

**REMEDIAL TECHNOLOGIES EVALUATION REPORT  
PETROLEUM CONTAMINATION OF SOIL AND GROUNDWATER  
AT FORMER UNDERGROUND STORAGE TANK FARMS**

Lockbourne Air Force Base  
Columbus, Ohio

Presented to:



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## 1.0 INTRODUCTION

S&A Environmental Consultants, LLC (S&A), SCS Engineers (SCS), and Short Elliott Hendrickson, Inc. (SEH) [S&A Team] have been contracted by the U.S. Army Corps of Engineers (USACE), Louisville District (CELRL) to evaluate various technologies for the remediation of subsurface petroleum contamination found in three areas of concern (AOCs) at the Lockbourne Air Force Base (LAFB), in Columbus, Ohio. The evaluation has been performed as specified in the CELRL Performance Work Statement (PWS) revised March 3, 2011, and in accordance with the *Work Plan for Remedial Technologies Evaluation* dated September 26, 2011. This report has been prepared to meet the requirements of Task 3 of the PWS.

### 1.1 PURPOSE AND SCOPE OF REMEDIAL TECHNOLOGIES EVALUATION

The objective of the remedial technologies evaluation is to produce a report comparing eight remedial technologies that could be used to address the fuel contamination present at the three AOCs at the LAFB. The eight technologies to be evaluated include:

- Natural Source Zone Depletion (NSZD)
- Excavation
- In-Situ Soil Mixing (ISSM)
- Multi-Phase Extraction (MPE)
- Multi-Phase Extraction with Heating (MPEH)
- In-situ Chemical Oxidation (ISCO)
- Surfactant Enhanced Light Nonaqueous Phase Liquid (LNAPL) Removal (SELR)
- Electrical Resistance Heating (ERH)

Although cleanup of all media (i.e., soil, groundwater, indoor air) to meet Ohio Department of Commerce Bureau of Underground Storage Tank Regulations (BUSTR) requirements is the objective, it is anticipated that the remedial technologies evaluation will focus on treatment of recalcitrant LNAPL at each of the AOCs. The evaluation will be based on current site conditions for AOCs 3 and 11, but as specified in the PWS, the AOC 8/9 evaluation will be based on future construction of a warehouse and paved area similar to development at AOC 3. Each technology will be described in detail and evaluated on the basis of effectiveness, implementability, and cost.

### 1.2 FORMER LOCKBOURNE AIR FORCE BASE SITE DESCRIPTION AND HISTORY

LAFB is located in Franklin County, Ohio, south of the City of Columbus in the central portion of the state (Figure 1). It began operation as the Lockbourne Army-Airfield in 1942 on approximately 1,574 acres and was used to train glider pilots during World War II. In the early 1950s, the base was redesigned for use by jet bombers and eventually renamed LAFB. By 1974 it had expanded to 4,400 acres, and the name was changed to Rickenbacker Air Force Base

(RAFB). RAFB was closed in 1980, and the land divided. Approximately half the property was licensed to the Ohio Air National Guard, and the remaining property was sold to the Rickenbacker Port Authority [now Columbus Regional Airport Authority (CRAA)] and private developers between 1980 and 1984. In 1994 the remaining base was closed and the entire property, including the former LAFB, became known as the Rickenbacker International Airport. The Ohio Air National Guard, Ohio Army National Guard, and U.S. Navy Air Reserves remain partial owners of the former AFB.

Three areas of the base are addressed in the PWS: AOC 3, AOC 8/9, and AOC 11 (Figure 2). The three AOCs were underground storage tank (UST) farms used for storing fuel for the jet bombers. The USACE previously removed the USTs from AOC 3 and AOC 8/9. Petroleum hydrocarbon contamination from jet fuel was documented during the removal activities, and several investigations have been performed at all the AOCs to evaluate the extent of jet fuel contamination. A Monitored Natural Attenuation (MNA) Assessment has been conducted to evaluate the potential for natural attenuation given the site geochemistry and hydrogeology, a Well Injection Depth Extraction (WIDE) pilot study was conducted on AOC 3, and free product recovery is ongoing on all three AOCs. No other active remediation has been implemented at any of the AOCs. No ordnance-related activities were ever found to have occurred in the area of the three AOCs, and no chemical releases except those associated with jet fuel have been found in these areas (Ref. 1).

In addition to UST removal, Buildings 1045 and 1055 at AOCs 3 and 8/9 have been demolished, and pipelines removed or closed in place. A new warehouse has been constructed, and associated parking areas, drives, and utilities installed on the south side of AOC 3. Similar construction is planned for AOC 8/9. The CRAA continues to use the jet fuel USTs and fuel pipelines at AOC 11 and has installed above-ground storage tanks for aviation gasoline (AVGAS) on the east side of AOC 11.

### 1.3 REMEDIAL ACTION OBJECTIVES

This section presents the remedial action objectives (RAOs) that will be used in evaluating the effectiveness of the alternatives.

#### 1.3.1 Regulatory Authority

USTs in Ohio are regulated by the Ohio Department of Commerce BUSTR. The applicable BUSTR regulations are located at Ohio Administrative Code (OAC) 1301:7-9-12, OAC 1301:7-9-13, OAC 1301:7-9-16, and OAC 1301:7-9-17, effective date March 1, 2005. A brief overview of the BUSTR regulations governing remediation of UST sites is presented in this section.

The initial Tier 1 evaluation of site investigation data compares concentrations detected in soil and groundwater to BUSTR delineation levels. Soil delineation levels are the lowest action level from the soil to indoor air, soil to non-drinking water, and soil direct contact exposure pathways. The groundwater delineation levels are based on the groundwater to indoor air exposure pathway action level divided by 10 or the groundwater ingestion exposure pathway action level, whichever is higher. According to the BUSTR *Technical Guidance Manual for Closure, Corrective Action, and Contaminated Soil Rules*, April 2005, the delineation levels are not risk-



based and may not be revised (Ref. 2). The delineation levels are included in the BUSTR tables in Appendix A.

If the Tier 1 evaluation identifies concentrations of contaminants of concern above the delineation levels, a Tier 2 evaluation may be performed. The Tier 2 evaluation is based on site-specific action levels established by BUSTR. Standards for free product, soil contamination, and groundwater contamination are determined by both absolute standards and through a risk-based evaluation. The evaluations take into consideration soil type, land use, groundwater use, and various exposure pathways.

Free product is defined by BUSTR in terms of both a separate phase liquid and soil saturation. It is considered a separate phase liquid if it is at least 0.01 foot thick on groundwater, surface water, or in an excavation. If a separate phase liquid is present at a site, it must be remediated through a free product recovery program “to the maximum extent practicable (e.g., when recovery is limited by the technology available or free product occurrence has become intermittent).” If free product is still present after a year of operation, the fire marshal may require a written re-evaluation of the recovery program to address the reliability, effectiveness, cost, and time needed to complete recovery.

Soil saturation is defined as the condition in which all the pores of a soil/rock material are entirely filled with contaminants of concern or petroleum and water, such that no more can be added without free-phase product existing. Soil saturation may be calculated, or BUSTR provides default values for three soil classifications. If saturated soil exists at the site, you must implement an interim response action or develop a Remedial Action Plan (RAP).

Risk-based cleanup standards for soil are determined based on the soil type and exposure pathway. Soils types are divided into three classes, with Class 1 being the most permeable and Class 3 being the least permeable. The following exposure pathways are to be evaluated:

- Soil to indoor air – residential
- Soil to indoor air – non-residential
- Soil to outdoor air – residential
- Soil to outdoor air – non-residential
- Soil to outdoor air – excavation worker
- Soil to groundwater – drinking water
- Soil to groundwater – non-drinking water
- Soil direct contact – residential
- Soil direct contact – non-residential
- Soil direct contact – excavation worker

Target concentrations are given for the following chemicals of concern for each soil class and exposure pathway: benzene; toluene; ethyl benzene; o,m, and p-xylene; methyl tertiary butyl ether; benzo(a)anthracene; benzo(b)pyrene; benzo(b)fluoranthene; benzo(k)fluoranthene; chrysene; dibenzo(a,b)anthracene; indeno(1,2,3-c,d)pyrene; and naphthalene. Target concentrations are also given for total petroleum hydrocarbons (TPH).

Cleanup standards for groundwater are determined based on the pathway, some of which take into account the soil class. The following pathways are to be evaluated:

- Groundwater to indoor air, varying by depth to groundwater and soil class
- Groundwater to outdoor air, varying by soil class
- Groundwater direct contact – residential
- Groundwater direct contact – non-residential
- Groundwater direct contact – excavation worker
- Groundwater ingestion

With the exception of TPH, the compounds of concern are the same for groundwater as for soil. The BUSTR action level tables are included in Appendix A.

If the Tier 2 action levels are exceeded, a RAP must be developed or a Tier 3 evaluation conducted. The owner/operator must provide the directly affected public notification of the proposed RAP, in a format approved by the Fire Marshal. The Fire Marshal may hold a public meeting before approving the RAP. The owner/operator must implement the RAP after approval by the Fire Marshal.

The RAP must include a monitoring plan. The objective of the monitoring plan is to document when the remedial action is complete. A completion report demonstrating that the objectives have been met must be submitted by the date provided in the RAP. Requests for extensions must be submitted to the Fire Marshal prior to the existing due date (Ref. 2).

The methods for storage, treatment, and disposal of petroleum contaminated soil are described in OAC 1301:7-9-16. Sampling and analysis of excavated soil for the purpose of treatment and disposal are described in OAC 1301:7-9-17.

### **1.3.2 BUSTR RAOs**

Because of the similarity of the site soils and current and likely future land use for each of the AOCs, one set of RAOs has been developed for all three areas using the BUSTR guidelines. The selection of RAOs relies heavily on the Tier 2 evaluation reports prepared for AOC 3 and AOC 8/9 and accepted by BUSTR (Refs. 3 and 4).

Because of the variability of the subsurface soils and the presence of the LNAPL and the highest contaminant concentrations in the more permeable soil lenses, Class 1 soil has been selected as the applicable soil type for risk-based RAOs for all three AOCs. Class 1 soil is defined as coarse grained soil with more than 50 percent of the material retained on a #200 sieve, and it includes gravel, sand, and sand with silt or clay fines. This approach to the soil classification is also consistent with the previous investigations submitted to BUSTR for each AOC. Current and planned land use is non-residential, so exposure pathways to be evaluated include those affecting non-residential and excavation workers<sup>1</sup>.

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<sup>1</sup> It is likely that land use restrictions will have to be incorporated to control potential future exposure pathways for remedial actions that are designed to meet non-residential RAOs.

There also are no current groundwater drinking water wells on the Lockbourne AFB, so RAOs for groundwater within the AOCs are non-residential standards. In the absence of property boundaries applicable to the AOCs and ordinances or other measures precluding use of the groundwater as a drinking water source, the default exposure point of 300 feet from the source area is applicable to all three AOCs. Dissolved concentrations of contaminants of concern in groundwater did not exceed BUSTR delineation levels outside the area of free product on any of the AOCs, so no groundwater exposure pathways are complete. Surface soil and surface water are not considered to be media of concern, so soil direct-contact non-residential and aquatic life and recreational exposure pathways are not complete.

The following soil exposure pathways were determined to be potentially complete:

- Soil to indoor air – non-residential
- Soil to outdoor air – non-residential
- Soil to outdoor air – excavation worker
- Soil to groundwater – non-drinking water
- Soil direct contact – excavation worker

The soil RAOs for each contaminant of concern (COC) were determined by identifying the lowest BUSTR action level for each of these pathways for soil Class 1. TPH-gasoline range organics (GRO) and diesel range organics (DRO) do not have exposure-pathway-based action levels, so the BUSTR-specified action levels were selected as the RAOs for those compounds. The BUSTR free product recovery (remediation) requirement has been included as the RAO for LNAPL. The resulting soil RAOs for contaminants of concern that exceeded delineation criteria at one or more of the AOCs are included in Table 1. Although not directly relevant, the groundwater action levels for soil Class 1 indoor air non-residential <15 feet below ground surface (bgs) are included in Table 1 for reference.

**Table 1. Remedial Action Objectives**

	<b>Soil Risk-Based RAO</b>	<b>Groundwater Risk-Based RAO</b>	<b>Soil Saturation Level</b>	<b>Free Phase Liquid</b>
<b>Compound</b>	(mg/kg)	(mg/L)	(mg/kg)	
Benzene	6.50	26.8	444.5	NA
Xylenes	194	670	268.2	NA
TPH-GRO	1,000	NA		NA
TPH-DRO	2,000	NA	2,000	NA
LNAPL				0.01 foot

## 1.4 ORGANIZATION OF THE REPORT

- Section 1.0, Introduction, presents the report purpose and scope, project background, remedial action objectives, and organization of the report.

- Section 2.0, Site Conditions and History, is a short summary of relevant site-specific topography, surface water, geology and soils, and hydrogeology, as well as previous activities performed at each AOC. The nature and extent of contamination for each AOC is summarized in this section.
- Section 3.0, Remedial Technologies Evaluated, includes general assumptions applicable to all the technologies, the conceptual site models (CSMs) for each AOC based on the general assumptions, and an overview of each of the remedial technologies, including a technology description, additional assumptions, data requirements, and work phases.
- Section 4.0, Detailed Development of Technologies by AOC, presents a discussion of the conceptual site model technology overlay, additional data requirements, design, access requirements, construction, operation, waste management, shutdown and demobilization, and site restoration for each technology at each AOC.
- Section 5.0, Remedial Technologies Evaluation, includes a review of each technology on the basis of effectiveness, implementability, and cost.
- Section 6.0, Summary and Conclusions, summarizes the results of the technology evaluation review.
- Section 7.0, References, specifies the references used in preparing the report.
- Section 8.0, Acronyms, is a list of acronyms and abbreviations used in the report.

Appendices include Appendix A, BUSTR Action Levels; Appendix B, Figures and Tables from the MNA Assessment; Appendix C, Figures from Previous Reports; Appendix D, Agency for Toxic Substances and Disease Registry (ATSDR) JP-4 Properties; Appendix E, Drawings Showing Existing and Proposed Structures; Appendix F, Technology Cost Tables.

## **2.0 SITE CONDITIONS AND HISTORY**

This section summarizes the general site physical conditions including topography, surface water hydrology, geology and soils, and hydrogeology, as well as the site history based on results of previous investigations at each of the AOCs

### **2.1 GENERAL SITE PHYSICAL CONDITIONS**

This section presents a summary of site physical conditions relevant to the remedial technologies evaluation. The information in this section is based primarily on the Remedial Investigation (RI) Phase II reports for AOCs 3, 8/9, and 11 (Ref. 1, 5, 6, and 7).

#### **2.1.1 Surface Features and Topography**

Most of the areas covered by the three AOCs are paved and relatively flat. Unpaved areas are grass that is regularly mowed. Topographic surveys performed during the various investigations indicated only slight relief, with surface elevations ranging from 733 to 746 feet above mean sea level. The overall slope of the land surface is to the southeast toward Walnut Creek, which at the closest point is approximately one mile southeast of AOC 3.

#### **2.1.2 Surface Water Hydrology**

Surface water flow on the former LAFB is controlled through an extensive storm drain network comprised of corrugated metal and concrete drainage pipes and open drainage ditches. Surface water from this network discharges to Walnut Creek. Walnut Creek flows north to south and discharges to the Scioto River (Ref. 1).

#### **2.1.3 Geology and Soils**

There are approximately 250 to 350 feet of glacial drift beneath the former LAFB. The glacial drift consists of unconsolidated, stratified and unstratified, clay, silt, sand, gravel, cobbles and boulders, which filled a pre-glacial bedrock valley. The glacial drift generally includes approximately 80 feet of clay and silt, containing relatively thin layers of sand and gravel. Below this is a sand and gravel layer, approximately 50 to 100 feet thick, underlain by a silt and clay layer up to 60 feet thick. Another sand and gravel layer, ranging from 50 to 100 feet thick, forms the base of the glacial drift. Included in these glacial deposits are fragments of the underlying shale of the Ohio and Olentangy Formations and limestone of the Columbus and Delaware Formations. These rock formations were formed during the Devonian Period (Ref. 1).

Data collected during previous studies at the LAFB indicate the presence of two distinguishable glacial tills located within the upper 40 feet of soils beneath the former LAFB. The uppermost (brown) till generally consists of a brown to gray, low plastic silty clay or clayey silt with scattered to abundant sand and gravel-sized particles. Discontinuous sand and gravel layers vary from a few inches to several feet thick and occur near the surface to approximately 10 to 15 feet bgs at various locations within the study area. The contact of the lower (gray) till was generally encountered within 15 feet of the ground surface and consisted of gray, low plastic, silty clay or

clayey silt with scattered to abundant sand and gravel-sized particles. Sand and gravel lenses in the lower till appeared to be thicker and more continuous than in the upper till (Ref. 1).

#### **2.1.4 Hydrogeology**

Drinking water is supplied to the region by the City of Columbus public water supply system, which utilizes both surface water from reservoirs and ground water from municipal wells. Pumping rates from 100 to 500 gallons per minute (gpm) of relatively good water quality are common in wells in all but the northeast part of Franklin County. Devonian and Silurian Period limestone and dolomitic limestone in the western half of the county and Pleistocene Epoch glacial sand and gravel deposits in the south-central and southeast part of the county are two of the major high-yielding aquifer types. Sand and gravel deposits along the Scioto River, Walnut Creek, and Big Walnut Creek can yield as much as 1000 gpm.

Data collected during previous studies at the LAFB identified at least three water-bearing zones beneath the former LAFB. The uppermost water-bearing zone is situated within poorly connected sand and gravel lenses found in the brown and gray till. The middle and lower aquifers are situated within the thick sand and gravel layers. Each of these sand and gravel layers is separated from the upper water-bearing zone by aquitards that consist of silty clay or clayey silt. Available monitoring well and water supply well logs indicated that these aquitards are possibly continuous beneath the site (Ref. 1).

The depth to groundwater from monitoring wells installed in the upper water-bearing zone of the Phase II RI study area ranges from approximately six to 20 feet bgs. Seasonal fluctuations in groundwater monitoring well elevations varied from approximately one foot in some areas of the AOCs to more than six feet in others. Groundwater flow direction of the upper water-bearing zone is variable within the study area. This is believed to be due to the discontinuous lenses of relatively permeable, unconsolidated deposits. Groundwater flow direction within these lenses is expected to follow the general surface topography. Groundwater velocities are expected to be low, as the hydraulic gradient of the site is relatively flat. Figures from the MNA assessment showing groundwater contours based on several quarters of groundwater level measurements at each of the AOCs are included in Appendix B. Groundwater recharge to the upper-water-bearing zone occurs through precipitation in the form of rain and snow. Groundwater discharge from perched water in the upper water-bearing zone is assumed to occur horizontally through surface ditches and utility trenches when the groundwater table is relatively high and vertically by gradual leakage through the underlying aquitard to the lower aquifer (Ref. 1).

The range of hydraulic conductivities (up to four orders of magnitude of variation) determined from slug tests performed during the Phase II RI on monitoring wells at AOCs 3, 8/9, and 11 reflect the heterogeneity of the shallow subsurface conditions and the highly discontinuous nature of the sand and gravel layers present in the glacial deposits at the site. The average hydraulic conductivity ranged from  $4.08 \times 10^{-4}$  to  $2.08 \times 10^{-1}$  centimeters per second (cm/s) for AOC 3, from  $3.93 \times 10^{-4}$  to  $3.05 \times 10^{-3}$  cm/s for AOC 8, from  $4.54 \times 10^{-6}$  to  $9.11 \times 10^{-2}$  cm/s for AOC 9, and from  $8.00 \times 10^{-5}$  to  $2.90 \times 10^{-3}$  cm/s for AOC 11 (Ref. 1, 5, 6, and 7).

## 2.2 PREVIOUS INVESTIGATIONS

This section presents a summary of the scope of previous investigations and information gathered for each AOC that will be addressed during the technology evaluation. This summary is based on the references included in Section 7.0, which are noted as applicable. Figures from previous reports showing the locations of former and existing site structures and the extent of free product and soil and groundwater contamination at each of the AOCs are included in Appendices C-1 through C-3. These figures are referenced as applicable.

### 2.2.1 AOC 3

In 1993, eight 50,000 gallon USTs that contained JP-4, one 25,000 gallon defueling tank, and one 2,000 gallon water/waste tank were removed. Portions of the fuel lines were removed and the remaining lines plugged and abandoned in place. The concrete anchors were left in place. (The former locations of the eight USTs, fuel lines, and other features are shown on Figure 4, Appendix C-1.) Liquids were pumped from the excavation and disposed of off-site. No other remediation was performed at that time due to budgetary/contract limitations, although soil contamination was observed (Ref. 1).

In 1994, a Phase I RI was performed for buildings 1045 (AOC 3), 1055, 1062, and 1076. As part of this investigation, six soil borings were drilled and one monitoring well was installed in the vicinity of AOC 3. Soil and groundwater samples were collected and analyzed. Numerous additional/supplemental field investigation programs were performed as part of the Phase I RI at AOC 3. In 1996, 30 direct push borings were performed. In 1998, 26 direct push boring were performed. In 1998, six groundwater monitoring wells were installed. In 1999, four additional borings were performed. In 2000, six additional groundwater monitoring wells were installed (Ref. 1). (The locations of AOC 3 borings and monitoring wells from this and subsequent investigations are shown on Figure 3, Appendix C-1.)

In 1995, the Building 1045 hydrant pit fuel lines were defueled, cleaned, and closed in place. The field investigation program associated with this effort included 13 test borings that were drilled to characterize potential soil contamination. Some contaminated soil was removed from an access pit and disposed of off-site (Ref. 1).

In 1997, free product removal was initiated at well LMW-4. In 1999, free product removal began at two additional wells, LMW-8 and LMW-9 (Ref. 1).

In 1996, the Phase II RI began. During the course of this investigation, approximately 103 soil samples were analyzed for benzene, toluene, ethyl benzene, and xylenes (BTEX) and TPH<sup>2</sup>. The AOC was also scored using BUSTR Site Feature Scoring System (SFSS) in place at the time, which classified the AOC as a Category 2 site. The results of the BTEX and TPH analyses of the soil samples were compared to BUSTR Category 2 action levels. Twenty-six of the samples exceeded BUSTR Category 2 action levels for BTEX and/or TPH. In general, on the basis of

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<sup>2</sup> Some samples collected during the Phase II RI were also analyzed for volatile organic compounds (VOCs) and polynuclear aromatic hydrocarbons (PAHs), which results were compared to EPA Region 9 Preliminary Remediation Goals. Since BUSTR is the applicable regulatory authority, and BTEX and TPH are representative of contamination on the AOCs, only those results are summarized in these discussions.

the analytical data, the average thickness of soils exceeding BUSTR action levels was considered to be between 12 and 18 feet bgs. (Ref. 1).

Thirteen monitoring wells were also installed in the vicinity of AOC 3 and sampled during the Phase II RI in December 1998. The groundwater samples were analyzed for TPH-GRO, BTEX, VOCs, semi-volatile organic compounds (SVOCs), and total and dissolved Resource Conservation and Recovery Act (RCRA) metals. Concentrations of benzene in four of the wells (LMW-4, LMW-8, LMW-9, and LMW-10) exceeded the BUSTR Category 2 action level of 0.005 mg/L. The groundwater plume above this level was considered to extend over 655,000 square feet centered on the former USTs (Ref. 1).

Soil and groundwater biofeasibility studies were also conducted during the Phase II RI at AOC 3. The Phase II RI report concluded that although there were several strains of bacteria present that were capable of biodegrading petroleum hydrocarbons, the numbers and growth rates of the bacterial strains were relatively low, which may indicate that the microbes are being stressed in their natural environment. The report stated that the potential stress may be the result of one or more of the following factors:

- Toxicity of the petroleum hydrocarbons to the aerobic bacteria.
- Limited food substrate source (i.e., petroleum hydrocarbons).
- Nutrient deficiency.
- Anaerobic conditions prevalent due to the lack of dissolved oxygen in the groundwater (Ref. 1).

Water quality parameters were also tested during the Phase II RI to evaluate whether conditions were suitable for natural attenuation of petroleum hydrocarbons and whether aerobic and/or anaerobic biodegradation are naturally occurring. Temperature, pH, dissolved oxygen (DO), oxidation/reduction potential (ORP), ferrous iron, alkalinity, sulfate, nitrate, conductivity, and chloride were evaluated. The results of the testing for these parameters appeared mixed with respect to biodegradation of contaminants at AOC 3. According to the report, sulfate and ferric iron results suggested some anaerobic degradation in wells with higher contaminant concentrations, while DO results indicated very little aerobic degradation. Alkalinity results indicated insignificant natural bioremediation, and ORP results suggested anaerobic/anoxic conditions in these wells (Ref. 1).

Free product delineation during the Phase II RI using the USACE's Site Characterization and Analysis Penetrometer System (SCAPS) laser induced fluorescence sensor estimated the free product plume (JP-4) to be 90,000 square feet with an average thickness of 1.5 feet at AOC 3 (Ref. 1).

A WIDE prototype was installed and operated in AOC 3 from October 2005 through early April 2007. The WIDE technology is a variation of dual-phase extraction. The final report concludes that "the difficulty of achieving complete remediation at the test site arises mainly from the nature of the 'wide cut' JP-4 contamination as well as from complex entrapment of jet fuel in the heterogeneous subsurface profile with such entrapment being in saturated and unsaturated



modes.” (JP-4 is called a wide-cut fuel because it is produced from a broad distillation temperature range and contains a wide array of carbon chain-lengths, from 4 to 16 carbons long.) The report goes on to recommend that “in addition to extraction of jet fuel available to gradient-induced flow, it seems that the approach to remediating the entrapped residual globules should encompass vapor and liquid extraction, air circulation for promoting mass transfer to gas phase, vapor extraction for removal of organic vapors, and bioventing (increase dissolved-oxygen concentration for subsurface microbial populations to degrade organic compounds)” (Ref. 8).

In August 2007, a BUSTR Tier 2 Evaluation was performed for AOC 3 using existing information. No additional field investigations were performed in support of the Tier 2 Evaluation report. The Tier 2 Evaluation determined applicable site-specific target levels (SSTLs) based on non-residential exposure pathways. (Groundwater was not considered to be a drinking water source.) Benzene, xylenes, TPH-GRO, and/or TPH-DRO in soil (at SB-11, SB-29, SB-306, SB-307, WDP-601, WDP-603, and WDP-604) were detected above the SSTLs. Benzene in groundwater (at monitoring wells LMW-8 and LMW-9) was detected above the delineation criterion (delineation criteria are the lowest BUSTR screening values), but not above the Tier 2 SSTLs. However, free product was determined to be present<sup>3</sup>. The Tier 2 Evaluation proposed continued free product removal, installation of additional sentinel groundwater monitoring wells, and preparation of a RAP (Ref. 3). The Tier 2 Evaluation was accepted by BUSTR in September 2007 (Ref. 9).

In November 2007, a final RAP was prepared for AOC 3. The RAP stated that remediation of free product in the area of AOC 3 would likely satisfy BUSTR remediation requirements and, therefore, focused on alternatives that address that issue. The RAP included an evaluation of the extent of the free product using WIDE free product thickness data and the delineated surface area of the free product in the site’s subsurface. Free product thickness within the free product zone was estimated at 0.25 feet over a 1.8 acre surface area with a soil porosity of 0.4 for an estimated volume of free product of 58,300 gallons of JP-4 (Ref. 10)<sup>4</sup>. Figure 3, Appendix C-1 shows the area of free product, while Figure 4, Appendix C-1 shows existing and former underground utilities and fuel piping and Figure 6B shows a cross section through AOCs 3 and 2.

The baseline alternative presented in the RAP was skimming of free product from three groundwater monitoring wells, which was ongoing at the time the RAP was prepared. The RAP evaluated five alternatives (two with subsets), and recommended the WIDE technology, if expanded free product removal is desired (Ref. 10).

BUSTR Free Product Recovery forms were submitted for AOC 3 in September 2011. The report documented recovery of 392 gallons of free product at AOC 3 (five wells and WIDE pilot study) since free product was identified in 1994. Tables showing monthly recovery quantities were provided for 2007 through September 2011, with a gap from July 2010 through March 2011. The amount of free product measured in the five wells varied from zero to 1.2 feet over that period. No measurable free product was observed in LMW-8 and measurable product was only observed once in TB-02 (the two southernmost monitoring wells) from February 2008 through

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<sup>3</sup> These referenced soil sample and groundwater sample locations are all within the free product area.

<sup>4</sup> Refer to Table 2 in Section 3.1 for a comparison with the most recent LNAPL volume estimates.

September 2011. The greatest thickness of product was observed in LMW-4 in January 2008 (Ref. 11).

### **2.2.2 AOC 8/9**

The general area of Building 1055 was designated AOC 8. The Building 1055 fuel hydrant pits were originally designated AOC 9. These AOCs have been combined for the purpose of the remedial technology evaluation because of the overlapping areas of contamination.

In 1991, a Phase I Environmental Assessment (EA) was performed of the Air Cargo Hub for the Rickenbacker Development Corporation. The investigation included the excavation of ten test pits along the abandoned jet fuel lines in the AOC 8/9 vicinity. Twelve soil samples and four groundwater samples were collected from the test pits and four water samples were collected from the hydrant pits. All the samples were analyzed for TPH. Reportable concentrations of TPH were detected in soil samples from three test pits and in groundwater samples from two test pits (Ref. 5).

Also in 1991, a Phase II EA was performed of the Air Cargo Hub for the Rickenbacker Development Corporation. This investigation included the drilling of 19 test borings in AOCs 1, 4, and 7-14, which were subsequently completed as monitoring wells<sup>5</sup>. (Most of the locations of AOC 8/9 borings and monitoring wells from this and subsequent investigations are shown on Figure 3, Appendix C-1.) Fifty-two soil samples (two to four samples/boring) and 19 groundwater samples (one/well) were collected and analyzed for BTEX or VOCs and TPH. BTEX and/or TPH were detected in soil samples collected from borings H-7 through 10, and H-12. BTEX and/or TPH concentrations were detected in groundwater samples collected from all the wells. LNAPL was present in well H-9. The samples of the product collected from each well were analyzed and then compared to Jet A and JP-4 aviation fuel standards. It was reported that both of the samples that were analyzed were an exact match for Jet A fuel<sup>6</sup> (Ref. 5).

In 1993, eight 50,000 gallon USTs that contained JP-4, one 25,000 gallon defueling UST, one 2,000 gallon water/waste UST, and the fuel lines were removed. At that time, approximately 3,300 tons of contaminated soil were excavated and disposed of off-site. The concrete anchors for nine of the ten tanks were not removed. The former locations of the eight USTs, fuel lines, and other features are shown on Figure 4, Appendix C-2. Liquids were pumped from the excavation and disposed of off-site. No other remediation was performed at that time due to budgetary/contract limitations, although additional soil contamination was observed (Ref. 5).

As part of a larger investigation of contamination associated with fuel lines also performed in 1993, soil samples were collected from the fuel lines associated with Building 1055. Soil samples selected based on field screening using a photo-ionization detector (PID) were submitted for laboratory analysis. Three soil samples from lines associated with the Building 1055 USTs exhibited elevated concentrations of petroleum hydrocarbons. PAHs were detected in soil

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<sup>5</sup> It is unclear how many of these borings were in AOC 8/9. H-1, H-2, H-4, H-5, H-6, and H-10 are discussed in the text of Ref. 6 or shown on figures from Ref. 13 for AOC 8/9. H-15 is shown on the figure from Ref. 15 for AOC 11.

<sup>6</sup> Note this is inconsistent with other information and evaluations that indicate the contents of the storage tanks and the free product are JP-4. Jet A fuel is characterized as a kerosene-type fuel, rather than a naphtha-type like JP-4. Jet A has a slightly higher density range, higher flashpoint (lower flammability), and lower freezing point than JP-4.

samples adjacent to the active bulk line, the inactive bulk line, and the lines associated with the USTs in the vicinity of Building 1055 (Ref. 5).

In 1994 through 1996, a Phase I RI was performed for buildings 1045, 1055 (AOC 8/9), 1062, and 1076. Eight test borings and one well were installed in 1994 in the vicinity of AOC 8/9. Twenty-four direct push borings were performed in the vicinity of AOC 8 in 1996. Thirty nine soil samples were analyzed for BTEX/TPH. One groundwater sample was analyzed for VOCs, SVOCs, and TPH. In 1997, an additional 35 soil samples were analyzed for BTEX/TPH.

In 1997, free product removal was initiated at one well in AOC 9. In 1999, free product removal began at a second well.

In 1996, the Phase II RI began. During the course of this investigation, approximately 81 soil samples from 45 borings in AOC 8 and 42 soil samples from 28 borings in AOC 9 were analyzed for BTEX and TPH. The AOCs were also scored using the BUSTR SFSS in place at the time, which classified the AOCs as Category 3 sites. The results of the BTEX and TPH analyses of the soil samples were compared to BUSTR Category 3 action levels. Soil samples from 15 of the AOC 8 borings and four of the AOC 9 borings exceeded the BUSTR Category 3 action levels for BTEX and/or TPH. In general, on the basis of the analytical data, the average thickness of soils exceeding BUSTR action levels was considered to be between 10 and 15 feet bgs at AOC 8 and between 10 and 18 feet bgs at AOC 9. (Ref. 5 and 6).

Groundwater samples from seven monitoring wells on AOC 8 and eight monitoring wells on AOC 9 were analyzed for TPH-GRO, TPH-DRO, BTEX, VOCs, SVOCs, and total and dissolved RCRA metals in December 1998. Concentrations of benzene in one well on AOC 8 (LMW-17) and two wells on AOC 9 (LMW-39 and H-9) exceeded the BUSTR Category 3 action level of 0.005 mg/L. The groundwater plume above this level was considered to extend over 215,000 square feet southeast of former Building 1055 on AOC 8 and 107,000 square feet south of Building 1055 on AOC 9 (Ref. 5 and 6).

Soil and groundwater biofeasibility studies were also conducted during the Phase II RI at AOCs 8 and 9. The Phase II RI report concluded based on the soil and groundwater biofeasibility studies at both AOCs that although there were several strains of bacteria present that were capable of biodegrading petroleum hydrocarbons, the numbers and growth rates of the bacterial strains were relatively low, which may indicate that the microbes are being stressed in their natural environment. The report stated that the potential stress may be the result of one or more of the following factors:

- Toxicity of the petroleum hydrocarbons to the aerobic bacteria.
- Limited food substrate source (i.e., petroleum hydrocarbons).
- Nutrient deficiency.
- Anaerobic conditions prevalent due to the lack of dissolved oxygen in the groundwater (Ref. 5 and 6).

Water quality parameters were also tested during the Phase II RI to evaluate whether conditions were suitable for natural attenuation of petroleum hydrocarbons and whether aerobic and/or anaerobic biodegradation are naturally occurring. Temperature, pH, DO, ORP, ferrous iron, alkalinity, sulfate, nitrate, conductivity, and chloride were evaluated. The results of these parameters appeared mixed with respect to biodegradation of contaminants in AOC 9. According to the report, sulfate, ferric iron, and nitrate results suggested some anaerobic degradation in wells with higher contaminant concentrations, while DO results also indicated some aerobic degradation might be progressing in the plume. Alkalinity results indicated insignificant natural bioremediation, and ORP results suggested anaerobic/anoxic conditions in the wells containing higher benzene concentrations (Ref. 6).

Free product delineation during the Phase II RI using the USACE's SCAPS laser-induced fluorescence sensor estimated the free product plume (JP-4) to be 9,500 square feet with an average thickness of two feet at AOC 9 (Ref. 6). No free product was encountered at AOC 8 (Ref. 5).

In September 2007, a BUSTR Tier 2 Evaluation was performed for AOC 8/9 using existing information. No additional field investigations were performed in support of this report. The Tier 2 Evaluation determined applicable SSTLs based on non-residential exposure pathways. (Groundwater was not considered to be a drinking water source.) TPH-GRO in soil at SB-504 and SB-506 exceeded the Tier 2 SSTLs. These locations are both outside (southwest) of the free product area. Benzene in groundwater at monitoring well H-9 exceeded the delineation criterion for benzene, but not the applicable Tier 2 SSTLs. However, free product was determined to be present. The Tier 2 Evaluation proposed continued free product removal, installation of additional sentinel groundwater monitoring wells, and preparation of a RAP (Ref. 4). The Tier 2 Evaluation was accepted by BUSTR in September 2007 (Ref. 12).

In December 2007, a final RAP was prepared for AOC 8/9. The RAP stated that remediation of free product in the area of AOC 8/9 would likely satisfy BUSTR remediation requirements and, therefore, focused on alternatives that address that issue. The RAP included an evaluation of the extent of the free product using free product thickness data collected from USACE representatives, available SCAPS data, and the delineated surface area of the free product in the site's subsurface. Free product thickness within the free product zone was estimated at 1.2 feet over an 8,000 square foot surface area with a soil porosity of 0.4 for an estimated volume of free product of 29,000 gallons of JP-4 (Ref. 13)<sup>4</sup>. Figure 6, Appendix C-2 shows the area of free product, while Figure 4, Appendix C-2 shows existing and former underground utilities and fuel piping and Figure 10, Appendix C-2 shows a cross section through AOCs 8 and 9.

The baseline alternative in the RAP was skimming of free product from two groundwater monitoring wells, which was ongoing at the time the RAP was prepared. The RAP evaluated five alternatives (one with a subset), and recommended expansion of skimming to a total of seven wells as a first step if increased free product removal was desired. If further recovery was needed, conversion of the wells to a dual-phase extraction system was recommended (Ref. 13).

In a letter dated January 9, 2008, the Ohio Department of Commerce commented that the RAP did not address soil containing concentrations of TPH-GRO above the SSTLs, and requested that an interim response be conducted, a Tier 3 evaluation performed, and/or re-sampling be

conducted after the RAP to see if natural attenuation had reduced concentrations below SSTLs (Ref. 14).

BUSTR Free Product Recovery forms were submitted for AOC 8/9 in September 2011. The report documents recovery of 3.03 gallons of free product from AOC 8/9 (two wells), since free product was identified in 1994. Tables showing monthly recovery quantities were provided for 2007 through September 2011, with a gap from July 2010 through March 2011. The amount of free product measured in the two wells varied from zero to 3.35 feet over that period. No measurable free product was observed in LMW-15 from January 2007 through September 2011. The largest thickness of LNAPL was observed in H-9 in May 2011, after the depth to water fell by almost two feet over the previous month (Ref. 11).

### **2.2.3 AOC 11**

A Phase II EA was conducted in 1991 of the Air Cargo Hub for the Rickenbacker Development Corporation. The Phase II EA included the drilling of 19 test borings in AOCs 1, 4, and 7-14, which were subsequently completed as monitoring wells<sup>7</sup>. Fifty-two soil samples (two to four samples/boring) and 19 groundwater samples (one/well) were collected and analyzed for BTEX or VOCs and TPH. BTEX and/or TPH were detected in soil samples collected from borings H-7 through 10, H-12, and H-15. (Most of the locations of AOC 11 borings and monitoring wells from this and subsequent investigations are shown on Figure 2-1, Appendix C-3.) BTEX and/or TPH concentrations were detected in groundwater samples collected from all the wells. LNAPL was present in wells H-9 and H-15. The samples of the product collected from each well were analyzed and then compared to Jet A and JP-4 aviation fuel standards. It was reported that both of the samples that were analyzed were an exact match for Jet A fuel (Ref. 7)<sup>6</sup>.

In 1993, a fuel line investigation was conducted that included collecting soil samples adjacent to the active fuel line between Buildings 1070 and 1076. Concentrations of petroleum hydrocarbons exceeded BUSTR Category 3 SFSS action levels in one sample along this fuel line. Also in 1993, an investigation was performed in the vicinity of the Building 1076 fuel island. The investigation consisted of a series of exploratory trenches. The trenches encountered contaminated soil and free product. Confirmatory trenches were excavated in the same area and the contamination was confirmed. A 25,000 gallon defueling tank in the area of the building was closed in place around this time (Ref. 12). (The building, tanks, fuel lines, utilities and other features are shown on Figure 1-3, Appendix C-3).

In 1994, a Phase I RI was performed for buildings 1045, 1055, 1062, and 1076 (AOC 11). Sixteen soil samples and two groundwater samples from the AOC 11 vicinity were analyzed. The soil samples were analyzed for VOCs, metals, and BTEX/TPH. The groundwater samples were analyzed for VOCs, SVOCs, and TPH.

