxygenation and ready-to-inject pair of tanks each day.

The total amount of substrate solution required for injection will be determined based on results of the push-pull test. If monitoring results at monitoring well KAFB-2622 indicate that the substrate solution has reached that well and created the desired reducing conditions, injection operations will be suspended to confirm that these conditions are stable. Injection will also be suspended if analytical results in other monitoring wells demonstrate unanticipated increases in concentrations of constituents of concern.

Prior to daily injection, the dissolved oxygen will be measured in the injection well water column to ensure it is sustaining anaerobic conditions. If not, it will be deoxygenated prior to injection. During injection, dissolved oxygen, oxidation-reduction potential, and pH will be monitored in injection well WP26-INJ1 using downhole electronic probes and a data logger. Water levels will also be frequently monitored immediately prior to injection and throughout each work day during injections. Additionally, wells KAFB-2622, KAFB-2625, KAFB-2633, KAFB-2634, and KAFB-2635 will be monitored monthly during injection for the analyses outlined in Table 5-1, as well as field parameters.

Each daily injection batch will be followed with approximately 100 gallons of chase water consisting of unamended potable water deoxygenated by sparging with argon gas. This is intended to push substrate solution away from the well screen and surrounding filter pack pore space and into the formation to mitigate localized biofouling.

### 5.2.2 Performance Monitoring of the Full-Scale Injection

Performance monitoring of the full-scale injection will commence after the target volume has been gravity-injected and within one month of the last sampling event conducted during injection. The performance monitoring well network will continue to consist of wells KAFB-2622, KAFB-2625, KAFB-2633, KAFB-2634, and KAFB-2635. Post-injection performance monitoring will be conducted for a total of 24 months at a monthly frequency for three months followed by quarterly monitoring for the remainder of the post-injection monitoring period. Table 5-1 lists the required analyses. Field parameters will be collected from each well during each monitoring event.

Within six months after the full-scale injection is completed, sufficient data should be available to determine if the full-scale injection at WP26-INJ1 is successful. This will also be the point at which a decision is reached as to whether additional injection wells are warranted. In brief, if data trends indicate that TCE concentrations within the WP-026 monitoring network are declining at a rate sufficient to drop below MCLs within a three year timeframe, monitored natural attenuation will continue and no additional injection wells will be installed. Conversely, if indications are that additional injection well(s) are needed to drive TCE concentrations to levels below the MCL within the 3 year timeframe, a technical memorandum will be submitted to the Air Force and NMED recommending the locations for the new
5.0 TREATABILITY STUDY PHASE REPORTING

Injection well(s). Upon concurrence with the recommended locations for the new injection well(s), the new wells will be installed and full scale injections at those locations will proceed following the same approach as described above for WP26-INJ1. Additional evaluation criteria include the following questions. As with the push-pull test, affirmative answers support proceeding to installation of additional injection wells. However, negative answers do not preclude further study, but would at least require re-evaluation of implementation procedures or the remedial approach prior to proceeding.

1. Was the planned full-scale injection volume injected within the anticipated time frame?
   Lower than anticipated full-scale injection volumes or longer time frames may render future injections impractical or require revision to procedures.

2. Did groundwater conditions in wells WP26-INJ1 and KAFB-2622 become and remain conducive to dechlorinating TCE and the daughter products?
   Multiple lines of evidence that the injection is being effective at creating an environment that will stimulate in situ bioremediation include:
   a. Dissolved oxygen concentrations established and maintained below 1 mg/L.
   b. Oxidation-reduction potential measurements established and maintained at or below -75 mv.
   c. Increase in orthophosphate concentration.
   d. Decreases in sulfate and nitrate concentrations.
   e. Increases in iron, manganese, or arsenic concentrations.

3. Was a sufficient population of *Dehalococcoides* (with vinyl chloride reductase) established to facility complete dechlorination both at WP26-INJ1 and at KAFB-2622?
   Over 10^7 gene copies/liter indicates a high potential for complete dechlorination.

4. Did TCE concentrations in wells WP26-INJ1 and KAFB-2622 decrease below MCLs?
   Concentrations decreases indicate either in situ bioremediation is working or combined with the result of dilution, but support a decision to continue with full-scale injections at new injection wells if trends do not support monitored natural attenuation within the defined time frame.

5. Did bromide concentration initially increase and then attenuate during post-injection monitoring?
   An initial increase in bromide concentration at a given location indicates that the substrate solution has been delivered to that point. Subsequent attenuation suggests advection of surrounding native groundwater into the treatment area.

6. Were TCE dechlorination daughter products produced?
   An increase followed by a decrease in TCE daughter products indicates dechlorination is occurring. Because concentrations of TCE are initially very low, it may be difficult to detect some or all daughter products. Inability to quantify dechlorination daughter products does not, in and of itself, indicate a lack of complete dechlorination.

7. Did results from other monitoring wells support the conclusion that further injections will not adversely impact perched groundwater?
Increases in bromide concentrations and increased concentrations of TCE or associated daughter products in the monitoring network could indicate that further injection may adversely impact perched groundwater.

The monitoring data collected during the full-scale injection and during the six months after injection is completed will be evaluated against the above criteria to determine if the treatability study should proceed to the installation of additional injection wells. These interim performance results and any associated revisions to procedures will be communicated to the NMED along with the recommendation as to future actions.