In 1996, the Phase II RI began. During the course of this investigation, approximately 71 soil samples from 45 soil borings at AOC 11 were analyzed for BTEX and TPH. The AOC was also scored using the BUSTR SFSS in place at the time, which classified the AOC as a Category 2 site. The results of the BTEX and TPH analyses of the soil samples were compared to BUSTR

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<sup>7</sup> It is unclear how many of these borings were in AOC 11. H-15 is shown on the figure from Ref. 13 for AOC 11. H-1, H-2, H-4, H-5, H-6, and H-10 are discussed in the text of Ref. 7 or shown on figures from Ref. 8 for AOC 8/9.

Category 2 action levels. Soil samples from 15 of the AOC 11 borings exceeded the BUSTR Category 2 action levels for BTEX and/or TPH. In general, on the basis of the analytical data, the average thickness of soils exceeding BUSTR action levels was considered to be between 13 to 20 feet bgs (Ref. 7).

Groundwater samples from nine monitoring wells on AOC 11 were analyzed for TPH-GRO, TPH-DRO, BTEX, VOCs, SVOCs, and total and dissolved RCRA metals. Phase II RI groundwater samples were collected in 1996, 1998, and 2000. Concentrations of benzene in two wells (LMW-41 and LMW-43) exceeded the BUSTR Category 2 action level of 0.005 mg/L. The groundwater plume above this level was considered to extend over 35,000 square feet southeast of the above ground storage tank (AST) containment area (Ref. 7).

Soil and groundwater biofeasibility studies were also conducted during the Phase II RI at AOC 11. The Phase II RI report concluded that although there were several strains of bacteria present that were capable of biodegrading petroleum hydrocarbons, the numbers and growth rates of the bacterial strains were relatively low, which may indicate that the microbes are being stressed in their natural environment. The report stated that the potential stress might be the result of one or more of the following factors:

- Toxicity of the petroleum hydrocarbons to the aerobic bacteria.
- Limited food substrate source (i.e., petroleum hydrocarbons).
- Nutrient deficiency.
- Anaerobic conditions prevalent due to the lack of dissolved oxygen in the groundwater (Ref. 7).

Water quality parameters were also tested during the Phase II RI to evaluate whether conditions were suitable for natural attenuation of petroleum hydrocarbons and whether aerobic and/or anaerobic biodegradation were naturally occurring. Temperature, pH, DO, ORP, ferrous iron, alkalinity, sulfate, nitrate, conductivity, and chloride were evaluated. The results of these parameters appear mixed with respect to biodegradation of contaminants in AOC 11. According to the report, sulfate, ferric iron, and nitrate results suggested some anaerobic degradation in wells with higher contaminant concentrations, while DO results also indicated some aerobic degradation in a hot spot within the contaminant plume. Alkalinity results indicated insignificant natural bioremediation, and ORP results suggested anaerobic/anoxic conditions in the wells containing higher benzene concentrations (Ref. 7).

Free product delineation during the Phase II RI using the USACE's SCAPS laser-induced fluorescence sensor estimated the free product plume (JP-4) to be 34,000 square feet with an average thickness of two feet at AOC 11 (Ref. 7).

In 2002, a Draft RAP was prepared for AOC 11. The RAP identified TPH, benzene, and xylene in soil and benzene in groundwater in excess of the Category 2 SFSSs in accordance with the Phase II RI results. It also identified the area of free product as 34,200 square feet with an average thickness of 2.25 feet for a total volume of 173,000 gallons<sup>4</sup> and stated that the goal of

any remedial action would be to maximize removal of the free product. Figure 2-1, Appendix C-3 shows the area of free product. The RAP initially evaluated eight soil remedial alternatives, seven groundwater remedial alternatives, and four technologies to remove free product. These were reduced to two alternatives for detailed evaluation: vacuum enhanced recovery (VER) and WICK with groundwater treatment with an oil water separator and activated carbon. The WICK technology involves a grid of shallow wells connected with manifold piping, which can be used to remediate low permeability soils by soil flushing, soil vapor extraction, air injection, and liquid extraction. VER was the recommended alternative (Ref. 15).

BUSTR Free Product Recovery forms were submitted for AOC 11 in September 2011. The report documented recovery of 1.41 gallons from AOC 11 (three wells) since free product was identified in 1994. Tables showing monthly recovery quantities were provided from January 2007 through September 2011. The amount of free product measured in the two wells varied from zero to one foot over that period. No measurable free product was observed in LMW-24 from February 2008 through September 2011, with a gap from July 2010 through March 2011. The greatest thickness of free product was observed in LMW-43 in April 2011, after the water table dropped by almost four feet from the last measurement in June 2010. No measurable free product had been observed in this well from February 2008 through June 2010 (Ref. 11).

#### **2.2.4 Monitored Natural Attenuation Assessment Investigation**

In 2009 and 2010, a MNA Assessment Investigation was performed that covered AOC 3, AOC 8/9, and AOC 11. Groundwater samples, along with free product samples (if present), were collected quarterly from selected wells in the three AOCs. Twelve wells were sampled in the AOC 3 area, with two additional wells added later in the investigation. Nine wells were sampled in the AOC 8/9 area. Eight wells were sampled in the AOC 11 area. None of the concentrations of COCs in the groundwater samples from any of the AOCs or in the LNAPL from AOC 11 exceeded the project action limits. Concentrations of naphthalene and xylenes in LNAPL samples for AOC 3 MW-04 and TB-01 exceeded the action limits, as did concentrations of benzene and xylenes in LNAPL samples for AOC 8/9 LMW-H9. The groundwater quality data were compared for wells located in the source area and further down the migration pathway. The free product samples were analyzed and compared to fresh JP-4.

In general, the groundwater quality results showed that compounds consumed during degradation processes decreased in concentration away from the source area, and byproducts of the degradation increased in concentration away from the source area. This indicated that natural attenuation was occurring. The free product analyses confirmed that the JP-4 had been degraded. The concentrations of the lighter, more easily degraded compounds had decreased. The continued presence of the heavier compounds that are more resistant to degradation indicates that natural attenuation of these compounds will proceed more slowly. Data tables from the 2010 MNA Assessment, including groundwater elevations, free product thickness measurements, and LNAPL analytical results are included in Appendix B (Ref. 16).

The following figures in Appendix B show seasonal variations in the groundwater flow at the AOCs based on quarterly monitoring during the MNA:

AOC 3: Figures 4-1a through 4-1d

AOC 8/9: Figures 4-2a through 4-2d

AOC 11: Figures 4-3a through 4-3d

Despite variations in elevations, flow at AOC 3 appears to be consistently inward along a trough located within the free product area during all events. Flow at AOC 8/9 is more variable. Two of the events indicate a groundwater depression in the area of the free product, while two indicate flow in that area toward the east. A groundwater mound appears to be located north of the free product area during all four events. Despite variations in elevations, flow at AOC 11 appears to be consistently toward the east/southeast during all events.

## 2.3 NATURE AND EXTENT OF CONTAMINATION

Discussions of the nature and extent of contamination at each AOC in this section are based on the previous reports summarized in Section 2.2. Figures showing existing or proposed structures on AOCs 3 and 8/9 are included in Appendix E.

### 2.3.1 AOC 3

The sources, free product, and soil and groundwater contamination at AOC 3 are summarized in this section.

#### 2.3.1.1 Sources

The sources of contamination at AOC 3 are presumed to be the eight 50,000 gallon USTs and the associated 25,000 gallon defueling tank, 2,000 gallon water/waste tank, and fuel lines (Figure 4, Appendix C-1). The tanks have been removed. Some fuel lines were removed and some closed in place. Tank installation details and dimensions are not known for the 50,000 gallon tanks, but based on typical tank dimensions and installation; it is assumed that they were installed with the bottom of the tanks at depths ranging from 12 to at most 15 feet bgs.

The predominant source of contamination appears to have been JP-4 jet fuel. JP-4 is called a wide-cut fuel because it is produced from a broad distillation temperature range and contains a wide array of carbon chain-lengths, from 4 to 16 carbons long. The composition of JP-4 is approximately 13% aromatic hydrocarbons, 1.0% olefin hydrocarbons, and 86% saturated hydrocarbons. Paraffins and cycloparaffins are the major components. The chemical and physical properties of JP-4 are summarized on the table in Appendix D from the ATSDR *Toxicological Profile for Jet Fuels JP-4 and JP-7*, June 1995 (Ref. 17).

#### 2.3.1.2 Free Product

On the basis of the SCAPS data, the area of free product is as shown on Figure 3, Appendix C-1 (Refs.1 and 10). According to the Draft Final MNA Report, free product was encountered with thicknesses ranging from 0.01 to 0.30 feet in AOC 3 (Ref. 16). In the RAP, free product



thickness within the free product zone was estimated at 0.25 feet over a 78,400 square feet surface area with a soil porosity of 0.4 for an estimated volume of free product of 58,300 gallons of JP-4 (Ref. 10). However, according to the September 2011 Free Product Recovery Reports, no measurable free product has been observed in monitoring well LMW-08 since October 2007, and measurable free product has only been observed in monitoring well TB-02 only once since February 2008 (0.12 inches in April 2011.)<sup>4</sup> Total recovery since free product recovery began in 1994 is 392 gallons, including recovery during the WIDE pilot study. Sand was the predominant soil identified at the free product interface, indicating that there is probably a strong correlation between the free product and the lenses of coarse-grained material observed at the site.

On the basis of analyses of LNAPL from three wells in AOC 3, the 2010 MNA Assessment concludes that volatile and soluble compounds (BTEX) have been depleted from the free product, so that the remaining LNAPL is likely to be less susceptible to volatilization and solution and, hence, biodegradation. The MNA Assessment also concludes that fluctuations observed in the groundwater elevations over time likely indicate that a smear zone of residual LNAPL may be present in the soil immediately above and below the mobile free product on the groundwater surface (Ref. 16).

#### **2.3.1.3 Soil**

Soil contamination seems to be localized in association within the areas of free product. Applying the RAOs identified in Section 1.3.2, concentrations of contaminants in only seven soil samples (from seven boring locations: SB-11, SB-29, SB-306, SB-307, WDP-601, WDP-603, and WDP-604) exceeded the action levels (Ref. 3). All seven locations were within the area of free product as identified in the preceding section. In addition, the sample depths ranged from 12 to 17 feet bgs, which indicates that they were probably within the LNAPL smear zone (or below the groundwater table). Three of the samples exceeded the RAO for benzene, three exceeded the RAO for TPH-GRO, two exceeded the RAO for xylenes, and one exceeded the RAO for TPH-DRO.

#### **2.3.1.4 Groundwater**

According to the groundwater analytical data summarized in the MNA Assessment, only concentrations of benzene in three wells within the free product area (LMW-4, LMW-8, and LMW-9) have exceeded the lowest BUSTR delineation criteria. None of the concentrations detected in any of the groundwater samples (including the samples from these wells) exceeded the Tier 2 SSTLs identified as the RAOs in Section 1.3.2 (Ref. 17). The new building (Appendix E) constructed south of AOC 3 is at least 150 feet at the nearest point from any well containing free product and approximately 300 feet from the location of the former USTs (source area). No contaminants of concern have been detected above delineation levels in the three monitoring wells closest to the building (LMW-7, LMW-37, and LMW-38).

### **2.3.2 AOC 8/9**

The sources, free product, and soil and groundwater contamination at AOC 8/9 are summarized in this section.

### **2.3.2.1 Sources**

The original sources of contamination at AOC 8/9 are presumed to be the eight 50,000 gallon USTs and the associated 25,000 gallon defueling tank, 2,000 gallon water/waste tank, fuel lines, and hydrant pits (Figures 4 and 6, Appendix C-2). The tanks and fuel lines have been removed, along with 3,300 tons of contaminated soil. Tank installation details and dimensions are not known for the 50,000 gallon tanks, but based on typical tank dimensions and installation; it is assumed that they were installed with the bottom of the tanks at depths ranging from 12 to at most 15 feet bgs.

The predominant source of contamination appears to have been JP-4 jet fuel. Refer to the discussion in Section 2.3.1.1 with respect to properties of JP-4.

### **2.3.2.2 Free Product**

On the basis of the SCAPS data, remaining free product is limited to AOC 9, as shown on Figure 6, Appendix C-2 (Refs. 6 and 13). The main free product zone is a contiguous area near the first Building 1055 hydrant pits. A much smaller area was identified in the vicinity of boring SB-504. According to the Draft Final MNA Report, free product was encountered with thicknesses ranging from 0.08 to 0.22 feet in AOC 9 (Ref. 16). In the RAP, free product thickness within the main free product zone was estimated at 1.2 feet over an 8,000 square foot surface area with a soil porosity of 0.4 for an estimated volume of free product of 29,000 gallons of JP-4 (Ref. 13)<sup>4</sup>. However, according to the September 2011 Free Product Recovery Reports, only 3.19 gallons of free product have been recovered from two wells since recovery began, and no free product has been detected in monitoring well LMW-15 since January 2007. Sand and silt were the predominant soils identified at the free product interface, indicating that there is probably a strong correlation between the free product and the lenses of coarse-grained material observed at the site.

On the basis of analyses of LNAPL from one well in AOC 9, the 2010 MNA Assessment concludes that volatile and soluble compounds (BTEX) have been depleted from the free product, so that the remaining LNAPL is likely to be less susceptible to volatilization and solution and, hence, biodegradation. The MNA Assessment also concludes that fluctuations observed in the groundwater elevations over time likely indicate that a smear zone of residual LNAPL may be present in the soil above the mobile free product on the groundwater surface (Ref. 16).

### **2.3.2.3 Soil**

Unlike AOC 3, soil contamination above BUSTR action levels in AOC 8/9 is present outside the current area of free product. Applying the RAOs identified in Section 1.3.2, concentrations of contaminants in only three soil samples [from three boring locations: SB-59 (AOC 8), SB-506 and SB-504 (AOC 9)] exceeded the action levels (Ref. 4). SB-59 and SB-506 are outside the areas delineated as containing free product. The sample depths were also variable: 4-6 feet in SB-506, 7-9 feet in SB-59, and 14-16 feet in SB-504. All three of the samples exceeded the RAO for TPH-GRO only.

#### **2.3.2.4 Groundwater**

According to the groundwater analytical data summarized in the MNA Assessment, only the concentration of benzene in one well (H-9) within the free product area has exceeded the BUSTR delineation criterion. None of the concentrations detected in any of the groundwater samples (including samples from this well) exceeded the Tier 2 SSTLs identified as the RAOs in Section 1.3.2 (Ref. 16). AOCs 8 and 9 are vacant at this time, and the nearest building is more than 300 feet from the free product or source areas. Proposed future construction in the area of this AOC is shown on the figure in Appendix E. Since none of the concentrations of contaminants of concern in groundwater outside the free product area exceeded the delineation levels, none of the groundwater exposure pathways at the point of exposure are complete.

#### **2.3.3 AOC 11**

The sources, free product, and soil and groundwater contamination at AOC 11 are summarized in this section.

##### **2.3.3.1 Sources**

Unlike the other AOCs, the sources of contamination at AOC 11 are still in place (Figure 2-1, Appendix C-3). These include the eight 50,000 gallon USTs and fuel lines. The 25,000 gallon defueling tank was closed in place. Tank installation details and dimensions are not known for the 50,000 gallon tanks, but based on typical tank dimensions and installation, it is assumed that they are installed with the bottom of the tanks at depths ranging from 12 to at most 15 feet bgs.

The predominant source of contamination appears to have been JP-4 jet fuel. Refer to the discussion in Section 2.3.1.1 with respect to properties of JP-4.

##### **2.3.3.2 Free Product**

On the basis of the SCAPS data, remaining free product is limited to the areas shown on Figure 2-1, Appendix C-1 (Refs. 7 and 15). The main free product zone is a contiguous area east of the USTs. A much smaller area was identified in the vicinity of boring SB-413, south of the USTs. According to the Draft Final MNA Report, free product was encountered with thicknesses ranging from 0.03 to 0.20 feet in AOC 11 (Ref. 16). In the RAP, free product thickness within the free product zone was estimated at 2.25 feet over an area of 34,200 square feet for a total volume of 173,000 gallons of JP-4 (Ref. 15).<sup>4</sup> However, according to the September 2011 Free Product Recovery Reports, only 1.41 gallons of free product have been recovered from three wells since recovery began, and no measurable free product has been observed in monitoring well LMW-24 since January 2007. Measurable free product was observed in the other two wells only intermittently. Sand was the predominant soil identified at the free product interface, indicating that there is probably a strong correlation between the free product and the lenses of coarse-grained material observed at the site.

On the basis of analyses of LNAPL from one well in AOC 11, the 2010 MNA Assessment concludes that volatile and soluble compounds (BTEX) have been depleted from the free product, so that the remaining LNAPL is likely to be less susceptible to volatilization and solution and, hence, biodegradation. The MNA Assessment also concludes that fluctuations

observed in the groundwater elevations over time likely indicate that a smear zone of residual LNAPL may be present in the soil above the mobile free product on the groundwater surface (Ref. 16).

### **2.3.3.3 Soil**

Soil contamination seems to be localized in association with the areas of free product. Applying the RAOs identified in Section 1.3.2 to re-evaluate the Phase II RI data, concentrations of contaminants from soil samples from eight boring locations (LMW-24, LMW-41, LMW-43, SB-113, SB-318, SB-319, SB-415, and SB-413) exceeded the action levels. Seven of the locations were within the main free product zone as identified in the preceding section. One was from the small free product area south of the USTs. The sample depths ranged from 7.7 to 19 feet bgs, which indicates that most were probably within the LNAPL smear zone (or below the groundwater table).

### **2.3.3.4 Groundwater**

According to the groundwater analytical data summarized in the MNA Assessment, none of the concentrations of the contaminants of concern in AOC 11 monitoring wells have exceeded the BUSTR delineation criteria or the Tier 2 SSTLs identified as the RAOs in Section 1.3.2 (Ref. 16). There are no occupied structures on AOC 11, and the nearest building is more than 200 feet up-gradient of the free product or source areas. A second down-gradient building is more than 300 feet from the free product or source areas. Since none of the concentrations of contaminants of concern in groundwater exceeded the delineation levels, none of the groundwater exposure pathways at the point of exposure are complete.

### 3.0 REMEDIAL TECHNOLOGIES EVALUATED

This section presents a general introduction to the remedial technologies that are evaluated with respect to applicability to each AOC in subsequent sections of the report. The first section below presents general assumptions applicable to all the technologies and the associated CSMs, while the remaining subsections briefly describe each technology and its applicability and limitations, as well as data requirements, additional assumptions, and work phasing requirements.

#### 3.1 GENERAL ASSUMPTIONS AND CONCEPTUAL SITE MODELS

This section presents general assumptions and the CSMs relevant to all the technologies discussed in the following sections. The assumptions are related to physical conditions at each of the AOCs, as discussed in preceding sections. The CSMs were developed using the assumptions presented in this section. The assumptions are as follows:

1. The predominant soil type excluding the more permeable lenses is silty clay at all the AOCs. The most representative soil type for the more permeable lenses is sand for AOCs 3 and 11 and silty sand for AOC 8/9.
2. With respect to BUSTR requirements, as previously stated, Class 1 soil has been selected as the applicable soil type for all three AOCs, because free product is presumed to be present primarily in the more permeable lenses. Class 1 soils are coarse-grained soils, including sand and silty sand<sup>8</sup>.
3. The ranges and average hydraulic conductivities for each AOC using well data from the Phase II RI slug tests from wells within the area of free product are as follows:

AOC 3:  $2.48 \times 10^{-2}$  to  $1.04 \times 10^{-1}$  cm/s, average  $6.44 \times 10^{-2}$  cm/s  
 AOC 9:  $3.10 \times 10^{-5}$  to  $2.00 \times 10^{-3}$  cm/s for AOC 9, average  $1.02 \times 10^{-3}$  cm/s  
 AOC 11:  $1.37 \times 10^{-4}$  to  $1.79 \times 10^{-3}$  cm/s, average  $7.51 \times 10^{-4}$  cm/s

4. Using hydraulic gradients measured at each AOC (below) during the MNA Assessment, effective porosity (0.3 for silty sand), and the average hydraulic conductivities in item 3 above, the following linear average groundwater flow velocities were calculated for each AOC ( $V=Ki/n_e$ , where K is hydraulic conductivity, i is the hydraulic gradient, and  $n_e$  is effective porosity):

	K (ft/day)	i (ft/ft)	$n_e$	V (ft/day)
AOC 3:	183	0.02	0.3	12.2
AOC 9:	2.89	0.075	0.3	0.723
AOC 11:	2.13	0.067	0.3	0.476

<sup>8</sup> Class 1 soil is defined as coarse grained soil with more than 50 percent of the material retained on a #200 sieve. and it includes gravel, sand, and sand with silt or clay fines.

On the basis of the overall slug test results at AOC 3 and those from the other AOCs, it appears that the hydraulic conductivity and flow velocity value for AOC 3 are misleadingly high, probably because of the discontinuity of the granular lenses. It has therefore been assumed in evaluating the technologies that the hydraulic conductivity of AOC 3 is <3 ft/day and the velocity <1 ft/day, consistent with values determined for AOCs 8/9 and 11.

5. The results of the MNA Assessment groundwater level measurements over multiple monitoring events have been assumed to be indicative with respect to groundwater flow directions at each of the AOCs. Despite variations in elevations, flow at AOC 3 appeared to be consistently inward along a trough located within the free product area during all events. Flow at AOC 8/9 was more variable. Two of the events indicated a groundwater depression in the area of the free product, while two indicated flow in that area toward the east. A groundwater mound appeared to be located north of the free product area during all four events. Despite variations in elevations, flow at AOC 11 appeared to be consistently toward the east/southeast during all events.
6. The minimum and maximum depths to groundwater measured in each monitoring well during the MNA Assessment four rounds of groundwater monitoring from July 2009 through April 2010 were averaged to provide an estimate of the reasonable depth and thickness of the smear zone at each AOC during this time period:

	Min. Depth (ft)	Max. Depth (ft)	Thickness (ft)
AOC 3:	11	16	5
AOC 9:	6	12	6
AOC 11:	11	13	2

7. The area of free product has been assumed to be that shown on the drawings included in Appendix C (Figure 3, Appendix C-1; Figure 6, Appendix C-2; and Figure 2-1, Appendix C-3) and as calculated in the RAPs and Phase II reports as follows:

AOC 3:	78,400 square feet
AOC 9:	8,000 square feet
AOC 11:	34,200 square feet

8. The volume of petroleum contaminated soil (i.e., soil with residual LNAPL) associated with the petroleum smear zone at each AOC was estimated using the footprint of the area of free product from Assumption 7 times the average thickness of the smear zone from Assumption 6. Using this approach, the following volumes of contaminated soil were estimated for use in evaluating technologies in this report:

AOC	Volume of Petroleum Contaminated Soil (CY) <sup>9</sup>
AOC 3	14,520
AOC 9	1,780
AOC 11	2,530

9. On the basis of the free product measurements during the MNA Assessment, the range of thickness of the free product contamination at each AOC is as follows:

AOC 3:	0.10 to 0.30 feet
AOC 9:	0.08 to 0.22 feet
AOC 11:	0.03 to 0.20 feet

10. An average porosity of 0.4 is assumed for sand and silty sand and 0.5 for silty clay.

11. The volume of LNAPL at each AOC based on the free product areas above, the maximum thickness of LNAPL measured during the MNA Assessment, and a specific volume factor from the Wisconsin Assessment Guidance for Sites with Residual Weathered Product (Ref. 18)<sup>10</sup>. These Remedial Technology Evaluation (RTE) volume calculations are compared in Table 2 to the volumes calculated in the Phase II RI and RAP for each AOC. The RTE volumes have been assumed in reviewing the technologies Phase II RI and in this report.

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<sup>9</sup> An alternative approach to estimate the petroleum contaminated soil quantities would be to use the depth intervals identified in the BUSTR Tier 2 Evaluation Reports as locations where BUSTR Tier 2 Action Levels were exceeded: 10-18 feet bgs at AOC 3, 10-18 feet at AOC 8/9, and 13-20 feet at AOC 11:

AOC	Volume of Petroleum Contaminated Soil Using Tier 2 Evaluation Report Intervals (CY)
AOC 3	23,230
AOC 9	2,370
AOC 11	8,870

These volumes are more conservative in that they consider greater depth to groundwater conditions during 1998 and a thicker petroleum smear zone that was present and sampled above the groundwater table. The average depth to the groundwater table in November 1998 associated with the BUSTR Tier 2 Evaluation Reports for each AOC was deeper than observed during the quarterly groundwater monitoring events in July 2009 through April 2010. This resulted in a greater petroleum smear zone thickness observed in 1998 compared to the July 2009 through April 2010 timeframe.

<sup>10</sup> Multiple references have noted that it is extremely difficult to estimate volumes of recoverable free product. Measurements in wells tend to overestimate the thickness, while boring log data tends to overestimate the area of LNAPL. EPA states that the reliability of such estimates is low, with accuracy within an order of magnitude (Ref. 19).

**Table 2. LNAPL Volume Estimates**

	<b>AOC 3</b>			<b>AOC 8/9</b>			<b>AOC 11</b>		
	RTE 2012	RAP 2007	RI 2002	RTE 2012	RAP 2007	RI 2002	RTE 2012	RAP 2002	RI 2002
Thickness (feet)	0.30	0.25	1.5	0.22	1.2	2.0	0.20	2.25	2.0
Area (square feet)	78,400	78,400	90,000	8,000	8,000	9,500	34,200	34,200	34,000
Porosity	NA	0.4	NA	NA	0.4	NA	NA	0.4	NA
Specific volume factor	0.06	NA	NA	0.03	NA	NA	0.025	NA	NA
Calculated Volume (gallons)	<b>35,200</b>	58,300	403,900	<b>1,800</b>	29,000	56,800	<b>6,400</b>	173,000	203,500

## Notes:

NA = not applicable

RTE used the Wisconsin Department of Commerce, *Assessment Guidance for Sites with Residual Weathered Product*, PUB-RR-878, February 2008. This method uses the maximum measured LNAPL thickness (measured in monitoring wells) with the soil type to determine the specific volume. This is done using a graph of specific volume versus well thickness. The graph is by soil type, but for the small thicknesses measured at the LAFB AOCs, the soil type is not very significant. Sand was used for all the AOCs based on Assumption 2 in Section 3.1.

RTE LNAPL volume in gallons = Specific Volume x LNAPL area in square feet x 7.48 gallons/cubic foot

RAP calculated LNAPL volume in gallons = LNAPL thickness in feet x LNAPL area in square feet x porosity (from WIDE study) x 7.48 gallons/cubic foot

RI data were used to calculate the volume using the methodology used in the RAP

12. The LNAPL is representative of degraded JP-4 fuel, consistent with the MNA Assessment results included in Appendix B.
13. Current and future above ground structures and underground utilities are those depicted on the figures in Appendices C (Figure 4, Appendix C-1; Figure 4, Appendix C-2; and Figure 1-3, Appendix C-3) and E.

### 3.1.1 Conceptual Site Models

The CSMs shown on Figures 3-38 are graphical conceptual models that have been developed in plan and cross section view for each of the AOCs. The base CSMs (Figures 3 through 5) illustrate the assumed physical, geologic and contaminant conditions presented in the preceding section, as well as site features including utilities and structures. They are not meant to provide a detailed representation of the precise location, size or distribution of soil types, site features or contaminant concentrations. Rather, these models are meant to portray, in a conceptual manner, the attributes of the site that may favor or hinder the application of the range of remedial technologies being considered for these AOCs. Relative soil permeability and heterogeneity; depth to groundwater; presence of free and residual phase product; presence of utilities, buried



structures, and existing infrastructure are some of the features represented on these models, although not necessarily to scale or located precisely. More precise information on the distribution of specific features may be required during the design phase to maximize the effectiveness of the selected remedial option. Overlays of the remedial technologies on the CSMs are presented in Figures 6 through 38 and are discussed in Section 4.0 with respect to development of each of the technologies.

## **3.2 NATURAL SOURCE ZONE DEPLETION**

### **3.2.1 Technology Summary**

NSZD is a combination of processes that reduces the mass of LNAPL in the subsurface. It occurs when certain processes act to (a) physically redistribute LNAPL components to the aqueous or gaseous phase and (b) biologically break down source zone components. These processes include dissolution of LNAPL constituents into groundwater and volatilization of LNAPL constituents into the vadose zone. In turn, LNAPL constituents dissolved to groundwater and volatilized to the vadose zone can be biodegraded by microbial and/or enzymatic activity. Biodegradation rates depend on the type and availability of electron acceptors (oxygen, nitrate, sulfate, ferrous iron, manganese, and methane) in the subsurface soils and groundwater.

NSZD is significant because it occupies a position in the spectrum of remediation options that can be used as a basis for comparing the performance and relative benefit of other remediation options. It is also significant because engineered remedial actions typically do not completely remove all LNAPL from soils and NSZD may be useful to address the residual hydrocarbon. Although considerable data are required to evaluate the potential effectiveness of this technology and to monitor its continued performance, the costs of collecting these data will typically be less than costs to implement more aggressive technologies. However, the presence of recalcitrant LNAPL and low groundwater flow conditions may limit the effectiveness of NSZD and increase the time to achieve remediation goals, and verification of depletion mechanisms will have to be established and demonstrated. It is likely that with weathered JP-4 LNAPL, the rate of dissolution of the free product will be the limiting factor for NSZD. With respect to this evaluation of technologies, NSZD serves as a baseline for evaluating the other technologies (Ref. 20 and 21).

### **3.2.2 General Assumptions**

Qualitative and quantitative evaluation of NSZD requires a significant amount of data, as discussed in the following section. In addition to the general assumptions, data from the MNA Assessment will be used to identify groundwater and vapor phase biodegradation parameters and LNAPL composition. Where additional assumptions must be made (e.g., effective diffusion coefficients), values will be taken or calculated from standard references.

### **3.2.3 Data Requirements**

Data requirements to both qualitatively and quantitatively assess the potential for NSZD as a remedial technology and to establish baseline conditions for long-term evaluation are considerable. The overall data requirements are summarized below:

- Detailed vadose zone site geology including soil type, grain size, and migration pathways.
- Detailed saturated zone site hydrostratigraphy including soil types, depth to groundwater, groundwater flow direction, hydraulic gradient, hydraulic conductivity, and preferential migration pathways.
- Dissolved groundwater contaminant concentrations and distribution.
- Source zone mass estimates.
- LNAPL chemical composition: identification of specific petroleum constituents and concentrations.
- LNAPL chemical and physical properties: e.g., boiling point, viscosity, solubility.
- LNAPL vadose zone horizontal and vertical distribution.
- LNAPL saturated zone horizontal and vertical distribution.
- Dissolved oxygen, nitrate, sulfate, iron and manganese concentrations up-gradient and down-gradient of the LNAPL source zone.
- Vertical hydrocarbon soil gas concentration profiles.
- Vertical oxygen and methane soil gas profiles.
- Effective diffusion coefficients (may be estimated from soil moisture and total porosity).
- Potential receptors.

Many of these data are available from previous investigations or can be estimated to evaluate the technology for the purposes of this report. However, bench-scale tests to evaluate LNAPL dissolution, volatilization, and leaching are recommended, if a decision is made to propose this as a remedial action to the regulatory agency. There are also predictive models that may be used to predict LNAPL dissolution and volatilization, groundwater fate and transport, and biodegradation.

### **3.2.4 Work Phases**

This technology would involve the following work phases:

1. Work Planning. This would include development of planning documents for subsequent phases, including a work plan, quality assurance project plan, and health and safety plan. It could include developing plans for bench-scale testing, if not previously conducted.
2. Bench-scale testing. This would involve laboratory tests to evaluate dissolution, volatilization, and leaching rates.
3. Field investigation. This would involve collecting any additional data required to establish baseline conditions and would likely include installation of additional monitoring wells to monitor both groundwater and soil vapor concentrations.
4. Monitoring. Long-term monitoring of this alternative would be required to evaluate the rate and effectiveness of NSZD. Monitoring would likely include LNAPL, soil vapor, and groundwater monitoring to evaluate changes in contaminant concentrations and distribution, as well as testing for biodegradation parameters to evaluate the progress of natural biodegradation of the contaminants.

### 3.3 EXCAVATION

#### 3.3.1 Technology Summary

Excavation is a conventional technology used to remove contaminated (saturated and unsaturated) soil from the subsurface. The contaminated soil is removed using an excavator and other typical construction equipment. For sites contaminated with petroleum hydrocarbons, soil excavation is combined with off-site disposal. Clean overburden soil may be stockpiled for use as fill in the excavation or may be mixed with wetter material to absorb free liquids. The excavated contaminated soil is loaded directly into trucks for transport to the off-site disposal facility or may be temporarily stockpiled, if necessary for waste characterization. Petroleum-contaminated soil usually may be disposed of as a special waste at a solid waste landfill, but waste characterization testing is required to demonstrate that the soil will not be considered a RCRA hazardous waste. Following excavation, confirmation sampling is conducted to document residual levels of contamination<sup>11</sup>, and the excavated area is backfilled with compacted clean fill.

If free liquids are present, dewatering and/or stabilization with some kind of absorbent may be required. If extensive excavation is required below the water table, sheet piling may be necessary, and the cost and difficulty of implementation will increase substantially. Dewatering is accomplished using pumps to remove liquid from the excavation. The collected liquid may be treated on-site or hauled to an off-site treatment/recycling facility. Stabilization requires the addition of an absorbent such as overburden soil or imported flyash to absorb free liquid. The absorbent is typically added to and mixed with the soil in the excavation.

Physical removal and disposal are standard, full-scale technologies. Nearly any contaminant, including LNAPL, can be addressed to some degree using removal and treatment. The primary advantages of excavation and removal are that they generally require shorter time periods than

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<sup>11</sup> This may not be applicable for excavation below the water table.

in-situ treatment and are generally more effective in remediating heterogeneous soils. However, excavation and removal may not be practical or cost effective if site conditions include numerous above and below ground structures or deep or widespread contamination (Ref. 22).

### **3.3.2 General Assumptions**

In addition to assumptions identified in Section 3.1, the following general assumption has been made with respect specifically to excavation:

- The depth of excavation would be limited to 16 feet. (This is consistent with the maximum depth at which free product was identified at any of the AOCs.)

### **3.3.3 Data Requirements**

The following data are required to fully evaluate and implement this alternative:

- Depth to and thickness of free phase product.
- Depth to groundwater.
- Rate of groundwater recharge.
- Soil waste characterization for disposal.
- Free liquid waste characterization for on-site treatment or disposal.
- Details concerning surface and subsurface structures (e.g., buildings, streets, parking lots, utilities) in the target removal area.

### **3.3.4 Work Phases**

Excavation would involve the following work phases:

1. **Work Planning.** This would include development of planning documents for subsequent phases: 1) work plan, quality assurance project plan, and health and safety plan for additional field work and construction; and 2) drawings and specifications and quality assurance plan as necessary for construction.
2. **Field investigation.** This would involve collecting any additional information necessary to meet the data requirements identified in Section 3.3.3 to plan and implement excavation at the site.
3. **Mobilization.** This would involve mobilizing personnel, equipment, and supplies to the site, including establishing a field office, work zones, and a decontamination pad for equipment. Equipment would be decontaminated before use on the site.
4. **Excavation and Disposal.** This would include field implementation of excavation, water management and/or stabilization, transportation, and disposal.

5. Site Restoration. This would include confirmation sampling, if applicable; backfilling with compacted fill; and surface restoration, as required.
6. Monitoring. It is likely that monitoring would be required for some period of time to demonstrate that groundwater RAOs were achieved as a result of removal of soil contaminated with free phase product.

### **3.4 IN-SITU SOIL MIXING**

#### **3.4.1 Technology Summary**

ISSM is a construction technology for remediating contaminated soils. Contaminated media is transformed through solidification and stabilization into durable, solid, low-hydraulic conductivity material in order to reduce the rate of contaminant migration. ISSM uses specialized hydraulically driven augers and mixing paddles to simultaneously drill and inject material. The auger flights loosen the soil as they move through the subsurface allowing the soils to be mixed with the paddles. The technique may be used to homogenize existing materials or to blend stabilizing material into the soil. Typically some grout is required to facilitate mixing of existing soil material. The homogenized material is then injected back out through the augers.

Stabilizing additives may include slurries of bentonite, cement, lime, and other additives (e.g., fly ash and slag that change the composition/durability of the material). ISSM creates individual columns of material, which can be overlapped to create walls or divided into block or grid patterns. This technology is most effective at depths of up to 40 feet, but has been used at depths of up to 120 feet depending on subsurface soil characteristics. For shallow applications with contaminated material depths of up to 20 feet, the area to be treated is typically divided into grid cells.

Because ISSM is an in-situ technique, disposal cost and worker exposure are minimized. ISSM generally uses simple, readily available equipment and materials and fixed treatment end points are reached in a relative short period of time. ISSM can also improve the structural properties of soil (e.g., strength) to facilitate beneficial reuse of land.

There are several potential challenges related to ISSM. Removal of debris or underground obstructions must be conducted prior to treatment as they can limit drilling ability. VOC emissions may need to be treated. Because not all contaminants are destroyed or removed, long-term stewardship may be required. ISSM requires surface access to all locations where soils are contaminated, which rules out its effective use if contamination underlies site structures. (Ref. 23 and 24).

#### **3.4.2 General Assumptions**

In addition to assumptions identified in Section 3.1, the following general assumption has been made with respect specifically to ISSM:

- The depth of ISSM would be limited to 20 feet. (This is consistent with the depth at which free product was identified at any of the AOCs. Mixing should extend slightly

below the maximum depth of contamination to assure adequate stabilization of contaminants).

### **3.4.3 Data Requirements**

The following data are required to completely evaluate and implement this alternative:

- Depth to free phase product.
- Depth to groundwater.
- Hydraulic gradients.
- Hydraulic conductivity.
- Bench scale testing of the effectiveness of mixing soil layers with and without additives with respect to immobilizing/stabilizing the LNAPL.
- Pilot scale testing to evaluate effectiveness under site hydrogeological conditions.
- Details concerning surface structures (e.g., buildings, streets, parking lots) overlying the target treatment area
- Details concerning subsurface structures and utilities at or in the vicinity of the target treatment area. Such details may include location, depth, size, materials of construction, etc.

### **3.4.4 Work Phases**

ISSM would involve the following work phases:

1. **Work Planning.** This would include development of planning documents for subsequent phases: 1) work plan, quality assurance project plan, and health and safety plan for additional field work and construction; and 2) drawings and specifications and quality assurance plan as necessary for construction.
2. **Field investigation.** This would involve collecting any additional information necessary to meet the data requirements identified in Section 3.4.3 to plan and implement ISSM at the site.
3. **Mobilization.** This would involve mobilizing personnel, equipment, and supplies to the site, including establishing a field office, work zones, and a decontamination pad for equipment. Equipment would be decontaminated before use on the site. In addition to mobilizing the mixing system, a batch plant consisting of storage silos, metering and blending devices, and pumps would be set up if stabilizing additives are proposed. Specialty equipment such as shrouds equipped with air controls to capture fugitive emissions would also be mobilized, if needed.

4. ISSM. This would include field implementation of ISSM, slurry management, and VOC emissions controls, if required.
5. Site Restoration. This would include surface restoration, as required.
6. Monitoring. It is likely that monitoring would be required for some period of time to demonstrate that groundwater remedial action objectives were achieved as a result of ISSM of soil contaminated with free phase product.

### 3.5 MULTI-PHASE EXTRACTION

#### 3.5.1 Technology Summary

MPE process was developed for the remediation of LNAPL, aromatic VOCs, total petroleum hydrocarbons, and chlorinated VOCs in moderate permeability subsurface formations. The technology is meant to address contaminants in free-phase liquid, residual and sorbed phases, and vapors. The process is a modification and combination of two conventional remediation technologies: soil vapor extraction (SVE) and groundwater extraction.

Traditional SVE is the process of stripping and extracting volatile compounds from the soil by inducing air flow through the soil. Soil vapor flow is induced by applying a vacuum to extraction wells. Generally, SVE is applied to soil above the groundwater table.

Unlike SVE alone, MPE simultaneously extracts both liquid (groundwater and LNAPL) and soil vapor. The groundwater table is lowered in order to dewater the saturated zone so that the SVE process can be applied to the newly exposed soil. This allows volatile compounds sorbed on the previously saturated soil to be stripped by the induced vapor flow and extracted. The increased air movement through the unsaturated zone also increases oxygen content and enhances aerobic bioremediation. The lowering of the water table also allows residual phase product trapped within the pore space of the previously saturated zone to coalesce into free phase liquid, allowing it to flow toward a recovery well, where a skimming pump may also be used to remove LNAPL.

MPE can be implemented using several different configurations. Most commonly, groundwater, soil vapor, and sometimes LNAPL, are extracted separately, although from the same well. In this configuration, centrifugal well pumps are placed in wells below the water table while a vacuum is applied to the top of the well, where it induces flow through a well screen placed above the water table. This configuration can also be supplemented by additional wells used only for soil vapor extraction. An alternate configuration for MPE is sometimes referred to as 'bioslurping' and uses total fluids extraction from a single suction pipe placed within a well to draw from slightly below the normal water table. The single suction pipe is connected to a liquid ring blower, which will draw water, LNAPL and vapor. In this configuration, liquids are separated from vapors using a separation tank at the surface. MPE will often require treatment of the extracted groundwater and vapor at the surface prior to discharge. LNAPL may also be collected separately for off-site disposal.

The use of MPE is not suggested for sites with very high permeability and is better suited for soils with low to moderate permeability to reduce the risk of short-circuiting. It is also not

recommended for use in soils with very low permeability because of a lack of secondary flow path. When used at sites with low to moderate permeability, this system can potentially create a large radius of influence causing greater capture of the contaminant plume and reducing the need for extra wells.

In order for MPE to work efficiently and cost effectively, the location should display a hydraulic conductivity between  $1.8 \times 10^{-4}$  and  $5.3 \times 10^{-3}$  cm/s and a water table depth of less than 30 ft bgs (the total fluids configuration requires an even shallower depth to water). The goal of this technology is to remove contaminant mass while promoting bioremediation and ultimately allowing natural attenuation to take over once the MPE system can no longer cost effectively remove contaminants (Ref. 25 and 26). Although it may eliminate LNAPL observed in wells and reduce concentrations of volatile compounds in vadose zone soils, residual contamination typically remains trapped in the soil matrix after treatment. In addition, MPE is likely to be less effective on weathered LNAPL, where the more volatile and biodegradable compounds have already been volatilized or degraded.

### **3.5.2 General Assumptions**

Qualitative and quantitative evaluation of MPE requires a significant amount of data, as discussed in the following section. In addition to the general assumptions, data from the MNA Assessment (Appendix B) will be used to identify LNAPL characteristics. Where additional assumptions must be made, values will be taken or calculated from standard references.

### **3.5.3 Data Requirements**

The following data are required to fully evaluate and implement this alternative:

- Detailed vadose zone site geology including soil type, grain size, and migration pathways.
- Naturally occurring organic fraction ( $f_{oc}$ ) of soils in target treatment zones.
- Detailed saturated zone site hydrostratigraphy including soil types, depth to groundwater, groundwater flow direction, hydraulic gradient, hydraulic conductivity, and preferential migration pathways.
- Source zone mass estimates.
- LNAPL vadose zone horizontal and vertical distribution.
- LNAPL saturated zone horizontal and vertical distribution and thickness.
- LNAPL chemical and physical properties: e.g., boiling point, viscosity, solubility.
- Details concerning surface structures (e.g., buildings, streets, parking lots) overlying the target treatment area



- Details concerning subsurface structures and utilities at or in the vicinity of the target treatment area. Such details may include location, depth, size, materials of construction, etc.

Many of these data are available from previous investigations or can be estimated to evaluate the technology for the purposes of this report.

### **3.5.4 Work Phases**

This technology would involve the following work phases:

1. **Work Planning.** This would include development of planning documents for subsequent phases, including a work plan, quality assurance project plan, and health and safety plan. It could include developing plans for field testing, if not previously conducted.
2. **Field Testing.** This would involve field testing to evaluate the effectiveness of MPE on the site.
3. **Field Investigation.** This would involve collecting any additional data required to establish baseline conditions and would likely include installation of additional monitoring wells to monitor both groundwater and soil vapor concentrations.
4. **Installation and Implementation of MPE.** This would involve the installation of the systems, then operation of extraction equipment. The system would be run in intervals with monitoring of the factors mentioned in the section above.
5. **Monitoring.** Long-term monitoring will likely include periodic LNAPL, soil vapor, and groundwater sampling to evaluate changes in contaminant concentration and distribution, as well as testing for biodegradation parameters to evaluate the progress of natural biodegradation of the contaminants over time.

## **3.6 MULTI-PHASE EXTRACTION WITH HEATING**

### **3.6.1 Technology Summary**

MPEH was developed for the remediation of LNAPL, aromatic VOCs, total petroleum hydrocarbons, and chlorinated VOCs in low to moderate permeability subsurface formations. The process is a modification of the conventional MPE system and is meant to address contaminants in free-phase liquid, residual and sorbed phases, and vapor. The information provided in the previous summary for MPE also applies to MPE with heating. This section will only address supplemental information associated with the addition of heating. Heating is added to conventional MPE to increase the rate of recovery or the range of contaminants that can be recovered by the process. Soil heating will volatilize higher molecular weight compounds that a traditional MPE system will not affect, will reduce the viscosity of free-phase and residual NAPL, and will increase chemical reaction rates for contaminant breakdown.

The source of heat to implement this technology could be from Electrical Resistance Heating (Section 3.9) or from soil heating technologies such as steam injection, hot compressed air injection, thermal conduction heating, or radio-frequency heating. The source of the required electrical power or waste heat from nearby utility or industrial applications is a critical consideration in application of this technology. There is also the opportunity to use renewable energy sources such as solar to provide power for heating or to use waste heat from the MPE process equipment. As for conventional MPE, the use of MPE with heating is not suggested for sites with very high permeability and is better suited for soils with low to moderate permeability to reduce the risk of short-circuiting. It is also not recommended for use in soils with very low permeability because of a lack of secondary flow paths. When used at sites with low to moderate permeability, this system can potentially create a large radius of influence causing greater capture of the contaminant plume and reducing the need for extra wells.

In order for MPE with heating to work efficiently and cost effectively, the location needs to have hydraulic conductivity between  $1.8 \times 10^{-4}$  and  $5.3 \times 10^{-3}$  cm/s, the water table be less than 30 ft to the surface, and ideally less than 0.5 ft of product. The goal of this technology is to remove contaminant mass while promoting bioremediation and ultimately allowing natural attenuation to take over once the system can no longer cost effectively remove contaminants (Ref. 27, 28, and 29).

### **3.6.2 General Assumptions**

General assumptions are the same as MPE (Section 3.5.2).

### **3.6.3 Data Requirements**

Data requirements are the same as MPE (Section 3.5.3), with the addition of information regarding potential local heat and energy sources.

### **3.6.4 Work Phases**

Work phases are the same as MPE (Section 3.5.4).

## **3.7 IN-SITU CHEMICAL OXIDATION**

### **3.7.1 Technology Summary**

ISCO employs the injection of chemical oxidants directly into the aquifer to react with and destroy dissolved-phase organic constituents. ISCO is most commonly employed for the treatment of dissolved phase organic constituents and is usually employed as a source control measure for high concentration dissolved contaminants at or near the original release site. With respect to petroleum constituents, which are comprised primarily of carbon and hydrogen, the oxidation products are carbon dioxide and water.

Chemical oxidants commonly employed in ISCO include:

- Hydrogen peroxide ( $\text{H}_2\text{O}_2$ )
- Ozone ( $\text{O}_3$ )
- Permanganates ( $\text{MnO}_4^-$ ): e.g., potassium permanganate; sodium permanganate
- Persulfate ( $\text{S}_2\text{O}_8^{2-}$ ): e.g., sodium persulfate

All of these compounds are potentially hazardous to human health and the environment. They require careful handling to assure the safety of workers and the public. It is also important to understand and control transport and reactions in the subsurface environment. Hydrogen peroxide and ozone are fast-acting and short-lived oxidants, while permanganates and persulfates are employed in a slow-release form in situations that require longer-term treatment (e.g., for the treatment of dissolved phase contaminants in lower concentration portions of the plume). The effectiveness of fast-acting oxidants can generally be evaluated in a few weeks to a few months, while slow-release oxidants can be effective for several years.

Most oxidizing agents are relatively non-selective and will react with many organic materials and some inorganic materials. The presence of high concentrations of naturally occurring organic materials will increase the oxidizing agent dose required for effective destruction and may decrease overall performance. Determination of the required oxidant dose must consider the total organic carbon load (sometimes referred to as the soil oxidant demand, natural organic matter, or  $f_{oc}$ ), not simply the target contaminant load.

Subsurface injection is generally performed using a network of permanent injection wells or temporary hydraulic probe injection points. Pilot-scale testing may be required to evaluate the radius of influence and appropriate well spacing. High pressure injection may be employed to increase the radius of influence and reduce the number of injection points. Multiple applications are often required to meet remedial endpoints.

Perhaps the greatest challenge in effectively employing ISCO is achieving effective oxidant delivery and contact with the target contaminants. ISCO is most effectively employed in homogeneous, highly conductive (permeable) matrices. The presence of low conductivity materials such as clays and non-homogeneous soils (e.g., stratified lenses) can reduce oxidant/contaminant contact, resulting in decreased ISCO effectiveness. Subsurface structures and utility lines may create physical obstacles to injection or may be damaged by oxidizing compounds.

Application of ISCO for LNAPL is uncommon, and generally limited to relatively small LNAPL zones. The mass of oxidant required to effectively destroy large LNAPL zones can be very large. In situations where significant LNAPL zones have been identified, removal by other methods is generally more cost effective than the use of ISCO. In addition, chemical oxidants are not miscible in NAPL, so contaminant oxidation occurs in the aqueous phase on dissolved contaminants. Therefore, the solubility of the contaminant ultimately controls the rate of possible oxidation (Ref. 30 and 31).

JP-4 is a complex mixture consisting of a broad range of hydrocarbons with differing volatilities, solubilities, and biodegradation potentials. The lighter aromatic components (e.g., benzene, toluene, ethyl benzene, and xylene) are relatively volatile and water soluble. Considering the age of the releases at the three AOCs, it is likely that the concentrations of lighter components have dropped over the years, and the remaining product is now comprised primarily of the heavier JP-4 components, which have reduced volatility and solubility.

### **3.7.2 General Assumptions**

General assumptions are the same as NSZD.

### **3.7.3 Data Requirements**

The following data are required to fully evaluate and implement this alternative:

- Detailed vadose zone site geology including soil type, grain size, and migration pathways.
- Naturally occurring organic fraction of soils in target treatment zones.
- Detailed saturated zone site hydrostratigraphy including soil types, depth to groundwater, groundwater flow direction, hydraulic gradient, hydraulic conductivity, and preferential migration pathways.
- Dissolved groundwater contaminant concentrations and distribution.
- Source zone mass estimates.
- LNAPL vadose zone horizontal and vertical distribution.
- LNAPL saturated zone horizontal and vertical distribution and thickness.
- LNAPL chemical composition: identification of specific petroleum constituents and concentrations.
- LNAPL chemical and physical properties: e.g., boiling point, viscosity, solubility.
- Details concerning surface structures (e.g., buildings, streets, parking lots) overlying the target treatment area.
- Details concerning subsurface structures and utilities at or in the vicinity of the target treatment area. Such details may include location, depth, size, materials of construction, etc.
- Potential receptors.
- Pilot scale testing to evaluate the radius of influence and injection well spacing.

### **3.7.4 Work Phases**

This technology would involve the following work phases:

1. **Work Planning.** This would include development of planning documents for subsequent phases, including a work plan, quality assurance project plan, and health and safety plan. It could include developing plans for bench-scale testing, if not previously conducted.
2. **Pilot scale testing.** Pilot scale testing is required to provide data regarding the radius of influence, required injection well spacing, and required oxidant injection dose. The results of the field-scale testing can be used to refine and optimize the work plans.
3. **Full-scale Implementation.** Injection of oxidants in numerous wells or injection points located throughout the target treatment zone. Monitoring would be required during injection to evaluate the progress of treatment and the distribution of the oxidant.
4. **Post-Remediation Monitoring.** Post-remediation monitoring of this alternative would be required to evaluate effectiveness and monitor for rebound. Monitoring would likely include periodic LNAPL monitoring combined with groundwater sampling/analysis.
5. **Secondary Application:** As discussed above, multiple rounds of oxidant injection and monitoring are often required to achieve remediation endpoints.

## **3.8 SURFACTANT ENHANCED LNAPL REMOVAL**

### **3.8.1 Technology Summary**

SELR is a technique to remove nonaqueous phase liquids from the saturated zone using chemical surfactants to mobilize contaminants and allow recovery using conventional groundwater extraction. Because SELR involves the introduction of a manufactured chemical to the environment to mobilize a known contaminant, the use of this technology requires a thorough understanding of the risks to receptors and a high degree of confidence in the physical containment of the contaminant plume during implementation.

Surfactants are chemicals that are amphiphilic, meaning they have a polar end and a non-polar end. These chemicals can also be classified as having a hydrophilic group and a hydrophobic group. Because of this property, surfactants serve as a ‘bridge’ between polar (e.g., water) and non-polar (e.g., oil) liquids. When surfactants are placed in an environment that has both polar and non-polar solvents, such as LNAPL (non-polar) mixed with groundwater (polar), they tend to migrate to the interfaces of the two different solvents and orient so that the polar group lies in water and the non-polar group lies in the non-polar solvent. When this orientation occurs, the surface tension between the two solvents is lowered and allows the non-polar chemical to more easily move through the water, thus expediting the removal of the chemical from groundwater.

There are three general classes of surfactants based on their dissociation in water: anionic, non-ionic, and cationic. Anionic surfactants have an anionic end, consisting of a negatively charged atom attached to a 12 to 18 carbon chain, and a cationic end. The non-polar end of the chemical

interacts with the non-polar solvent and the negatively charged anionic end forms a hydrogen bond with the water, helping to lower the surface tension between the two solvents.

Non-ionic surfactants do not ionize because their hydrophilic groups are of a non-dissociable type such as alcohols, phenols, or esters. Cationic surfactants are relatively rare because of the high cost of production. As a consequence of their high cost, cationic surfactants are only used as a bactericide or as a positively charged substance that is able to adsorb on negatively charged substrates to produce antistatic and hydrophobant effects when there is no cheaper substitute.

High to moderate permeabilities are necessary for surfactant enhanced LNAPL removal to be effective. When the appropriate surfactant is chosen for the removal of the contaminant, it is highly recommended that a pilot study be performed. This will help investigate system performance and cost feasibility prior to a full-scale implementation. Pilot tests will also help determine whether the gradients necessary for capturing the contaminant and surfactant fluids can be maintained for improved contaminant contact and recovery. It is ideal that the pilot test occur in the up-gradient area of the source zone to prevent possible spreading of the contaminant near the down-gradient area.

After the pilot-scale testing is completed, then full-scale implementation can commence. The most common technique for the use of surfactants is a flooding configuration. This involves the preparation of low viscosity surfactant solutions that is pumped through the contaminated zone. The surfactant is put into the ground through up-gradient injection points and then removed down-gradient through extraction wells. In the case of free product being present, it is common that the free product will be removed through pumping and water flooding operations prior to the injection of the surfactant. This technology will not address contamination that is present in the smear zone at an elevation above the water level (Refs. 32-35).

### **3.8.2 General Assumptions**

General assumptions are the same as MPE (Section 3.5.2).

### **3.8.3 Data Requirements**

The following data are required to fully evaluate and implement this alternative:

- Detailed vadose zone site geology including soil type, grain size, and migration pathways.
- Detailed saturated zone site hydrostratigraphy including soil types, depth to groundwater, groundwater flow direction, hydraulic gradient, hydraulic conductivity, and preferential migration pathways.
- LNAPL vadose zone horizontal and vertical distribution.
- LNAPL saturated zone horizontal and vertical distribution and thickness.
- LNAPL chemical and physical properties: e.g., boiling point, viscosity, solubility.

- Details concerning surface structures (e.g., buildings, streets, parking lots) overlying the target treatment area.
- Details concerning subsurface structures and utilities at or in the vicinity of the target treatment area. Such details may include location, depth, size, materials of construction, etc.
- Potential receptors.
- Pilot tests to determine whether the gradients necessary for capturing the contaminant and surfactant fluids can be maintained for improved contaminant contact and recovery.

### **3.8.4 Work Phases**

This technology would involve the following work phases:

1. **Work Planning.** This would include development of planning documents for subsequent phases, including a work plan, quality assurance project plan, and health and safety plan. It could include developing plans for bench-scale testing, if not previously conducted.
2. **Field-scale testing.** Field-scale testing is used to provide data regarding Surfactant Enhanced LNAPL Removal, injection well spacing, and surfactant injection dose. The results of the field-scale testing can be used to refine and optimize the work plans.
3. **Full-scale Implementation.** Injection of surfactant in numerous wells or injection points located throughout the target treatment zone.
4. **Post-Remediation Monitoring.** Post-remediation monitoring of this alternative would be required to evaluate effectiveness and monitor for rebound. Monitoring would likely include periodic LNAPL monitoring combined with groundwater sampling/analysis.
5. **Secondary Application:** Multiple rounds of surfactant injection and monitoring might be required to achieve remediation endpoints.

## **3.9 ELECTRICAL RESISTANCE HEATING**

### **3.9.1 Technology Summary**

ERH is an intensive remediation process that uses the heat resulting from the resistance of soil to the flow of electricity to evaporate and release contaminants from soil and groundwater. The resistance to electric flow by the soil causes the formation of heat resulting in increased temperatures until the boiling point of water is reached. As the heat is applied, contaminants are volatilized and mobilized within the soil matrix. The source of the required electrical power from nearby utility or industrial applications is a critical consideration in application of this technology. There is also the opportunity to use renewable energy sources such as solar to provide power for heating.

Once the contaminants have been volatilized they are more mobile and available for collection and treatment. Collection of contaminants is typically accomplished using a vacuum system such as Soil Vapor Extraction (SVE), while treatment often consists of combustion to destroy the compounds.

There are two different types of ERH systems. The first uses a three phase system with the electrodes arranged in a repeating triangle formation with each electrode giving off a different level of voltage. This technique was originally created to enhance oil recovery. The second ERH system is a six phase system arranged in a hexagonal pattern with a neutral electrode in the middle to absorb the electrical imbalances generated by the difference in soil resistance. There is a possibility with the six phase ERH system that cold and hot spots will develop. Therefore, it is recommended that these systems be used in small circular areas with a diameter less than 65 feet. ERH is adaptable to all soil types, as well as sedimentary bedrock, and is effective in both the vadose and saturated zones. Because of its flexibility, pilot testing of ERH is not always required, but it can provide valuable design information.

ERH usually takes three to six months to complete treatment under ideal conditions. Having a lighter, more volatile, contaminant will also improve the effectiveness of this system. Once the treatment is completed, the soil temperatures will remain elevated and over time will decrease to ambient temperatures.

It should be noted that during the operation of ERH, “stray” voltages can appear outside of the electrode pattern. These “stray” voltages can energize metallic objects that are in contact with the ground, resulting in significant safety issues. Some ways to combat the safety issues are to limit access to the area through the use of wooden fencing. Another necessary precaution is the installation of a grounding ring that is connected to any above ground equipment to eliminate any electrical potential differences between components. A wire mesh equipotential mat should also be placed over the electrified zone and be connected to the grounding ring to help eliminate the possibilities for step-touch potentials (Ref. 36-41).

### **3.9.2 General Assumptions**

General assumptions are the same as MPE (Section 3.5.2).

### **3.9.3 Data Requirements**

Data requirements are the same as MPE with heating (Section 3.6.3).

### **3.9.4 Work Phases**

This technology would involve the following work phases:

1. **Work Planning.** This would include development of planning documents for subsequent phases, including a work plan, quality assurance project plan, and health and safety plan. It could include developing plans for bench-scale testing, if not previously conducted.



2. Field-scale testing. Field-scale testing is required to provide data regarding ERH, required electrode well spacing, and required SVE well placement. The results of the field-scale testing can be used to refine and optimize the work plans.
3. Full-scale Implementation. Placement of electrode wells throughout the target treatment zone and operation and monitoring during treatment.
4. Post-Remediation Monitoring. Post-remediation monitoring of this alternative would be required to evaluate effectiveness and monitor for rebound. Monitoring would likely include periodic LNAPL monitoring combined with groundwater sampling/analysis.



## 4.0 DETAILED DEVELOPMENT OF REMEDIAL TECHNOLOGIES BY AOC

This section presents detailed descriptions of the implementation of each of the eight technologies at each of the three AOCs. A RAP, in accordance with BUSTR requirements would have to be submitted for BUSTR approval before implementing any of the technologies. In addition, a monitoring plan would have to be prepared and implemented for each technology to demonstrate that RAOs are achieved and that no further action is appropriate. To minimize repetition in each section, RAP and monitoring plan components are summarized below:

### RAP

1. A description of remedial activities to be implemented.
2. Proposed target levels, identified by contaminant of concern and environmental media.
3. A conceptual design.
4. A brief description of remedial action alternatives considered, including a discussion of the reliability, effectiveness, relative cost, and time needed for completion, and the rationale for the selected program.
5. A monitoring plan describing the sampling methodologies and locations for determining whether action levels are being achieved.
6. A description of reporting frequency and proposed report content.
7. A description of permits or other governmental approvals required for implementing the plan.
8. A description of activities or studies, if any, that must be performed prior to implementing the proposed RAP.
9. An implementation schedule, projected completion date, and the submittal date for the completion report of the proposed remedial action.

### Monitoring Plan

1. A description of the purpose and objective of the monitoring activities.
2. A description of the planned monitoring activities, including those conducted to implement and to verify the effectiveness of the remedial actions.
3. The location of the points of demonstration and points of exposure.
4. A summary of the sampling procedures.

5. A description of the anticipated length and frequency of the monitoring activities.
6. Identification and description of the termination criteria for remedial monitoring activities.
7. Operation and maintenance data for equipment and engineering controls.

It has been assumed that all the technologies would require post-implementation groundwater monitoring. Since dissolved concentrations of COCs in groundwater outside the free product areas are already below the BUSTR action levels, it has been assumed that four quarters of monitoring would be sufficient to obtain a no further action ruling for those technologies that would eliminate or immobilize the free product. However, if the objectives of the monitoring plan are not met, BUSTR might require continued monitoring activities.

## **4.1 AOC 3**

Implementation of each of the technologies at AOC 3 is described in the following subsections.

### **4.1.1 Natural Source Zone Depletion**

NSZD occurs when certain natural processes act to (a) physically redistribute LNAPL components to the aqueous or gaseous phase and (b) biologically break down these source zone components. NSZD is significant because it occupies a position in the spectrum of remediation options that can be used as a basis for comparing the performance and relative benefit of other remediation options. The presence of recalcitrant LNAPL and discontinuous sand and gravel layers interspersed with zones of lower hydraulic conductivity at AOC 3 will limit the effectiveness of NSZD and increase the time to achieve remediation goals.

#### **4.1.1.1 Conceptual Model**

Since this alternative would not involve any construction except installation of additional monitoring wells, a CSM overlay has not been prepared. The NSZD processes include dissolution of LNAPL constituents into groundwater and volatilization of LNAPL constituents into the vadose zone. In turn, LNAPL constituents dissolved to groundwater and volatilized to the vadose zone can be biodegraded by microbial and/or enzymatic activity. The dissolution, volatilization, and biodegradation rates are critical factors in evaluating this technology. The dissolution and volatilization rates depend on the characteristics of the LNAPL constituents, while the biodegradation rates depend on these characteristics and the type and availability of electron acceptors. The rates of all these processes also depend on the permeability and transmissivity of the subsurface soils.

#### **4.1.1.2 Additional Data Requirements**

Data requirements for NSZD are identified in Section 3.2.3. In general, a significant amount of the data has already been collected. The site geology and hydrogeology, concentrations and distributions of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, biodegradation parameters up-

gradient and down-gradient of the source area, and potential receptors have all been to some extent previously investigated at AOC 3. Some of these data are summarized in Section 2.0 and 3.1. In addition, the draft MNA assessment made the following determinations:

- Lower benzene concentrations in monitoring wells down-gradient of the free product area suggest that biodegradation of benzene is occurring.
- However, because most of the dissolved petroleum hydrocarbon concentrations down-gradient of the free product area are below reporting limits, it is not possible to develop concentration profiles along a flow line to estimate the rate of NSZD.
- Similar DO concentrations in monitoring wells up-gradient and within the free product area are not indicative of aerobic biodegradation.
- Higher sulfate concentrations in monitoring wells up-gradient of the free product area suggest that biological sulfate reduction is occurring.
- Higher ferrous iron and methane concentrations within the free product area suggest that biological reduction of organic compounds is occurring.
- Alkalinity and pH data are inconclusive.
- Concentrations of benzene, 1,2,4-trimethylbenzene, and naphthalene in the LNAPL relative to the composition of JP-4 suggest that the more biodegradable compounds within the LNAPL are being preferentially removed, and that the remaining compounds are less readily degraded.

A few outstanding data gaps/uncertainties have been identified:

- Vertical soil gas profiles need to be developed to evaluate NSZD in the vapor phase. Installation of nested gas wells to monitor gas concentrations at various levels has been assumed for this alternative.
- LNAPL dissolution, volatilization, and leaching rates should be evaluated. A bench scale study to evaluate these rates has been assumed for this alternative.
- The groundwater flow needs to be further evaluated. The groundwater elevations determined during the MNA assessment indicate that flow is generally inward toward the axis of a trough on the water table surface that trends from southeast to northwest (Ref. 16). Identification of up-gradient and down-gradient wells is somewhat suspect under these apparent flow conditions. Installation of additional monitoring wells to evaluate NSZD and better define groundwater flow has been assumed for this alternative.
- Further analysis of the LNAPL to evaluate the percentages of various petroleum hydrocarbons is needed to evaluate the extent to which lighter fractions have been biodegraded. Collection of additional samples for fuel analysis to compare percentages of alkanes and aromatics to typical JP-4 has been assumed for this alternative. The effective solubility of the LNAPL would also be tested.

#### **4.1.1.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. **Work Planning.** This would include development of the RAP and monitoring plan, as well as planning documents for additional investigation and bench-scale testing. The latter documents would include a work plan, quality assurance project plan, and health and safety plan.
2. **Field investigation.** This would involve collecting any additional data required to establish baseline conditions. It is assumed to include:
  - Three additional groundwater monitoring wells installed to a depth of approximately 25 feet bgs along the centerline of the free product area.
  - Four nests of gas wells installed inside the free product area and one gas well nest installed at background location. The number of nested wells would be contingent on the depth to groundwater at the specific location, but assuming an average depth of 15 feet, three nested wells would be installed to monitor soil from 3-7 feet, 7-11, and 11-15 feet bgs.
  - Collection of four quarters of groundwater samples from ten wells, including five wells along the centerline of the free product area, as well as sentinel wells on either side of the LNAPL plume. All the samples would be analyzed for BTEX, methyl tert-butyl ether (MTBE), PAHs, TPH-Light Distillate Fraction and Middle Distillate Fraction, nitrate, sulfate, iron, and manganese (degradation products). Ferrous iron, ORP, pH, specific conductivity, DO, and turbidity would be measured in the field.
  - Collection of LNAPL samples from the three wells inside the LNAPL plume for fuel component analysis.
  - Collection of soil gas samples from the 15 soil gas wells and analysis for benzene using a portable gas chromatograph and methane and oxygen using a portable gas analyzer. Two samples would be collected and sent to a laboratory for chemical analysis for BTEX and methane to verify field testing results.
  - Bench-scale testing. This would involve laboratory tests to evaluate dissolution, volatilization, and leaching rates.

#### **4.1.1.4 Physical Access Requirements**

The only physical access required would be for well installation and gas and groundwater monitoring. Although there are some utilities in the area, it is assumed that the proposed activities would work around those locations. Air Cargo Terminal #4 and associated parking areas and utilities would not be affected by the implementation of this alternative.

#### **4.1.1.5 Construction/Implementation**

With the exception of the gas and groundwater monitoring wells that would be installed during the planning phase, this technology does not involve construction.

#### **4.1.1.6 Operation**

This technology would require long-term groundwater and soil vapor monitoring to evaluate the rate and effectiveness of NSZD. It has been assumed that annual soil gas and groundwater monitoring would be conducted as specified under work planning, with the exception of fuel component analysis of the LNAPL. A 30-year monitoring period has been assumed.

#### **4.1.1.7 Waste Management**

Waste management would be limited to disposal of drums of soil cuttings and monitoring well purge water. Relatively small quantities of these would be generated during investigation and monitoring activities. On the basis of concentrations detected in samples within the free product area, the soil would be disposed of as a special waste, and the groundwater would be disposed of at a publicly owned wastewater treatment plant.

#### **4.1.1.8 System Shutdown and Demobilization**

System shutdown would involve plugging up to sixteen monitoring wells. The wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.1.1.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

### **4.1.2 Excavation**

Excavation is a traditional and quick solution to remediate contaminated soil and source material. It involves removing the contaminated material from the site, then backfilling with clean soil. While this method has proven to be effective in areas where little development has occurred, excavating contamination in developed areas can become expensive when working around utilities, storm sewers, parking lots, buildings, etc. However, where applicable, excavation can be completed in a fraction of the time of other remedial solutions and usually does not require any long-term operation and maintenance or monitoring. A project involving the removal of 21,800 tons of contaminated soil and stockpiling another 48,000 tons could potentially be completed in three to six months.

#### **4.1.2.1 Conceptual Model**

The overlays of the AOC 3 CSM plan and cross section for the excavation technology are shown on Figures 9 and 10. All the soil within the free product area would be removed to below the maximum depth of free product impact and replaced with clean fill material. This area has a

footprint of approximately 78,400 sq. feet and extends to an average depth of 16 feet below ground surface for a total volume of approximately 46,500 cubic yards.

#### **4.1.2.2 Additional Data Requirements**

Data requirements for excavation are identified in Section 3.3.3. In general, a significant amount of the data has already been collected. Specifically, the depth to free product and groundwater, the thickness of the free product, and the potential smear zone are assumed to be 11 to 16 feet bgs. An average depth of excavation of 16 feet has been assumed for AOC 3 based on this information.

A few outstanding data gaps/uncertainties have been identified:

- The rate of groundwater recharge needs to be evaluated. Removal of the source material (LNAPL) would require some excavation below the groundwater table. If the rate of groundwater recharge is too rapid, it could make excavation impractical or too expensive (i.e., if isolation and/or extensive dewatering are required). A test pit would need to be excavated in order to evaluate the groundwater recharge rate. An assumption was made that the groundwater recharge would be at a low rate based on the presumed heterogeneity of the subsurface and likely discontinuity of the granular lenses. It has also been assumed that any free liquid would be pumped out of the excavation, treated on site, analyzed, and discharged to the sanitary sewer under an appropriate permit.
- The soil needs to be characterized for disposal. These samples would be collected during the preliminary field investigation. It has been assumed that soil would have relatively low concentrations of VOCs, and it would be possible to dispose of the soil as a special waste at a solid waste landfill. The landfill would require waste characterization sampling to be completed before the soil was transported from the site. The landfill would require approximately one composite sample per 5,000 cubic yards of excavation for large quantities of soil.
- Details concerning surface and subsurface structures in the target removal area need to be determined. Telephone, water, storm sewer, and electrical lines are believed to be within the proposed excavation area. These utilities would have to be located, disconnected, removed, and replaced or relocated. Former pipelines that were closed in place and associated anchors would be removed during excavation.

#### **4.1.2.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. Work Planning. This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.



2. Field investigation. This would involve collecting any additional information necessary to design the removal action. It is assumed to include:

- Excavation of test pits to evaluate groundwater recharge, the thickness of the free product, characteristics of soil for disposal, and volume and quality of free liquids entering the excavation (to determine treatment requirements).
- Soil sampling and analysis. Composite soil samples would be tested by the toxicity characteristics leaching procedure (TCLP) for VOCs, SVOCs, and metals and for any other characteristics required by the landfill for disposal of the soil as a special waste.
- Free liquid analysis. Samples of liquid entering the excavation would be analyzed for VOCs and SVOCs, total suspended solids, oil and grease, and total organic carbon to evaluate treatment/disposal requirements.
- Surveying. A utility survey and coordination with utility providers to remove and relocate utility lines would be completed.

#### **4.1.2.4 Physical Access Requirements**

Physical access constraints include utility lines, easements, and property lines. According to previous reports and the site visit, water, electric and telephone lines would have to be removed during construction. This means all utilities should be located before the design drawings are completed. The plan should minimize damage and downtime to utilities that would be disturbed during excavation.

Excavation would also disturb 20,000 square feet of paved surfaces. This would temporarily reduce the only access to a nearby building to one lane. The time during which these areas are disturbed should be minimized. Compacted backfill should be placed as soon as possible once excavation was completed in those areas. A secondary temporary access route might have to be set up by the contractor before construction begins to allow access to the nearby buildings.

#### **4.1.2.5 Construction/Implementation**

The contractor would mobilize personnel, equipment, and supplies to the site. This would include establishing a field office, work zones, storage tanks, a storage area for excavated material to use for backfill, and a decontamination pad for equipment. An on-site water treatment system would be provided at this time. Equipment would be decontaminated before use on the site.

In order to minimize water management requirements, excavation should be conducted during the dry time of the year (i.e., mid-summer). Excavation would start in an unimproved area where contamination is likely. The planned excavation depth would be defined by data from previous investigations, but would continue until the free product had been removed. Less contaminated unsaturated soil would be stockpiled for testing and used as backfill or for blending with wetter soil. It has been assumed in developing the costs that this overburden would be used for backfilling. Once the desired excavation depth has been reached, the excavation would then

progress laterally, adjusting the depth as needed to include only contaminated soil. Any water that entered the excavation would be pumped out, treated, and disposed of in an appropriate manner.

Contaminated soil would be placed directly into a truck that would haul the soil off-site to the nearest approved landfill for disposal. Clean overburden soil would be stockpiled on site until analysis confirmed that the soil was acceptable to be used as backfill. This would involve storing an estimated 48,000 tons of clean soil that would be used as backfill. The contractor would have to remove an estimated 21,800 tons of contaminated soil, assuming that the smear zone extends from 11 to 16 feet bgs. This would result in approximately 1,453 truckloads assuming each truck hauled 15 tons per load. As the excavation proceeds, backfilling the previously excavated areas would be simultaneously occurring to minimize flooding of the excavation during rain events, limit the size of the open excavation, minimize the clean soil stockpile, and stabilize excavation side walls. Uncontaminated soil would be stockpiled on site pending analysis and use as backfill.

Berms would be constructed around the active excavation areas to minimize run-on and run-off. Temporary construction fencing would be placed around all disturbed construction areas until the site was safe for the general public to access.

Based on previous reports and the site visit, existing utilities including water, telephone, storm sewer and electrical lines would have to be removed and replaced. In addition, 20,000 square feet of asphalt road and parking lot would be removed and replaced.

#### **4.1.2.6 Operation**

No long term operation or maintenance would be required for this technology. However, some period of monitoring would be required to demonstrate that concentrations of the contaminants of concern in the groundwater achieve the RAOs after the free product has been excavated. Since some of the wells within the free product area would be removed during excavation, it has been assumed that two new wells would be installed within the former free product area and that eight wells would be monitored quarterly for one year to demonstrate that free product has been removed and concentrations in groundwater outside the area remain below RAOs. Groundwater samples would be analyzed for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction.

#### **4.1.2.7 Waste Management**

The site is located in Franklin County, Ohio which is controlled by the Solid Waste Authority of Central Ohio (SWACO). SWACO landfills in the area can only accept soil contaminated with petroleum-based products after the waste characteristics have been received or with the Executive Director's approval.

Another landfill was identified outside of Franklin County approximately 50 miles away that would accept the waste. However, a fee would apply for simply removing the waste from the County limits. It has been assumed for the technology evaluation that the soil could be disposed at this landfill.

#### **4.1.2.8 System Shutdown and Demobilization**

System shutdown and demobilization would involve removal of temporary field offices, fences, storage tanks, and decontamination pads from the site, and well closure, after monitoring has been completed. The wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.1.2.9 Site Restoration**

Site restoration would include backfilling with structural backfill in areas where structures are planned. All other areas would be backfilled with excavated material or a generic backfill to minimize cost, and then capped with a compacted soil layer and with a layer of soil capable of sustaining vegetative growth. Storm sewers, telephone line, electrical lines, water lines and all other utilities would be returned to working order. The parking lot and road way would be repaved with concrete to restore them to the original condition. Once all major construction traffic had been eliminated from the site, previously vegetated areas would be seeded. Straw bales would be used around the storm sewer inlets until vegetative growth had been stabilized to minimize sediment entering the sewers as a result of erosion. Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

#### **4.1.3 In-Situ Soil Mixing**

ISSM is a construction technology for remediating contaminated soils. Contaminated media is transformed through solidification and stabilization into durable, solid, low hydraulic conductivity material to reduce the rate of contaminant migration. In the case of the LAFB AOCs, the process would also blend and distribute the LNAPL product over the soil column. This mixing process would result in absorption and adsorption of the free product into the soil matrix. ISSM uses specialized hydraulically driven augers and mixing paddles to simultaneously drill and inject material. The auger flights loosen the soil as they move through the subsurface allowing the soils to be mixed with the paddles. The technique may be used to homogenize existing materials or to blend materials into the soil. ISSM can also improve the structural properties of soil (e.g., strength) to facilitate beneficial reuse of land. As described below, ISSM of AOC 3 would take approximately six months to complete.

##### **4.1.3.1 Conceptual Model**

The overlays of the AOC 3 CSM plan and cross section for the ISSM technology are shown on Figures 11 and 12. The process creates individual columns of material, which are overlapped to create walls or divided to create block or grid patterns. The actual column size and depth depend on site conditions and equipment capabilities and would be determined through bench scale testing (to determine mixing ratios and rates) and site observations (e.g., the maximum depth of the LNAPL smear zone).

##### **4.1.3.2 Additional Data Requirements**

Data requirements for ISSM are identified in Section 3.4.3. In general, a significant amount of the data has already been collected. Specifically, the depth to free product and groundwater, the thickness of the free product, and the potential smear zone are assumed to be 11 to 16 feet bgs.

A few outstanding data gaps/uncertainties have been identified:

- Bench-scale testing would be conducted to evaluate the effectiveness of mixing soil layers using various ratios of grout and mixing times with respect to immobilizing/stabilizing the LNAPL. Although soil mixing can be used as a delivery system for a variety of remediation additives (e.g., zero valent metals, biological agents, potassium permanganate, etc), only mixing with grout has been assumed for this alternative. Bench scale testing would also provide useful information to determine optimum equipment operation specifications such as auger advancement rates, grout injection rates, and number of augers strokes necessary to produce a homogeneous mixture.
- Details concerning surface structures and utilities (e.g., buildings, streets, parking lots) overlying the target treatment area. Such details might include location, depth, size, materials of construction, etc.

#### **4.1.3.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. Work Planning. This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation and bench-scale testing. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. Field investigation. This would involve collecting any additional information necessary to establish baseline conditions and implementation of ISSM techniques. It is assumed to include:
  - Collection of soil samples for bench-scale testing. The soils investigation would include Standard Penetration Tests (SPT), grain-size analysis, soils classification, and chemical analysis. A drill rig would be required to perform SPTs. Soil samples for grain-size analysis and soil classification would be collected from various depths and locations in order to produce results that allow for natural spatial variability. It is assumed that up to 25 locations would be evaluated with a maximum of 3 soil samples collected from each location, depending on the subsurface conditions encountered.
  - Bench-scale testing. This would be conducted to evaluate optimum mix ratios and to determine equipment operation specifications including auger advancement and injection rates. Pre-construction laboratory batch testing would be performed on representative soil samples using simulated soil mixing. The testing would be performed in a series of steps: 1) soil samples collected from the site would be run for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction to establish untreated conditions; 2) the grout content of the slurry would be varied by weight and the slurry addition rate would be varied by volume to determine optimal mix ratios; 3) various pre-determined mixing times (i.e., 30, 60, 90, and 120 minutes) would be analyzed; and 4) the soils would be retested

for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction to analyze the varied impacts of each of these treatments.

- Surveying. This would be conducted to delineate the plume boundaries and lay out the drilling grid pattern. A utility survey and coordination with utility providers to remove and relocate utility lines would be completed.

#### **4.1.3.4 Physical Access Requirements**

Removal of debris or underground obstructions must be conducted prior to treatment as they can limit drilling ability. ISSM requires surface access to all locations where soils are contaminated, which rules out its effective use if contamination underlies buildings.

The estimated extent of free phase product underlies portions of the parking lot and access roads associated with Air Cargo Terminal #4. Portions of the parking lot and access roads would have to be removed prior to conducting ISSM in these areas. This would also temporarily reduce access to the building to one lane, and a second temporary access route might need to be established to allow unimpeded access to all nearby buildings.

Utilities including water, telephone, electric, storm sewer, and abandoned fuel lines are present within the estimated extent of the free phase product plume. Active utilities would have to be relocated prior to conducting ISSM in these areas. Portions of the fuel lines were removed and the remaining lines were plugged in place. The concrete anchors associated with the fuel lines were also left in place. The remaining jet fuel lines and concrete anchors would have to be removed prior to conducting ISSM in these areas.