5.3 Impact on Groundwater and Additional Monitoring

Biodegradation is intended to reduce TCE concentrations in the aquifer through reductive dechlorination. Reductive dechlorination occurs under anaerobic and reducing conditions in the perched aquifer. The process of developing strongly anaerobic redox conditions is likely to result in solubilization and mobilization of some naturally occurring oxidized metals and metalloids, most particularly iron, manganese, and arsenic, as a result of direction reduction and mineral dissolution. Increases in dissolved iron and manganese concentrations are indicators of biodegradation in an anaerobic and reducing environment. However, the solubilization of these metals is generally a transient phenomenon and is limited to the treatment zone. Solubilized metals and metalloids will precipitate into solid form once they leave the anaerobic treatment zone or after the aquifer returns to aerobic conditions in the treatment zone.

Concentrations of dissolved iron, manganese, and arsenic will be monitored within the treatability study treatment zone (refer to Table 5-1). In order to monitor the impact of substrate solution discharge on groundwater outside the treatment zone, wells KAFB-2622, KAFB-2625, KAFB-2633, KAFB-2634, and KAFB-2635 will be monitored for dissolved iron, manganese, and arsenic. These wells are chosen because of their proximity to the treatment zone as wells nearest to the in situ bioremediation injection. Dissolved iron, manganese, and arsenic will be monitored on a quarterly basis.
6.0 FIELD PROCEDURES

This section summarizes the procedures that will be followed in the field for collection of vadose zone soil samples during drilling, screening soil samples for VOCs using a photoionization detector (PID), collecting groundwater samples in support of the treatability study, and subsequent full-scale implementation (if necessary), collecting groundwater level measurements, performing the slug test, and decontaminating equipment.

6.1 Vadose Zone Soil Sampling

Vadose zone soil samples will be collected using split spoon samplers.

- Verify calibration checks on field monitoring equipment have been performed.
- Don personal protective equipment as specified in the health and safety plan.
- Determine the ambient VOC background levels in the immediate vicinity with a PID.
- Advance the split spoon sampler to the desired depth and retrieve the soil sample.
- Open the sampler taking care to minimize disturbance of the sample.
- Using the Munsell Soil Color Charts, visually describe the material and record observation on the soil sample field data sheet. Classify any pieces of gravel found as granitic, phyllitic, or calc-silicate, if possible.
- Obtain VOC and TPH-GRO samples directly from the sample material immediately upon opening to minimize loss due to volatilization. Sample material will be collected using samplers provided by the laboratory following the accompanying procedure specific to the sampler.
- Following collection of VOC and TPH-GRO samples, the remaining material will be transferred to a stainless steel mixing bowl and mixed to homogenize the soil.
- Soil samples for the remaining analyses will be collected in appropriate sample jars provided by the analytical laboratory.
- All equipment that has come in contact with soil will be decontaminated in accordance with the requirements outlined in Section 6.6.

6.2 Field Measurements

Soil samples will be screened for VOCs using a PID.

1. Prior to use, calibrate the PID using the isobutylene calibration gas.
2. Connect new, clean tubing from the valved sampling port to a new Tedlar® bag.
3. Connect new, clean tubing from the Tedlar® bag outlet to the pump.
4. Open the valve to the sampling port.
5. Turn on the pump and draw a minimum of three purge volumes from the sampling port.
6. Following the purge, fill the bag and close the bag valves.
7. Turn off the pump.
8. Disconnect the tubing between the Tedlar® bag and the sampling port.
6.3 Groundwater Sampling

Groundwater samples will be collected in accordance with the requirements described below:

Before purging or sampling, pumps and hoses, water level measurement devices, and other sampling equipment that may come in contact with the sample will be decontaminated in accordance with procedures outlined in Section 3.6, with the exception of equipment still in the original packaging (for example, disposable bailers). While decontamination of the pump/hose assembly may generally be performed at a central decontamination area, mobile decontamination supplies will be available so that accessory equipment (e.g., electronic water level indicators) can be decontaminated in the field.

The purpose of well purging is to remove stagnant water from the well and obtain a representative sample from the geologic formation being sampled while minimizing disturbance of the water column during sample collection. A minimum of three pore volumes will be purged from the well prior to sample collection. The low-flow purge methodology will be followed as described below:

1. Inspect the well and surrounding area for security, damage, and evidence of tampering.
2. Establish the exclusion zone around the work area, using traffic cones and caution tape where necessary.
3. Don personal protective equipment as specified in the project-specific Health and Safety Plan or Safe Work Plan, as applicable.
4. Locate the well survey reference point. This is usually an indelible mark or V-notch cut in the top of the well casing. If this point is missing, make one on the north side of the well casing.
5. Measure the static water level in the well in accordance with Section 3.4.
6. Containerize wastewater until analytical data are available to determine the proper disposal process.
7. Install the pump to the depth prescribed in the sampling documentation. This depth should correspond to approximately the middle of the screened interval, five feet below the water table or in the instance where the well screen is submerged, 5 feet below the top of the screen.
8. Reinsert the water level meter to monitor water levels during purging.
9. Start the pump at a low flow rate until surface discharge occurs. Check the water level, if no drawdown occurs, gradually increase the pump rate until the flow is optimized with minimal drawdown. The maximum allowable drawdown is 0.3 feet.
10. Connect the pump discharge tubing directly to the flow-through-cell of the multi-parameter meter.
11. Using a stopwatch and appropriate volume measuring device (e.g., graduated cylinder), monitor and record water level and pumping rate every three to five minutes (or as appropriate) during purging.