#### **4.1.3.5 Construction/Implementation**

Temporary field offices, work zones, and a decontamination pad for equipment would need to be established. A mixing system and batch plant consisting of storage silos, metering and blending devices, and pumps would need to be set up for the addition of grout. Water and electricity sources would need to be established for the batch plant system. Utilities, remaining fuel lines, and concrete anchors discussed in the preceding section would be removed or relocated prior to initiating ISSM.

Specialty equipment including shrouds equipped with air controls to capture fugitive emissions would be mobilized. It is anticipated that VOC emissions and odors would need to be treated and controlled during the ISSM phase. A Soil Vapor Extraction (SVE) unit would be used to control emissions. The unit consists of a metal shroud or hood that is placed over the mixing area to trap potentially hazardous vapors and fugitive dust releases from the soils. Vapors and fugitive dust are drawn through a vacuum hose attached to a shroud. The vapors then enter a treatment unit, which typically includes an air separator, high-efficiency particulate air filter, and activated carbon unit(s). After treatment, air would be released to the atmosphere.

The free phase product area would be surveyed and gridded prior to beginning ISSM. ISSM would progress laterally according to the grid system. A column size of 8 feet diameter with 20 percent column overlap has been assumed. The vertical distribution of free phase product has

been estimated to range from 11-16 feet bgs. ISSM would be performed to an approximate depth of 20 feet bgs to extend below the maximum LNAPL smear zone.

Soil samples would be collected for visual evaluation and analytical and characteristic testing during mixing. The samples would be visually inspected for homogeneity and the presence of NAPL, and confirmation samples collected for laboratory analysis. Confirmation samples would be collected at a frequency of once per 1,000 cubic yards and analyzed for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction (58 samples). Selected soils would also be tested to determine the BUSTR soil classification, so that analytical results could be correctly evaluated with respect to RAOs.

Temporary construction fencing would be placed around all disturbed construction areas until the site has been restored to a manner in which it would be safe for general public access.

#### **4.1.3.6 Operation**

No long term operation or maintenance would be required for this technology. However, per BUSTR requirements, monitoring would be required to demonstrate that remedial action objectives have been achieved, and that no further action is appropriate due to concentrations below action levels as a result of ISSM of soil contaminated with free phase product.

It has been assumed that quarterly groundwater monitoring would be conducted for one year following the ISSM remedial action. Samples would be collected from ten existing on-site wells outside the treatment area and analyzed for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction. Because of the stabilizing objectives of the treatment, new monitoring wells would not be installed within the treated area. Soil sampling during mixing should adequately demonstrate treatment effectiveness within that area.

#### **4.1.3.7 Waste Management**

Because ISSM is an in-situ technique, disposal cost and worker exposure are minimized and dewatering would not be necessary. Only a small amount of grout is typically added during mixing, so the increase in soil volume is usually slight. It has been conservatively estimated that up to 15 percent of the original soil volume would be disposed of as a special waste at a solid waste landfill (refer to Section 4.1.2.7) to account for increases in volume and to maintain the existing site elevation with the addition of topsoil.

The activated carbon units from the soil vapor extraction system would be reprocessed or disposed of in accordance with applicable regulations.

#### **4.1.3.8 System Shutdown and Demobilization**

System shutdown and demobilization would involve removal of temporary field offices, decontamination pads, mixing system, and batch plant. All equipment and augers would be decontaminated prior to demobilization.

#### **4.1.3.9 Site Restoration**

Site restoration would include backfilling, grading, and capping with six inches of topsoil capable of sustaining vegetative growth. Utilities would be restored as necessary. Parking lots and roadways would be repaved with asphalt and concrete curbs would be replaced to original condition. Once all major construction traffic has been eliminated from the site, previously vegetated areas would be seeded. Straw bales would be placed around storm sewer inlets until vegetative growth has been stabilized to prevent sediment from erosion from entering the sewers.

#### **4.1.4 Multi-phase Extraction**

The MPE process was developed for the remediation of LNAPL, aromatic VOCs, TPH, and chlorinated VOCs in moderate permeability subsurface formations. The technology is meant to address contaminants in free-phase liquid, residual and adsorbed phases, and vapors. MPE simultaneously extracts both liquid (groundwater and LNAPL) and soil vapor.

##### **4.1.4.1 Conceptual Model**

The overlays of the AOC 3 CSM plan and cross section for the MPE technology are shown on Figures 13 and 14. In MPE, the groundwater table is lowered in order to dewater the saturated zone so that the SVE process can be applied to the exposed soil. This allows VOCs adsorbed on the previously saturated soil to be stripped by the induced vapor flow and extracted. The increased air movement through the unsaturated zone also increases oxygen content and enhances aerobic bioremediation. The lowering of the water table also allows residual phase product trapped within the pore space of the previously saturated zone to coalesce into free phase liquid, allowing it to flow toward a recovery well, where a skimming pump may also be used to remove LNAPL.

##### **4.1.4.2 Additional Data Requirements**

In general, a significant amount of the data has already been collected. The site geology and hydrogeology, concentrations and distributions of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, biodegradation parameters up-gradient and down-gradient of the source area, and potential receptors have all been to some extent previously investigated at AOC 3. Some of these data are summarized in Section 2.0 and 3.1.

In addition, the WIDE pilot study provides an indication of potential extraction rates and waste generation from an MPE system. It also indicates that while MPE would be effective in removing a certain mass of subsurface contaminants, additional remedial measures or long term monitoring might be needed before RAOs are met. The draft MNA assessment determined that some of the more biodegradable compounds are declining in the contaminated zone, but that aerobic degradation is not occurring at a significant rate. This is relevant both to the potential for MPE to enhance biodegradation and for biodegradation of residual contamination following MPE. A few outstanding data gaps/uncertainties have been identified:

- The most effective MPE configuration needs to be determined for site conditions. This includes determining the appropriate well spacing based on the well radius of influence and the most effective type of extraction system. On the basis of the WIDE pilot study, it appears that total fluids extraction would be the most effective MPE system, but a pilot study has been assumed to further evaluate this and determine the appropriate well spacing.
- Vertical soil gas profiles need to be developed to evaluate baseline soil vapor conditions and to evaluate contaminant removal and biodegradation during and after MPE. Installation of nested gas wells to monitor gas concentrations at various levels has been assumed for this alternative.
- Waste streams resulting from the operation of a multi-phase extraction system need to be characterized for regulatory compliance and the need for possible treatment. Waste streams to be characterized would include: 1) discharged wastewater, 2) collected free product, and 3) air emissions from soil vapor extraction. This information could be obtained during the pilot study.

#### **4.1.4.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. Work Planning. This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation and pilot-scale testing (aquifer pump test). The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. Field investigation. This would involve collecting any additional data required to establish baseline conditions. It is assumed to include:
  - Four nests of soil vapor wells installed within the vadose zone inside the free product area and one soil vapor well nest installed at a background location. The number of nested wells would be contingent on the depth to groundwater at the specific location, but assuming an average depth of 15 feet, three nested wells would be installed to monitor soil from 3-7 feet, 7-11, and 11-15 feet bgs.
  - Groundwater level measurements, free product measurements, and collection of groundwater samples from existing wells to evaluate baseline conditions. All the samples would be analyzed for BTEX, MTBE, PAHs, TPH-Light Distillate Fraction and Middle Distillate Fraction, nitrate, sulfate, iron, and manganese (degradation products). Ferrous iron, ORP, pH, specific conductivity, DO, and turbidity would be measured in the field.
  - Collection of soil gas samples from the 15 soil vapor wells and analysis for benzene using a portable gas chromatograph and methane and oxygen using a portable gas analyzer. Two samples would be collected and sent to a laboratory for chemical analysis for BTEX and methane to verify field testing results.



- Installation of an MPE well and performance of a test to evaluate radius of influence, recoveries of all phases, and treatment and disposal requirements for vapor, groundwater, and LNAPL.

#### **4.1.4.4 Physical Access Requirements**

Physical access would be required for well installation, soil vapor and groundwater monitoring, installation of the MPE extraction and treatment systems, waste storage, and system operation. Although there are some utilities in the area, it is assumed that the proposed activities would work around those locations. Air Cargo Terminal #4 and associated parking areas and utilities would not be affected by the implementation of this alternative. If needed, a driveway sealant may be applied to the pavement to make it water-resistant and somewhat impervious to air flow. If a highly permeable sub-grade is present beneath the pavement, it may be necessary to place a barrier at the edge of the paved area to prevent the high permeability zone from leaking air. There appears to be sufficient space for the equipment, waste storage, and treatment system facilities that would be required to implement this option.

#### **4.1.4.5 Construction/Implementation**

Soil vapor monitoring wells would be installed during the planning phase. The MPE system and waste storage and treatment systems would be installed during the implementation phase. It has been assumed that the MPE system would consist of 443 wells with screened sections, using a total fluid extraction system similar to the WIDE pilot study.

#### **4.1.4.6 Operation**

This technology would require on-site operation and monitoring of the MPE system for an estimated time of approximately three to eight years. This would include treating and disposing of extracted LNAPL, vapor, and groundwater. It has been assumed that a compressor or compressors would be used to generate a vacuum through a manifold piping and well system similar to the WIDE system. The combined waste stream would be routed to blow-down, liquid/gas separation tanks. Quantities of LNAPL and VOCs generated would be tracked, and soil, vapor, and groundwater concentrations monitored during operation. Since it is likely that residual contamination would remain after MPE has been completed, annual soil vapor and groundwater monitoring has been assumed for a minimum of 10 years following treatment. Monitoring would be conducted as specified for NSZD (Section 4.1.1.6).

#### **4.1.4.7 Waste Management**

Waste management during the investigation, construction and monitoring phases would be limited to disposal of drums of soil cuttings and monitoring well purge water. During the operational phase, LNAPL and contaminated vapor and groundwater would be generated. It has been assumed that LNAPL would be disposed of through a fuel recycler, and contaminated groundwater would be treated in an on-site treatment system. Treated groundwater would be discharged to the sanitary sewer. Although the WIDE system released gas vapors to the air without treatment, it has been assumed that carbon would be used to treat vapors prior to release at least initially during full-scale implementation until contaminant concentrations begin to decrease. Depending on the extent of contamination, the carbon adsorption units might need to

be replaced to ensure thorough removal of contaminants from the extracted groundwater and off-gas. Permits would likely be needed for wastewater discharge and air emissions. Actual waste generation rates and treatment and disposal requirements would be determined during the pilot study.

#### **4.1.4.8 System Shutdown and Demobilization**

System shutdown would involve dismantling piping and removing storage tanks and the treatment system from the site. Monitoring and MPE wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.1.4.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

### **4.1.5 Multi-phase Extraction with Heating**

MPEH was developed for the remediation of LNAPL, aromatic VOCs, TPH, and chlorinated VOCs in low to moderate permeability subsurface formations. The process is a modification of the conventional MPE system and is meant to address contaminants in free-phase liquid, residual and adsorbed phases, and vapor.

The information provided in the previous summary for MPE also applies to MPEH. Heating is added to conventional MPE to increase the rate of recovery, or the range of contaminants that can be recovered, by the process. Soil heating will volatilize higher molecular weight compounds that a traditional MPE system will not affect, will reduce the viscosity of free-phase and residual NAPL, and will increase chemical reaction rates for contaminant breakdown.

#### **4.1.5.1 Conceptual Model**

The overlays of the AOC 3 CSM plan and cross section for the MPEH technology are shown on Figures 15 and 16. Similar to traditional MPE, the groundwater table is lowered in order to dewater the saturated zone so that the SVE process can be applied to the exposed soil. The added heating component is achieved through the use of technologies such as steam injection, hot compressed air injection, electrical resistance heating, or radio-frequency heating. This technology requires electrical power or waste heat from a nearby utility or industrial source. The use of hot air from the vapor condensation process equipment has been assumed in developing this technology, but the actual heating system would need to be selected in the work planning and design phases.

The use of MPEH should be distinguished from ERH as described in Section 4.1.8. Although electrical resistance is among the technologies that may be used as a heat source in MPEH, the temperatures and rate of vapor generation in this application are much lower than those generated for ERH as a stand-alone technology.

#### **4.1.5.2 Additional Data Requirements**

In general, a significant amount of the data has already been collected. The site geology and hydrogeology, concentrations and distributions of contaminants in soil and groundwater; chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, biodegradation parameters up-gradient and down-gradient of the source area, and potential receptors have all been to some extent previously investigated at AOC 3. Some of these data are summarized in Section 2.0 and 3.1.

In addition, the WIDE pilot study provides an indication of potential extraction rates and waste generation from an MPE system. The draft MNA assessment determined that some of the more biodegradable compounds are declining in the contaminated zone, but that aerobic degradation is not occurring at a significant rate. This is relevant both to the potential for MPEH to enhance biodegradation and for biodegradation of residual contamination following MPEH.

A few outstanding data gaps/uncertainties have been identified:

- The most effective MPEH configuration needs to be determined for site conditions. This includes determining the appropriate well spacing based on the well radius of influence and the most effective type of extraction system. On the basis of the WIDE pilot study, it appears that total fluids extraction would be the most effective MPE system, but a pilot study has been assumed to further evaluate this and determine the appropriate well spacing. Because heating would be used to enhance MPE rather than as a stand-alone technology, a pilot study is not considered necessary to determine the heating system design.
- Vertical soil gas profiles need to be developed to evaluate baseline soil vapor conditions and to evaluate contaminant removal and biodegradation during and after MPEH. Installation of nested gas wells to monitor gas concentrations at various levels has been assumed for this alternative.
- Waste streams resulting from the operation of a multi-phase extraction system need to be characterized for regulatory compliance and the need for possible treatment. Waste streams to be characterized would include: 1) discharged wastewater, 2) collected free product, and 3) air emissions from soil vapor extraction. This information could be obtained during the pilot study.

#### **4.1.5.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. Work Planning. This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation and pilot-scale testing. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.

2. Field investigation. This would involve collecting any additional data required to establish baseline conditions. It is assumed to include:
  - Four nests of soil vapor wells installed within the vadose zone inside the free product area and one soil vapor well nest installed at a background location. The number of nested wells would be contingent on the depth to groundwater at the specific location, but assuming an average depth of 15 feet, three nested wells would be installed to monitor soil from 3-7 feet, 7-11, and 11-15 feet bgs.
  - Groundwater level measurements, free product measurements, and collection of groundwater samples from existing wells to evaluate baseline conditions. All the samples would be analyzed for BTEX, MTBE, PAHs, TPH-Light Distillate Fraction and Middle Distillate Fraction, nitrate, sulfate, iron, and manganese (degradation products). Ferrous iron, ORP, pH, specific conductivity, DO, and turbidity would be measured in the field.
  - Collection of soil gas samples from the 15 soil vapor wells and analysis for benzene using a portable gas chromatograph and methane and oxygen using a portable gas analyzer. Two samples would be collected and sent to a laboratory for chemical analysis for BTEX and methane to verify field testing results.
  - Installation of an MPE well and performance of a test to evaluate radius of influence, recoveries of all phases, and treatment and disposal requirements for vapor, groundwater, and LNAPL.
  - Surveying. This would be conducted to delineate the plume boundaries and lay out the heating element pattern, if ERH is used.

#### **4.1.5.4 Physical Access Requirements**

Physical access would be required for well installation; soil vapor and groundwater monitoring; installation of the MPEH extraction, heating, and treatment systems; waste storage; and system operation. Although there are some utilities in the area, it is assumed that the proposed activities would work around those locations. Air Cargo Terminal #4 and associated parking areas and utilities would not be affected by the implementation of this alternative. If needed, a driveway sealant may be applied to the pavement to make it water-resistant and somewhat impervious to air flow. If a highly permeable sub-grade is present beneath the pavement, it may be necessary to place a barrier at the edge of the paved area to prevent the high permeability zone from leaking air. There appears to be sufficient space for the equipment, waste storage, and treatment system facilities that would be required to implement this option. Power is available within the area to support various heating technologies, such as steam injection, electrical resistance heating, or radio-frequency heating.

#### **4.1.5.5 Construction/Implementation**

Soil vapor monitoring wells would be installed during the planning phase. The MPE, heating, waste storage, and treatment systems would be installed during the implementation phase. It has

been assumed that the MPE system would consist of 390 wells with screened sections, using a total fluid extraction system similar to the WIDE pilot study.

Equipment related to power generation, power control, and vapor destruction, if needed, would be brought or constructed on site. If low temperature in-situ thermal desorption using hot air injection is chosen as the heating technology, approximately 975 heating wells would be utilized. Waste heat from the vapor condensation process equipment would be captured and injected into the vadose zone to increase vadose zone temperatures, thereby increasing the volatilization of the contaminants. A matrix of thermocouples would be installed in the treatment area to monitor the temperature at various locations below ground.

It is assumed that existing utilities at the site would be left in place. If it is determined that polyvinyl chloride (PVC) pipes are located in the thermal treatment area, those would need to be removed. Temporary construction fencing would be placed around the thermally-treated area until the site has been restored to a manner in which it would be safe for general public access.

#### **4.1.5.6 Operation**

This technology would require on-site operation and monitoring of the MPEH system for an estimated time of approximately two to three years. This would include treating, and disposing of extracted LNAPL, vapor, and groundwater. It has been assumed that a compressor or compressors would be used to generate a vacuum through a manifold piping and well system similar to the WIDE system. The combined waste stream would be routed to blow-down, liquid/gas separation tanks. Quantities of LNAPL and VOCs generated would be tracked, and soil, vapor, and groundwater concentrations monitored during operation. Since it is likely that some residual contamination would remain after MPEH has been completed (although less than MPE), annual soil vapor and groundwater monitoring has been assumed for a minimum of 5 years following treatment. Monitoring would be conducted as specified for NSZD (Section 4.1.1.6).

#### **4.1.5.7 Waste Management**

Waste management during the investigation, construction and monitoring phases would be limited to disposal of drums of soil cuttings and monitoring well purge water. During the operational phase, LNAPL and contaminated vapor and groundwater would be generated. It has been assumed that LNAPL would be disposed of through a fuel recycler, and contaminated groundwater would be treated in an on-site treatment system. Treated groundwater would be discharged to the sanitary sewer. Although the WIDE system released gas vapors to the air without treatment, it has been assumed that carbon would be used to treat vapors prior to release at least initially during full-scale implementation until contaminant concentrations begin to decrease. Depending on the extent of contamination, the carbon adsorption units might need to be replaced to ensure thorough removal of contaminants from the extracted groundwater and off-gas. Permits would likely be needed for wastewater discharge and air emissions. Actual waste generation rates and treatment and disposal requirements would be determined during the pilot study.

#### **4.1.5.8 System Shutdown and Demobilization**

System shutdown would involve dismantling piping and removing wells, electrodes, storage tanks, and the treatment system from the site. Monitoring and MPE wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.1.5.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

### **4.1.6 In-Situ Chemical Oxidation**

ISCO employs the injection of chemical oxidants directly into the aquifer to react with and destroy dissolved-phase organic constituents. ISCO is usually employed as a source control measure for high concentration *dissolved-phase* contaminants at or near the original release. The presence of high concentrations of naturally occurring organic materials will increase the oxidizing agent dose required for effective destruction, and may decrease overall performance.

Because this technology involves the introduction of oxidant solution into the subsurface, excellent hydraulic control and containment are necessary to prevent spreading contaminants over a larger area. Before design and implementation of this technology, geologic conditions must be well characterized through investigation and pilot testing. Since this technology is difficult to implement at sites with geologic conditions that are significantly heterogeneous or with low hydraulic conductivities, and since it is most effective on dissolved contaminants, it is likely to be ineffective at any of the three LAFB AOCs.

#### **4.1.6.1 Conceptual Site Model**

Because this technology is not likely to be effective, the number of injection wells and likely support facilities have not been evaluated in detail, and CSM overlays have not been prepared. Subsurface injection is generally performed using direct push technology or a network of temporary or permanent injection wells. Considering that ISCO would require numerous applications at AOC 3, the construction of permanent injection wells would be most cost effective and practical. A pilot study is recommended to evaluate the radius of influence and appropriate well spacing. High pressure injection may be employed to increase the radius of influence and reduce the number of injection points. Multiple applications are often required to meet remedial endpoints.

#### **4.1.6.2 Additional Data Requirements**

Data requirements to both qualitatively and quantitatively assess the potential for ISCO as a remedial technology and to establish baseline conditions for long-term evaluation are considerable. However, a significant amount of the data has already been collected. The site geology and hydrogeology, concentrations and distributions of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, and potential receptors have all been to some extent previously

investigated at AOC 3. Some of these data are summarized in Section 2.0 and 3.1. A few outstanding data gaps/uncertainties have been identified:

- The radius of influence and associated number of injection points would need to be determined based on site conditions. A pilot study would be needed to further evaluate injection hydraulics and to determine the appropriate well spacing.
- The potential for adverse impacts such as reduction in permeability and re-solubilization of metals due to the oxidizing effects needs to be evaluated under site conditions. This would also be evaluated during the pilot study.
- The oxidant demand associated with both the contaminants and naturally occurring organic materials needs to be determined. This could be obtained from soil and groundwater samples collected during the pilot study.
- Details need to be obtained regarding subsurface structures and utilities to avoid potential physical or chemical damage to these items during installation and treatment. This includes location, depth, size, materials of construction, etc.

#### **4.1.6.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. Work Planning. This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation and pilot-scale testing. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. Pilot-scale Testing. Pilot-scale testing is required to provide data regarding radius of influence, required injection well spacing, and required oxidant injection dose.
3. Final Design. The results of the pilot test would be used to refine and optimize the work plans and finalize the design for full-scale implementation. The final design would specify well spacing, oxidant type and dose, and required on-site facilities for storage and periodic injection of the chemicals. Protection or relocation of subsurface structures and utilities would be addressed as necessary to avoid adverse impacts

#### **4.1.6.4 Physical Access Requirements**

Physical access required would be for pilot testing, injection well installation, storage structure construction, and groundwater monitoring. Although there are some utilities in the area, it is assumed that the proposed activities would work around those locations. Air Cargo Terminal #4 and associated parking areas and utilities would not be affected by the implementation of this alternative. There appears to be sufficient space for a storage structure, equipment, and waste storage facilities that would be required to implement this option.

#### **4.1.6.5 Construction/Implementation**

Injection wells, as well as groundwater monitoring and extraction wells, a storage structure (for storage of ISCO chemicals, mixing and injection equipment), and a waste storage pad would need to be constructed. The quantity and placement of these structures would be dependent on the results of the pilot test.

#### **4.1.6.6 Operation**

Full-scale implementation would include injection of the selected ISCO solution in numerous wells or injection points located throughout the target treatment zone. Post-remediation monitoring would follow the injection process. Multiple rounds of oxidant injection and monitoring would be required to achieve remediation endpoints.

This technology would require quarterly groundwater monitoring following the remediation (one or more injections) to evaluate the effectiveness of the treatment and potential adverse effects.

#### **4.1.6.7 Waste Management**

Because ISCO is an in-situ technology, the amount of waste that is generated is relatively small in comparison with many ex-situ remediation approaches. Waste management during investigation and monitoring activities would be limited to disposal of drums of soil cuttings and monitoring well purge water, and the original drums/containers in which the oxidant is shipped. On the basis of concentrations detected in samples within the free product area, the soil would be disposed of as a special waste, and the purge water would be disposed of at a publicly owned wastewater treatment plant.

#### **4.1.6.8 System Shutdown and Demobilization**

System shutdown would involve abandoning ISCO injection points and monitoring wells. The injection points and wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9. Above-ground pumps, treatment equipment, waste storage facilities and any temporary remediation buildings would need to be removed.

#### **4.1.6.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

#### **4.1.7 Surfactant Enhanced LNAPL Removal**

SELR is a technique to remove LNAPL from the saturated zone by introducing a manufactured chemical surfactant to mobilize contaminants and allow recovery using conventional groundwater extraction. The introduction of surfactant allows free-phase and residual-phase LNAPL to be dispersed into the aqueous phase, where it is more easily recoverable through groundwater extraction. Because this technology involves the introduction of a manufactured chemical into the subsurface, excellent hydraulic control and containment are necessary to



prevent spreading LNAPL and surfactants over a larger area. Before design and implementation of this technology, geologic conditions must be well characterized through investigation and pilot testing. Since this technology is more difficult to implement at sites with geologic conditions that are significantly heterogeneous or with hydraulic conductivities less than  $10^{-3}$  cm/sec, it is likely to be ineffective at any of the three LAFB AOCs. It should be noted that this technology also will not address contaminants that are present in the smear zone at an elevation above the water level.

#### **4.1.7.1 Conceptual Model**

Because this technology is not likely to be effective, it has not been developed in detail, and CSM overlays have not been prepared. The most common technique for the use of surfactants is a flooding configuration. This involves the preparation of low viscosity surfactant solutions that are injected into the subsurface and then migrate through the contaminated zone based on the hydraulic gradient. The surfactant is put into the ground through up-gradient injection points and then removed down-gradient through extraction wells located within the capture zone. The extracted fluid requires treatment or off-site disposal. An extensive down-gradient groundwater monitoring network should be established to prevent and document the risk of possible breakthrough.

#### **4.1.7.2 Additional Data Requirements**

A significant amount of the data required for this technology has already been collected. The site geology and hydrogeology, concentrations and distribution of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, and details regarding subsurface structures in and around the target area have all been previously investigated.

The following data are required to fully evaluate and implement this alternative:

- Identification of potential receptors that may be impacted by possible migration of the LNAPL and surfactant beyond the intended capture zone.
- Soil and contaminant characteristics that would determine the flushing fluids required, flushing fluid compatibility, and changes in flushing fluids with changes in contaminants.
- Groundwater flow conditions. A pilot test would need to be completed to determine whether the gradients necessary for capturing the contaminant and surfactant fluids can be established for sufficient contaminant contact and recovery. Heterogeneous soil environments may not allow sufficient chemical contact or sufficiently uniform gradients for successful implementation.
- Waste streams resulting from the operation need to be characterized for regulatory compliance and treatment or off-site disposal. Waste streams to be characterized would include discharged wastewater containing surfactant and recovered product.

#### **4.1.7.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. **Work Planning.** This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation and pilot-scale testing. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. **Field investigation.** This would involve collecting any additional data required to establish baseline conditions as well as completing a field-scale testing. It is assumed to include:
  - An extensive study of subsurface soil conditions to: 1) document soil heterogeneities, 2) measure hydraulic conductivities on a scale consistent with the size of the heterogeneities, and 3) identify if sufficiently continuous flow paths exist within the subsurface. This study should include hydraulic probe sampling on a grid with approximate 10 foot centers throughout the area of implementation.
  - Groundwater level measurements, free product measurements, and collection of LNAPL samples for fuel component analysis and chemical and physical properties.
  - A pilot test to provide data regarding surfactant enhanced LNAPL removal, required injection well spacing, and required surfactant injection dose. The results of the field-scale testing would be used to refine and optimize the RAP and monitoring plans.

#### **4.1.7.4 Physical Access Requirements**

Physical access required would be for pilot testing, injection point installation, well installation, treatment building construction, SELR operation, and groundwater monitoring. Although there are some utilities in the area, it is assumed that the proposed activities would work around those locations. Air Cargo Terminal #4 and associated parking areas and utilities would not be affected by the implementation of this alternative. There appears to be sufficient space for the building, equipment, and waste storage facilities that would be required to implement this option.

#### **4.1.7.5 Construction/Implementation**

Injection and extraction wells, extraction piping, storage tanks, and a treatment system would have to be constructed/installed at the site. The number of injection and extraction wells and the treatment system capacity would be dependent on findings from the pilot test.

#### **4.1.7.6 Operation**

Before beginning to inject surfactant, as much free product as possible would be recovered from the extraction wells. Once this has been completed, surfactant would be injected at numerous wells or injection points located throughout the target treatment zone. Surfactant and mobilized

LNAPL and groundwater would be pumped from the extraction wells to the treatment system. If feasible, surfactant would be separated from the contaminated water for re-use. Multiple rounds of surfactant injection and monitoring might be required to achieve remediation endpoints.

This technology would require quarterly groundwater monitoring following remediation (one or more injections) to evaluate the effectiveness. Groundwater samples would be analyzed for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction.

#### **4.1.7.7 Waste Management**

Waste management during investigation and monitoring activities would be limited to disposal of drums of soil cuttings and monitoring well purge water. On the basis of concentrations detected in samples within the free product area, the soil would be disposed of as a special waste, and the groundwater would be disposed of at a publicly owned wastewater treatment plant.

Following the injection process, treatment of extracted water would include separation of surfactant (as feasible), and water treatment to remove contaminants to acceptable levels for discharge to the sanitary sewer. Air emissions of volatile contaminants from recovered flushing fluids should be collected and treated according to regulatory guidance. Permits would likely be needed for wastewater discharge and air emissions.

#### **4.1.7.8 System Shutdown**

System shutdown would involve dismantling piping and removing storage tanks and the treatment system from the site. Monitoring, injection, and extraction wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.1.7.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

### **4.1.8 Electrical Resistance Heating**

As discussed in Section 3.9.1, ERH uses the heat resulting from the resistance of soil to the flow of electricity to evaporate and release contaminants from soil and groundwater. The resistance to electric flow by the soil causes the formation of heat resulting in increased temperatures until the boiling point of water is reached. As the heat is applied, contaminants are volatilized and mobilized within the soil matrix. Thermal methods can be particularly useful for both dense and light nonaqueous phase liquids (DNAPL and LNAPL). ERH is distinguished from MPEH (discussed in Section 4.1.5) in that the heating in ERH would be more aggressive, operate at a higher temperature, and would not include the pumping of groundwater. It is most effective on organic compounds that are readily volatilized and requires greater energy input to treat less volatile compounds. For remediation of DNAPL or LNAPL, ERH is often co-located with a MPE system to aid in recovering the less volatile contaminants.

#### **4.1.8.1 Conceptual Model**

The overlays of the AOC 3 CSM plan and cross section for the ERH technology are shown on Figures 17 and 18. ERH uses arrays of electrodes installed around a central neutral electrode to create a concentrated flow of current toward the central point. Resistance to flow in the soils generates heat greater than 100°C, producing steam and volatilized contaminants that are recovered via vacuum extraction. Recovery wells maintain vacuum during ERH operations and ensure the capture of vapors and steam from the subsurface. Each vapor recovery well is connected to pipes which convey vapor and steam to the condenser unit.

ERH can be utilized to reach very low contaminant concentrations and is effective in low-permeable hydrogeology such as clays, silts, and tills. Residual heat that may remain for months or years after treatment may also enhance continuing attenuation through biodegradation, hydrolysis, etc.

#### **4.1.8.2 Additional Data Requirements**

A significant amount of the data required for this technology has already been collected. The site geology and hydrogeology, concentrations and distribution of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, and details regarding subsurface structures in and around the target area have all been previously investigated.

A few outstanding data gaps/uncertainties have been identified that are especially relevant to the installation of the electrode array:

- Location, depth, and dimensions of portions of fuel lines that were plugged and abandoned in place, as well as concrete tank anchors left in place.
- Details concerning subsurface structures and utilities at or in the vicinity of the target treatment area. Such details may include location, depth, size, and materials of construction.
- Naturally occurring  $f_{oc}$  of soils in target treatment zones.
- LNAPL distribution, thickness, and chemical and physical properties.
- Waste streams resulting from the operation of an ERH system need to be characterized for regulatory compliance and the need for possible treatment. Waste streams to be characterized would include: 1) condensate and 2) air emissions from vapor extraction.

#### **4.1.8.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. Work Planning. This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation. The investigation

planning documents would include a work plan, quality assurance project plan, and health and safety plan.

2. Field investigation. This would involve collecting any additional data required to establish baseline conditions. It is assumed to include:
  - Groundwater level measurements, free product measurements, and collection of LNAPL samples for fuel component analysis and chemical and physical properties.
  - Collection of soil samples to evaluate residual contaminant concentrations and distribution and  $f_{oc}$ .
  - Surveying. This would be conducted to delineate the plume boundaries and lay out the electrode pattern.

#### **4.1.8.4 Physical Access Requirements**

Access to the area near the contamination is required, but ERH can be applied to treat contaminated soils under existing structures, so direct access to affected soil is not required. Although there are some utilities in the area, it is assumed that the proposed activities would work around those locations. Air Cargo Terminal #4 and associated parking areas and utilities would not be affected by the implementation of this alternative. There appears to be sufficient space for a treatment building and equipment that would be required to implement this option. Power requirements and availability would need to be evaluated during design, but are not expected to be a constraint.

#### **4.1.8.5 Construction/Implementation**

Existing electrical power at the site would be utilized, or power may be generated on-site via fuel combustion or solar energy. Equipment related to power generation, power control, soil vapor and steam recovery, and vapor destruction, if needed, would be brought to or constructed on site. A utility transformer and a power control unit would be brought to the site to step down voltage for controlled distribution into the electrodes.

A field of electrodes and vapor recovery wells would be installed below ground to depths defining the limits of contamination. Electrodes and vapor recovery wells would be designed and installed based on site characteristics. These two design features could be co-located to reduce project costs and improve system efficiency.

Assuming an average electrode placement of one electrode per 280 square feet of contamination, it is estimated that approximately 280 electrodes would be utilized. The electrodes would be installed to a depth of approximately 21 feet. A matrix of temperature monitoring points would be installed in the treatment area to monitor the temperature at various locations below ground. Each temperature monitoring point would contain strings of thermocouples installed at about 5-foot depth intervals.

Existing utilities at the site would be left in place. If it is determined that PVC pipes are located in the treatment area, those would need to be removed. Operators would be able to remotely run the system via the internet, monitoring treatment temperature, and controlling power and energy application to the system,

Temporary construction fencing would be placed around the affected area until the site has been restored to a manner in which it would be safe for general public access.

#### **4.1.8.6 Operation**

ERH would require frequent on-site monitoring of system operation during implementation. ERH is generally a rapid form of remediation with case studies of effective treatment of soil and groundwater in less than 40 days. It is assumed that remediation using this technology would last no more than nine months. Quarterly groundwater monitoring events are expected for one year following remediation activities.

Ongoing monitoring of surface voltages would be implemented during operation to ensure that surface voltages remain below Occupational Safety and Health Administration (OSHA) standards.

#### **4.1.8.7 Waste Management**

Drums of soil cuttings would be generated during system installation. On the basis of concentrations detected in samples within the free product area, these would be disposed of as a special waste. The ERH condenser separates contaminant vapors from steam. A majority of the contaminants (>99.5% by mass) remain in the vapor state, while the rest are captured in the steam condensate. The resulting condensate is not considered a waste stream and can be recycled back to the process. Any excess condensate can typically be discharged without further treatment.

Contaminant vapors are treated before discharge to the atmosphere. Typical treatment options are activated carbon or thermal or catalytic oxidation. Spent activated carbon would be treated as hazardous waste and properly disposed of. Air emission permits would likely be required.

#### **4.1.8.8 System Shutdown and Demobilization**

Once levels of contamination have been effectively reduced, all equipment related to treatment would be removed from site by the contractor. Monitoring wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.1.8.9 Site Restoration**

Once the electrodes and vapor recovery wells are removed, a small amount of grading and seeding would be completed to restore the site to its original state. Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

## 4.2 AOC 8/9

Implementation of each of the technologies at AOC 8/9 is described in the following subsections.

### 4.2.1 Natural Source Zone Depletion

NSZD occurs when certain natural processes act to (a) physically redistribute LNAPL components to the aqueous or gaseous phase and (b) biologically break down these source zone components. NSZD is of significance because it occupies a position in the spectrum of remediation options that can be used as a basis for comparing the performance and relative benefit of other remediation options.

#### 4.2.1.1 Conceptual Model

Since this alternative would not involve any construction except installation of additional monitoring wells, a CSM overlay has not been prepared. These processes include dissolution of LNAPL constituents into groundwater and volatilization of LNAPL constituents into the vadose zone. In turn, LNAPL constituents dissolved to groundwater and volatilized to the vadose zone can be biodegraded by microbial and/or enzymatic activity. The dissolution, volatilization, and biodegradation rates are critical factors in evaluating this technology. The dissolution and volatilization rates depend on the characteristics of the LNAPL constituents, while the biodegradation rates depend on these characteristics and the type and availability of electron acceptors. The rates of all these processes also depend on the permeability and transmissivity of the subsurface soils. The presence of recalcitrant LNAPL and discontinuous sand and gravel layers interspersed with zones of lower hydraulic conductivity at AOC 8/9 will limit the effectiveness of NSZD and increase the time to achieve remediation goals.

#### 4.2.1.2 Additional Data Requirements

Data requirements for NSZD are identified in Section 3.2.3. In general, a significant amount of the data has already been collected. The site geology and hydrogeology, concentrations and distributions of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, biodegradation parameters up-gradient and down-gradient of the source area, and potential receptors have all been to some extent previously investigated at AOC 8/9. Some of these data are summarized in Sections 2.0 and 3.1. In addition, the draft MNA assessment made the following determinations relevant to NSZD:

- Benzene data are inconclusive, because too many of the data points were below the reporting limits.
- Because most of the dissolved petroleum hydrocarbon concentrations down-gradient of the free product area are below reporting limits, it is not possible to develop concentration profiles along a flow line to estimate the rate of NSZD.
- Similar DO and nitrate concentrations in monitoring wells up-gradient and within the free product area are not indicative of aerobic biodegradation.

- Higher sulfate concentrations in monitoring wells up-gradient of the free product area suggest that biological sulfate reduction is occurring.
- Higher ferrous iron and methane concentrations within the free product area suggest that biological reduction of organic compounds is occurring.
- pH data are inconclusive.
- A slight increase in alkalinity down-gradient of the source area suggests that biodegradation is occurring.
- Concentrations of benzene, 1,2,4-trimethylbenzene, and naphthalene in the LNAPL relative to the composition of JP-4 suggest that the more biodegradable compounds within the LNAPL are being preferentially removed, and that the remaining compounds are less readily degraded.

A few outstanding data gaps/uncertainties have been identified:

- Vertical soil gas profiles need to be developed to evaluate NSZD in the vapor phase. Installation of nested gas wells to monitor gas concentrations at various levels has been assumed for this alternative.
- LNAPL dissolution, volatilization, and leaching rates should be evaluated. A bench scale study to evaluate these rates has been assumed for this alternative.
- The groundwater flow needs to be further evaluated. There are discrepancies between groundwater flow contours developed in the MNA assessment and other reports. The MNA assessment states that the overall groundwater flow direction is to the northeast, while the BUSTR Tier 2 Evaluation report indicates it is to the southeast. The groundwater contours developed within the free product area during the four MNA assessment monitoring events are variable. During two of the events, the flow in the free product area appears to be east or southeast, while during the other two events, the flow appears to have an overall inward flow component (Figures 4-2a through 4-2d, Appendix B). Installation of additional monitoring wells to evaluate NSZD and better define groundwater flow has been assumed for this alternative.
- Unlike AOC 3, contamination above the BUSTR Tier 2 SSTLs is not clearly limited to the main free product area at AOC 8/9. Concentrations of TPH-GRO in two soil borings (SB-506 and SB-504) southwest of the main free product area were above the SSTL. A small pocket of free product was noted in the area of SB-504. Installation of additional monitoring wells to monitor this area has been assumed for this alternative.
- Further analysis of the LNAPL to evaluate the percentages of various petroleum hydrocarbons is needed to evaluate the extent to which lighter fractions have been biodegraded. Collection of additional samples for fuel analysis to compare percentages of alkanes and aromatics to typical JP-4 has been assumed for this alternative. The effective solubility of the LNAPL would also be tested.



#### **4.2.1.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. **Work Planning.** This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. **Field investigation.** This would involve collecting any additional data required to establish baseline conditions. It is assumed to include:
  - Six additional groundwater monitoring wells installed to a depth of approximately 25 feet bgs. Two of these would be installed within the main free product area, one would be to the northeast and one southwest of that area, one would be next to SB-504, and one would be south-southwest of SB-504.
  - Two nests of gas wells installed inside the free product area and one gas well nest installed at a background location. The number of nested wells would be contingent on the depth to groundwater at the specific location, but assuming an average depth of 10 feet, two nested wells would be installed to monitor soil from 3-7 feet and 7-10 feet bgs.
  - Collection of four quarters of groundwater samples from nine wells, including four wells within the free product areas, as well as five wells outside these areas. All the samples would be analyzed for BTEX, MTBE, PAHs, TPH-Light Distillate Fraction and Middle Distillate Fraction, nitrate, sulfate, iron, and manganese (degradation products). Ferrous iron, ORP, pH, specific conductivity, DO, and turbidity would be measured in the field.
  - Collection of LNAPL samples from the three wells inside the LNAPL plume for fuel component analysis.
  - Collection of soil gas samples from the six soil gas wells and analysis for benzene using a portable gas chromatograph and methane and oxygen using a portable gas analyzer. Two samples would be collected and sent to a laboratory for chemical analysis for BTEX and methane to verify field testing results.
  - Bench-scale testing. This would involve laboratory tests to evaluate dissolution, volatilization, and leaching rates.

#### **4.2.1.4 Physical Access Requirements**

The only physical access required would be for well installation and gas and groundwater monitoring. Although there are some utilities in the area, it is assumed that the proposed activities would work around those locations. No structures are present in the area that would be affected by this alternative. Proposed construction south of the free product area would not interfere with or be affected by this alternative.

#### **4.2.1.5 Construction/Implementation**

With the exception of the gas and groundwater monitoring wells that would be installed during the planning phase, this technology does not involve construction.

#### **4.2.1.6 Operation**

This technology would require long-term groundwater and soil vapor monitoring to evaluate the rate and effectiveness of NSZD. It has been assumed that annual soil gas and groundwater monitoring would be conducted as specified under work planning, with the exception of fuel component analysis of the LNAPL. A 30-year monitoring period has been assumed.

#### **4.2.1.7 Waste Management**

Waste management would be limited to disposal of drums of soil cuttings and monitoring well purge water. Relatively small quantities of these would be generated during investigation and monitoring activities. On the basis of concentrations detected in samples within the free product area, the soil would be disposed of as a special waste, and the groundwater would be disposed of at a publicly owned wastewater treatment plant.

#### **4.2.1.8 System Shutdown and Demobilization**

System shutdown would involve plugging up to thirteen monitoring wells. The wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.2.1.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

### **4.2.2 Excavation**

Excavation is a traditional and quick solution to remediate contaminated soil and source material. It involves removing the contaminated material from the site, then backfilling with clean soil. While this method has proven to be effective in areas where little development has occurred, excavating contamination in developed areas can become expensive when working around utilities, storm sewers, parking lots, buildings, etc. However, where applicable, excavation can be completed in a fraction of the time of other remedial solutions, and usually does not require any long-term operation and maintenance or monitoring. A project involving the removal of 2,700 tons of contaminated soil and stockpiling another 2,700 tons could potentially be completed in two to four weeks.

#### **4.2.2.1 Conceptual Model**

The overlays of the AOC 8/9 CSM plan and cross section for the excavation technology are shown on Figures 19 and 20. All the soil within the free product areas would be removed to below the maximum depth of free product impact and replaced with clean fill material. Two

areas have a combined footprint of approximately 8,000 square feet and extend to an average depth of 12 feet below ground surface for a total volume of approximately 3,600 cubic yards.

#### **4.2.2.2 Additional Data Requirements**

Data requirements for excavation are identified in Section 3.2.3. In general, a significant amount of the data has already been collected. Specifically, the depth to free product and groundwater, the thickness of the free product, and the potential smear zone are assumed to be 6 to 12 feet bgs. An average depth of excavation of 12 feet has been assumed for AOC 8/9 based on this information.

Other data gaps are identified below:

A few outstanding data gaps/uncertainties have been identified:

- The rate of groundwater recharge needs to be evaluated. Removal of the source material (LNAPL) will require some excavation below the groundwater table. If the rate of groundwater recharge is too rapid, it could make excavation impractical or too expensive (i.e., if isolation and/or extensive dewatering are required). A test pit would need to be excavated in order to evaluate the groundwater recharge rate. An assumption was made that the groundwater recharge would be at a low rate based on the presumed heterogeneity of the subsurface and likely discontinuity of the granular lenses. It has also been assumed that any free liquid would be pumped out of the excavation, treated on site, analyzed, and discharged to the sanitary sewer under an appropriate permit.
- The soil needs to be characterized for disposal. These samples would be collected during the preliminary field investigation. It has been assumed that the soil would have relatively low concentrations of VOCs, allowing disposal of the soil as a special waste at a solid waste landfill. The landfill would require waste characterization sampling to be completed before the soil was transported from the site. The landfill would require approximately one composite sample per 5,000 cubic yards of excavation.
- Details concerning surface and subsurface structures in the target removal area need to be determined. A utility survey would be completed to verify that no utilities are located within the proposed excavation area. If any utilities are found then they would have to be disconnected, removed, and replaced or relocated. Former pipelines that were closed in place and associated anchors would be removed during excavation.

#### **4.2.2.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. Work Planning. This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.

2. Field investigation. This would involve collecting any additional information necessary to design the removal action. It is assumed to include:

- Excavation of test pits to evaluate groundwater recharge, the thickness of the free product, characteristics of soil for disposal, and volume and quality of free liquids entering the excavation (to determine treatment requirements).
- Soil sampling and analysis. Composite soil samples would be tested by the toxicity characteristics leaching procedure (TCLP) for VOCs, SVOCs, and metals and for any other characteristics required by the landfill for disposal of the soil as a special waste.
- Free liquid analysis. Samples of liquid entering the excavation would be analyzed for VOCs and SVOCs, total suspended solids, oil and grease, and total organic carbon to evaluate treatment/disposal requirements.
- Surveying. A utility survey and coordination with utility providers to remove and relocate utility lines would be completed (if needed).

#### **4.2.2.4 Physical Access Requirements**

There are few, if any, physical access constraints at AOC 8/9. According to previous reports storm sewer, electric, and telephone lines are outside the free product area and would not have to be removed during construction. Nevertheless, all utilities should be located before the design drawings are completed. The plan should minimize damage and downtime to utilities that would be disturbed during excavation.

No structures are present in the area that would be affected by this alternative, and jet fuel pipelines appear to have been removed, rather than closed in place. There is no regular vehicle traffic across the area, and remnants of paving are in poor condition. Excavation would require removal of approximately 2,400 square feet of paved surfaces. Compacted backfill would be placed once excavation activities had been completed in those areas.

#### **4.2.2.5 Construction/Implementation**

The contractor would mobilize personnel, equipment, and supplies to the site. This would include establishing a field office, work zones, storage tanks, a storage area for excavated material to use for backfill, and a decontamination pad for equipment. An on-site water treatment system would be provided at this time. Equipment would be decontaminated before use on the site.

In order to minimize water management requirements, excavation should be conducted during the dry time of the year (i.e., mid-summer). Excavation would start in an unimproved area where contamination is likely. The planned excavation depth would be defined by data from previous investigations, but would continue until the free product had been removed. It has been assumed in developing the costs that the overburden would be used for backfilling. Once the desired excavation depth has been reached the excavation would then progress laterally, adjusting the

depth as needed to include only contaminated soil. Any water that entered the excavation would be pumped out, treated, and disposed of in an appropriate manner.

Contaminated soil would be placed directly into a truck that would haul the soil off site to the nearest approved landfill for disposal. Clean overburden soil would be stockpiled on site until analysis confirmed that the soil was acceptable to be used as backfill. This would involve storing an estimated 2,700 tons of clean soil that would be used as backfill. The contractor would have to remove an estimated 2,700 tons of contaminated soil assuming that the smear zone extends from 6 to 12 feet bgs. This would result in approximately 180 truckloads assuming each truck hauled 15 tons per load. As the excavation proceeds, backfilling the previously excavated areas would be simultaneously occurring to minimize flooding of the excavation during rain events, limit the size of the open excavation, minimize the clean soil stockpile and stabilize excavation side walls. Uncontaminated soil would be stockpiled on site pending analysis and use as backfill.

Berms would be constructed around the active excavation areas to minimize run-on and run-off. Temporary construction fencing would be placed around all disturbed construction areas until the site was safe for the general public to access. In addition 2,400 square feet of pavement would be removed.

#### **4.2.2.6 Operation**

No long term operation or maintenance would be required for this technology. However, some period of monitoring would be required to demonstrate that concentrations of the contaminants of concern in the groundwater achieve the RAOs after the free product has been excavated. Since some of the wells within the free product area would be removed during excavation, it has been assumed that two new wells would be installed within the former free product area and that eight wells would be monitored quarterly for one year to demonstrate that free product has been removed and concentrations in groundwater outside the area remain below RAOs. Samples would be analyzed for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction.

#### **4.2.2.7 Waste Management**

The site is located in Franklin County, Ohio which is controlled by the Solid Waste Authority of Central Ohio (SWACO). SWACO landfills in the area can only accept soil contaminated with petroleum-based products after the waste characteristics have been received or with the Executive Director's approval.

Another landfill was identified outside of Franklin County approximately 50 miles away that would accept the waste. However, a fee would apply for simply removing the waste from the County limits. It has been assumed for the technology evaluation that the soil could be disposed of at this landfill.

#### **4.2.2.8 System Shutdown and Demobilization**

System shutdown and demobilization would involve removal of temporary field offices, fences, storage tanks, and decontamination pads from the site, and well closure after monitoring has

been completed. The wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.2.2.9 Site Restoration**

The free product footprint is within the planned boundaries of Phase 10 Construction, therefore all excavated areas should be backfilled with structural backfill or compacted excavated material. It has been assumed that pavement would be replaced during future development. Once all major construction traffic has been eliminated from the site, previously vegetated areas would be seeded. Straw bales or silt fence should be used around the excavation until vegetative growth has been stabilized, to prevent erosion. Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

#### **4.2.3 In-Situ Soil Mixing**

ISSM is a construction technology for remediating contaminated soils. Contaminated media is transformed through solidification and stabilization into durable, solid, low hydraulic conductivity material in order to reduce the rate of contaminant migration. In the case of the LAFB AOCs, the process would also blend and distribute the LNAPL product over the soil column. This mixing process would result in absorption and adsorption of the free product into the soil matrix. ISSM uses specialized hydraulically driven augers and mixing paddles to simultaneously drill and inject material. The auger flights loosen the soil as they move through the subsurface allowing the soils to be mixed with the paddles. The technique may be used to homogenize existing materials or to blend materials into the soil. ISSM can also improve the structural properties of soil (e.g., strength) to facilitate beneficial reuse of land. As described below, ISSM of AOC 8/9 is estimated to take three months to complete.

##### **4.2.3.1 Conceptual Model**

The overlays of the AOC 8/9 CSM plan and cross section for the ISSM technology are shown on Figures 21 and 22. The process creates individual columns of material, which are overlapped to create walls or divided to create block or grid patterns. The actual column size and depth depend on site conditions and equipment capabilities and would be determined through bench-scale testing (to determine mixing ratios and rates) and site observations (e.g., the maximum depth of the LNAPL smear zone).

##### **4.2.3.2 Additional Data Requirements**

Data requirements for ISSM are identified in Section 3.4.3. In general, a significant amount of the data has already been collected. Specifically, the depth to free product and groundwater, the thickness of the free product, and the potential smear zone are assumed to be 11 to 16 feet bgs. An average depth of excavation of 16 feet has been assumed for AOC 8/9 based on this information.

A few outstanding data gaps/uncertainties have been identified:

- Bench-scale testing would be conducted to evaluate the effectiveness of mixing soil layers using various ratios of grout and mixing times with respect to

immobilizing/stabilizing the LNAPL. Although soil mixing can be used as a delivery system for a variety of remediation additives (e.g., zero valent metals, biological agents, potassium permanganate, etc), only mixing with grout has been assumed for this alternative. Bench-scale testing would also provide useful information to determine optimum equipment operation specifications such as auger advancement rates, grout injection rates, and number of augers strokes necessary to produce a homogeneous mixture.

- Details concerning utilities in the area. Such details might include location, depth, size, materials of construction, etc.

#### **4.2.3.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. **Work Planning.** This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. **Field investigation.** This would involve collecting any additional information necessary to establish baseline conditions and implementation of ISSM techniques. It is assumed to include:
  - **Collection of soil samples for bench-scale testing.** The soils investigation would include SPTs, grain-size analysis, soils classification, and chemical analysis. A drill rig would be required to perform SPTs. Soil samples for grain-size analysis and soil classification would be collected from various depths and locations in order to produce results that allow for natural spatial variability. It is assumed that up to four locations would be evaluated with a maximum of three soil samples collected from each location, depending on the subsurface conditions encountered.
  - **Bench-scale testing.** This would be conducted to evaluate optimum mix ratios and to determine equipment operation specifications including auger advancement and injection rates. Pre-construction laboratory batch testing would be performed on representative soil samples using simulated soil mixing. The testing would be performed in a series of steps: 1) soil samples collected from the site will be run for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction to establish untreated conditions; 2) the grout content of the slurry would be varied by weight and the slurry addition rate would be varied by volume to determine optimal mix ratios; 3) various pre-determined mixing times (i.e., 30, 60, 90, and 120 minutes) would be analyzed; and 4) the soils would be retested for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction to analyze the varied impacts of each of these treatments.

- Surveying. This would be conducted to delineate the plume boundaries and layout the drilling grid pattern. A utility survey and coordination with utility providers to remove and relocate utility lines would be completed, as needed.

#### **4.2.3.4 Physical Access Requirements**

There are few, if any, physical access constraints at AOC 8/9. According to previous reports storm sewer, electric, and telephone lines are outside the free product area and would not have to be removed during construction. Nevertheless, all utilities should be located before the design drawings are completed. The plan should minimize damage and downtime to utilities that would be disturbed during excavation.

No structures are present in the area that would be affected by this alternative, and jet fuel pipelines appear to have been removed, rather than closed in place. There is no regular vehicle traffic across the area, and remnants of paving are in poor condition. ISSM would require removal of approximately 2,400 square feet of paved surfaces. Compacted backfill would be placed once excavation activities had been completed in those areas.

#### **4.2.3.5 Construction/Implementation**

Temporary field offices, work zones, and a decontamination pad for equipment would need to be established. A mixing system and batch plant consisting of storage silos, metering and blending devices, and pumps would need to be set up for the addition of stabilizing additives (i.e., grout) proposed. A water and electricity source would need to be established for the batch plant system.

Specialty equipment including shrouds equipped with air controls to capture fugitive emissions would be mobilized. It is anticipated that VOC emissions and odors would need to be treated and controlled during the ISSM phase. A SVE unit would be used to control emissions. The unit consists of a metal shroud or hood that is placed over the mixing area to trap potentially hazardous vapors and fugitive dust releases from the soils. Vapors and fugitive dust are drawn through a vacuum hose attached to a shroud. The vapors then enter a treatment unit, which typically includes an air separator, high-efficiency particulate air filter, and activated carbon unit(s). After treatment, air would be released to the atmosphere.

The free phase product area would be surveyed and gridded prior to beginning ISSM. ISSM would progress laterally according to the grid system. A column size of 8 feet diameter with 20 percent column overlap has been assumed. The vertical distribution of free phase product has been estimated to range from 6-12 feet bgs. ISSM would be performed to an approximate depth of 15 feet bgs to extend below the maximum LNAPL smear zone. Samples would be visually inspected for homogeneity and the presence of NAPL and confirmation samples collected at the time of mixing for laboratory analysis and characterization testing. Confirmation samples would be collected at a frequency of once per 1,000 cubic yards and analyzed for BTEX, PAHs, TPH-Light Distillate Fraction and Middle Distillate Fraction (6 samples). Selected soils would also be tested to determine the BUSTR soil classification, so that analytical results could be correctly evaluated with respect to RAOs.



Temporary construction fencing would be placed around all disturbed construction areas until the site has been restored to a manner in which it would be safe for general public access.

#### **4.2.3.6 Operation**

No long term operation or maintenance would be required for this technology. However, per BUSTR requirements, monitoring would be required to demonstrate that remedial action objectives have been achieved, and that no further action is appropriate due to concentrations below action levels as a result of ISSM of soil contaminated with free phase product.

It has been assumed that quarterly groundwater monitoring would be conducted for one year following the ISSM remedial action as specified under work planning. Samples would be collected from eight existing on-site wells outside the treatment area and analyzed for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction. Because of the stabilizing objectives of the treatment, new monitoring wells would not be installed within the treated area. Soil sampling during mixing should adequately demonstrate treatment effectiveness within that area.

#### **4.2.3.7 Waste Management**

Because ISSM is an in-situ technique, disposal cost and worker exposure are minimized and dewatering would not be necessary. Only a small amount of grout is typically added during mixing, so the increase in soil volume is usually slight. It has been conservatively estimated that up to 15 percent of the original soil volume would be disposed of as a special waste at a solid waste landfill (refer to Section 4.2.2.7) to account for increases in volume and to maintain the existing site elevation with the addition of topsoil.

The activated carbon units from the soil vapor extraction system would be reprocessed or disposed of in accordance with applicable regulations.

#### **4.2.3.8 System Shutdown and Demobilization**

System shutdown and demobilization would involve removal of temporary field offices, decontamination pads, mixing system, and batch plant. All equipment and augers would be decontaminated prior to demobilization.

#### **4.2.3.9 Site Restoration**

Site restoration would include placement of six inches of topsoil capable of sustaining vegetative growth. The free product footprint is within the planned boundaries of Phase 10 Construction, therefore all areas should be backfilled with structural backfill. It is assumed that pavement would be replaced during future development. Once all major construction traffic has been eliminated from the site, previously vegetated areas would be seeded. Straw bales would be placed around storm sewer inlets until vegetative growth has been stabilized to prevent sediment from erosion from entering the sewers.

#### **4.2.4 Multi-phase Extraction**

The MPE process was developed for the remediation of LNAPL, aromatic VOCs, TPH, and chlorinated VOCs in moderate permeability subsurface formations. The technology is meant to address contaminants in free-phase liquid, residual and adsorbed phases, and vapors. MPE simultaneously extracts both liquid (groundwater and LNAPL) and soil vapor.

##### **4.2.4.1 Conceptual Model**

The overlays of the AOC 8/9 CSM plan and cross section for the excavation technology are shown on Figures 23 and 24. In MPE, the groundwater table is lowered in order to dewater the saturated zone so that the SVE process can be applied to the exposed soil. This allows VOCs adsorbed on the previously saturated soil to be stripped by the induced vapor flow and extracted. The increased air movement through the unsaturated zone also increases oxygen content and enhances aerobic bioremediation. The lowering of the water table also allows residual phase product trapped within the pore space of the previously saturated zone to coalesce into free phase liquid, allowing it to flow toward a recovery well, where a skimming pump may also be used to remove LNAPL.

##### **4.2.4.2 Additional Data Requirements**

In general, a significant amount of the data has already been collected. The site geology and hydrogeology; concentrations and distributions of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL biodegradation parameters up-gradient and down-gradient of the source area, and potential receptors have all been to some extent previously investigated at AOC 8/9. Some of these data are summarized in Section 2.0 and 3.1.

In addition, the WIDE pilot study provides an indication of potential extraction rates and waste generation from an MPE system. It also indicates that while MPE would be effective in removing a certain mass of subsurface contaminants, additional remedial measures or long term monitoring might be necessary before RAOs are met. The draft MNA assessment determined that some of the more biodegradable compounds are declining in the contaminated zone, but that aerobic degradation is not occurring at a significant rate. This is relevant both to the potential for MPE to enhance biodegradation and for biodegradation of residual contamination following MPE. A few outstanding data gaps/uncertainties have been identified:

- The most effective MPE configuration needs to be determined for site conditions. This includes determining the appropriate well spacing based on the well radius of influence and the most effective type of extraction system. On the basis of the WIDE pilot study at AOC 3, it appears that total fluids extraction would be the most effective MPE system, but a pilot study has been assumed to further evaluate this and determine the appropriate well spacing.
- Vertical soil gas profiles need to be developed to evaluate baseline soil vapor conditions and to evaluate contaminant removal and biodegradation during and after MPE. Installation of nested gas wells to monitor gas concentrations at various levels has been assumed for this alternative.

- Waste streams resulting from the operation of a multi-phase extraction system need to be characterized for regulatory compliance and the need for possible treatment. Waste streams to be characterized would include: 1) discharged wastewater, 2) collected free product, and 3) air emissions from soil vapor extraction. This information could be obtained during the pilot study.

#### **4.2.4.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. **Work Planning.** This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation and pilot-scale testing. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. **Field investigation.** This would involve collecting any additional data required to establish baseline conditions. It is assumed to include:
  - Two nests of gas wells installed inside the free product area and one gas well nest installed at a background location. The number of nested wells would be contingent on the depth to groundwater at the specific location, but assuming an average depth of 10 feet, two nested wells would be installed to monitor soil from 3-7 feet and 7-10 feet bgs.
  - Groundwater level measurements, free product measurements, and collection of groundwater samples from existing wells to evaluate baseline conditions. All the samples would be analyzed for BTEX, MTBE, PAHs, TPH-Light Distillate Fraction and Middle Distillate Fraction, nitrate, sulfate, iron, and manganese (degradation products). Ferrous iron, ORP, pH, specific conductivity, DO, and turbidity would be measured in the field.
  - Collection of soil gas samples from the six soil vapor wells and analysis for benzene using a portable gas chromatograph and methane and oxygen using a portable gas analyzer. Two samples would be collected and sent to a laboratory for chemical analysis for BTEX and methane to verify field testing results.
  - Installation of an MPE well and performance of a test to evaluate radius of influence, recoveries of all phases, and treatment and disposal requirements for vapor, groundwater, and LNAPL.

#### **4.2.4.4 Physical Access Requirements**

Physical access would be required for well installation, soil vapor and groundwater monitoring, installation of the MPE extraction and treatment systems, waste storage, and system operation. Although there are some utilities in the area, it is assumed that the proposed activities would work around those locations. No structures are present in the area that would be affected by this alternative. Proposed construction south of the free product area would not interfere with or be

affected by this alternative. There appears to be sufficient space for the equipment, waste storage, and treatment system facilities that would be required to implement this option.

#### **4.2.4.5 Construction/Implementation**

Soil vapor monitoring wells would be installed during the planning phase. The MPE system and waste storage and treatment systems would be installed during the implementation phase. It has been assumed that the MPE system would consist of 60 wells with screened sections, using a total fluid extraction system similar to the WIDE pilot study.

#### **4.2.4.6 Operation**

This technology would require on-site operation and monitoring of the MPE system for an estimated time of approximately three to eight years. This would include treating and disposing of extracted LNAPL, vapor, and groundwater. It has been assumed that a compressor or compressors would be used to generate a vacuum through a manifold piping and well system similar to the WIDE system. The combined waste stream would be routed to blow-down, liquid/gas separation tanks. Quantities of LNAPL and VOCs generated would be tracked, and soil, vapor, and groundwater concentrations monitored during operation. Since it is likely that residual contamination would remain after MPE has been completed, annual soil vapor and groundwater monitoring has been assumed for a minimum of 10 years following treatment. Monitoring would be conducted as specified for NSZD (Section 4.2.1.6).

#### **4.2.4.7 Waste Management**

Waste management during the investigation, construction and monitoring phases would be limited to disposal of drums of soil cuttings and monitoring well purge water. During the operational phase, LNAPL and contaminated vapor and groundwater would be generated. It has been assumed that LNAPL would be disposed of through a fuel recycler, and contaminated groundwater would be treated in an on-site treatment system. Treated groundwater would be discharged to the sanitary sewer. Although the WIDE system released gas vapors to the air without treatment, it has been assumed that carbon would be used to treat vapors prior to release at least initially during full-scale implementation until contaminant concentrations began to decrease. Depending on the extent of contamination, the carbon adsorption units might need to be replaced to ensure thorough removal of contaminants from the extracted groundwater and off-gas. Permits would likely be needed for wastewater discharge and air emissions. Actual waste generation rates and treatment and disposal requirements would be determined during the pilot study.

#### **4.2.4.8 System Shutdown and Demobilization**

System shutdown would involve dismantling piping and removing storage tanks and the treatment system from the site. Monitoring and MPE wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.2.4.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

#### **4.2.5 Multi-phase Extraction with Heating**

MPEH was developed for the remediation of LNAPL, aromatic VOCs, TPH, and chlorinated VOCs in low to moderate permeability subsurface formations. The process is a modification of the conventional MPE system and is meant to address contaminants in free-phase liquid, residual and adsorbed phases, and vapor.

The information provided in the previous summary for MPE also applies to MPEH. Heating is added to conventional MPE to increase the rate of recovery, or the range of contaminants that can be recovered, by the process. Soil heating will volatilize higher molecular weight compounds that a traditional MPE system will not affect, will reduce the viscosity of free-phase and residual NAPL, and will increase chemical reaction rates for contaminant breakdown.

##### **4.2.5.1 Conceptual Model**

The overlays of the AOC 8/9 CSM plan and cross section for the MPEH technology are shown on Figures 25 and 26. Similar to traditional MPE, the groundwater table is lowered in order to dewater the saturated zone so that the SVE process can be applied to the exposed soil. The added heating component is achieved through the use of technologies such as steam injection, hot compressed air injection, electrical resistance heating, or radio-frequency heating. This technology requires electrical power or waste heat from a nearby utility or industrial source. The use of hot air from the vapor condensation process equipment has been assumed in developing this technology, but the actual heating system would need to be selected in the work planning and design phases.

The use of MPEH should be distinguished from ERH as described in Section 4.2.8. Although electrical resistance is among the technologies that may be used as a heat source in MPEH, the temperatures and rate of vapor generation in this application are much lower than those generated for ERH as a stand-alone technology.

##### **4.2.5.2 Additional Data Requirements**

In general, a significant amount of the data has already been collected. The site geology and hydrogeology, concentrations and distributions of contaminants in soil and groundwater; chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, biodegradation parameters up-gradient and down-gradient of the source area, and potential receptors have all been to some extent previously investigated at AOC 8/9. Some of these data are summarized in Section 2.0 and 3.1.

In addition, the WIDE pilot study at AOC 3 provides an indication of potential extraction rates and waste generation from an MPE system. It also indicates that while MPE would be effective in removing a certain mass of subsurface contaminants, additional remedial measures or long

term monitoring might be needed to achieve RAOs. The draft MNA assessment determined that some of the more biodegradable compounds are declining in the contaminated zone, but that aerobic degradation is not occurring at a significant rate. This is relevant both to the potential for MPEH to enhance biodegradation and for biodegradation of residual contamination following MPEH.

A few outstanding data gaps/uncertainties have been identified:

- The most effective MPEH configuration needs to be determined for site conditions. This includes determining the appropriate well spacing based on the well radius of influence and the most effective type of extraction system. On the basis of the WIDE pilot study, it appears that total fluids extraction would be the most effective MPE system, but a pilot study has been assumed to further evaluate this and determine the appropriate well spacing. Because heating would be used to enhance MPE rather than as a stand-alone technology, a pilot study is not considered necessary to determine the heating system design.
- Vertical soil gas profiles need to be developed to evaluate baseline soil vapor conditions and to evaluate contaminant removal and biodegradation during and after MPEH. Installation of nested gas wells to monitor gas concentrations at various levels has been assumed for this alternative.
- Waste streams resulting from the operation of a multi-phase extraction system need to be characterized for regulatory compliance and the need for possible treatment. Waste streams to be characterized would include: 1) discharged wastewater, 2) collected free product, and 3) air emissions from soil vapor extraction. This information could be obtained during the pilot study.

#### **4.2.5.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. **Work Planning.** This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation and pilot-scale testing. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. **Field investigation.** This would involve collecting any additional data required to establish baseline conditions. It is assumed to include:
  - Two nests of gas wells installed inside the free product area and one gas well nest installed at a background location. The number of nested wells would be contingent on the depth to groundwater at the specific location, but assuming an average depth of 10 feet, two nested wells would be installed to monitor soil from 3-7 feet and 7-10 feet bgs.
  - Groundwater level measurements, free product measurements, and collection of groundwater samples from existing wells to evaluate baseline conditions. All the

samples would be analyzed for BTEX, MTBE, PAHs, TPH-Light Distillate Fraction and Middle Distillate Fraction, nitrate, sulfate, iron, and manganese (degradation products). Ferrous iron, ORP, pH, specific conductivity, DO, and turbidity would be measured in the field.

- Collection of soil gas samples from the six soil vapor wells and analysis for benzene using a portable gas chromatograph and methane and oxygen using a portable gas analyzer. Two samples would be collected and sent to a laboratory for chemical analysis for BTEX and methane to verify field testing results.
- Installation of a MPE well and performance of a test to evaluate radius of influence, recoveries of all phases, and treatment and disposal requirements for vapor, groundwater, and LNAPL.
- Surveying. This would be conducted to delineate the plume boundaries and lay out the heating element pattern.

#### **4.2.5.4 Physical Access Requirements**

Physical access would be required for well installation, soil vapor and groundwater monitoring, installation of the MPE extraction and treatment systems, waste storage, and system operation. Although there are some utilities in the area, it is assumed that the proposed activities would work around those locations. No structures are present in the area that would be affected by this alternative. Proposed construction south of the free product area would not interfere with or be affected by this alternative. There appears to be sufficient space for the equipment, waste storage, and treatment system facilities that would be required to implement this option.

#### **4.2.5.5 Construction/Implementation**

Soil vapor monitoring wells would be installed during the planning phase. The MPE, heating, waste storage, and treatment systems would be installed during the implementation phase. It has been assumed that the MPE system would consist of 45 wells with screened sections, using a total fluid extraction system similar to the WIDE pilot study.

If low temperature thermal desorption using hot air injection is chosen as the heating technology, approximately 110 heating wells would be utilized. Waste heat from the vapor condensation process equipment would be captured and injected into the vadose zone to increase vadose zone temperatures, thereby increasing the volatilization of the contaminants. A matrix of thermocouples would be installed in the treatment area to monitor the temperature at various locations below ground.

Temporary construction fencing would be placed around the thermally-treated area until the site has been restored to a manner in which it would be safe for general public access.

#### **4.2.5.6 Operation**

This technology would require on-site operation and monitoring of the MPEH system for an estimated time of approximately two to three years. This would include treating and disposing of

extracted LNAPL, vapor, and groundwater. It has been assumed that a compressor or compressors would be used to generate a vacuum through a manifold piping and well system similar to the WIDE system. The combined waste stream would be routed to blow-down, liquid/gas separation tanks. Quantities of LNAPL and VOCs generated would be tracked, and soil, vapor, and groundwater concentrations monitored during operation. Since it is likely that some residual contamination would remain after MPEH has been completed (although less than MPE), annual soil vapor and groundwater monitoring has been assumed for a minimum of 5 years following treatment. Monitoring would be conducted as specified for NSZD (Section 4.2.1.6).

#### **4.2.5.7 Waste Management**

Waste management during the investigation, construction and monitoring phases would be limited to disposal of drums of soil cuttings and monitoring well purge water. During the operational phase, LNAPL and contaminated vapor and groundwater would be generated. It has been assumed that LNAPL would be disposed of through a fuel recycler and contaminated groundwater would be treated in an on-site treatment system. Treated groundwater would be discharged to the sanitary sewer. Although the WIDE system released gas vapors to the air without treatment, it has been assumed that carbon would be used to treat vapors prior to release during full-scale implementation. Permits would be needed for wastewater discharge and air emissions. Actual waste generation rates and treatment and disposal requirements would be determined during the pilot study.

#### **4.2.5.8 System Shutdown and Demobilization**

System shutdown would involve dismantling piping and removing wells, electrodes, storage tanks, and the treatment system from the site. Monitoring and MPE wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.2.5.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

#### **4.2.6 In-Situ Chemical Oxidation**

ISCO employs the injection of chemical oxidants directly into the aquifer to react with and destroy dissolved-phase organic constituents. ISCO is usually employed as a source control measure for high concentration *dissolved-phase* contaminants at or near the original release. The presence of high concentrations of naturally occurring organic materials will increase the oxidizing agent dose required for effective destruction, and may decrease overall performance.

Because this technology involves the introduction of oxidant solution into the subsurface, excellent hydraulic control and containment are necessary to prevent spreading contaminants over a larger area. Before design and implementation of this technology, geologic conditions must be well characterized through investigation and pilot testing. Since this technology is difficult to implement at sites with geologic conditions that are significantly heterogeneous or



with low hydraulic conductivities, and since it is most effective on dissolved contaminants, it is likely to be ineffective at any of the three LAFB AOCs.

#### **4.2.6.1 Conceptual Model**

Because this technology is not likely to be effective, the number of injection points and likely support facilities have not been evaluated in detail, and CSM overlays have not been prepared. Subsurface injection is generally performed using direct push technology or a network of temporary or permanent injection wells. Considering that ISCO would require numerous applications at AOC 9, the construction of permanent injection wells would be most cost effective and practical. A pilot study is recommended to evaluate the radius of influence and appropriate well spacing. High pressure injection may be employed to increase the radius of influence and reduce the number of injection points. Multiple applications are often required to meet remedial endpoints.

#### **4.2.6.2 Additional Data Requirements**

Data requirements to both qualitatively and quantitatively assess the potential for ISCO as a remedial technology and to establish baseline conditions for long-term evaluation are considerable. However, a significant amount of the data has already been collected. The site geology and hydrogeology, concentrations and distributions of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, and potential receptors have all been to some extent previously investigated at AOC 3. Some of these data are summarized in Section 2.0 and 3.1. A few outstanding data gaps/uncertainties have been identified:

- The radius of influence and associated number of injection points would need to be determined based on site conditions. A pilot study would be needed to further evaluate injection hydraulics and to determine the appropriate well spacing.
- The potential for adverse impacts such as reduction in permeability and re-solubilization of metals due to the oxidizing effects needs to be evaluated under site conditions. This would also be evaluated during the pilot study.
- The oxidant demand associated with both the contaminants and naturally occurring organic materials needs to be determined. This could be obtained from soil and groundwater samples collected during the pilot study.
- Details need to be obtained regarding subsurface structures and utilities to avoid potential physical or chemical damage to these items during installation and treatment. This includes location, depth, size, materials of construction, etc.

#### **4.2.6.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. **Work Planning.** This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation and pilot-scale

testing. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.

2. Pilot-scale Testing. Pilot-scale testing is required to provide data regarding radius of influence, required injection well spacing, and required oxidant injection dose.
  - Final Design. The results of the pilot test would be used to refine and optimize the work plans and finalize the design for full-scale implementation. The final design would specify well spacing, oxidant type and dose, and required on-site facilities for storage and periodic injection of the chemicals. Protection or relocation of utilities would be addressed as necessary to avoid adverse impacts

#### **4.2.6.4 Physical Access Requirements**

Physical access required would be for pilot testing, injection well installation, storage structure construction, and groundwater monitoring. Although there are some utilities in the area, it is assumed that the proposed activities would work around those locations. No structures are present in the area that would be affected by this alternative. Proposed construction south of the free product area would not interfere with or be affected by this alternative. There appears to be sufficient space for a storage structure, equipment, and waste storage facilities that would be required to implement this option.

#### **4.2.6.5 Construction/Implementation**

Injection wells, as well as groundwater monitoring and extraction wells, a storage structure (for storage of ISCO chemicals, mixing and injection equipment), and a waste storage pad would need to be constructed. The quantity and placement of these structures would be dependent on the results of the pilot test.

#### **4.2.6.6 Operation**

Full-scale implementation would include injection of the selected ISCO solution in numerous wells located throughout the target treatment zone. Post-remediation monitoring would follow the injection process. Multiple rounds of oxidant injection and monitoring would be required to achieve remediation endpoints.

This technology would require quarterly groundwater monitoring following the remediation (one or more injections) to evaluate the effectiveness of the treatment and potential adverse effects.

#### **4.2.6.7 Waste Management**

Because ISCO is an in-situ technology, the amount of waste that is generated is relatively small in comparison with many ex-situ remediation approaches. Waste management during investigation and monitoring activities would be limited to disposal of drums of soil cuttings and monitoring well purge water, and the original drums/containers in which the oxidant is shipped. On the basis of concentrations detected in samples within the free product area, the soil would be disposed of as a special waste, and the purge water would be disposed of at a publicly owned wastewater treatment plant.

#### **4.2.6.8 System Shutdown and Demobilization**

System shutdown would involve abandonment of ISCO injection points and monitoring wells. The injection points and wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9. Above-ground pumps, treatment equipment, waste storage facilities and any temporary remediation buildings would need to be removed.

#### **4.2.6.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

### **4.2.7 Surfactant Enhanced LNAPL Removal**

SELR is a technique to remove LNAPL from the saturated zone by introducing a manufactured chemical surfactant to mobilize contaminants and allow recovery using conventional groundwater extraction. The introduction of surfactant allows free-phase and residual-phase LNAPL to be dispersed into the aqueous phase, where it is more easily recoverable through groundwater extraction. Because this technology involves the introduction of a manufactured chemical into the subsurface, excellent hydraulic control and containment are necessary to prevent spreading LNAPL and surfactants over a larger area. Before design and implementation of this technology, geologic conditions must be well characterized through investigation and pilot testing. Since this technology is more difficult to implement at sites with geologic conditions that are significantly heterogeneous or with hydraulic conductivities less than  $10^{-3}$  cm/sec, it is likely to be ineffective at any of the three LAFB AOCs. It should be noted that this technology also will not address contaminants that are present in the smear zone at an elevation above the water level.

#### **4.2.7.1 Conceptual Model**

Because this technology is not likely to be effective, it has not been developed in detail, and CSM overlays have not been prepared. The most common technique for the use of surfactants is a flooding configuration. This involves the preparation of low viscosity surfactant solutions that are injected into the subsurface and then migrate through the contaminated zone based on the hydraulic gradient. The surfactant is put into the ground through up-gradient injection points and then removed down-gradient through extraction wells located within the capture zone. The extracted fluid requires treatment or off-site disposal. An extensive down-gradient groundwater monitoring network should be established to prevent and document the risk of possible breakthrough.

#### **4.2.7.2 Additional Data Requirements**

A significant amount of the data required for this technology has already been collected. The site geology and hydrogeology, concentrations and distribution of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, and details regarding subsurface structures in and around the target area have all been previously investigated.

The following data are required to fully evaluate and implement this alternative:

- Identification of potential receptors that may be impacted by possible migration of the LNAPL and surfactant beyond the intended capture zone.
- Soil and contaminant characteristics that would determine the flushing fluids required, flushing fluid compatibility, and changes in flushing fluids with changes in contaminants.
- Groundwater flow conditions. A pilot test would need to be completed to determine whether the gradients necessary for capturing the contaminant and surfactant fluids can be established for sufficient contaminant contact and recovery. Heterogeneous soil environments may not allow sufficient chemical contact or sufficiently uniform gradients for successful implementation.
- Waste streams resulting from the operation need to be characterized for regulatory compliance and treatment or off-site disposal. Waste streams to be characterized would include discharged wastewater containing surfactant and recovered product.

#### **4.2.7.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. Work Planning. This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation and pilot-scale testing. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. Field investigation. This would involve collecting any additional data required to establish baseline conditions as well as completing a field-scale testing. It is assumed to include:
  - An extensive study of subsurface soil conditions to: 1) document soil heterogeneities, 2) measure hydraulic conductivities on a scale consistent with the size of the heterogeneities, and 3) identify if sufficiently continuous flow paths exist within the subsurface. This study should include hydraulic probe sampling on a grid with approximate 10 foot centers throughout the area of implementation.
  - Groundwater level measurements, free product measurements, and collection of LNAPL samples for fuel component analysis and chemical and physical properties.
  - A pilot test to provide data regarding surfactant enhanced LNAPL removal, required injection well spacing, and required surfactant injection dose. The results of the field-scale testing would be used to refine and optimize the RAP and monitoring plans.

#### **4.2.7.4 Physical Access Requirements**

Physical access required would be for pilot testing, injection point installation, well installation, treatment building construction, SELR operation, and groundwater monitoring. Although there are some utilities in the area, it is assumed that the proposed activities would work around those locations. No structures are present in the area that would be affected by this alternative. Proposed construction south of the free product area would not interfere with or be affected by this alternative. There appears to be sufficient space for the building, equipment, and waste storage facilities that would be required to implement this option.

#### **4.2.7.5 Construction/Implementation**

Injection and extraction wells, extraction piping, storage tanks, and a treatment system would have to be constructed/installed at the site. The number of injection and extraction wells and the treatment system capacity would depend on findings from the pilot test.

#### **4.2.7.6 Operation**

Before beginning to inject surfactant, as much free product as possible would be recovered from the extraction wells. Once this has been completed, surfactant would be injected at numerous wells or injection points located throughout the target treatment zone. Surfactant and mobilized LNAPL and groundwater would be pumped from the extraction wells to the treatment system. If feasible, surfactant would be separated from the contaminated water for re-use. Multiple rounds of surfactant injection and monitoring might be required to achieve remediation endpoints.

This technology would require quarterly groundwater monitoring following remediation (one or more injections) to evaluate the effectiveness. Groundwater samples would be analyzed for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction.

#### **4.2.7.7 Waste Management**

Waste management during investigation and monitoring activities would be limited to disposal of drums of soil cuttings and monitoring well purge water. On the basis of concentrations detected in samples within the free product area, the soil would be disposed of as a special waste, and the groundwater would be disposed of at a publicly owned wastewater treatment plant.

Following the injection process, treatment of extracted water would include separation of surfactant (as feasible), and water treatment to remove contaminants to acceptable levels for discharge to the sanitary sewer. Air emissions of volatile contaminants from recovered flushing fluids should be collected and treated according to regulatory guidance. Permits would be needed for wastewater discharge and air emissions.