12. During well purging, monitor selected indicator field parameters (e.g., turbidity, temperature, specific conductance, pH, oxidation-reduction potential, dissolved oxygen) every three to five minutes using the multiple parameter water quality meter.

13. When the field parameters have stabilized, disconnect the flow cell from the water path before collecting samples. Water samples for laboratory analyses must be collected before the water has passed through the cell to prevent cross-contamination or chemistry changes. Stabilization is achieved when three consecutive readings show the following:
   - Temperature – ± 1 degree Celsius
   - pH – ± 0.1 pH unit
   - Turbidity – ≤ 10 NTU or ± 10%
   - Conductivity – ± 5%
   - Dissolved Oxygen – ± 10%
   - Oxidation-Reduction Potential – ± 10 millivolts

Regardless of the purging methodology, samples for laboratory analyses will be collected immediately following purging. For wells that were purged dry, samples will be collected as soon as possible after a sufficient volume of groundwater is available in the well. The following sampling procedure will be used at each well.

1. Immediately following purging, the pump will be used to collect the groundwater sample. The pump should not be removed between purging and sampling.
2. Fill out identification labels for samples bottles for each well.
3. Fill containers until almost full. Samples will be preserved and managed in accordance with the analytical method.
4. Record the sampling information in the field logbook and/or the field data sheets.
5. After samples have been collected, immediately place the samples in a cooler with ice for transport to the analytical laboratory.
6. Complete all chain-of-custody information.

Remove the pump and equipment from the well, replace the well cap, and secure the lock.

6.4 Groundwater Level Measurements

Groundwater elevation measurements will be collected each time the well is sampled. This will be done before any water is withdrawn from the well and before any purging or sampling equipment enters the well. The following steps will be followed for obtaining the water level in the well:

1. Test the water level probe to ensure that it is working properly.
2. Decontaminate the water level indicator probe as described below in Section 3.6.
3. Unlock and open the well. If necessary, let the well vent any gases that may be present in the well casing. Also, this allows the water to equilibrate to barometric changes.

4. After opening the well cover, locate the water level measuring point. If a measuring point is not marked, the measurement should be taken from the north side of the well casing, if possible.

5. With the water level indicator switched on, slowly lower the probe until it contacts the water surface as indicated by the audible alarm.

6. Raise the probe out of the water until the alarm turns off. Three or more measurements will be taken at the well until two measurements agree to within +/- 0.01 feet.

7. Record the reading on the cable at the established reference point to the nearest 0.01 foot on the field data sheet. In addition, document the measuring point location. Compare the measurement with past measurements to verify that the measurement is reasonable before leaving the well. If the measurement does not seem reasonable, repeat the water level measurement.

8. If the water level indicator fails to activate and is operating properly, lower the water level probe to the bottom of the well to ensure that the well is dry. Document that the well is dry, and record the total depth of the well.

During the course of collecting water level measurements, observations of well condition will be collected and recorded. Water level measurements will be collected from the groundwater monitoring wells located at WP-026 during each groundwater sampling event. Static water levels and total well depth will be measured prior to purging activities.

6.5 Slug Testing

In a slug test, a known volume of water or solid slug is rapidly removed from or introduced into a well, after which the rate in the rise or fall of the water level in the well is measured. From these measurements, the hydraulic conductivity or transmissivity of the aquifer materials in the vicinity of the well can be estimated.

Slug testing is well suited for gaining a preliminary estimate of aquifer parameters in areas where no observation wells are available or hydraulic conductivities are too small to conduct a pumping test. In the case of WP-026, the saturated thickness of the perched aquifer is estimated to be less than 20 feet precluding an accurate performance of a pumping test making slug testing the preferred alternative.

6.5.1 Testing Equipment

The following equipment is required for conducting the slug tests:

1. Electronic water level measuring device (sounder) and back-up unit;
2. A “slug” (a solid volume that will fit easily into the well; a solid slug can be a sealed sand or water-filled length of clean polyvinyl chloride [pvc] pipe);
3. Low pounds per square inch pressure transducer with downhole logger, line, and hangers for suspending the unit in the well;
4. Laptop computer or device for communicating with the datalogger and communication cables;
5. Slug test data forms; and
6. Decontamination equipment for cleaning downhole equipment prior to installation in each well.
With the exception of Well KAFB-0506 which is 5-inch diameter, all other perched wells installed at the WP-026 sewage lagoons are 4-inch diameter. Table 6-1 provides the displacement calculations for a slug design.