#### **4.2.7.8 System Shutdown**

System shutdown would involve dismantling piping and removing storage tanks and the treatment system from the site. Monitoring, injection, and extraction wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.2.7.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

### **4.2.8 Electrical Resistance Heating**

As discussed in Section 3.9.1, ERH uses the heat resulting from the resistance of soil to the flow of electricity to evaporate and release contaminants from soil and groundwater. The resistance to electric flow by the soil causes the formation of heat resulting in increased temperatures until the boiling point of water is reached. As the heat is applied, contaminants are volatilized and mobilized within the soil matrix. Thermal methods can be particularly useful for both DNAPL and LNAPL. ERH is distinguished from MPEH (discussed in Section 4.1.5) in that the heating in ERH would be more aggressive, operating at a higher temperature, and would not include the pumping of groundwater. It is most effective on organic compounds that are readily volatilized and requires greater energy input to treat less volatile compounds. For remediation of DNAPL or LNAPL, ERH is often co-located with a MPE system to aid in recovering the less volatile contaminants.

#### **4.2.8.1 Conceptual Model**

The overlays of the AOC 9/9 CSM plan and cross section for the ERH technology are shown on Figures 27 and 28. ERH uses arrays of electrodes installed around a central neutral electrode to create a concentrated flow of current toward the central point. Resistance to flow in the soils generates heat greater than 100°C, producing steam and volatilized contaminants that are recovered via vacuum extraction. Recovery wells maintain vacuum during ERH operations and ensure the capture of vapors and steam from the subsurface. Each vapor recovery well is connected to pipes which convey vapor and steam to the condenser unit.

ERH can be utilized to reach very low contaminant concentrations and is effective in low-permeable hydrogeology such as clays, silts, and tills. Residual heat that may remain for months or years after treatment may also enhance continuing attenuation through biodegradation, hydrolysis, etc.

#### **4.2.8.2 Additional Data Requirements**

A significant amount of the data required for this technology has already been collected. The site geology and hydrogeology, concentrations and distribution of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, and details regarding subsurface structures in and around the target area have all been previously investigated.

A few outstanding data gaps/uncertainties have been identified that are especially relevant to the installation of the electrode array:

- Location, depth, and dimensions of portions of fuel lines that were plugged and abandoned in place, as well as concrete tank anchors left in place.

- Details concerning subsurface structures and utilities at or in the vicinity of the target treatment area. Such details may include location, depth, size, and materials of construction.
- Naturally occurring  $f_{oc}$  of soils in target treatment zones.
- LNAPL distribution, thickness, and chemical and physical properties.
- Waste streams resulting from the operation of an ERH system need to be characterized for regulatory compliance and the need for possible treatment. Waste streams to be characterized would include: 1) condensate and 2) air emissions from vapor extraction.

#### **4.2.8.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. Work Planning. This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. Field investigation. This would involve collecting any additional data required to establish baseline conditions. It is assumed to include:
  - Groundwater level measurements, free product measurements, and collection of LNAPL samples for fuel component analysis and chemical and physical properties.
  - Collection of soil samples to evaluate residual contaminant concentrations and distribution and  $f_{oc}$ .
  - Surveying. This would be conducted to delineate the plume boundaries and lay out the electrode pattern.

#### **4.2.8.4 Physical Access Requirements**

Access to the area near the contamination is required, but ERH can be applied to treat contaminated soils under existing structures, so direct access to affected soil is not required. Although there are some utilities in the area, it is assumed that the proposed activities would work around those locations. No structures are present in the area that would be affected by this alternative. Proposed construction south of the free product area would not interfere with or be affected by this alternative. There appears to be sufficient space for a treatment building and equipment that would be required to implement this option. Power requirements and availability would need to be evaluated during design, but are not expected to be a constraint.

#### **4.2.8.5 Construction/Implementation**

Existing electrical power at the site would be utilized, or power may be generated on-site via fuel combustion or solar energy. Equipment related to power generation, power control, soil vapor and steam recovery, and vapor destruction, if needed, would be brought to or constructed on site. A utility transformer and a power control unit would be brought to the site to step down voltage for controlled distribution into the electrodes.

A field of electrodes and vapor recovery wells would be installed below ground to depths defining the limits of contamination. Electrodes and vapor recovery wells would be designed and installed based on site characteristics. These two design features could be co-located to reduce project costs and improve system efficiency.

Assuming an average electrode placement of one electrode per 250 ft<sup>2</sup> of contamination, it is estimated that approximately 30 electrodes would be utilized. The electrodes would be installed to depths of about 26 feet. A matrix of temperature monitoring points would be installed in the treatment area to monitor the temperature at various locations below ground. Each temperature monitoring point would contain strings of thermocouples installed at about 5-foot depth intervals.

Existing utilities at the site would be left in place. If it is determined that PVC pipes are located in the treatment area, those would need to be removed. Operators would be able to remotely run the system via the internet, monitoring treatment temperature, and controlling power and energy application to the system,

Temporary construction fencing would be placed around the affected area until the site has been restored to a manner in which it would be safe for general public access.

#### **4.2.8.6 Operation**

ERH would require frequent on-site monitoring of system operation during implementation. ERH is generally a rapid form of remediation with case studies of effective treatment of soil and groundwater in less than 40 days. It is assumed that remediation using this technology would last no more than nine months. Quarterly groundwater monitoring events are expected following remediation activities for one year.

Ongoing monitoring of surface voltages would be implemented during operation to ensure that surface voltages remain below OSHA standards.

#### **4.2.8.7 Waste Management**

Drums of soil cuttings would be generated during system installation. On the basis of concentrations detected in samples within the free product area, these would be disposed of as a special waste. The ERH condenser separates contaminant vapors from steam. A majority of the contaminants (>99.5% by mass) remain in the vapor state, while the rest are captured in the steam condensate. The resulting condensate is not considered a waste stream and can be



recycled back to the process. Any excess condensate can typically be discharged without further treatment.

Contaminant vapors are treated before discharge to the atmosphere. Typical treatment options are activated carbon or thermal or catalytic oxidation. Spent activated carbon would be treated as hazardous waste and properly disposed of. Air emission permits would likely be required.

#### **4.2.8.8 System Shutdown and Demobilization**

Once levels of contamination have been effectively reduced, all equipment related to treatment would be removed from site by the contractor. Monitoring wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.2.8.9 Site Restoration**

Once the electrodes and vapor recovery wells are removed, a small amount of grading and seeding would be completed to restore the site to its original state. Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

### **4.3 AOC 11**

Implementation of the technologies at AOC 11 is described in the following subsections.

#### **4.3.1 Natural Source Zone Depletion**

NSZD occurs when certain natural processes act to (a) physically redistribute LNAPL components to the aqueous or gaseous phase and (b) biologically break down these source zone components. NSZD is of significance because it occupies a position in the spectrum of remediation options that can be used as a basis for comparing the performance and relative benefit of other remediation options.

##### **4.3.1.1 Conceptual Model**

Since this alternative would not involve any construction except installation of additional monitoring wells, CSM overlays have not been prepared. These processes include dissolution of LNAPL constituents into groundwater and volatilization of LNAPL constituents into the vadose zone. In turn, LNAPL constituents dissolved to groundwater and volatilized to the vadose zone can be biodegraded by microbial and/or enzymatic activity. The dissolution, volatilization, and biodegradation rates are critical factors in evaluating this technology. The dissolution and volatilization rates depend on the characteristics of the LNAPL constituents, while the biodegradation rates depend on these characteristics and the type and availability of electron acceptors. The rates of all these processes also depend on the permeability and transmissivity of the subsurface soils. The presence of recalcitrant LNAPL and discontinuous sand and gravel layers interspersed with zones of lower hydraulic conductivity at AOC 11 will limit the effectiveness of NSZD and increase the time to achieve remediation goals.

#### 4.3.1.2 Additional Data Requirements

Data requirements for NSZD are identified in Section 3.2.3. In general, a significant amount of the data has already been collected. The site geology and hydrogeology, concentrations and distributions of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, biodegradation parameters up-gradient and down-gradient of the source area, and potential receptors have all been to some extent previously investigated at AOC 11. Specifically, the draft MNA assessment (Ref. 16) made the following determinations:

- The groundwater contours developed from water levels measured during all the MNA monitoring events show an overall flow direction toward the east/southeast.
- Hydrocarbon fingerprinting of free product at AOC 11 by CRAA and CELRL in 2006 indicated a high degree of evaporative weathering and practically complete depletion of n-alkanes by biodegradation.
- None of the concentrations of COCs in groundwater samples or the LNAPL sample collected from AOC 11 monitoring wells during the MNA assessment exceeded the RAOs.
- Lower benzene concentrations in monitoring wells down-gradient of the free product area suggest that biodegradation of benzene is occurring.
- However, because most of the dissolved petroleum hydrocarbon concentrations down-gradient of the free product area are below reporting limits, it is not possible to develop concentration profiles along a flow line to estimate the rate of NSZD.
- Similar DO and nitrate concentrations in monitoring wells up-gradient and within the free product area are not indicative of aerobic biodegradation.
- Higher sulfate concentrations in monitoring wells up-gradient of the free product area suggest that biological sulfate reduction is occurring.
- Higher ferrous iron and methane concentrations within the free product area suggest that biological reduction of organic compounds is occurring.
- Alkalinity and pH data are inconclusive.
- Concentrations of benzene, 1,2,4-trimethylbenzene, and naphthalene in the LNAPL relative to the composition of JP-4 suggest that the more biodegradable compounds within the LNAPL are being preferentially removed, and that the remaining compounds are less readily degraded.

A few outstanding data gaps/uncertainties have been identified:

- Vertical soil gas profiles need to be developed to evaluate NSZD in the vapor phase. Installation of nested gas wells to monitor gas concentrations at various levels has been assumed for this alternative.
- LNAPL dissolution, volatilization, and leaching rates should be evaluated. A bench scale study to evaluate these rates has been assumed for this alternative.
- Although the groundwater flow direction appears to be better defined than for AOC 3 or 8/9, there appears to be only one down-gradient monitoring well (LMW-42). Installation of additional down-gradient wells is assumed for this technology.
- The 2006 LNAPL fingerprinting should be reviewed to evaluate the extent to which lighter fractions have been biodegraded. The effective solubility of the LNAPL would need to be tested.

#### **4.3.1.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. **Work Planning.** This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. **Field investigation.** This would involve collecting any additional data required to establish baseline conditions. It is assumed to include:
  - Three additional groundwater monitoring wells installed to a depth of approximately 25 bgs along the centerline of the free product area, and two additional down-gradient monitoring wells.
  - Three nests of gas wells installed inside the free product area and one gas well nest installed at background location. The number of nested wells would be contingent on the depth to LNAPL at the specific location, but assuming an average depth of 14 feet, three nested wells would be installed to monitor soil from 3-7 feet, 7-11, and 11-14 feet bgs.
  - Collection of four quarters of groundwater samples from nine wells, including five wells along the centerline of the free product area, as well as sentinel wells on either side of the LNAPL plume. All the samples would be analyzed for BTEX, MTBE, PAHs, TPH-Light Distillate Fraction and Middle Distillate Fraction, nitrate, sulfate, iron, and manganese (degradation products). Ferrous iron, ORP, pH, specific conductivity, DO, and turbidity would be measured in the field.
  - Collection of soil gas samples from the 12 soil gas wells and analysis for benzene using a portable gas chromatograph and methane and oxygen using a portable gas

analyzer. Two samples would be collected and sent to a laboratory for chemical analysis for BTEX and methane to verify field testing results.

- Collection of LNAPL samples from the three wells inside the LNAPL plume for fuel component analysis.
- Bench-scale testing. This would involve laboratory tests to evaluate dissolution, volatilization, and leaching rates.

#### **4.3.1.4 Physical Access Requirements**

The only physical access required would be for well installation and gas and groundwater monitoring. Although there are quite a few structures and utilities in the area, it is assumed that the proposed activities would work around those locations and would not affect jet fuel storage or delivery or the operation of the AVGAS containment area.

#### **4.3.1.5 Construction/Implementation**

With the exception of the gas and groundwater monitoring wells that would be installed during the planning phase, this technology does not involve construction.

#### **4.3.1.6 Operation**

This technology would require long-term groundwater and soil vapor monitoring to evaluate the rate and effectiveness of NSZD. It has been assumed that annual soil gas and groundwater monitoring would be conducted as specified under work planning, with the exception of fuel component analysis of the LNAPL.

#### **4.3.1.7 Waste Management**

Waste management would be limited to disposal of drums of soil cuttings and monitoring well purge water. Relatively small quantities of these would be generated during investigation and monitoring activities. On the basis of concentrations detected in samples within the free product area, the soil would be disposed of as a special waste, and the groundwater would be disposed of at a publicly owned wastewater treatment plant.

#### **4.3.1.8 System Shutdown and Demobilization**

System shutdown would involve plugging up to thirteen monitoring wells. The wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.3.1.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

### **4.3.2 Excavation**

Excavation is a traditional and quick solution to remediate contaminated soil and source material. It involves removing the contaminated material from the site, then backfilling with clean soil. While this method has proven to be effective in areas where little development has occurred, excavating contamination in developed areas can become expensive when working around utilities, storm sewers, parking lots, buildings, etc. However, where applicable, excavation can be completed in a fraction of the time of other remedial solutions, and usually does not require any long-term operation and maintenance or monitoring. A project involving the removal of 3,800 tons of contaminated soil and stockpiling another 20,900 tons could potentially be completed in three to five months.

#### **4.3.2.1 Conceptual Model**

The overlays of the AOC 11 CSM plan and cross section for the excavation technology are shown on Figures 29 and 30. All the soil within the free product area would be removed to below the maximum depth of free product impact and replaced with clean fill material. This area has a footprint of approximately 34,200 square feet and extends to an average depth of 13 feet bgs for a total volume of 16,500 cubic yards.

#### **4.3.2.2 Additional Data Requirements**

Data requirements for excavation are identified in Section 3.2.3. In general, a significant amount of the data has already been collected. Specifically, the depth to free product and groundwater, the thickness of the free product, and the potential smear zone are assumed to be between 11 and 13 feet bgs. An average depth of excavation of 13 feet has been assumed for AOC 11 based on this information.

A few outstanding data gaps/uncertainties have been identified:

- The rate of groundwater recharge needs to be evaluated. Removal of the source material (LNAPL) will require some excavation below the groundwater table. If the rate of groundwater recharge is too rapid, it could make excavation impractical or too expensive (i.e., if isolation and/or extensive dewatering are required). A test pit would need to be excavated in order to evaluate the groundwater recharge rate. An assumption was made that the groundwater recharge would be at a low rate based on the presumed heterogeneity of the subsurface and likely discontinuity of the granular lenses. It has also been assumed that any free liquid would be pumped out of the excavation, analyzed, treated and then removed from the site under an appropriate permit.
- The soil needs to be characterized for disposal. These samples would be collected during the preliminary field investigation. It has been assumed that soil would be mixed to reduce the free liquids and that based on the relatively low concentrations of VOCs, it would be possible to dispose of the soil as a special waste at a solid waste landfill. The landfill would require VOC and metal sampling to be completed before the soil was transported from the site. The landfill would require approximately one composite sample per 5,000 cubic yards of excavation.

- Details concerning surface and subsurface structures in the target removal area need to be determined. Fuel, water, sanitary sewer, and electrical lines are believed to be within the proposed excavation area. These utilities would have to be located, disconnected, removed, and replaced or relocated. Former pipelines that were closed in place and associated anchors would be removed during excavation.

#### **4.3.2.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. **Work Planning.** This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. **Field investigation.** This would involve collecting any additional information necessary to design the removal action. It is assumed to include:
  - Excavation of test pits to evaluate groundwater recharge, the thickness of the free product, characteristics of soil for disposal, and volume and quality of free liquids entering the excavation (to determine treatment requirements).
  - Soil sampling and analysis. Composite soil samples would be tested by the toxicity characteristics leaching procedure (TCLP) for VOCs, SVOCs, and metals and for any other characteristics required by the landfill for disposal of the soil as a special waste.
  - Free liquid analysis. Samples of liquid entering the excavation would be analyzed for VOCs and SVOCs, total suspended solids, oil and grease, and total organic carbon to evaluate treatment/disposal requirements.
  - Surveying. A utility survey and coordination with utility providers to remove and relocate utility lines would be completed.

#### **4.3.2.4 Physical Access Requirements**

Physical access constraints within the free product footprint include paved areas acting as access roads. According to previous reports and the site visit sanitary sewer, electrical, water, and fuel lines are believed to be within the free product footprint. All nearby utilities would be located before the design drawings are completed. The plan should minimize damage and downtime to any utilities that would be disturbed during excavation.

Excavation would disturb 25,200 square feet of paved surfaces. This would reduce access to a jet fuel A and AVGAS 100LL dispensing station. The AVGAS 100LL AST's would have to be relocated in order to complete a full excavation of the area. Access to the remaining buildings surrounding the area of excavation should not be restricted.

#### **4.3.2.5 Construction/Implementation**

The contractor would mobilize personnel, equipment, and supplies to the site. This would include establishing a field office, work zones, storage tanks, a storage area for excavated material to use for backfill, and a decontamination pad for equipment. An on-site water treatment equipment system would be provided at this time, if required, but has not been assumed in developing this technology. Equipment would be decontaminated before use on the site.

In order to minimize water management requirements, excavation should be conducted during the dry time of the year (i.e., mid-summer). Excavation would start in an unimproved area where contamination is likely. The planned excavation depth would be defined by data from previous investigations, but would continue until the free product had been removed. Less contaminated unsaturated soil would be stockpiled for testing and used as backfill or for blending with wetter soil. It has been assumed in developing the costs that this overburden would be used for backfill. Once the desired excavation depth has been reached the excavation would then progress laterally, adjusting the depth as needed to include only contaminated soil. Any water that enters the excavation would be pumped out, treated, and disposed of in an appropriate manner.

Contaminated soil would be placed directly into a truck that would haul the soil off site to the nearest approved landfill for disposal. Clean overburden soil would be stockpiled on site until analysis confirmed that the soil was acceptable to be used as backfill. This would involve storing an estimated 20,900 tons of clean soil that would be used as backfill. The contractor would have to remove an estimated 3,800 tons of contaminated soil assuming that the smear zone extends from 11 to 13 feet bgs. This would result in approximately 253 truckloads assuming each truck hauled 15 tons per load. As the excavation proceeds, backfilling the previously excavated areas would be simultaneously occurring to minimize flooding of the excavation during rain events, limit the size of the open excavation, minimize the clean soil stockpile and stabilize excavation side walls. Uncontaminated soil would be stockpiled on site pending analysis and use as backfill.

Berms would be constructed as needed around the active excavation areas to minimize run-on and run-off. Temporary construction fencing would be placed around all disturbed construction areas until the site is safe for the general public to access. In addition, 25,200 square feet of 18-inch-thick concrete pavement would have to be removed and replaced.

#### **4.3.2.6 Operation**

No long term operation or maintenance would be required for this technology. However, some period of monitoring would be required to demonstrate that concentrations of the contaminants of concern in the groundwater achieve the RAOs after the free product has been excavated. Since some of the wells within the free product area would be removed during excavation, it has been assumed that two new wells would be installed within the former free product area and that eight wells would be monitored quarterly for one year to demonstrate that free product has been removed and concentrations in groundwater outside the area remain below RAOs. Groundwater samples would be analyzed for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction.

#### **4.3.2.7 Waste Management**

The site is located in Franklin County, Ohio which is controlled by SWACO. SWACO landfills in the area can only accept soil contaminated with petroleum-based products after the waste characteristics have been received or with the Executive Director's approval.

Another landfill was identified outside of Franklin County approximately 50 miles away that would accept the waste. However, a fee would apply for simply removing the waste from the County limits. It has been assumed for the technology evaluation that the soil could be disposed of at this landfill.

#### **4.3.2.8 System Shutdown and Demobilization**

System shutdown and demobilization would involve removal of temporary field offices, fences, storage tanks, and decontamination pads from the site, and well closure after monitoring has been completed. The wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.3.2.9 Site Restoration**

Site restoration would include backfilling with structural backfill in all areas due to the heavy traffic in this area. The paved areas should be replaced to original condition. Utilities would be reinstalled, as necessary, and the AVGAS tanks would be returned to their original location. Once all major construction traffic had been eliminated from the site, previously vegetated areas would be seeded. Straw bales or silt fence should be used around the excavation until vegetative growth has been stabilized, to prevent erosion. Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

### **4.3.3 In-Situ Soil Mixing**

ISSM is a construction technology for remediating contaminated soils. Contaminated media is transformed through solidification and stabilization into durable, solid, low hydraulic conductivity material in order to reduce the rate of contaminant migration. In the case of the LAFB AOCs, the process would also blend and distribute the LNAPL product over the soil column. This mixing process would result in absorption and adsorption of the free product into the soil matrix. ISSM uses specialized hydraulically driven augers and mixing paddles to simultaneously drill and inject material. The auger flights loosen the soil as they move through the subsurface allowing the soils to be mixed with the paddles. The technique may be used to homogenize existing materials or to blend materials into the soil. ISSM can also improve the structural properties of soil (e.g., strength) to facilitate beneficial reuse of land. As described below, ISSM of AOC 11 is estimated to take 5-6 months to complete.

#### **4.3.3.1 Conceptual Model**

The overlays of the AOC 11 CSM plan and cross section for the ISSM technology are shown on Figures 31 and 32. The process creates individual columns of material, which are overlapped to



create walls or divided to create block or grid patterns. The actual column size and depth depend on site conditions and equipment capabilities and would be determined through bench scale testing (to determine mixing ratios and rates) and site observations (e.g., the maximum depth of the LNAPL smear zone).

#### **4.3.3.2 Additional Data Requirements**

Data requirements for ISSM are identified in Section 3.4.3. In general, a significant amount of the data has already been collected. Specifically, the depth to free product and groundwater, the thickness of the free product, and the potential smear zone are assumed to be 11 to 13 feet bgs. An average depth of mixing of 15 feet has been assumed for AOC 11 based on this information.

A few outstanding data gaps/uncertainties have been identified:

- Bench-scale testing to evaluate the effectiveness of mixing soil layers using various ratios of grout and mixing times with respect to immobilizing/stabilizing the LNAPL. Although soil mixing can be used as a delivery system for a variety of remediation additives (e.g. zero valent metals, biological agents, potassium permanganate, etc.), only mixing with grout has been assumed for this alternative. Bench scale testing will also provide useful information to determine optimum equipment operation specifications such as auger advancement rates, grout injection rates, and number of augers strokes necessary to produce a homogeneous mixture.
- Details concerning surface structures and utilities (e.g., buildings, streets, parking lots) overlying the target treatment area. Such details may include location, depth, size, materials of construction, etc.

#### **4.3.3.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. Work Planning. This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. Field investigation. This would involve collecting any additional information necessary to establish baseline conditions and implementation of ISSM techniques. It is assumed to include:
  - Collection of soil samples for bench-scale testing. The soils investigation would include SPT, grain-size analysis, soils classification, and chemical analysis. A drill rig would be required to perform SPTs. Soil samples for grain-size analysis and soil classification would be collected from various depths and locations in order to produce results that allow for natural spatial variability. It is assumed that up to 15 locations would be evaluated with a maximum of three soil samples collected from each location, depending on the subsurface conditions encountered.

- Bench-scale testing. This would be conducted to evaluate optimum mix ratios and to determine equipment operation specifications including auger advancement and injection rates. Pre-construction laboratory batch testing would be performed on representative soil samples using simulated soil mixing. The testing would be performed in a series of steps: 1) soil samples collected from the site will be run for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction to establish untreated conditions; 2) the grout content of the slurry would be varied by weight and the slurry addition rate would be varied by volume to determine optimal mix ratios; 3) various pre-determined mixing times (i.e., 30, 60, 90, and 120 minutes) would be analyzed; and 4) the soils would be retested for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction to analyze the varied impacts of each of these treatments.
- Surveying. This would be conducted to delineate the plume boundaries and layout the drilling grid pattern. A utility survey and coordination with utility providers to remove and relocate utility lines would be completed.

#### **4.3.3.4 Physical Access Requirements**

Removal of debris or underground obstructions must be conducted prior to treatment as they can limit drilling ability. ISSM requires surface access to all locations where soils are contaminated, which rules out its effective use if contamination underlies buildings.

The estimated extent of free phase product underlies paved portions of the parking lot and roads. Portions of the parking lot and access roads would have to be removed prior to conducting ISSM in these areas. This would reduce access to the Jet Fuel A and AVGAS 100LL dispensing station.

All nearby utilities would be located before the design drawings are completed in order to minimize damage and downtime to any utilities that would be disturbed. According to previous reports and site visits, utilities including water, electric, sanitary sewer, and fuel lines are present within the estimated extent of the free phase product plume. Active utilities would likely have to be relocated prior to conducting ISSM in these areas. The concrete anchors associated with the fuel lines would also have to be removed. The AVGAS 100LL AST would have to be relocated in order to complete ISSM of the free phase product area.

#### **4.3.3.5 Construction/Implementation**

Temporary field offices, work zones, and a decontamination pad for equipment would need to be established. A mixing system and batch plant consisting of storage silos, metering and blending devices, and pumps would need to be set up for the addition of stabilizing additives (i.e., grout) proposed. A water and electricity source would need to be established for the batch plant system. Utilities, remaining fuel lines, and concrete anchors discussed in the preceding section would be removed or relocated prior to initiating ISSM.

Specialty equipment including shrouds equipped with air controls to capture fugitive emissions would be mobilized. It is anticipated that VOC emissions would need to be treated and controlled during the ISSM phase. A SVE unit would be used to control odors. The unit

consists of a metal shroud or hood that is placed over the mixing area to trap potentially hazardous vapors and fugitive dust releases from the soils. Vapors and fugitive dust are drawn through a vacuum hose attached to a shroud. The vapors then enter a treatment unit, which typically includes an air separator, high-efficiency particulate air filter, and activated carbon unit(s). After treatment, air would be released to the atmosphere.

The free phase product area would be surveyed and gridded prior to beginning ISSM. ISSM would progress laterally according to the grid system. A column size of 8 feet diameter with 20 percent column overlap has been assumed. The vertical distribution of free phase product has been estimated to range from 11-13 feet bgs. ISSM would be performed to an approximate depth of 15 feet bgs to extend below the maximum LNAPL smear zone. Samples would be visually inspected for homogeneity and the presence of NAPL and confirmation samples collected at the time of mixing for laboratory analysis and soil characterization testing. Confirmation samples would be collected at a frequency of once per 1,000 cubic yards and analyzed for BTEX, PAHs, TPH-Light Distillate Fraction, and Middle Distillate Fraction (25 samples). Selected soils would also be tested to determine the BUSTR soil classification, so that analytical results could be correctly evaluated with respect to RAOs.

Temporary construction fencing would be placed around all disturbed construction areas until the site has been restored to a manner in which it would be safe for general public access.

#### **4.3.3.6 Operation**

No long term operation or maintenance would be required for this technology. However, per BUSTR requirements, monitoring would be required to demonstrate that remedial action objectives have been achieved and that no further action is appropriate due to concentrations below action levels as a result of ISSM of soil contaminated with free phase product.

It has been assumed that quarterly groundwater monitoring would be conducted for one year following the ISSM remedial action as specified under work planning. Samples would be collected from seven existing on-site wells outside the treatment area and would be analyzed for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction. Because of the stabilizing objectives of the treatment, new monitoring wells would not be installed within the treated area. Soil sampling during mixing should adequately demonstrate treatment effectiveness within that area.

#### **4.3.3.7 Waste Management**

Because ISSM is an in-situ technique, disposal cost and worker exposure are minimized and dewatering would not be necessary. Only a small amount of grout is typically added during mixing, so the increase in soil volume is usually slight. It has been conservatively estimated that up to 15 percent of the original soil volume would be disposed of as a special waste at a solid waste landfill (refer to Section 4.3.2.7) to account for increases in volume and to maintain the existing site elevation with the addition of topsoil.

The activated carbon units from the soil vapor extraction system would be reprocessed or disposed of in accordance with applicable regulations.

#### **4.3.3.8 System Shutdown and Demobilization**

System shutdown and demobilization would involve removal of temporary field offices, decontamination pads, mixing system, and batch plant. All equipment and augers would be decontaminated prior to demobilization.

#### **4.3.3.9 Site Restoration**

Site restoration would include placement of six inches of topsoil capable of sustaining vegetative growth. Due to heavy traffic in this area, structural backfill would be used. Utilities would be restored as necessary. Parking lots and roadways would be repaved with asphalt and concrete curbs would be replaced to original condition. Once all major construction traffic has been eliminated from the site, previously vegetated areas would be seeded. Straw bales would be placed around storm sewer inlets until vegetative growth has been stabilized to prevent sediment from erosion from entering the sewers.

#### **4.3.4 Multiphase Extraction**

The MPE process was developed for the remediation of LNAPL, aromatic VOCs, TPH, and chlorinated VOCs in moderate permeability subsurface formations. The technology is meant to address contaminants in free-phase liquid, residual and adsorbed phases, and vapors. MPE simultaneously extracts both liquid (groundwater and LNAPL) and soil vapor.

##### **4.3.4.1 Conceptual Model**

The overlays of the AOC 11 CSM plan and cross section for the MPE technology are shown on Figures 33 and 34. In MPE, the groundwater table is lowered in order to dewater the saturated zone so that the SVE process can be applied to the exposed soil. This allows VOCs adsorbed on the previously saturated soil to be stripped by the induced vapor flow and extracted. The increased air movement through the unsaturated zone also increases oxygen content and enhances aerobic bioremediation. The lowering of the water table also allows residual phase product trapped within the pore space of the previously saturated zone to coalesce into free phase liquid, allowing it to flow toward a recovery well, where a skimming pump may also be used to remove LNAPL.

##### **4.3.4.2 Additional Data Requirements**

In general, a significant amount of the data has already been collected. The site geology and hydrogeology; concentrations and distributions of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, biodegradation parameters up-gradient and down-gradient of the source area, and potential receptors have all been to some extent previously investigated at AOC 11. Some of these data are summarized in Section 2.0 and 3.1.

In addition, the WIDE pilot study at AOC 3 provides an indication of potential extraction rates and waste generation from an MPE system. It also indicates that while MPE would be effective

in removing a certain mass of subsurface contaminants, additional remedial measures or long term monitoring might be needed before RAOs are met. The draft MNA assessment determined that some of the more biodegradable compounds are declining in the contaminated zone, but that aerobic degradation is not occurring at a significant rate. This is relevant both to the potential for MPE to enhance biodegradation and for biodegradation of residual contamination following MPE. A few outstanding data gaps/uncertainties have been identified:

- The most effective MPE configuration needs to be determined for site conditions. This includes determining the appropriate well spacing based on the well radius of influence and the most effective type of extraction system. On the basis of the WIDE pilot study, it appears that total fluids extraction would be the most effective MPE system, but a pilot study has been assumed to further evaluate this and determine the appropriate well spacing.
- Vertical soil gas profiles need to be developed to evaluate baseline soil vapor conditions and to evaluate contaminant removal and biodegradation during and after MPE. Installation of nested gas wells to monitor gas concentrations at various levels has been assumed for this alternative.
- Waste streams resulting from the operation of a multi-phase extraction system need to be characterized for regulatory compliance and the need for possible treatment. Waste streams to be characterized would include: 1) discharged wastewater, 2) collected free product, and 3) air emissions from soil vapor extraction. This information could be obtained during the pilot study.

#### **4.3.4.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. Work Planning. This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation and pilot-scale testing. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. Field investigation. This would involve collecting any additional data required to establish baseline conditions. It is assumed to include:
  - Three nests of gas wells installed inside the free product area and one gas well nest installed at background location. The number of nested wells would be contingent on the depth to LNAPL at the specific location, but assuming an average depth of 14 feet, three nested wells would be installed to monitor soil from 3-7 feet, 7-11, and 11-14 feet bgs.
  - Groundwater level measurements, free product measurements, and collection of groundwater samples from existing wells to evaluate baseline conditions. All the samples would be analyzed for BTEX, MTBE, PAHs, TPH-Light Distillate Fraction and Middle Distillate Fraction, nitrate, sulfate, iron, and manganese

(degradation products). Ferrous iron, ORP, pH, specific conductivity, DO, and turbidity would be measured in the field.

- Collection of soil gas samples from the 12 soil vapor wells and analysis for benzene using a portable gas chromatograph and methane and oxygen using a portable gas analyzer. Two samples would be collected and sent to a laboratory for chemical analysis for BTEX and methane to verify field testing results.
- Installation of an MPE well and performance of a test to evaluate radius of influence, recoveries of all phases, and treatment and disposal requirements for vapor, groundwater, and LNAPL.

#### **4.3.4.4 Physical Access Requirements**

Existing fueling facilities, underground utilities, and concrete parking areas and taxiways present significant hindrance to access for investigation and implementation of MPE at AOC 11. Much of the contaminated area lies beneath substantial concrete and in the vicinity of an operating fueling station. Further investigation and implementation of the remedy may be possible with strategic placement of wells, utilities and other facilities, but design compromises are likely. It is assumed that demolition and reconstruction of existing facilities at AOC 11 is impractical and was not considered for implementation of this option.

Physical access would be required for well installation, soil vapor and groundwater monitoring, installation of the MPE extraction and treatment systems, waste storage, and system operation. If needed, a driveway sealant may be applied to the pavement to make it water-resistant and somewhat impervious to air flow. If a highly permeable sub-grade is present beneath the pavement, it may be necessary to place a barrier at the edge of the paved area to prevent the high permeability zone from leaking air. There appears to be sufficient space for the building, equipment, and waste storage facilities that would be required to implement this option. Power is available nearby.

#### **4.3.4.5 Construction/Implementation**

Soil vapor monitoring wells would be installed during the planning phase. The MPE system and waste storage and treatment systems would be installed during the implementation phase. It has been assumed that the MPE system would consist of 257 wells with screened sections, using a total fluid extraction system similar to the WIDE pilot study.

#### **4.3.4.6 Operation**

This technology would require on-site operation and monitoring of the MPE system for an estimated time of approximately three to eight years. This would include treating and disposing of extracted LNAPL, vapor, and groundwater. It has been assumed that a compressor or compressors would be used to generate a vacuum through a manifold piping and well system similar to the WIDE system. The combined waste stream would be routed to blow-down, liquid/gas separation tanks. Quantities of LNAPL and VOCs generated would be tracked, and soil, vapor, and groundwater concentrations monitored during operation. Since it is likely that residual contamination would remain after MPE has been completed, annual soil vapor and

groundwater monitoring has been assumed for a minimum of 10 years following treatment. Monitoring would be conducted as specified for NSZD (Section 4.3.1.6).

#### **4.3.4.7 Waste Management**

Waste management during the investigation, construction and monitoring phases would be limited to disposal of drums of soil cuttings and monitoring well purge water. During the operational phase, LNAPL and contaminated vapor and groundwater would be generated. It has been assumed that LNAPL would be disposed of through a fuel recycler, and contaminated groundwater would be treated in an on-site treatment system. Treated groundwater would be discharged to the sanitary sewer. Although the WIDE system released gas vapors to the air without treatment, it has been assumed that carbon would be used to treat vapors prior to release at least initially during full-scale implementation until contaminant concentrations begin to decrease. Depending on the extent of contamination, the carbon adsorption units might need to be replaced to ensure thorough removal of contaminants from the extracted groundwater and off-gas. Permits would likely be needed for wastewater discharge and air emissions. Actual waste generation rates and treatment and disposal requirements would be determined during the pilot study.

#### **4.3.4.8 System Shutdown and Demobilization**

System shutdown would involve dismantling piping and removing storage tanks and the treatment system from the site. Monitoring and MPE wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.3.4.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

### **4.3.5 Multi-phase Extraction with Heating**

MPEH was developed for the remediation of LNAPL, aromatic VOCs, TPH, and chlorinated VOCs in low to moderate permeability subsurface formations. The process is a modification of the conventional MPE system and is meant to address contaminants in free-phase liquid, residual and adsorbed phases, and vapor.

The information provided in the previous summary for MPE also applies to MPEH. Heating is added to conventional MPE to increase the rate of recovery, or the range of contaminants that can be recovered, by the process. Soil heating will volatilize higher molecular weight compounds that a traditional MPE system will not affect, will reduce the viscosity of free-phase and residual NAPL, and will increase chemical reaction rates for contaminant breakdown.

#### **4.3.5.1 Conceptual Model**

The overlays of the AOC 11 CSM plan and cross section for the MPEH technology are shown on Figures 35 and 36. Similar to traditional MPE, the groundwater table is lowered in order to

dewater the saturated zone so that the SVE process can be applied to the exposed soil. The added heating component is achieved through the use of technologies such as steam injection, hot compressed air injection, electrical resistance heating, or radio-frequency heating. This technology requires electrical power or waste heat from a nearby utility or industrial source. The use of hot air from the vapor condensation process equipment has been assumed in developing this technology, but the actual heating system would need to be selected in the work planning and design phases.

The use of MPEH should be distinguished from ERH as described in Section 4.3.8. Although electrical resistance is among the technologies that may be used as a heat source in MPEH, the temperatures and rate of vapor generation in this application are much lower than those generated for ERH as a stand-alone technology.

#### **4.3.5.2 Additional Data Requirements**

In general, a significant amount of the data has already been collected. The site geology and hydrogeology, concentrations and distributions of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, biodegradation parameters up-gradient and down-gradient of the source area, and potential receptors have all been to some extent previously investigated at AOC 11. Some of these data are summarized in Section 2.0 and 3.1.

In addition, the WIDE pilot study at AOC 3 provides an indication of potential extraction rates and waste generation from an MPE system. The draft MNA assessment determined that some of the more biodegradable compounds are declining in the contaminated zone, but that aerobic degradation is not occurring at a significant rate. This is relevant both to the potential for MPEH to enhance biodegradation and for biodegradation of residual contamination following MPEH.

A few outstanding data gaps/uncertainties have been identified:

- The most effective MPEH configuration needs to be determined for site conditions. This includes determining the appropriate well spacing based on the well radius of influence and the most effective type of extraction system. On the basis of the WIDE pilot study, it appears that total fluids extraction would be the most effective MPE system, but a pilot study has been assumed to further evaluate this and determine the appropriate well spacing. Because heating would be used to enhance MPE rather than as a stand-alone technology, a pilot study is not considered necessary to determine the heating system design.
- Vertical soil gas profiles need to be developed to evaluate baseline soil vapor conditions and to evaluate contaminant removal and biodegradation during and after MPEH. Installation of nested gas wells to monitor gas concentrations at various levels has been assumed for this alternative.
- Waste streams resulting from the operation of a multi-phase extraction system need to be characterized for regulatory compliance and the need for possible treatment. Waste streams to be characterized would include: 1) discharged wastewater, 2) collected free



product, and 3) air emissions from soil vapor extraction. This information could be obtained during the pilot study.

#### **4.3.5.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. **Work Planning.** This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation and pilot-scale testing. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. **Field investigation.** This would involve collecting any additional data required to establish baseline conditions. It is assumed to include:
  - Three nests of gas wells installed inside the free product area and one gas well nest installed at background location. The number of nested wells would be contingent on the depth to LNAPL at the specific location, but assuming an average depth of 14 feet, three nested wells would be installed to monitor soil from 3-7 feet, 7-11, and 11-14 feet bgs.
  - Groundwater level measurements, free product measurements, and collection of groundwater samples from existing wells to evaluate baseline conditions. All the samples would be analyzed for BTEX, MTBE, PAHs, TPH-Light Distillate Fraction and Middle Distillate Fraction, nitrate, sulfate, iron, and manganese (degradation products). Ferrous iron, ORP, pH, specific conductivity, DO, and turbidity would be measured in the field.
  - Collection of soil gas samples from the 12 soil vapor wells and analysis for benzene using a portable gas chromatograph and methane and oxygen using a portable gas analyzer. Two samples would be collected and sent to a laboratory for chemical analysis for BTEX and methane to verify field testing results.
  - Installation of a MPE well and performance of a test to evaluate radius of influence, recoveries of all phases, and treatment and disposal requirements for vapor, groundwater, and LNAPL.
  - Surveying. This would be conducted to delineate the plume boundaries and lay out the heating element pattern.

#### **4.3.5.4 Physical Access Requirements**

Existing fueling facilities, underground utilities, and concrete parking areas and taxiways present significant hindrance to access for investigation and implementation of MPE at AOC 11. Much of the contaminated area lies beneath substantial concrete and in the vicinity of an operating fueling station. Further investigation and implementation of the remedy may be possible with strategic placement of wells, utilities and other facilities, but design compromises are likely. It is

assumed that demolition and reconstruction of existing facilities at AOC 11 is impractical and was not considered for implementation of this option.