**Table 6-1. Slug Design Displacement Calculations**

<table>
<thead>
<tr>
<th>Well Nominal pipe diameter (inches)</th>
<th>Well Inside diameter sched 40 (inches)</th>
<th>Slug Nominal pipe diameter (inches)</th>
<th>Slug Outside diameter sched 40 (inches)</th>
<th>Annular Space (inches)</th>
<th>Well Volume (ft³/ft)</th>
<th>Slug Volume (ft³/ft)</th>
<th>Minimum length of Slug (feet)</th>
<th>Well Displacement (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3.998</td>
<td>3</td>
<td>3.500</td>
<td>0.249</td>
<td>0.087</td>
<td>0.067</td>
<td>4.5</td>
<td>3.45</td>
</tr>
<tr>
<td>5</td>
<td>5.016</td>
<td>4</td>
<td>4.500</td>
<td>0.258</td>
<td>0.137</td>
<td>0.110</td>
<td>4.0</td>
<td>3.21</td>
</tr>
</tbody>
</table>

\( \frac{ft^3}{ft} = \text{cubic feet per foot} \)

**6.5.2 Slug Construction**

Slug construction will consist of the following:

1. For 4-inch diameter, Schedule 40 wells, use 4.5 feet of 3-inch diameter thin-wall PVC;
2. For 5-inch diameter, Schedule 40 wells, use 4.0 feet of 4-inch diameter thin-wall PVC;
3. Use flush mount, slip joint bushings;
4. Drill and mount eyebolt, seal with silicone caulk;
5. Attach bottom cap/plug with pop rivet or low-VOC glue;
6. Fill slug with sufficient sand to exceed the buoyancy of the PVC pipe;
7. Secure the top cap/plug with low VOC glue or pop rivet; and
8. Hang on enough sturdy rope to suspend below the water level in all wells.

**6.5.3 Slug Test Performance**

Follow the procedures below to conduct the slug testing:

1. Conduct slug testing only during stable weather conditions (steady barometric pressure) when the threat of sudden storms or barometric pressure changes are minimal. Document atmospheric conditions in the logbook and on the field data forms.
2. Use weather service data to check for possible barometric effects on the data.
3. Establish the work zone as directed in the project health and safety plan.
4. Decontaminate all equipment that will enter the well in accordance with Section 6.6.
5. Measure the depth to static water with the water level indicator and record the reading in the field logbook and on the field data forms.
6. Use a transducer and downhole logger with the lowest possible pressure rating requiring minimum submergence appropriate for the estimated hanging position and required submergence. Set the record time at the shortest interval. Short measurement intervals will ultimately result in better data. Test the transducer calibration and programming in a bucket of water or PVC pipe by
raising or lowering the transducer and comparing the known change with the change indicated by the pressure transducer.

7. Please the pressure transducer inside the well casing, ensuring that the height of the water column above the transducer is sufficient for it to remain under water and function efficiently even at maximum drawdown. Hang the transducer 10 feet above the point of maximum submergence for the pressure rating of the transducer, or 1 foot above the top of fill in the well, whichever is the smaller depth that is still deeper than the bottom of the slug when submerged below static water level. Throughout the test, the slug should always be above the transducer in the well casing. Hang the transducer such that it cannot slip. Mark the transducer suspension line so that any slippage or lack thereof can be documented. Start the data logger and collect a minimum of 10 minutes of background data to document the water level is stable.

8. Set up the slug rope with two hanging points (rope knotted loops); #1 for hanging the slug with the bottom one foot above the static water level (pre-test), and #2 for hanging the slug with the top one foot below the static water level (testing position).

9. Hang the sounder one foot above the top of the slug at #1 position.

**Slug Introduction Test**

Slug data from slug removal is preferable to slug introduction, but both will be collected. Slug introduction data are influenced by the larger saturated column with the part above static water level being variably saturated, but may still be useful for comparison.

1. Lower the slug as quickly as possible and hang in position #2.

2. Collect manual sounder measurements as quickly as possible at first. Use a stop watch to record time of measurements, with lap mode to record time as accurately as possible. If the transducer fails, this manual data may be used.

3. Collect data until the water level has returned to the pre-test static water level. As the rate of water level change slows, the measurement interval can be spaced out appropriately.

4. Collect a minimum of 10 minutes of data after reaching the pre-test static water level to document that the level is stable.

**Slug Removal Test**

Remove sounder from well. Remove slug from well as rapidly as possible. Lower the sounder and take manual measurements as rapidly as possible, recording measurement time.

1. Conduct manual measurements until the water level recovers to at least 90 percent of the static water level allowing the well to full recover, if possible, before removing the pressure transducer. Enter manual measurements into the field forms.

2. Remove the transducer, download the data, and compare to manual measurements.

3. Conduct the slug test on relatively undisturbed wells. If a slug test is conducted on a well that has recently been purged for sample collection, the water level must be within 0.10 feet of the pre-purge water level before initiating the slug test. The measurement of water levels over several days will indicate when equilibrium is achieved and slug testing can be conducted.
4. If possible, plot well recovery curves in the field to evaluate the success of the test. The use of electronic data loggers and laptop computers allows field evaluation to be completed relatively quickly. If the data are too irregular to fit curves or straight lines, the field personnel will determine whether retesting is necessary.

5. Any water added to the well will be from a known uncontaminated source that has undergone laboratory analysis. Properly containerize any water removed for disposal according to procedures outlined in the groundwater monitoring plan. Slug test data will be documented in the field logbook and on field data forms.

6.6 Decontamination

Non-dedicated sampling equipment will be decontaminated following the procedures described below:

Procedures for decontamination of sampling equipment apply to:

- Reusable equipment that will and has come in contact with a sample medium
- Wash and rinse tubs/buckets
- Water levels probes
- Sample bottles and coolers.

Disposable items such as disposable filters and tubing that are certified clean by the manufacturer are not subject to decontamination requirements. Decontamination of sampling equipment will in general be performed at individual sample locations. However, any pre-rinsing or decontamination of reusable equipment prior to sampling can be performed at other specified locations suitably established for such activities.