Physical access would be required for well installation; soil vapor and groundwater monitoring, installation of the MPEH extraction, heating, and treatment systems; waste storage; and system operation. If needed, a driveway sealant may be applied to the pavement to make it water-resistant and somewhat impervious to air flow. If a highly permeable sub-grade is present beneath the pavement, it may be necessary to place a barrier at the edge of the paved area to prevent the high permeability zone from leaking air. There appears to be sufficient space for the building, equipment, and waste storage facilities that would be required to implement this option. Power is available nearby.

#### **4.3.5.5 Construction/Implementation**

Soil vapor monitoring wells would be installed during the planning phase. The MPE, heating, waste storage, and treatment systems would be installed during the implementation phase. It has been assumed that the MPE system would consist of 193 wells with screened sections, using a total fluid extraction system similar to the WIDE pilot study.

If low temperature in-situ thermal desorption using hot air injection is chosen as the heating technology, approximately 480 heating wells would be utilized. Waste heat from the vapor condensation process equipment would be captured and injected into the vadose zone to increase vadose zone temperatures, thereby increasing the volatilization of the contaminants. A matrix of thermocouples would be installed in the treatment area to monitor the temperature at various locations below ground.

Temporary construction fencing would be placed around the thermally-treated area until the site has been restored to a manner in which it would be safe for general public access.

#### **4.3.5.6 Operation**

This technology would require on-site operation and monitoring of the MPEH system for an estimated time of approximately two to three years. This would include treating and disposing of extracted LNAPL, vapor, and groundwater. It has been assumed that a compressor or compressors would be used to generate a vacuum through a manifold piping and well system similar to the WIDE system. The combined waste stream would be routed to blow-down, liquid/gas separation tanks. Quantities of LNAPL and VOCs generated would be tracked, and soil, vapor, and groundwater concentrations monitored during operation. Since it is likely that some residual contamination would remain after MPEH has been completed (although less than MPE), annual soil vapor and groundwater monitoring has been assumed for a minimum of 5 years after treatment. Monitoring would be conducted as specified for NSZD (Section 4.3.1.6).

#### **4.3.5.7 Waste Management**

Waste management during the investigation, construction and monitoring phases would be limited to disposal of drums of soil cuttings and monitoring well purge water. During the operational phase, LNAPL and contaminated vapor and groundwater would be generated. It has been assumed that LNAPL would be disposed of through a fuel recycler and contaminated

groundwater would be treated in an on-site treatment system. Treated groundwater would be discharged to the sanitary sewer. Although the WIDE system released gas vapors to the air without treatment, it has been assumed that carbon would be used to treat vapors prior to release during full-scale implementation. Permits would likely be needed for wastewater discharge and air emissions. Actual waste generation rates and treatment and disposal requirements would be determined during the pilot study.

#### **4.3.5.8 System Shutdown and Demobilization**

System shutdown would involve dismantling piping and removing wells, electrodes, storage tanks, and the treatment system from the site. Monitoring and MPE wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.3.5.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

### **4.3.6 In-Situ Chemical Oxidation**

ISCO employs the injection of chemical oxidants directly into the aquifer to react with and destroy dissolved-phase organic constituents. ISCO is usually employed as a source control measure for high concentration *dissolved-phase* contaminants at or near the original release. The presence of high concentrations of naturally occurring organic materials will increase the oxidizing agent dose required for effective destruction, and may decrease overall performance.

Because this technology involves the introduction of oxidant solution into the subsurface, excellent hydraulic control and containment are necessary to prevent spreading contaminants over a larger area. Before design and implementation of this technology, geologic conditions must be well characterized through investigation and pilot testing. Since this technology is difficult to implement at sites with geologic conditions that are significantly heterogeneous or with low hydraulic conductivities, and since it is most effective on dissolved contaminants, it is likely to be ineffective at any of the three LAFB AOCs.

#### **4.3.6.1 Conceptual Model**

Because this technology is not likely to be effective, the number of injection points and likely support facilities have not been evaluated in detail, and CSM overlays have not been prepared. Subsurface injection is generally performed using direct push technology or a network of temporary or permanent injection wells. Considering that ISCO would likely require numerous applications at AOC 11, the construction of permanent injection wells would be most cost effective and practical. A pilot study is recommended to evaluate the radius of influence and appropriate well spacing. High pressure injection may be employed to increase the radius of influence and reduce the number of injection points. Multiple applications are often required to meet remedial endpoints.

#### **4.3.6.2 Additional Data Requirements**

Data requirements to both qualitatively and quantitatively assess the potential for ISCO as a remedial technology and to establish baseline conditions for long-term evaluation are considerable. However, a significant amount of the data has already been collected. The site geology and hydrogeology, concentrations and distributions of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, and potential receptors have all been to some extent previously investigated at AOC 3. Some of these data are summarized in Section 2.0 and 3.1. A few outstanding data gaps/uncertainties have been identified:

- The radius of influence and associated number of injection points would need to be determined based on site conditions. A pilot study would be needed to further evaluate injection hydraulics and to determine the appropriate well spacing.
- The potential for adverse impacts such as reduction in permeability and re-solubilization of metals due to the oxidizing effects needs to be evaluated under site conditions. This would also be evaluated during the pilot study.
- The oxidant demand associated with both the contaminants and naturally occurring organic materials needs to be determined. This could be obtained from soil and groundwater samples collected during the pilot study.
- Details need to be obtained regarding subsurface structures and utilities to avoid potential physical or chemical damage to these items during installation and treatment. This includes location, depth, size, materials of construction, etc. This is a more significant issue for AOC 11 than for AOC 3 or AOC 9.

#### **4.3.6.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. **Work Planning.** This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation and pilot-scale testing. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. **Pilot-scale Testing.** Pilot-scale testing is required to provide data regarding radius of influence, required injection well spacing, and required oxidant injection dose. Underground structures and utilities would be surveyed and evaluated, as necessary.
3. **Final Design.** The results of the pilot test would be used to refine and optimize the work plans and finalize the design for full-scale implementation. The final design would specify well spacing, oxidant type and dose, and required on-site facilities for storage and periodic injection of the chemicals. Protection or relocation of subsurface structures and utilities would be addressed as necessary to avoid adverse impacts.

#### **4.3.6.4 Physical Access Requirements**

Physical access required would be for pilot testing, injection well installation, storage structure construction, and groundwater monitoring. Although there are some utilities in the area, it is assumed that the proposed activities would work around those locations. Air Cargo Terminal #4 and associated parking areas and utilities would not be affected by the implementation of this alternative. There appears to be sufficient space for a storage structure, equipment, and waste storage facilities that would be required to implement this option.

#### **4.3.6.5 Construction/Implementation**

Injection wells, as well as groundwater monitoring and extraction wells, a storage structure (for storage of ISCO chemicals, mixing and injection equipment), and a waste storage pad would need to be constructed. The quantity and placement of these structures would be dependent on the results of the pilot test.

#### **4.3.6.6 Operation**

Full-scale implementation would include injection of the selected ISCO solution in numerous wells located throughout the target treatment zone. Post-remediation monitoring would follow the injection process. Multiple rounds of oxidant injection and monitoring would be required to achieve remediation endpoints.

This technology would require quarterly groundwater monitoring following the remediation (one or more injections) to evaluate the effectiveness of the treatment and potential adverse effects.

#### **4.3.6.7 Waste Management**

Because ISCO is an in-situ technology, the amount of waste that is generated is relatively small in comparison with many ex-situ remediation approaches. Waste management during investigation and monitoring activities would be limited to disposal of drums of soil cuttings and monitoring well purge water, and the original drums/containers in which the oxidant is shipped. On the basis of concentrations detected in samples within the free product area, the soil would be disposed of as a special waste, and the purge water would be disposed of at a publicly owned wastewater treatment plant.

#### **4.3.6.8 System Shutdown and Demobilization**

System shutdown would involve abandonment of ISCO injection points and monitoring wells. The injection points and wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9. Above-ground pumps, treatment equipment, waste storage facilities and any temporary remediation buildings would need to be removed.

#### **4.3.6.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

#### **4.3.7 Surfactant Enhanced LNAPL Removal**

SELR is a technique to remove LNAPL from the saturated zone by introducing a manufactured chemical surfactant to mobilize contaminants and allow recovery using conventional groundwater extraction. The introduction of surfactant allows free-phase and residual-phase LNAPL to be dispersed into the aqueous phase, where it is more easily recoverable through groundwater extraction. Because this technology involves the introduction of a manufactured chemical into the subsurface, excellent hydraulic control and containment are necessary to prevent spreading LNAPL and surfactants over a larger area. Before design and implementation of this technology, geologic conditions must be well characterized through investigation and pilot testing. Since this technology is more difficult to implement at sites with geologic conditions that are significantly heterogeneous or with hydraulic conductivities less than  $10^{-3}$  cm/sec, it is likely to be ineffective at any of the three LAFB AOCs. It should be noted that this technology also will not address contaminants that are present in the smear zone at an elevation above the water level.

##### **4.3.7.1 Conceptual Model**

Because this technology is not likely to be effective, it has not been developed in detail, and CSM overlays have not been prepared. The most common technique for the use of surfactants is a flooding configuration. This involves the preparation of low viscosity surfactant solutions that are injected into the subsurface and then migrate through the contaminated zone based on the hydraulic gradient. The surfactant is put into the ground through up-gradient injection points and then removed down-gradient through extraction wells located within the capture zone. The extracted fluid requires treatment or off-site disposal. An extensive down-gradient groundwater monitoring network should be established to prevent and document the risk of possible breakthrough.

##### **4.3.7.2 Additional Data Requirements**

A significant amount of the data required for this technology has already been collected. The site geology and hydrogeology, concentrations and distribution of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, and details regarding subsurface structures in and around the target area have all been previously investigated.

The following data are required to fully evaluate and implement this alternative:

- Identification of potential receptors that may be impacted by possible migration of the LNAPL and surfactant beyond the intended capture zone.
- Soil and contaminant characteristics that would determine the flushing fluids required, flushing fluid compatibility, and changes in flushing fluids with changes in contaminants.

- Groundwater flow conditions. A pilot test would need to be completed to determine whether the gradients necessary for capturing the contaminant and surfactant fluids can be established for sufficient contaminant contact and recovery. Heterogeneous soil environments may not allow sufficient chemical contact or sufficiently uniform gradients for successful implementation.
- Waste streams resulting from the operation need to be characterized for regulatory compliance and treatment or off-site disposal. Waste streams to be characterized would include discharged wastewater containing surfactant and recovered product.

#### **4.3.7.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. Work Planning. This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation and pilot-scale testing. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. Field investigation. This would involve collecting any additional data required to establish baseline conditions as well as completing a field-scale testing. It is assumed to include:
  - An extensive study of subsurface soil conditions to: 1) document soil heterogeneities, 2) measure hydraulic conductivities on a scale consistent with the size of the heterogeneities, and 3) identify if sufficiently continuous flow paths exist within the subsurface. This study should include hydraulic probe sampling on a grid with approximate 10 foot centers throughout the area of implementation.
  - Groundwater level measurements, free product measurements, and collection of LNAPL samples for fuel component analysis and chemical and physical properties.
  - A pilot test to provide data regarding surfactant enhanced LNAPL removal, required injection well spacing, and required surfactant injection dose. The results of the field-scale testing would be used to refine and optimize the RAP and monitoring plans.

#### **4.3.7.4 Physical Access Requirements**

Physical access required would be for pilot testing, injection point installation, well installation, treatment building construction, SELR operation, and groundwater monitoring. The only physical access required would be for well installation and gas and groundwater monitoring. Although there are quite a few structures and utilities in the area, it is assumed that the proposed activities would work around those locations and would not affect jet fuel storage or delivery or the operation of the AVGAS containment area. There appears to be sufficient space for the building, equipment, and waste storage facilities that would be required to implement this option.

#### **4.3.7.5 Construction/Implementation**

Injection and extraction wells, extraction piping, storage tanks, and a treatment system would have to be constructed/installed at the site. The number of injection and extraction wells and the treatment system capacity would be dependent on findings from the pilot test.

#### **4.3.7.6 Operation**

Before beginning to inject surfactant, as much free product as possible would be recovered from the extraction wells. Once this has been completed, surfactant would be injected at numerous wells or injection points located throughout the target treatment zone. Surfactant and mobilized LNAPL and groundwater would be pumped from the extraction wells to the treatment system. If feasible, surfactant would be separated from the contaminated water for re-use. Multiple rounds of surfactant injection and monitoring might be required to achieve remediation endpoints.

This technology would require quarterly groundwater monitoring following remediation (one or more injections) to evaluate the effectiveness. Groundwater samples would be analyzed for BTEX, PAHs, and TPH-Light Distillate Fraction and Middle Distillate Fraction.

#### **4.3.7.7 Waste Management**

Waste management during investigation and monitoring activities would be limited to disposal of drums of soil cuttings and monitoring well purge water. On the basis of concentrations detected in samples within the free product area, the soil would be disposed of as a special waste, and the groundwater would be disposed of at a publicly owned wastewater treatment plant.

Following the injection process, treatment of extracted water would include separation of surfactant (as feasible), and water treatment to remove contaminants to acceptable levels for discharge to the sanitary sewer. Air emissions of volatile contaminants from recovered flushing fluids should be collected and treated according to regulatory guidance. Permits would be needed for wastewater discharge and air emissions.

#### **4.3.7.8 System Shutdown**

System shutdown would involve dismantling piping and removing storage tanks and the treatment system from the site. Monitoring, injection, and extraction wells would be sealed in accordance with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.3.7.9 Site Restoration**

Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

### **4.3.8 Electrical Resistance Heating**

As discussed in Section 3.9.1, ERH uses the heat resulting from the resistance of soil to the flow of electricity to evaporate and release contaminants from soil and groundwater. The resistance to



electric flow by the soil causes the formation of heat resulting in increased temperatures until the boiling point of water is reached. As the heat is applied, contaminants are volatilized and mobilized within the soil matrix. Thermal methods can be particularly useful for both DNAPL and LNAPL. ERH is distinguished from MPEH (discussed in Section 4.3.5) in that the heating in ERH would be more aggressive, operating at a higher temperature, and would not include the pumping of groundwater. It is most effective on organic compounds that are readily volatilized and requires greater energy input to treat less volatile compounds. For remediation of DNAPL or LNAPL, ERH is often co-located with a MPE system to aid in recovering the less volatile contaminants.

#### **4.3.8.1 Conceptual Model**

The overlays of the AOC 11 CSM plan and cross section for the ERH technology are shown on Figures 37 and 38. ERH uses arrays of electrodes installed around a central neutral electrode to create a concentrated flow of current toward the central point. Resistance to flow in the soils generates heat greater than 100°C, producing steam and volatilized contaminants that are recovered via vacuum extraction. Recovery wells maintain vacuum during ERH operations and ensure the capture of vapors and steam from the subsurface. Each vapor recovery well is connected to pipes which convey vapor and steam to the condenser unit.

ERH can be utilized to reach very low contaminant concentrations and is effective in low-permeable hydrogeology such as clays, silts, and tills. Residual heat that may remain for months or years after treatment may also enhance continuing attenuation through biodegradation, hydrolysis, etc.

#### **4.3.8.2 Additional Data Requirements**

A significant amount of the data required for this technology has already been collected. The site geology and hydrogeology, concentrations and distribution of contaminants in soil and groundwater, chemical and physical properties of the LNAPL, horizontal and vertical distribution of the LNAPL, and details regarding subsurface structures in and around the target area have all been previously investigated.

A few outstanding data gaps/uncertainties have been identified that are especially relevant to the installation of the electrode array:

- Location, depth, and dimensions of portions of fuel lines that were plugged and abandoned in place, as well as concrete tank anchors left in place.
- Details concerning subsurface structures and utilities at or in the vicinity of the target treatment area. Such details may include location, depth, size, and materials of construction.
- Naturally occurring  $f_{oc}$  of soils in target treatment zones.
- L distribution, thickness, and chemical and physical properties.

- Waste streams resulting from the operation of an ERH system need to be characterized for regulatory compliance and the need for possible treatment. Waste streams to be characterized would include: 1) condensate and 2) air emissions from vapor extraction.

#### **4.3.8.3 Plan Development (Design)**

This technology would involve the following planning phases:

1. Work Planning. This would include development of the RAP, monitoring plan, and bid documents, as well as planning documents for additional investigation. The investigation planning documents would include a work plan, quality assurance project plan, and health and safety plan.
2. Field investigation. This would involve collecting any additional data required to establish baseline conditions. It is assumed to include:
  - Groundwater level measurements, free product measurements, and collection of LNAPL samples for fuel component analysis and chemical and physical properties.
  - Collection of soil samples to evaluate residual contaminant concentrations and distribution and  $f_{oc}$ .
  - Surveying. This would be conducted to delineate the plume boundaries and lay out the electrode pattern.

#### **4.3.8.4 Physical Access Requirements**

Access to the area near the contamination is required, but ERH can be applied to treat contaminated soils under existing structures so direct access to affected soil is not required. Although there are some utilities in the area, it is assumed that the proposed activities would work around those locations. There appears to be sufficient space for a treatment building and equipment that would be required to implement this option. Power requirements and availability will need to be evaluated during design, but is not expected to be a constraint.

#### **4.3.8.5 Construction/Implementation**

Existing electrical power at the site would be utilized, or power may be generated on-site via fuel combustion or solar energy. Equipment related to power generation, power control, soil vapor and steam recovery, and vapor destruction, if needed, would be brought to or constructed on site. A utility transformer and a power control unit would be brought to the site to step down voltage for controlled distribution into the electrodes.

A field of electrodes and vapor recovery wells would be installed below ground to depths defining the limits of contamination. Electrodes and vapor recovery wells would be designed and installed based on site characteristics. These two design features could be co-located to reduce project costs and improve system efficiency.

Assuming an average electrode placement of one electrode per 280 ft<sup>2</sup> of contamination, it is estimated that approximately 120 electrodes would be utilized. The electrodes would be installed to a depth of approximately 26 feet. A matrix of temperature monitoring points would be installed in the treatment area to monitor the temperature at various locations below ground. Each temperature monitoring point would contain strings of thermocouples installed at about 5-foot depth intervals.

Existing utilities at the site would be left in place. If it is determined that PVC pipes are located in the treatment area, those would need to be removed. The existing petroleum USTs and fuel lines would be left in place. Standard grounding techniques would be implemented to prevent belowground metal structures such as these from carrying electrical current outside the remediation area. Operators would be able to remotely run the system via the internet, monitoring treatment temperature, and controlling power and energy application to the system.

Temporary construction fencing would be placed around the affected area until the site has been restored to a manner in which it would be safe for general public access.

#### **4.3.8.6 Operation**

ERH would require frequent on-site monitoring of system operation during implementation. ERH is generally a rapid form of remediation with case studies of effective treatment of soil and groundwater in less than 40 days. It is assumed that remediation using this technology would last no more than nine months. Quarterly groundwater monitoring events are expected for one year following remediation activities.

Ongoing monitoring of surface voltages would be implemented during operation to ensure that surface voltages remain below OSHA standards.

#### **4.3.8.7 Waste Management**

Drums of soil cuttings would be generated during system installation. On the basis of concentrations detected in samples within the free product area, these would be disposed of as a special waste. The ERH condenser separates contaminant vapors from steam. A majority of the contaminants (>99.5% by mass) remain in the vapor state, while the rest are captured in the steam condensate. The resulting condensate is not considered a waste stream and can be recycled back to the process. Any excess condensate can typically be discharged without further treatment.

Contaminant vapors are treated before discharge to the atmosphere. Typical treatment options are activated carbon or thermal or catalytic oxidation. Spent activated carbon would be treated as hazardous waste and properly disposed of. Air emission permits would likely be required.

#### **4.3.8.8 System Shutdown and Demobilization**

Once levels of contamination have been effectively reduced, all equipment related to treatment would be removed from site by the contractor. Monitoring wells would be sealed in accordance

with the Ohio Environmental Protection Agency Water Well Standards Ohio Administrative Code 3745-9.

#### **4.3.8.9 Site Restoration**

Once the electrodes and vapor recovery wells are removed, a small amount of grading and seeding would be completed to restore the site to its original state. Former well locations would be restored by adding topsoil and grass seed or repairing surface concrete, as appropriate.

## 5.0 EVALUATION OF TECHNOLOGIES BY AOC

This section presents the evaluation of each technology with respect to application at each of the three AOCs. The evaluation criteria are based on a streamlined version of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial alternative evaluation criteria, as identified in the EPA *Guidance for Performing Remedial Investigations and Feasibility Studies under CERCLA*, EPA/540/G-89/004, October 1988 (Ref. 41). Each technology is evaluated based on three general criteria: effectiveness, implementability, and cost. For effectiveness, the evaluation considers protection of public safety, compliance with BUSTR requirements, and long-term and short-term effectiveness. For implementability, the evaluation considers technical and administrative feasibility, regulator and community acceptance, and availability of services and materials. Evaluations of the technologies rely on information from the sources cited in Section 3.0, and on the evaluation factors identified in the ITRC *Technical/Regulatory Guidance Evaluating LNAPL Remedial Technologies for Achieving Project Goals*, December 2009 (Ref. 20).

Costs are estimated using general costing assumptions, which are presented in Table 3, and are based on the requirements of each technology and the information and assumptions regarding each AOC presented in Sections 2 and 3. Cost estimates are considered to provide feasibility study level accuracy of +50, -30 percent using available data from previous studies at the AOCs. Detailed cost tables for each technology at each AOC are included in Appendix F.

**Table 3. Cost Assumptions**

Cost Estimate Components	Cost Estimate Assumptions
<p><u>Direct Capital Costs</u>: Includes expenditures for the equipment, labor and materials necessary to implement the technology. Types of direct capital costs considered in this are construction, equipment, land and site development, buildings and services, transportation and disposal costs, analytical costs, and treatment costs.</p>	<p>Costs are in 2012 dollars.</p>
<p><u>Indirect Capital Costs</u>: Includes expenditures for engineering, permitting, financial, and other services that are not part of actual installation activities but are required to complete the installation of the removal alternative. Types of indirect capital costs considered in this are contingencies (bid and scope), permitting and legal costs, and engineering design and construction services.</p>	<p><u>Bid and scope contingencies</u>: unknown costs for items such as adverse weather conditions, strikes, and unfavorable market conditions, as well as changes in scope during design and implementation: 15 percent of the total direct capital cost.</p> <p><u>Permitting and legal costs</u>: 5 percent of total direct capital costs.</p>

Cost Estimate Components	Cost Estimate Assumptions
	<p><u>Engineering design and construction services:</u> design and process development, preparation of specification and bid documents, drafting, and construction oversight/monitoring and testing: 20 percent of the total direct capital cost.</p>
<p><u>Long Term Costs:</u> Periodic costs necessary to ensure the continued effectiveness of an alternative over the lifetime of the alternative. These include administrative oversight, monitoring, periodic replacement, and routine operation and maintenance.</p>	<p>Long term O&amp;M and monitoring costs are developed based on annual expenditure. Equipment replacement frequency may vary with the technology.</p>
<p><u>Present Worth Analysis:</u> Evaluates expenditures that occur over different time periods by discounting all future costs to a common base year. The cost of the technologies can then compared on the basis of a single figure representing the amount of money that, if invested in the base year, would be sufficient to cover all costs associated with each technology over its planned life.</p>	<p>Discount rate is 5 percent before taxes.</p> <p>An annual rate of inflation is incorporated into the discount rate.</p> <p>Capital costs occur in Year 0.</p> <p>Long term costs are for a maximum of 30 years.</p>

The critical issue in evaluating the effectiveness, implementability, and cost of all the technologies at all the AOCs is the volume of LNAPL present in both the saturated and unsaturated zones. In addition, the mass and characteristics of the individual contaminants present in the LNAPL, and the rate of dissolution, volatilization, and biodegradation of those contaminants are critical to some of the technologies. Similarly, the depth of saturated soil and the potential rate of groundwater transport (and extraction or infiltration) are significant to evaluation of some of the technologies. There are multiple site challenges associated with determining these variables, including:

- The heterogeneity of the subsurface conditions. On the basis of the SCAPS data, there may be multiple discontinuous sand lenses that are associated with LNAPL pockets. This makes defining the horizontal width and vertical thickness of the LNAPL extremely difficult. It also complicates estimating groundwater extraction, infiltration, and transport rates.
- The fluctuating groundwater table. This increases the difficulty of estimating the vertical thickness of LNAPL even further, since the smear zone may be several feet thick, and the quantity of LNAPL in the saturated and unsaturated zones may vary with the fluctuating water table.

- The poorly defined groundwater flow conditions, particularly at AOC 3 and 8/9. Groundwater flow in the AOC 3 free product area appears to be predominantly inward along the axis of a trough on the water table surface (Ref. 16), making the designation of “up-gradient” and “down-gradient” relatively meaningless. Similarly, a groundwater depression has been observed in the free product area at AOC 9. These conditions limit the ability to predict subsurface transport of injected materials.

The challenges posed by these conditions and the need for further investigation and/or bench and pilot-scale testing have been assumed in the following evaluations of the technologies. To the extent possible, the standard assumptions identified in Section 3.1 have been applied to all the alternatives. However, due to variations in the technologies themselves, it is nearly impossible to apply the evaluation criteria on an entirely objective and equal basis to all the technologies.

## 5.1 AOC 3

### 5.1.1 Natural Source Zone Depletion

On the basis of the low concentrations of dissolved contaminants outside the free product area, it appears that the rate of dissolution is controlling NSZD at AOC 3. This rate is likely extremely slow because of the subsurface heterogeneity, consequent wide range of hydraulic conductivities, and relatively flat and variable groundwater gradient, as well as low solubility of the COCs remaining in the weathered LNAPL. The qualitative evaluation in the remainder of this section takes into consideration these challenges.

#### 5.1.1.1 Effectiveness

The future effectiveness of this technology is difficult to assess without additional data. However, to the extent that residual free product and COCs above RAOs remain within the free product area, it does not appear that this technology would be effective in achieving the RAOs within a reasonable period of time. The time to achieve RAOs is presumed to be extremely long based on the site conditions and the LNAPL characteristics previously discussed.

The WIDE pilot study commented on “the complex entrapment of jet fuel in the heterogeneous subsurface,” while the draft MNA Assessment concluded that the more soluble and volatile petroleum hydrocarbons have been naturally removed from the LNAPL and that “the remaining LNAPL will be less susceptible to MNA processes, and can be expected to be removed slowly by natural processes.” In addition, LNAPL present in the smear zone will continue to be periodically released as measurable free product on the groundwater surface whenever the water table drops. Therefore, depending on the remaining extent of free product and COCs above RAOs, the long-term effectiveness of this technology alone might be limited in terms of protection of human health and the environment. Protectiveness could be increased by implementing land use restrictions that would minimize potential exposure to subsurface contaminants.

Because this technology involves only well installation and groundwater sampling, the short-term effectiveness is high, in that exposure of workers or the public to contamination at the site during implementation would be limited.

### **5.1.1.2 Implementability**

The technical feasibility of this alternative is high with respect to implementation requirements. The technology requires only conventional, short-term, and demonstrated activities including drilling, sampling, chemical analysis, and disposal of small quantities of contaminated soil and groundwater. Facilities, equipment, and labor necessary to implement these activities are readily available. The site is accessible, and drilling can be planned around existing underground utilities.

Energy requirements and greenhouse gas (GHG) emissions would be very low. Land use restrictions would probably be required, and property owner, regulatory, and public acceptance might be low, since contaminants above RAOs would remain in place for an indeterminate length of time. Long-term monitoring would be required to evaluate the progress of NSZD and verify that no additional migration of dissolved contaminants was occurring. Minimal site restoration would be required after wells have been sealed.

### **5.1.1.3 Cost**

The cost for this is relatively low: \$234,000 capital cost, \$418,000 present worth cost (Table F-1).

## **5.1.2 Excavation**

The critical issues in evaluating the effectiveness, implementability, and cost of excavation are the contaminated soil quantity and characteristics, the depth of excavation, the presence of surface and subsurface obstructions, and the need to manage fluids entering the excavation. Excavation is almost always effective and implementable, but the cost may be excessive if the soil quantity is large, the excavation deep, subsurface structures and utilities must be removed or relocated, or excessive quantities of water must be managed.

### **5.1.2.1 Effectiveness**

Proper construction oversight would make excavation an effective method for permanently removing the majority of the contamination on this site. On the basis of the existing data, excavation in the free product area would remove both the source of the groundwater contamination and soil containing concentrations above the BUSTR RAOs. Assuming all free product is removed during the excavation activities, the site should not see a resurgence of free product in the monitoring wells after construction is completed. Since concentrations of contaminants detected in monitoring wells outside the free product area are already below the BUSTR RAOs, excavation would achieve all the RAOs within the time required to complete excavation (three to six months) and post-remediation monitoring (one year).

Excavation of free product from the site would be effective in protecting the human health and the environment in both the short and the long term. All excavated contaminated material would be removed from the site and disposed of in a RCRA Subtitle D permitted landfill. Although contaminants are not destroyed using this technology, potential exposure to them is minimized by removal from the site and containment in the off-site landfill.



The highest exposure risk would occur during the short term excavation and transportation process. Workers would risk exposure to contaminants through inhalation and dermal contact, and the public could also be exposed to contaminants in the air. Additional releases could occur through surface water runoff from contaminated areas. These potential short-term risks would be minimized by monitoring and controls during the excavation process. Workers would use appropriate personal protective equipment, and air monitoring would be conducted. Controls would be implemented for dust and run-on/run-off, and soil would be transported in covered trailers. On the basis of the relatively low remaining concentrations of volatile organics in the LNAPL, it is unlikely that additional controls would be required for air emissions.

#### **5.1.2.2 Implementability**

Excavation is readily implemented with conventional equipment and services. Commonly available excavation equipment including at a minimum an excavator, front loader, and dump trucks would be required to complete excavation of the site. A primary landfill and a secondary landfill have been identified as potential acceptors of the contaminated media. Both landfills have contaminated soils listed on their website as acceptable waste. The biggest challenges involve relocation of the utilities that intersect the free product footprint, ensuring access to surrounding buildings during excavation, removing and replacing concrete pavement, and pumping and treating groundwater that may enter the excavation. However, although these challenges would affect the project cost, they do not present insurmountable difficulties.

This technology has high energy requirements and GHG emissions associated with on-site excavation and waste transportation. However, administrative requirements should be minimal. It is anticipated that the owner would readily provide access to the property, and permitting requirements would be limited to a construction stormwater and wastewater pretreatment permit. Petroleum-contaminated soil is frequently disposed of as a special waste at Subtitle D landfills, so approval for disposal should be relatively easily obtained. Coordination with utilities regarding relocations would be required. However, since most (if not all) are located on property owned by CRAA, this should not be difficult to arrange.

If additional contamination was found at a later date, excavation could resume at the limits of the previous excavation project. Installation of a few monitoring wells and short-term monitoring should be sufficient to demonstrate the effectiveness of the excavation technology. Because contamination above RAOs would be removed from the site, this technology is anticipated to be acceptable to BUSTR and the public.

#### **5.1.2.3 Cost**

The cost of excavation in this area of concern was elevated due to the presence of multiple utility lines, existing pavement for roads and parking lot, and a large volume of soil to remove from the site. The estimated cost to complete a generic scope of work is \$3,627,000 (Table F-2).

### **5.1.3 In-Situ Soil Mixing**

The critical issues in evaluating the effectiveness, implementability, and cost of ISSM are the area and depth of mixing, the presence of surface and subsurface obstructions, and the need for

air emission controls. ISSM may not be practical or cost effective for large quantities of soil or where structures and/or utilities have to be demolished, removed, or relocated.

#### **5.1.3.1 Effectiveness**

Proper field oversight and confirmation sampling would make ISSM an effective method for permanently homogenizing and stabilizing the majority of the contamination on this site. In the case of the LAFB AOCs, the process would blend and distribute the NAPL product over the soil column and stabilize/solidify the free product and soil containing concentrations above the BUSTR RAOs. The site should not see a resurgence of free product in the monitoring wells after construction is completed. Since concentrations of contaminants detected in monitoring wells outside the free product area are already below the BUSTR RAOs, ISSM would achieve all the RAOs within the time required to complete ISSM (six months) and post-remediation monitoring (one year).

Application of ISSM in the free product area would be effective in protecting human health and the environment in both the short and the long term. Although the contaminants remain on the site, the ISSM process binds them into a matrix that minimizes the potential for direct exposure to or migration of contaminants. This protection would be enhanced by implementation of land use restrictions that would limit site activities that could disturb the subsurface. Because ISSM is an in-situ technique, worker exposure is minimized.

The highest exposure risk would occur during the ISSM process. Workers would risk exposure to contaminants through inhalation and dermal contact, and the public could also be exposed to contaminants in the air. These potential short-term risks would be minimized by monitoring and controls during the ISSM process. Workers would use appropriate personal protective equipment, fugitive emissions would be minimized using shrouds and air controls if needed, and air monitoring would be conducted. On the basis of the relatively low remaining concentrations of volatile organics in the LNAPL, it is unlikely that controls would be required for air emissions.

#### **5.1.3.2 Implementability**

ISSM is readily implemented using drill rigs with specialized hydraulically driven augers and mixing paddles to simultaneously drill and inject material. Several contractors are available that provide these services. The biggest challenges involve relocation of the utilities that intersect the free product footprint, removing any underground obstructions, and removing and replacing concrete pavement. However, although these challenges would affect the project cost, they do not present insurmountable difficulties. Short-term monitoring should be sufficient to demonstrate the effectiveness of the ISSM technology.

This technology has high energy requirements and GHG emissions associated with on-site drilling. However, administrative requirements should be moderate. It is anticipated that the owner would readily provide access to the property. Permitting requirements would include construction stormwater, air emissions, and underground injection permits. Coordination with utilities regarding relocations would be required. However, since most (if not all) are located on property owned by CRAA, this should not be difficult to arrange.

Since the contaminants remain on-site, land use restrictions would have to be implemented. Acceptance of this technology by regulators, owners, and the public may be reduced by the fact that 1) contaminants are not destroyed, 2) land use restrictions would be required, and 3) the treatment might physically limit site use (e.g., subsurface installation of utilities).

### **5.1.3.3 Cost**

The cost of ISSM in this area of concern was elevated due to the presence of multiple utility lines, concrete fuel-line anchors, and existing pavement for roads and parking lot. The estimated cost to complete a generic scope of work is \$6,932,000 (Table F-3).

### **5.1.4 Multi-phase Extraction**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the permeability of the subsurface, the depth of the water table, the volumes of materials to be removed, and susceptibility of the contaminants to biodegradation. The use of MPE is not suggested for sites with very high permeability and is better suited for soils with low to moderate permeability to reduce the risk of short-circuiting. It is also not recommended for use in soils with very low permeability because of a lack of secondary flow paths. When used at sites with low to moderate permeability, this system can potentially create a large radius of influence causing greater capture of the contaminant plume and reducing the need for extra wells.

In order for MPE to work efficiently and cost effectively, the location needs to have hydraulic conductivity between  $1.8 \times 10^{-4}$  and  $5.3 \times 10^{-3}$  cm/s and a water table depth of less than 30 ft bgs (the total fluids configuration requires an even shallower depth to water). The goal of this technology is to remove contaminant mass while promoting bioremediation and ultimately allowing natural attenuation to take over once the MPE system can no longer cost effectively remove contaminants.

#### **5.1.4.1 Effectiveness**

Although hydraulic conductivity and depth to groundwater at the site appear to be within the recommended range for this technology, the LNAPL appears to be present within disconnected sand lenses in a highly heterogenous soil environment. Identifying preferred pathways for extraction may prove impossible, and a large number of extraction wells equipped with pumps would be required. In addition, the LNAPL characteristics discussed in Section 5.1.1.1 would likely limit the effectiveness of bioremediation and natural attenuation in reducing contaminant concentrations over time. The time to achieve the RAOs with respect to reduction of free phase liquid to <0.01 ft is estimated to be three to eight years, but it is likely that concentrations of COCs in soil and groundwater within the free product area may remain above RAOs for some time.

During implementation there would be some potential for exposure to workers and the public to contaminated media. Extracted product, groundwater, and vapors would have to be treated on site or disposed of off site. Exposure to the contaminated material would be minimized by the use of appropriate worker personal protective equipment and engineering controls (e.g., treatment of air emissions, if required).

#### **5.1.4.2 Implementability**

The physical implementation of this alternative is very feasible, as there are few technical or regulatory barriers to hinder its design, installation, or operation. The technology requires drilling, sampling, chemical analysis, disposal of small quantities of contaminated soil, and extraction and treatment of groundwater and vapors. Facilities, equipment, and labor necessary to implement these activities are available and have been implemented at multiple sites. The site is accessible, and drilling can be planned around existing underground utilities. Minimal site restoration would be required after wells have been sealed.

Energy requirements and GHG emissions for treatment and compressors would be moderate. Permits would likely be required for air emissions and treated water discharges, and land use restrictions might be required if soil and groundwater RAOs are not met. Due to noise and air emissions, acceptability to regulators and the public would be contingent on the effectiveness of the technology in achieving RAOs within a reasonable time.

#### **5.1.4.3 Cost**

The cost to implement MPE at AOC 3 is anticipated to be \$4,036,000 capital cost and \$4,129,000 present worth cost (Table F-4).

### **5.1.5 Multi-phase Extraction with Heating**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the permeability of the subsurface, the depth of the water table, the volumes of materials to be removed, and susceptibility of the contaminants to biodegradation. The use of MPEH is not suggested for sites with very high permeability and is better suited for soils with low to moderate permeability to reduce the risk of short-circuiting. It is also not recommended for use in soils with very low permeability because of a lack of secondary flow paths. When used at sites with low to moderate permeability, this system can potentially create a large radius of influence causing greater capture of the contaminant plume and reducing the need for extra wells.

In order for MPEH to work efficiently and cost effectively, the location needs to have hydraulic conductivity between  $1.8 \times 10^{-4}$  and  $5.3 \times 10^{-3}$  cm/s, a water table depth of less than 30 ft to the surface (the total fluids configuration requires an even shallower depth to water), and ideally less than 0.5 foot of product. The goal of this technology is to remove contaminant mass while promoting bioremediation and ultimately allowing natural attenuation to take over once the MPE with heating system can no longer cost effectively remove contaminants.

#### **5.1.5.1 Effectiveness**

Hydraulic conductivity, depth to groundwater, and LNAPL thickness at the site appear to be within the recommended range for this technology. Adding heat to conventional MPE will increase the effectiveness of the process by volatilizing higher molecular weight compounds than traditional MPE, reducing the viscosity of free-phase and residual NAPL, and increasing chemical reaction rates for contaminant breakdown. Although this process would be more effective than traditional MPE, the LNAPL appears to be present within disconnected sand lenses in a highly heterogeneous soil environment. Identifying preferred pathways for extraction

(and hot air or steam injection) may prove impossible, and a large number of extraction/injection wells might be required. Effectively locating extraction wells and heating equipment to avoid existing infrastructure would inevitably involve compromise and might prove impractical. In addition, the LNAPL characteristics discussed in Section 5.1.1.1 would likely limit the effectiveness of bioremediation and natural attenuation in reducing contaminant concentrations over time. Although the addition of heating to MPE should reduce the time to achieve RAOs over MPE alone, the time to achieve RAOs is still estimated to be two to three years.

During implementation there would be some potential for exposure to workers and the public to contaminated media. Extracted product, groundwater, and vapors would have to be treated on site or disposed of off site. Exposure to the contaminated material would be minimized by the use of appropriate worker personal protective equipment and engineering controls (e.g., treatment of air emissions, if required).

#### **5.1.5.2 Implementability**

The physical implementation of this alternative is very feasible, as there are few technical or regulatory barriers to hinder its design, installation, or operation. The technology requires drilling, sampling, chemical analysis, disposal of small quantities of contaminated soil, and extraction and treatment of groundwater and vapors. Facilities, equipment, and labor necessary to implement these activities are available and have been implemented at other sites. Availability of power for heating needs further assessment based on the heating technology selected, but should be implementable at this site. The site is accessible, and drilling can be planned around existing underground utilities. Minimal site restoration would be required after wells have been sealed.

Energy requirements and GHG emissions for treatment and compressors would be moderate, if waste heat were used for the heating component. Permits would likely be required for air emissions, underground injection, and treated water discharges, and land use restrictions might be required, if soil and groundwater RAOs are not met. Due to noise and potential air emissions, acceptability to regulators and the public would be contingent on the effectiveness of the technology in achieving RAOs within a reasonable time.

#### **5.1.5.3 Cost**

The cost to remediate this AOC utilizing MPE supplemented with low temperature in-situ thermal desorption is approximately \$3,633,000 capital cost and \$3,685,000 present worth cost (Table F-5). (This assumes that waste heat from the MPE process will be injected to enhance VOC mass removal, leading to lower operational costs. The source of heat is essentially free, and the rate of remediation is accelerated, so the time to achieve RAOs is shorter and costs are lower than MPE alone.)