1. Don appropriate PPE as specified in the project-specific HASP. To note, new latex gloves shall be worn when performing equipment decontamination.

2. Scrape off gross contamination from equipment at the sampling site and place in containers specified for investigation-derived waste (IDW).

3. Place the equipment in a wash tub containing detergent solution or spray the equipment with a detergent solution contained within a water sprayer. Scrub the equipment with a bristle brush or similar utensil (if possible).

4. Triple rinse the equipment with deionized or distilled water from a water sprayer or wash bottles catching the rinsate in a second wash tub or bucket.

5. In a third wash tub or bucket, rinse equipment with a 10% nitric acid solution or reagent grade methanol, as applicable. A nitric acid rinse will be used when samples are collected for metals analysis with a methanol rinse used for collecting semi-volatile organic compounds.

6. Re-rinse the equipment with deionized or distilled water (note that if time allows for air drying after performing a methanol rinse, this step shall be omitted).

7. Allow equipment to gravity drain or air dry.
5.07.0 REPORTING

Reporting will be comprised of a Interim Measures Report and annual LTM reports.

5.47.1 Interim Measures Report

Documentation of the project will include field notes and forms, photographs (if allowed), and analytical data. The Interim Measures Report will be prepared following completion of the interim measures detailing the activities conducted to address contamination at the Site. The report will be submitted for USAF and NMED review. The Interim Measures Report will include, at a minimum, the following elements:

- A description of the interim measures implemented
- As-built drawings showing the SVE system injection well and monitoring well construction diagrams including the well installation and electrical installation details
- Summaries of LTM analytical results
- Summaries of problems encountered and deviations from the planned work scope
- Summaries of accomplishments and/or effectiveness of the interim measures
- Recommendations for disposition of the site.

The Interim Measures Report will include VLEACH vapor modeling and an evaluation of risk associated with any residual constituents that remain in the vadose zone and groundwater underlying the site. VLEACH is a one-dimensional, finite difference model used to make preliminary assessments of the effects on groundwater from the leaching of volatile, sorbed constituents through the vadose zone. The program models four main processes including liquid-phase advection, solid-phase sorption, vapor-phase diffusion, and three-phase equilibration. The software is available on-line at the following EPA web address: [http://www.epa.gov/ada/csmos/models/vleach.html](http://www.epa.gov/ada/csmos/models/vleach.html)

5.47.2 Long-Term Monitoring Reports

Annual LTM reports will be prepared to document the results of the groundwater sampling and well gauging activities completed during the fiscal year. The annual monitoring reports will provide evaluation of the data and associated trends and provide recommendations as to future monitoring requirements and optimization actions. Concentration versus time trend analysis for key constituents will be performed using appropriate statistical analysis software such as the Monitoring and Remediation Optimization System, which was developed by GSI Environmental Inc. of Houston, Texas and the University of Houston for the Air Force Center for Environmental Excellence in accordance with the organization’s Long-Term Monitoring Optimization guide. Other appropriate statistical methods may be employed with approval of the USAF.

In addition to the above reports, analytical data will be exported for upload to AFCEC’s Environmental Restoration Program Information Management System database within 90 days of sample collection.
6.08.0 PROJECT SCHEDULE

An integrated master schedule has been prepared for the overall anticipated sequence of activities to be performed in support of the interim measures at the Site (see Table 1). The schedule is dependent on many independent factors including, but not limited to, USAF and NMED review and comment, subcontractor availability, weather, and site conditions. The USAF and NMED will be notified 30 days prior to the implementation of interim measure field activities. Additionally, during implementation of the interim measures, monthly status reports will be submitted to Kirtland AFB ERP personnel by electronic mail. These reports will summarize the previous week’s activities, the planned activities for the following week, and any other pertinent information.

The interim measures implementation schedule will allow for evaluation of screening level data during field work to allow for timely response to changing conditions. Post-interim measures groundwater monitoring will be conducted to monitor effectiveness of the interim measures implemented, to augment the implemented interim measures with additional actions if determined to be necessary in order to achieve the project objectives, and to demonstrate that the interim measures have successfully addressed contamination at the site based on mitigation of contaminant impacts on groundwater underlying the site thereby supporting a corrective action completion without controls determination.

The Interim Measures Report will be submitted for review and approval by USAF and NMED personnel.

<table>
<thead>
<tr>
<th>Table 6-1. Project Schedule</th>
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<tbody>
<tr>
<td><strong>Milestone Tasks</strong></td>
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<tr>
<td>Deliver draft Interim Measures Work Plan for USAF review</td>
</tr>
<tr>
<td>USAF review of draft Interim Measures Work Plan</td>
</tr>
<tr>
<td>Deliver draft final Interim Measures Work Plan for NMED review</td>
</tr>
<tr>
<td>NMED review of draft final Interim Measures Work Plan</td>
</tr>
<tr>
<td>Deliver final Interim Measures Work Plan</td>
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<tr>
<td><strong>Long-Term Monitoring Plan</strong></td>
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<tr>
<td>Deliver final Long-Term Monitoring Plan</td>
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<tr>
<td><strong>Fiscal Year (FY) 2014 Annual Groundwater/Soil Vapor Monitoring and Reporting</strong></td>
</tr>
<tr>
<td>Complete 3rd Quarter Groundwater/Soil Vapor Sampling and Well Gauging</td>
</tr>
<tr>
<td>Complete 4th Quarter Groundwater/Soil Vapor Sampling and Well Gauging</td>
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<tr>
<td>Deliver draft FY 2014 LTM Report for USAF review</td>
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## 06.0 PROJECT SCHEDULE

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<th>Milestone Tasks</th>
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<tr>
<td>Deliver draft FY 2015 LTM Report for USAF review</td>
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<tr>
<td>Deliver draft final FY 2015 LTM Report for NMED review</td>
<td>October 21, 2015</td>
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<tr>
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<td>April 6, 2016</td>
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<td>June 1, 2016</td>
</tr>
<tr>
<td><strong>FY 2016 Annual Groundwater/Soil Vapor Monitoring and Reporting</strong></td>
<td></td>
</tr>
<tr>
<td>Complete 1\textsuperscript{st} Quarter Groundwater/Well Gauging</td>
<td>October 16, 2015</td>
</tr>
<tr>
<td>Complete 2\textsuperscript{nd} Quarter Groundwater/Soil Vapor Sampling and Well Gauging</td>
<td>January 15, 2016</td>
</tr>
<tr>
<td>Complete 3\textsuperscript{rd} Quarter Groundwater/Soil Vapor Sampling and Well Gauging</td>
<td>April 15, 2016</td>
</tr>
<tr>
<td>Complete 4\textsuperscript{th} Quarter Groundwater/Soil Vapor Sampling and Well Gauging</td>
<td>July 15, 2016</td>
</tr>
<tr>
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<td>October 19, 2016</td>
</tr>
<tr>
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<td>December 14, 2016</td>
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<td>Complete 2\textsuperscript{nd} Quarter Groundwater/Soil Vapor Sampling and Well Gauging</td>
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<tr>
<td>Complete 3\textsuperscript{rd} Quarter Groundwater/Soil Vapor Sampling and Well Gauging</td>
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<td>Complete 2\textsuperscript{nd} Quarter Groundwater/Soil Vapor Monitoring and Well Gauging</td>
<td>January 12, 2018</td>
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<td>Complete 4\textsuperscript{th} Quarter Groundwater/Soil Vapor Monitoring and Well Gauging</td>
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<td>July 24, 2019</td>
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<tr>
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<td>Complete 1\textsuperscript{st} Quarter Groundwater/Soil Vapor Monitoring</td>
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<tr>
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<td>Preparation Tasks</td>
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<td>-------------------</td>
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</tr>
<tr>
<td>Soil Vapor Extraction Well Installation</td>
<td></td>
</tr>
<tr>
<td>Complete Pre-Fieldwork Activities</td>
<td>November 7, 2016</td>
</tr>
<tr>
<td>Install new soil vapor extraction wells</td>
<td>December 7, 2016</td>
</tr>
<tr>
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</tr>
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<td>October 4, 2017</td>
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<td>Deliver final Well Completion Report</td>
<td>November 29, 2017</td>
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<table>
<thead>
<tr>
<th>Soil Vapor Extraction System Installation</th>
<th></th>
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<tbody>
<tr>
<td>Install Soil Vapor Extraction System Components</td>
<td>January 10, 2018</td>
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<tr>
<td>Perform Operational Checks</td>
<td>January 17, 2018</td>
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</tbody>
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<table>
<thead>
<tr>
<th>SVE System Monitoring</th>
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<tr>
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<td>February 13, 2018</td>
</tr>
<tr>
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<td>March 15, 2018</td>
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<tr>
<td>Monthly System Operational Monitoring – March 2018</td>
<td>April 16, 2018</td>
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<tr>
<td>Monthly System Operational Monitoring – April 2018</td>
<td>May 16, 2018</td>
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<td>July 16, 2018</td>
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<tr>
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<td>January 14, 2019</td>
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<tr>
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<td>Monthly System Operational Monitoring – February 2019</td>
<td>March 15, 2019</td>
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<tr>
<td>SVE Rebound Test – March 2019</td>
<td>April 15, 2019</td>
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<td>Monthly System Operational Monitoring – May 2019</td>
<td>June 13, 2019</td>
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<tr>
<td>Monthly System Operational Monitoring – June 2019</td>
<td>July 11, 2019</td>
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<table>
<thead>
<tr>
<th>Interim Measures Completion Report</th>
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<tbody>
<tr>
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<td>August 22, 2019</td>
</tr>
<tr>
<td>Perform VLEACH Vapor Modeling and Prepare Risk Evaluation</td>
<td>September 5, 2019</td>
</tr>
<tr>
<td>USAF review of draft Interim Measures Completion Report</td>
<td>October 10, 2019</td>
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<tr>
<td>Deliver draft final Interim Measures Completion Report for NMED review</td>
<td>November 14, 2019</td>
</tr>
<tr>
<td>NMED review of draft final Interim Measures Completion Report</td>
<td>January 25, 2021</td>
</tr>
<tr>
<td>Deliver final Interim Measures Completion Report</td>
<td>March 15, 2021</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Well Abandonment and Reporting</th>
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</thead>
<tbody>
<tr>
<td>Submit Required Abandonment Documentation</td>
<td>September 13, 2021</td>
</tr>
<tr>
<td>Mobilize for Well Abandonment</td>
<td>October 25, 2021</td>
</tr>
<tr>
<td>Demobilize SVE System Components</td>
<td>December 8, 2021</td>
</tr>
<tr>
<td>Complete Well Abandonment Field Work</td>
<td>November 22, 2021</td>
</tr>
<tr>
<td>Demobilize from Well Abandonment</td>
<td>November 25, 2021</td>
</tr>
<tr>
<td>Deliver draft Well Abandonment Report for USAF Review</td>
<td>January 10, 2022</td>
</tr>
<tr>
<td>USAF review of draft Well Abandonment Report</td>
<td>February 14, 2022</td>
</tr>
<tr>
<td>Deliver draft final Well Abandonment Report for NMED Review</td>
<td>March 21, 2022</td>
</tr>
<tr>
<td>Milestone Tasks</td>
<td>Completion Date</td>
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<tr>
<td>-----------------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>NMED review of draft final Well Abandonment Report</td>
<td>September 5, 2022</td>
</tr>
<tr>
<td>Deliver final Well Abandonment Report</td>
<td>October 24, 2022</td>
</tr>
<tr>
<td><strong>Interim Action Completion Proposal</strong></td>
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</tr>
<tr>
<td>Deliver draft Interim Action Completion Proposal for USAF Review</td>
<td>May 17, 2021</td>
</tr>
<tr>
<td>USAF review of draft Interim Action Completion Proposal</td>
<td>June 7, 2021</td>
</tr>
<tr>
<td>Deliver draft final Interim Action Completion Proposal for NMED Review</td>
<td>October 25, 2021</td>
</tr>
<tr>
<td>Prepare and Publish Newspaper Notice</td>
<td>November 1, 2021</td>
</tr>
<tr>
<td>Complete Public Comment Period</td>
<td>December 31, 2021</td>
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<tr>
<td>Public Meeting</td>
<td>December 2, 2021</td>
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<tr>
<td>NMED review of draft final Correction Action Completion Proposal</td>
<td>July 28, 2022</td>
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<td>NMED Approval of Final Interim Action Completion Proposal</td>
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</table>

FY—fiscal year
LTM—long-term monitoring
NMED—New Mexico Environment Department
SVE—soil vapor extraction
USAF—U.S. Air Force
7.09.0 REFERENCES


APPENDIX A

ELECTRON DONOR DEMAND AND MASS CALCULATIONS
ELECTRON DONOR DEMAND AND MASS CALCULATIONS

The following spreadsheets present the calculations to estimate the mass of ethyl lactate needed to meet electron donor demand in groundwater within the projected treatment area for each full-scale injection to be implemented during the treatability study.

The spreadsheet first presents the dimensions of the treatment area for one injection location. Subsequent injection locations, if needed, are assumed to have the same treatment zone dimensions and effective porosity. Electron donor demand also used electron acceptor concentrations from monitoring well KAFB-2622 where constituent concentrations are highest. Electron donor demand calculations will be performed on a location-specific basis based on initial sampling results from injection wells once they are installed and these results will be used to refine substrate solution constituent ratios prior to injection.

Electron donor demand was divided into two categories that calculate demand based on a stoichiometric ratio:

- Electron donor demand for competing terminal electron acceptors (TEAs)
- Electron donor demand for dissolved volatile organic compounds (VOCs)

Based on work previously performed by Sandia National Laboratory as presented in Appendix A of the Revised Treatability Study Work Plan for In-Situ Bioremediation at the Technical Area-V Groundwater Area of Concern (Sandia, 2016), electron donor demand for VOCs sorbed to saturated soil is negligible; therefore, the calculation was not performed for this category.

As discussed in the Sandia work plan, experience from projects at similar sites shows that the theoretical stoichiometric value is often not sufficient to create the desired conditions. Research has shown that only 30 percent of the electron donor is utilized for dechlorination (referred to as the ‘McCarty’ factor). The McCarty factor was applied to calculate electron donor demand based on stoichiometry. A safety factor of 10 was then applied based on Sandia’s field experience and to account for low permeability of the saturated sediments at the site.

Estimated delivery timeframe per full-scale injection is also presented based on the assumption that 5,000 gallons per day of potable water mixed with the electron donor, amendments, and bioaugmentation culture could be gravity-injected each work day, plus an additional three weeks to allow for system setup and optimization.

Due to very low concentrations of VOCs, the electron donor demand is almost completely governed by concentrations of competing terminal electron acceptors in groundwater (dissolved oxygen, nitrate, iron, manganese, and sulfate). The bulk of electron donor will be adjusted in-situ for reductive dechlorination to take place.
## Electron Donor (Ethyl Lactate) Demand and Mass Calculations

### Dimensions of Treatment Area (one injection well)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Delivery Radius (ft)</td>
<td>60</td>
</tr>
<tr>
<td>Effective Porosity</td>
<td>0.25</td>
</tr>
<tr>
<td>Area (ft(^2))</td>
<td>11,310</td>
</tr>
<tr>
<td>Volume of Soil Matrix (CY)</td>
<td>6,283</td>
</tr>
<tr>
<td>Thickness (ft)</td>
<td>20</td>
</tr>
<tr>
<td>Pore Volume (ft(^3))</td>
<td>56,549</td>
</tr>
<tr>
<td>Total Target Volume (ft(^3))</td>
<td>226,195</td>
</tr>
<tr>
<td>Pore Volume (L)</td>
<td>1,601,280</td>
</tr>
<tr>
<td>Total Target Volume (CY)</td>
<td>8,378</td>
</tr>
<tr>
<td>Pore Volume (gal)</td>
<td>423,013</td>
</tr>
</tbody>
</table>

### Electron Donor Demand for Competing Terminal Electron Acceptors (TEAs)

<table>
<thead>
<tr>
<th>Terminal Electron Acceptor</th>
<th>Concentration (mg/L)</th>
<th>Molecular Weight (g/mol)</th>
<th>Molar Ratio (mol electron donor/mol TEA)</th>
<th>Electron Donor Demand (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved Oxygen</td>
<td>6.04</td>
<td>32</td>
<td>1/6</td>
<td>3.7152</td>
</tr>
<tr>
<td>Nitrate</td>
<td>3.8</td>
<td>62</td>
<td>5/24</td>
<td>1.5080</td>
</tr>
<tr>
<td>Iron</td>
<td>0</td>
<td>55.9</td>
<td>1/24</td>
<td>0.0000</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.7</td>
<td>54.9</td>
<td>1/12</td>
<td>0.1255</td>
</tr>
<tr>
<td>Sulfate</td>
<td>110</td>
<td>96</td>
<td>1/3</td>
<td>45.1076</td>
</tr>
<tr>
<td>Electron Donor: Ethyl Lactate</td>
<td>118.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total electron donor demand (mg/L): 50.456
Total electron donor demand (mg): 80,794,753
Total electron donor demand for competing TEAs (lbs) - rounded to nearest 0.1 lb: 178.2
### Electron Donor Demand for Dissolved Volatile Organic Compounds

<table>
<thead>
<tr>
<th>Volatile Organic Compound</th>
<th>Concentration (µg/L)</th>
<th>Molecular Weight (g/mol)</th>
<th>Molar Ratio (mol electron donor/mol VOC)</th>
<th>Electron Donor Demand (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetrachloroethene</td>
<td>0</td>
<td>165.8</td>
<td>1/3</td>
<td>0.0000</td>
</tr>
<tr>
<td>Trichloroethene</td>
<td>15</td>
<td>131.4</td>
<td>1/4</td>
<td>3.3704</td>
</tr>
<tr>
<td>cis-1,2-Dichloroethene</td>
<td>3.5</td>
<td>96.9</td>
<td>1/6</td>
<td>0.7110</td>
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<tr>
<td>Vinyl Chloride</td>
<td>0</td>
<td>62.5</td>
<td>1/12</td>
<td>0.0000</td>
</tr>
<tr>
<td>Electron Donor: Ethyl Lactate</td>
<td></td>
<td></td>
<td></td>
<td>118.1</td>
</tr>
<tr>
<td>Subtotal electron donor demand (µg/L) (based on ethyl lactate)</td>
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<td></td>
<td></td>
<td>4.081</td>
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<tr>
<td>Treatment area pore volume (L)</td>
<td></td>
<td></td>
<td></td>
<td>1,601,280</td>
</tr>
<tr>
<td>Total electron donor demand (mg)</td>
<td></td>
<td></td>
<td></td>
<td>6,535,449</td>
</tr>
<tr>
<td>Total electron donor demand for competing TEAs (lbs) - rounded to nearest 0.1 lb</td>
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<td></td>
<td></td>
<td>0.014</td>
</tr>
</tbody>
</table>

### Mass of Electron Donor to be Injected

- Total electron donor demand for competing terminal electron acceptors (lbs) 178.2
- Total electron donor demand for dissolved volatile organic compounds (lbs) 0.014
- Total electron donor demand as ethyl lactate (lbs) 178.2
- Adjusted total accounting for the McCarty Factor (30% efficiency) (lbs) 594
- Safety factor for Low K sediment 10
- Total electron donor to be injected in one pore volume (lbs) 5,940
- Total electron donor to be injected per 1,000 gallons of water (lbs) 8.9
## Injection Timeframe

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<thead>
<tr>
<th>Description</th>
<th>Value</th>
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<tbody>
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<td>Target Volume (gal)</td>
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</tr>
<tr>
<td>Number of injection wells</td>
<td>1</td>
</tr>
<tr>
<td>Total injection volume (gal)</td>
<td>423,013</td>
</tr>
<tr>
<td>Batch volume (gal)</td>
<td>5,000</td>
</tr>
<tr>
<td>Batches per day</td>
<td>1</td>
</tr>
<tr>
<td>Estimated injection rate (gal per day)</td>
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</tr>
<tr>
<td>Total injection batches for one pore volume (rounded up to the nearest whole batch)</td>
<td>85</td>
</tr>
<tr>
<td>Total injection timeframe (days)</td>
<td>85</td>
</tr>
<tr>
<td>Total injection timeframe (weeks) - assumes 5 days per week plus 3 weeks for system set-up, optimization, and demobilization.</td>
<td>20</td>
</tr>
</tbody>
</table>

**Abbreviations:**
- CY – cubic yard
- ft - feet
- ft² – square feet
- ft³ – cubic feet
- gal – gallon
- g/mol – grams per mole
- L - liter
- lbs – pounds
- mol - mole
- TEA – terminal electron acceptor
- µg/L – micrograms per liter
- VOC – volatile organic compound