### **5.1.6 In-Situ Chemical Oxidation**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the permeability of the subsurface, mass of contaminants to be treated, and the physical condition of the contaminant (i.e., dissolved, adsorbed, or free phase). ISCO is best implemented

in relatively homogeneous soils with higher conductivities, and at sites where the target contaminant (in this case, aged JP-4) is present in the dissolved phase.

#### **5.1.6.1 Effectiveness**

As described in the preceding section, the conditions necessary for successful implementation of ISCO do not exist at AOC 3. The discontinuity of the granular lenses and the low permeability of the remaining soil are not favorable to distribution of the oxidant. In addition, the free product is the target contamination, and dissolution of the weathered JP-4 LNAPL is occurring at a very slow rate based on the absence of dissolved contaminants outside the free product area. The hydrogeological conditions and contaminant characteristics are both limiting factors in achieving adequate contact between the oxidant and the dissolved contaminant compounds.

On the basis of this analysis, it does not appear that ISCO would be effective in achieving the RAOs due to the limitations of the heterogeneous subsurface conditions and the presence of relatively large quantities of free phase product and contaminants adsorbed to the soil matrix.

#### **5.1.6.2 Implementability**

Equipment and facilities necessary to implement this technology are available and could be installed at the site. The technology requires drilling, sampling, chemical analysis, disposal of small quantities of contaminated soil and groundwater, and the mixing and injection of the ISCO solution. The site is accessible, and drilling can be planned around existing underground utilities. Although there are a few underground utilities in relatively close proximity to the free product area, this is less of a concern than at AOC 11. However, these utilities might have to be protected or relocated to prevent adverse impacts from the oxidizing compound.

Energy requirements and GHG emissions would be low for this technology, but a permit would be required for underground injection. Injection of oxidizing chemicals into the subsurface might not be acceptable to regulators or the public. Minimal site restoration would be required after wells have been sealed.

#### **5.1.6.3 Cost**

Oxidant demand is the controlling factor with respect to cost at sites with large masses of contamination, such as AOC 3. Oxidation of a large mass of contamination requires the injection of a very large mass of oxidant, and will require multiple injections. The total oxidant demand is the sum of the contaminant oxidant demand and the natural oxidant demand (also referred to as the soil oxidant demand). The contaminant demand represents the stoichiometric mass of oxidant required to oxidize the target contaminant.

The contaminant oxidant demand for potassium permanganate is 19.7 pounds per pound of contaminant, assuming naphthalene as a surrogate for JP-4. Using this value, the stoichiometric mass of potassium permanganate required to oxidize the assumed volume of free product at AOC 3 (35,200 gallons, or 246,400 pounds of JP-4 at 7 pounds per gallon) is 4.85 million pounds. At a unit cost of \$1.80 per pound, the cost of the oxidant alone would be \$8.74 million (Ref. 30).

However, due to the challenges associated with achieving direct contact between the oxidant and the contaminants in in-situ applications, as well as the presence of naturally occurring organics, the actual mass of permanganate that must be injected is typically greater than this stoichiometric requirement based on the contaminant mass alone. This cost also does not include the costs associated with construction of injection points and the mixing/injection of the oxidant solution, or any costs associated with effectiveness monitoring and reporting.

Considering the high cost and the fact that ISCO is not appropriate or effective for large quantities of LNAPL, ISCO is not an appropriate remedial technology for AOC 3.

### **5.1.7 Surfactant Enhanced LNAPL Removal**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the permeability of the subsurface, groundwater flow conditions, the volume of contaminants to be removed and their physical condition of the contaminant (i.e., dissolved, adsorbed, or free phase). SELR is best implemented over small free product areas and in relatively homogeneous soils with hydraulic conductivities of  $10^{-3}$  cm/s or higher. The fluctuating groundwater table will likely reduce effectiveness by limiting contact between the surfactant and flushing fluid and the contaminants. As noted previously, surfactant enhanced removal will only address contaminants that are present below the water table.

#### **5.1.7.1 Effectiveness**

As described in the preceding section, the site characteristics necessary for successful implementation of this technology do not exist at AOC 3, and SELR should be considered an ineffective option for this site.

#### **5.1.7.2 Implementability**

Equipment and facilities necessary to implement this technology are available, and the technology could be readily installed and implemented at the site. The technology requires conventional activities including drilling, sampling, chemical analysis, injection of surfactant, extraction and separation/treatment of surfactant and contaminated groundwater, and disposal of contaminated soil and discharge of treated groundwater/vapors. The site is accessible, and drilling can be planned around existing underground utilities. Minimal site restoration would be required after wells have been sealed.

Energy requirements and GHG emissions would be low, but permits would likely be required for treated wastewater discharge, underground injection, and possibly air emissions. Injection of surfactant chemicals into the subsurface might not be acceptable to regulators or the public, due to the potential for increased contaminant migration.

Overall, the hydrogeologic conditions and large area of free product at the site are not conducive for implementation of this remediation method. This method should not be considered further for remediation of the site.

### **5.1.7.3 Cost**

Because the site does not exhibit hydrogeologic and geologic conditions conducive to the application of this remediation technology, costs have not been estimated as part of this effort.

## **5.1.8 Electrical Resistance Heating**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the volume of LNAPL present and the chemical composition of the contaminants. Overall, ERH has been shown to be an effective but costly technology.

### **5.1.8.1 Effectiveness**

Remediation projects using thermally enhanced vapor generation and recovery are highly dependent upon the specific soil and chemical properties of the contaminated media. ERH is most effective on VOCs with boiling points at or below that of water (100°C). Of the contaminants targeted for remediation at this site, benzene and TPH-GRO are easily removed with ERH. Less volatile contaminants, including xylenes and TPH-DRO, can be remediated with ERH, but more energy will be required to volatilize those chemicals. Installing a MPE system alongside ERH would help in recovering the less volatile contaminants.

ERH can be effective for all soil types, but soil that has a high moisture content or is tight will have a lower permeability to air, requiring more energy input to increase temperature and vacuum. Lower operating costs are associated with using ERH in more permeable soils. Additionally, soils with high organic content will respond less favorably to ERH due to the soil's high VOC-sorption capacity.

Compared to other remediation technologies, the time to achieve RAOs with ERH is low. ERH usually takes three to six months to complete treatment under ideal conditions. At this AOC, the time to achieve RAOs is not expected to exceed nine months, with a post-completion monitoring period. Assuming that ERH could cost effectively achieve RAOs at AOC 3, the long-term effectiveness of ERH is high. The contaminants would be volatilized from the subsurface and treated, leaving residual concentrations that would be protective of human health and the environment.

The highest exposure risk would occur during process implementation. Workers and the public could risk exposure to contaminants through inhalation of volatilized contaminants, and the electrical equipment and steam generated represent safety hazards. These potential short-term risks would be minimized by monitoring and controls during the ERH process. Workers would use appropriate personal protective equipment and safety precautions, fugitive emissions would be minimized by the vapor collection and treatment system, and air monitoring would be conducted.

### **5.1.8.2 Implementability**

Facilities, equipment, and labor necessary to implement this technology are significant and intensive, but available. The site is accessible, and the placement of electrodes and vapor



recovery wells can be planned around existing underground utilities. As previously noted in Section 3.1, the hydraulic conductivity and flow velocity values for AOC 3 may be misleadingly high, because of the discontinuity of the granular lenses. Due to this fact, and the presence of low hydraulic conductivities and flow velocities measured at AOCs 8/9 and 11, it is assumed that the groundwater flow velocity and hydraulic gradient at AOC 3 are favorable to implementing the technology. These favorable conditions could potentially lower the cost to implement ERH at AOC 3. Minimal site restoration would be required after equipment has been moved off site and wells have been sealed.

The energy costs for this technology are high, but off-set by the relatively short duration of treatment. Permits may be required for air emissions and underground injection of water, which may be required to maintain the electric current. Because of the short treatment time and the effectiveness of the technology, acceptance by regulators and the public is anticipated to be high.

#### **5.1.8.3 Cost**

The cost to implement ERH at AOC 3 is anticipated to be \$7,400,000 (Table F-6).

### **5.2 AOC 8/9**

The evaluation of each of the technologies at AOC 8/9 is presented in the following subsections.

#### **5.2.1 Natural Source Zone Depletion**

On the basis of the low concentrations of dissolved contaminants outside the free product area, it appears that the rate of dissolution is controlling NSZD at AOC 9. This rate is likely extremely slow because of the subsurface heterogeneity, consequent wide range of hydraulic conductivities, and relatively flat and variable groundwater gradient, as well as low solubility of the COCs remaining in the weathered LNAPL. The qualitative evaluation in the remainder of this section takes into consideration these challenges.

##### **5.2.1.1 Effectiveness**

The future effectiveness of this technology is difficult to assess without additional data, but the extent of free product originally estimated at AOC 9 is less than one fourth of the area estimated at AOC 11 and less than one ninth of the area estimated at AOC 3. However, to the extent that residual free product and COCs above RAOs remain within the free product areas, it does not appear that this technology would be effective in achieving the RAOs within a reasonable period of time. The time to achieve RAOs is presumed to be extremely long based on the site conditions and the LNAPL characteristics previously discussed.

The draft MNA Assessment concluded that the more soluble and volatile petroleum hydrocarbons have already been naturally removed from the LNAPL and that “the remaining LNAPL will be less susceptible to MNA processes, and can be expected to be removed slowly by natural processes.” In addition, LNAPL present in the smear zone will continue to be periodically released as measurable free product on the groundwater surface whenever the water table drops. Therefore, depending on the remaining extent of free product and COCs above

RAOs, the long-term effectiveness of this technology alone might be limited in terms of protection of human health and the environment. Protectiveness could be increased by implementing land use restrictions that would minimize the potential exposure to subsurface contaminants.

Because this technology involves only well installation and groundwater sampling, the short-term effectiveness is high, in that exposure of workers or the public to contamination at the site during implementation would be limited.

#### **5.2.1.2 Implementability**

The technical feasibility of this alternative is high with respect to implementation requirements. The technology requires only conventional, short-term, and demonstrated activities including drilling, sampling, chemical analysis, and disposal of small quantities of contaminated soil and groundwater. Facilities, equipment, and labor necessary to implement these activities are readily available. The site is accessible, and drilling can be planned around existing underground utilities.

Energy use and GHG emissions would be low for this technology. Land use restrictions would probably be required, and property owner, regulatory, and public acceptance might be low, since contaminants above RAOs would remain in place for an indeterminate length of time. Long-term monitoring would be required to evaluate the progress of NSZD and verify that no additional migration of dissolved contaminants was occurring. Minimal site restoration would be required after wells have been sealed.

#### **5.2.1.3 Cost**

The cost to implement this technology is relatively low: \$235,000 capital cost, \$419,000 present worth cost (Table F-7).

### **5.2.2 Excavation**

The critical issues in evaluating the effectiveness, implementability, and cost of excavation are the contaminated soil quantity and characteristics, the depth of excavation, the presence of surface and subsurface obstructions, and the need to manage fluids entering the excavation. Excavation is almost always effective and implementable, but the cost may be excessive if the soil quantity is large, the excavation deep, subsurface structures and utilities must be removed or relocated, or excessive quantities of water must be managed. On the basis of existing data, AOC 9 contains the smallest area of free product and contaminated soil, and also the fewest utilities and structures of all the AOCs. Therefore, excavation of contaminated soil from AOC 9 would be relatively more implementable and less expensive than at AOC 3 or 11.

#### **5.2.2.1 Effectiveness**

Proper construction oversight would make excavation an effective method for permanently removing the majority of the contamination on this site. On the basis of the existing data, excavation in the free product area would remove both the source of the groundwater contamination and soil containing concentrations above the BUSTR RAOs. Assuming all free

product is removed during the excavation activities, the site should not see a resurgence of free product in the monitoring wells after construction is completed. Since concentrations of contaminants detected in monitoring wells outside the free product area are already below the BUSTR RAOs, excavation would achieve all the RAOs within the time required to complete excavation (one month) and post-remediation monitoring (one year).

Excavation of free product from the site would be effective in protecting the human health and the environment in both the short and the long term. All excavated contaminated material would be removed from the site and disposed of in a RCRA Subtitle D permitted landfill. Although contaminants are not destroyed using this technology, potential exposure to them is minimized by removal from the site and containment in the off-site landfill.

The highest exposure risk would occur during the short term excavation and transportation process. Workers would risk exposure to contaminants through inhalation and dermal contact, and the public could also be exposed to contaminants in the air. Additional releases could occur through surface water runoff from contaminated areas. These potential short-term risks would be minimized by monitoring and controls during the excavation process. Workers would use appropriate personal protective equipment, and air monitoring would be conducted. Controls would be implemented for dust and run-on/run-off, and soil would be transported in covered trailers. On the basis of the relatively low remaining concentrations of volatile organics in the LNAPL, it is unlikely that additional controls would be required for air emissions.

#### **5.2.2.2 Implementability**

Excavation is readily implemented with conventional equipment and services. At AOC 8/9, there are fewer surface or subsurface obstructions than at either of the other AOCs, which increases the implementability and lowers the cost of excavation at this location. Commonly available excavation equipment including at a minimum an excavator, front loader, and dump trucks would be required to complete excavation of the site. A primary landfill and a secondary landfill have been identified as potential acceptors of the contaminated media. Both landfills have contaminated soils listed on their website as acceptable waste. The biggest challenge at AOC 8/9 would involve pumping and treating groundwater that may enter the excavation. However, although this would affect the project cost, it does not present an insurmountable difficulty.

This technology has high energy requirements and GHG emissions associated with on-site excavation and waste transportation. However, administrative requirements should be minimal. It is anticipated that the owner would readily provide access to the property, and permitting requirements would be limited to a construction stormwater and wastewater pretreatment permit. Petroleum-contaminated soil is frequently disposed of as a special waste at Subtitle D landfills, so approval for disposal should be relatively easily obtained. Coordination with utilities regarding relocations would be required. However, since most (if not all) are located on property owned by CRAA, this should not be difficult to arrange.

If additional contamination was found at a later date, excavation could resume at the limits of the previous excavation project. Installation of a few monitoring wells and short-term monitoring should be sufficient to demonstrate the effectiveness of the excavation technology. Because

contamination above RAOs would be removed from the site, this technology is anticipated to be acceptable to BUSTR and the public.

### **5.2.2.3 Cost**

The cost of excavation in this area of concern was primarily driven by the amount of soil to be removed and existing paved areas that will have to be replaced. The estimated cost to complete a generic scope of work is \$551,000 (Table F-8).

## **5.2.3 In-Situ Soil Mixing**

The critical issues in evaluating the effectiveness, implementability, and cost of ISSM are the area and depth of mixing, the presence of surface and subsurface obstructions, and the need for air emission controls. ISSM may not be practical or cost effective for large quantities of soil or where structures and/or utilities have to be demolished, removed, or relocated. At AOC 8/9, there are fewer surface or subsurface obstructions than at either of the other AOCs, which increases the implementability and lowers the cost of ISSM at this location.

### **5.2.3.1 Effectiveness**

Proper field oversight and confirmation sampling would make ISSM an effective method for permanently homogenizing and stabilizing the majority of the contamination on this site. In the case of the LAFB AOCs, the process would blend and distribute the NAPL product over the soil column and stabilize/solidify the free product and soil containing concentrations above the BUSTR RAOs. The site should not see a resurgence of free product in the monitoring wells after construction is completed. Since concentrations of contaminants detected in monitoring wells are already below the BUSTR RAOs, ISSM would achieve all the RAOs within the time required to complete ISSM (six months) and post-remediation monitoring (one year).

Application of ISSM in the free product area would be effective in protecting human health and the environment in both the short and the long term. Although the contaminants remain on the site, the ISSM process binds them into a matrix that minimizes the potential for direct exposure to or migration of contaminants. This protection would be enhanced by implementation of land use restrictions that would limit site activities that could disturb the subsurface. Because ISSM is an in-situ technique, worker exposure is minimized.

The highest exposure risk would occur during the ISSM process. Workers would risk exposure to contaminants through inhalation and dermal contact, and the public could also be exposed to contaminants in the air. These potential short-term risks would be minimized by monitoring and controls during the ISSM process. Workers would use appropriate personal protective equipment, fugitive emissions would be minimized using shrouds and air controls if needed, and air monitoring would be conducted. On the basis of the relatively low remaining concentrations of volatile organics in the LNAPL, it is unlikely that controls would be required for air emissions.

### **5.2.3.2 Implementability**

ISSM is readily implemented using drill rigs with specialized hydraulically driven augers and mixing paddles to simultaneously drill and inject material. Several contractors are available that provide these services. At AOC 8/9, there are fewer surface or subsurface obstructions than at either of the other AOCs, which increases the implementability and lowers the cost of ISSM at this location. Short-term monitoring should be sufficient to demonstrate the effectiveness of the ISSM technology.

This technology has high energy requirements and GHG emissions associated with on-site drilling. However, administrative requirements should be moderate. It is anticipated that the owner would readily provide access to the property. Permitting requirements would include construction stormwater, air emissions, and underground injection permits. Coordination with utilities regarding relocations would be required. However, since most (if not all) are located on property owned by CRAA, this should not be difficult to arrange.

Since the contaminants remain on-site, land use restrictions would have to be implemented. Acceptance of this technology by regulators, owners, and the public may be reduced by the fact that 1) contaminants are not destroyed, 2) land use restrictions would be required, and 3) the treatment might physically limit site use (e.g., subsurface installation of utilities).

### **5.2.3.3 Cost**

The estimated cost to complete a generic scope of work is \$746,000 (Table F-9).

## **5.2.4 Multi-Phase Extraction**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the permeability of the subsurface, the depth of the water table, the volumes of materials to be removed, and susceptibility of the contaminants to biodegradation. The use of MPE is not suggested for sites with very high permeability and is better suited for soils with low to moderate permeability to reduce the risk of short-circuiting. It is also not recommended for use in soils with very low permeability because of a lack of secondary flow paths. When used at sites with low to moderate permeability, this system can potentially create a large radius of influence causing greater capture of the contaminant plume and reducing the need for extra wells.

In order for MPE to work efficiently and cost effectively, the location needs to have hydraulic conductivity between  $1.8 \times 10^{-4}$  and  $5.3 \times 10^{-3}$  cm/s and a water table depth of less than 30 ft to the surface (the total fluids configuration requires an even shallower depth to water). The goal of this technology is to remove contaminant mass while promoting bioremediation and ultimately allowing natural attenuation to take over once the MPE system can no longer cost effectively remove contaminants.

### **5.2.4.1 Effectiveness**

Although hydraulic conductivity and depth to groundwater at the site appear to be within the recommended range for this technology, the LNAPL appears to be present within disconnected sand lenses in a highly heterogeneous soil environment. Identifying preferred pathways for

extraction may prove impossible, and a large number of extraction wells equipped with pumps would be required. In addition, the LNAPL characteristics discussed in Section 5.1.1.1 would likely limit the effectiveness of bioremediation and natural attenuation in reducing contaminant concentrations over time. The time to achieve the RAOs with respect to reduction of free phase liquid to <0.01 ft is estimated to be three to eight years, but it is likely that concentrations of COCs in soil and groundwater within the free product area may remain above RAOs for some time.

During implementation there would be some potential for exposure to workers and the public to contaminated media. Extracted product, groundwater, and vapors would have to be treated on site or disposed of off site. Exposure to the contaminated material would be minimized by the use of appropriate worker personal protective equipment and engineering controls (e.g., treatment of air emissions, if required).

#### **5.2.4.2 Implementability**

The physical implementation of this alternative is very feasible, as there are few technical or regulatory barriers to hinder its design, installation, or operation. The technology requires drilling, sampling, chemical analysis, disposal of small quantities of contaminated soil, and extraction and treatment of groundwater and vapors. Facilities, equipment, and labor necessary to implement these activities are available and have been implemented at multiples sites. The site is accessible, and drilling can be planned around existing underground utilities. Minimal site restoration would be required after wells have been sealed.

Energy requirements and GHG emissions for treatment and compressors would be moderate. Permits would likely be required for air emissions and treated water discharges, and land use restrictions might be required if soil and groundwater RAOs are not met. Due to noise and air emissions, acceptability to regulators and the public would be contingent on the effectiveness of the technology in achieving RAOs within a reasonable time.

#### **5.2.4.3 Cost**

The cost to implement MPE at AOC 8/9 is anticipated to be \$1,226,000 capital cost and \$1,319,000 present worth cost (Table F-10).

### **5.2.5 Multi-phase Extraction with Heating**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the permeability of the subsurface, the depth of the water table, the volumes of materials to be removed, and susceptibility of the contaminants to biodegradation. The use of MPEH is not suggested for sites with very high permeability and is better suited for soils with low to moderate permeability to reduce the risk of short-circuiting. It is also not recommended for use in soils with very low permeability because of a lack of secondary flow paths. When used at sites with low to moderate permeability, this system can potentially create a large radius of influence causing greater capture of the contaminant plume and reducing the need for extra wells.

In order for MPEH to work efficiently and cost effectively, the location needs to have hydraulic conductivity between  $1.8 \times 10^{-4}$  and  $5.3 \times 10^{-3}$  cm/s, a water table depth of less than 30 ft to the surface (the total fluids configuration requires an even shallower depth to water), and ideally less than 0.5 foot of product. The goal of this technology is to remove contaminant mass while promoting bioremediation and ultimately allowing natural attenuation to take over once the MPEH can no longer cost effectively remove contaminants.

#### **5.2.5.1 Effectiveness**

Hydraulic conductivity, depth to ground water, and the thickness of free product are all within acceptable ranges at this AOC. Adding heat to conventional MPE will increase the effectiveness of the process by volatilizing higher molecular weight compounds than traditional MPE, reducing the viscosity of free-phase and residual NAPL, and increasing chemical reaction rates for contaminant breakdown. Although this process would be more effective than traditional MPE, the LNAPL appears to be present within disconnected sand lenses in a highly heterogeneous soil environment. Identifying preferred pathways for extraction may prove impossible, and a large number of extraction wells equipped with pumps might be required. In addition, the LNAPL characteristics discussed in Section 5.1.1.1 would likely limit the effectiveness of bioremediation and natural attenuation in reducing contaminant concentrations over time. Although the addition of heating to MPE should reduce the time to achieve RAOs over MPE alone, the time to achieve RAOs is estimated to be two to three years.

During implementation there would be some potential for exposure to workers and the public to contaminated media. Extracted product, groundwater, and vapors would have to be treated on site or disposed of off site. Exposure to the contaminated material would be minimized by the use of appropriate worker personal protective equipment and engineering controls (e.g., treatment of air emissions, if required). Additionally, the number of receptor extraction wells equipped with extraction pumps would be numerous.

#### **5.2.5.2 Implementability**

The physical implementation of this alternative is very feasible, as there are few technical or regulatory barriers to hinder its design, installation or operation. The technology requires drilling, sampling, chemical analysis, disposal of small quantities of contaminated soil, and extraction and treatment of groundwater and vapors. Facilities, equipment, and labor necessary to implement these activities are available and have been implemented at other sites. Availability of power for heating needs further assessment based on the heating technology selected, but should be implementable at this site. Minimal site restoration would be required after wells have been sealed.

Energy requirements and GHG emissions for treatment and compressors would be moderate, if waste heat were used for the heating component. Permits would likely be required for air emissions, underground injection, and treated water discharges, and land use restrictions might be required, if soil and groundwater RAOs are not met. Due to noise and potential air emissions, acceptability to regulators and the public would be contingent on the effectiveness of the technology in achieving RAOs within a reasonable time.

### **5.2.5.3 Cost**

The cost to remediate this AOC utilizing MPE supplemented with low temperature in-situ thermal desorption is approximately \$1,118,000 capital cost and \$1,170,000 present worth cost (Table F-11). (This assumes that waste heat from the MPE process will be injected to enhance VOC mass removal, leading to lower operational costs. The source of heat is essentially free, and the rate of remediation is accelerated, so the time to achieve RAOs is shorter and costs are lower than MPE alone.)

### **5.2.6 In-Situ Chemical Oxidation**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the permeability of the subsurface, mass of contaminants to be treated, and the physical condition of the contaminant (i.e., dissolved, adsorbed, or free phase). ISCO is best implemented in relatively homogeneous soils with higher conductivities, and at sites where the target contaminant (in this case, weathered JP-4) is present in the dissolved phase.

#### **5.2.6.1 Effectiveness**

As described in the preceding section, the conditions necessary for successful implementation of ISCO do not appear to exist at AOC 9. The discontinuity of the granular lenses and the low permeability of the remaining soil are not favorable to distribution of the oxidant. In addition, the free product is the target contamination, and dissolution of the weathered JP-4 LNAPL is occurring at a very slow rate based on the absence of dissolved contaminants outside the free product area. The hydrogeological conditions and contaminant characteristics are both limiting factors in achieving adequate contact between the oxidant and the dissolved contaminant compounds.

On the basis of this analysis, it does not appear that ISCO would be effective in achieving the RAOs due to the limitations of the heterogeneous subsurface conditions and the presence of relatively large quantities of free phase product and contaminants adsorbed to the soil matrix.

#### **5.2.6.2 Implementability**

Equipment and facilities necessary to implement this technology are available and could be installed at the site. The technology requires drilling, sampling, chemical analysis, disposal of small quantities of contaminated soil and groundwater, and the mixing and injection of the ISCO solution. The site is accessible, and drilling can be planned around existing underground utilities. Although there are a few underground utilities in relatively close proximity to the free product area, this is less of a concern than at AOC 3 or AOC 11. However, these utilities might have to be protected or relocated to prevent adverse impacts from the oxidizing compound.

Energy requirements and GHG emissions would be low for this technology, but a permit would be required for underground injection. Injection of oxidizing chemicals into the subsurface might not be acceptable to regulators or the public. Minimal site restoration would be required after wells have been sealed.



### **5.2.6.3 Cost**

Oxidant demand is the controlling factor with respect to cost for ISCO. However, the mass of contamination is much smaller at AOC 9 than at AOC 3, so it will require a proportionally smaller mass of oxidant. The total oxidant demand is the sum of the contaminant oxidant demand and the natural oxidant demand (also referred to as the soil oxidant demand). The contaminant demand represents the stoichiometric mass of oxidant required to oxidize the target contaminant.

The contaminant oxidant demand for potassium permanganate is 19.7 pounds per pound of contaminant, assuming naphthalene as a surrogate for JP-4. Using this value, the stoichiometric mass of potassium permanganate required to oxidize the assumed volume of free product at AOC 9 (1,800 gallons, or 12,600 pounds of JP-4 at 7 pounds per gallon) is 248,220 pounds. At a unit cost of \$1.80 per pound, the cost of the oxidant alone would be \$446,800 (Ref. 30). However, due to the challenges associated with achieving direct contact between the oxidant and the contaminants in in-situ applications, as well as the presence of naturally occurring organics, the actual mass of permanganate that must be injected is typically greater than this stoichiometric requirement based on the contaminant mass alone. This cost also does not include the costs associated with construction of injection points and the mixing/injection of the oxidant solution, or any costs associated with effectiveness monitoring and reporting.

## **5.2.7 Surfactant Enhanced LNAPL Removal**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the permeability of the subsurface, groundwater flow conditions, the volume of contaminants to be removed and their physical condition of the contaminant (i.e., dissolved, adsorbed, or free phase). SELR is best implemented over small areas of free product and in relatively homogeneous soils with hydraulic conductivities of  $10^{-3}$  cm/s or higher. The fluctuating groundwater table will likely reduce effectiveness by limiting contact between the surfactant and flushing fluid and the contaminants. As noted previously, this technology only addresses contamination that is present below the water table.

### **5.2.7.1 Effectiveness**

As described in the preceding section, although the free product area is smaller at AOC 8/9, other conditions necessary for successful implementation of this technology do not exist at this AOC, and surfactant enhanced LNAPL removal should be considered an ineffective option for this site.

### **5.2.7.2 Implementability**

Equipment and facilities necessary to implement this technology are available, and the technology could be readily installed and implemented at the site. The technology requires conventional activities including drilling, sampling, chemical analysis, injection of surfactant, extraction and separation/treatment of surfactant and contaminated groundwater, and disposal of contaminated soil and discharge of treated groundwater/vapors. The site is accessible, and drilling can be planned around existing underground utilities. Minimal site restoration would be required after wells have been sealed.

Energy requirements and GHG emissions would be low, but permits would likely be required for treated wastewater discharge, underground injection, and possibly air emissions. Injection of surfactant chemicals into the subsurface might not be acceptable to regulators or the public, due to the potential for increased contaminant migration.

Overall, the hydrogeologic conditions and large area of free product at the site are not conducive for implementation of this remediation method. This method should not be considered further for remediation of the site.

### **5.2.7.3 Cost**

Because the site does not exhibit hydrogeologic and geologic conditions conducive to the application of this remediation technology, costs have not been estimated as part of this effort.

## **5.2.8 Electrical Resistance Heating**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the volume of LNAPL present and the chemical composition of the contaminants. Overall, ERH has been shown to be an effective but costly technology.

### **5.2.8.1 Effectiveness**

Remediation projects using thermally enhanced vapor generation and recovery are highly dependent upon the specific soil and chemical properties of the contaminated media. ERH is most effective on VOCs with boiling points at or below that of water (100°C). Of the contaminants targeted for remediation at this site, benzene and TPH-GRO are easily removed with ERH. Less volatile contaminants, including xylenes and TPH-DRO, can be remediated with ERH, but more energy will be required to volatilize those chemicals. Installing a MPE system alongside ERH would help in recovering the less volatile contaminants.

ERH can be effective for all soil types, but soil that has a high moisture content or is tight will have a lower permeability to air, requiring more energy input to increase temperature and vacuum. Lower operating costs are associated with using ERH in more permeable soils. Additionally, soils with high organic content will respond less favorably to ERH due to the soil's high VOC-sorption capacity.

Compared to other remediation technologies, the time to achieve RAOs with ERH is low. ERH usually takes three to six months to complete treatment under ideal conditions. At this AOC, the time to achieve RAOs is not expected to exceed nine months, with a post-completion monitoring period of one year. Assuming that ERH could cost effectively achieve RAOs at AOC 8/9, the long-term effectiveness of ERH is high. The contaminants would be volatilized from the subsurface and treated, leaving residual concentrations that would be protective of human health and the environment.

The highest exposure risk would occur during process implementation. Workers and the public could risk exposure to contaminants through inhalation of volatilized contaminants. This

potential short-term risk would be minimized by monitoring and controls during the ERH process. Workers would use appropriate personal protective equipment, fugitive emissions would be minimized by the vapor collection and treatment system, and air monitoring would be conducted.

#### **5.2.8.2 Implementability**

Facilities, equipment, and labor necessary to implement this technology are significant and intensive, but available. The site is accessible, and the placement of electrodes and vapor recovery wells can be planned around existing underground utilities. The low groundwater flow velocity and hydraulic gradient at AOC 8/9 are favorable to implementing the technology. These favorable conditions could potentially lower the cost to implement ERH at AOC 8/9. Minimal site restoration would be required after equipment has been moved off site and wells have been sealed.

The energy costs for this technology are high, but off-set by the relatively short duration of treatment. Permits may be required for air emissions and underground injection of water, which may be required to maintain the electric current. Because of the short treatment time and the effectiveness of the technology, acceptance by regulators and the public is anticipated to be high.

#### **5.2.8.3 Cost**

The cost to implement ERH at AOC 8/9 is anticipated to be \$1,358,000 (Table F-12).

### **5.3 AOC 11**

The evaluation of each of the technologies at AOC 11 is presented in the following subsections. Note that existing fueling facilities, underground utilities, and concrete parking areas and taxiways present significant hindrance to access for investigation and implementation of a remedy at AOC 11. Much of the contaminated area lies beneath substantial concrete and in the vicinity of an operating fueling station. Further investigation and implementation of an in-situ remedy may be possible with strategic placement of injection points and other facilities, but design compromises are likely. It is assumed that demolition and reconstruction of existing facilities at AOC 11 is impractical and was not considered for implementation of any of the technologies. The need for continued access to and provision of fueling services at AOC 11 would likely hamper implementation of most of the technologies at this location.

#### **5.3.1 Natural Source Zone Depletion**

On the basis of the low concentrations of dissolved contaminants outside the free product area, it appears that the rate of dissolution is controlling NSZD at AOC 11. This rate is likely extremely slow because of the subsurface heterogeneity, consequent wide range of hydraulic conductivities, and relatively flat and variable groundwater gradient, as well as low solubility of the COCs remaining in the weathered LNAPL. The qualitative evaluation in the remainder of this section takes into consideration these challenges.

### **5.3.1.1 Effectiveness**

The future effectiveness of this technology is difficult to assess without additional data, but the extent of free product originally estimated at AOC 11 is less than one half of the area estimated at AOC 3. However, to the extent that residual free product and COCs above RAOs remain within the free product areas, it does not appear that this technology would be effective in achieving the RAOs within a reasonable period of time. The draft MNA Assessment concluded that the more soluble and volatile petroleum hydrocarbons have already been naturally removed from the LNAPL and that “the remaining LNAPL will be less susceptible to MNA processes, and can be expected to be removed slowly by natural processes.” In addition, LNAPL present in the smear zone will continue to be periodically released as measurable free product on the groundwater surface whenever the water table drops. Therefore, depending on the remaining extent of free product and COCs above RAOs, the long-term effectiveness of this technology alone might be limited in terms of protection of human health and the environment. Protectiveness could be increased by implementing land use restrictions that would minimize the potential exposure to subsurface contaminants.

Because this technology involves only well installation and groundwater sampling, the short-term effectiveness is high, in that exposure of workers or the public to contamination at the site during implementation would be limited.

### **5.3.1.2 Implementability**

The technical feasibility of this alternative is high with respect to implementation requirements, but probably low with respect to the time to achieve RAOs within the remaining free product area. The technology requires only conventional, short-term, and demonstrated activities including drilling, sampling, chemical analysis, and disposal of small quantities of contaminated soil and groundwater. Facilities, equipment, and labor necessary to implement these activities are readily available. The site is accessible, and drilling can be planned around existing underground utilities.

Energy requirements and GHG emissions would be low for this technology, and no permits are required. However, land use restrictions would probably be required, and property owner, regulatory, and public acceptance might be low, since contaminants above RAOs would remain in place for an indeterminate length of time. Long-term monitoring would be required to evaluate the progress of NSZD and verify that no additional migration of dissolved contaminants was occurring. Minimal site restoration would be required after wells have been sealed.

### **5.3.1.3 Cost**

The cost to implement this technology is relatively low: \$231,000 capital cost, \$416,000 present worth cost (Table F-13).

## **5.3.2 Excavation**

The critical issues in evaluating the effectiveness, implementability, and cost of excavation are the contaminated soil quantity and characteristics, the depth of excavation, the presence of surface and subsurface obstructions, and the need to manage fluids entering the excavation.

Excavation is almost always effective and implementable, but the cost may be excessive if the soil quantity is large, the excavation deep, subsurface structures and utilities must be removed or relocated, or excessive quantities of water must be managed. The removal of contaminated material from AOC 11 will likely take three to five months, preceded by two to four months of relocating existing structures including utilities and the aviation fueling station.

### **5.3.2.1 Effectiveness**

Proper construction oversight would make excavation an effective method for permanently removing the majority of the contamination on this site. On the basis of the existing data, excavation in the free product area would remove both the source of the groundwater contamination and soil containing concentrations above the BUSTR RAOs. Assuming all free product is removed during the excavation activities, the site should not see a resurgence of free product in the monitoring wells after construction is completed. Since concentrations of contaminants detected in monitoring wells outside the free product area are already below the BUSTR RAOs, excavation would achieve all the RAOs within the time required to complete excavation (five to nine months) and post-remediation monitoring (one year).

Excavation of free product from the site would be effective in protecting the human health and the environment in both the short and the long term. All excavated contaminated material would be removed from the site and disposed of in a RCRA Subtitle D permitted landfill. Although contaminants are not destroyed using this technology, potential exposure to them is minimized by removal from the site and containment in the off-site landfill.

The highest exposure risk would occur during the short term excavation and transportation process. Workers would risk exposure to contaminants through inhalation and dermal contact, and the public could also be exposed to contaminants in the air. Additional releases could occur through surface water runoff from contaminated areas. These potential short-term risks would be minimized by monitoring and controls during the excavation process. Workers would use appropriate personal protective equipment, and air monitoring would be conducted. Controls would be implemented for dust and run-on/run-off. On the basis of the relatively low remaining concentrations of volatile organics in the LNAPL, it is unlikely that additional controls would be required for air emissions.

### **5.3.2.2 Implementability**

Excavation is readily implemented with conventional equipment and services. Commonly available excavation equipment including at a minimum an excavator, front loader and dump trucks would be required to complete excavation of the site. A primary landfill and a secondary landfill have been identified as potential acceptors of the contaminated media. Both landfills have contaminated soils listed on their website as acceptable waste. The biggest challenges involve relocation of the utilities that intersect the free product footprint, ensuring access to surrounding buildings during excavation, removing and replacing concrete pavement, and pumping and treating groundwater that may enter the excavation. More surface and subsurface structures, utilities, and piping requiring relocation are present at AOC 11 than at either of the other two AOCs. However, although these challenges would affect the project cost, they do not present insurmountable difficulties.

This technology has high energy requirements and GHG emissions associated with on-site excavation and waste transportation. However, administrative requirements should be minimal. It is anticipated that the owner would readily provide access to the property, and permitting requirements would be limited to a construction stormwater and wastewater pretreatment permit. Petroleum-contaminated soil is frequently disposed of as a special waste at Subtitle D landfills, so approval for disposal should be relatively easily obtained. Coordination with utilities regarding relocations would be required. However, since most (if not all) are located on property owned by CRAA, this should not be difficult to arrange.

If additional contamination was found at a later date, excavation could resume at the limits of the previous excavation project. Installation of a few monitoring wells and short-term monitoring should be sufficient to demonstrate the effectiveness of the excavation technology. Because contamination above RAOs would be removed from the site, this technology is anticipated to be acceptable to BUSTR and the public.

#### **5.3.2.3 Cost**

The cost of excavation in this area of concern was elevated due to the presence of multiple utility lines, existing pavement for roads and parking lot, and a large volume of soil to remove from the site. The estimated cost to complete a generic scope of work is \$1,501,000 (Table F-14).

### **5.3.3 In-Situ Soil Mixing**

The critical issues in evaluating the effectiveness, implementability, and cost of ISSM are the area and depth of mixing, the presence of surface and subsurface obstructions, and the need for air emission controls. ISSM may not be practical or cost effective for large quantities of soil or where structures and/or utilities have to be demolished, removed, or relocated.

#### **5.3.3.1 Effectiveness**

Proper field oversight and confirmation sampling would make ISSM an effective method for permanently homogenizing and stabilizing the majority of the contamination on this site. In the case of the LAFB AOCs, the process would blend and distribute the NAPL product over the soil column and stabilize/solidify the free product and soil containing concentrations above the BUSTR RAOs. Assuming all free product is homogenized during the ISSM activities, the site should not see a resurgence of free product in the monitoring wells after construction is completed. Since concentrations of contaminants detected in monitoring wells outside the free product area are already below the BUSTR RAOs, ISSM would achieve all the RAOs within the time required to complete ISSM (six months) and post-remediation monitoring (one year).

Application of ISSM in the free product area would be effective in protecting human health and the environment in both the short and the long term. Although the contaminants remain on the site, the ISSM process binds them into a matrix that minimizes the potential for direct exposure to or migration of contaminants. This protection would be enhanced by implementation of land use restrictions that would limit site activities that could disturb the subsurface. Because ISSM is an in-situ technique, worker exposure is minimized.

The highest exposure risk would occur during the ISSM process. Workers would risk exposure to contaminants through inhalation and dermal contact, and the public could also be exposed to contaminants in the air. These potential short-term risks would be minimized by monitoring and controls during the ISSM process. Workers would use appropriate personal protective equipment, fugitive emissions would be minimized using shrouds and air controls if needed, and air monitoring would be conducted. On the basis of the relatively low remaining concentrations of volatile organics in the LNAPL, it is unlikely that controls would be required for air emissions.

#### **5.3.3.2 Implementability**

ISSM is readily implemented using drill rigs with specialized hydraulically driven augers and mixing paddles to simultaneously drill and inject material. Several contractors are available that provide these services. The time to achieve RAOs is relatively short, and long-term monitoring should not be required. The biggest challenges involve relocation of the utilities that intersect the free product footprint, removing any underground obstructions, and removing and replacing concrete pavement. More surface and subsurface structures, utilities, and piping requiring relocation are present at AOC 11 than at either of the other two AOCs. However, although these challenges would affect the project cost, they do not present insurmountable difficulties. Short-term monitoring should be sufficient to demonstrate the effectiveness of the ISSM technology.

This technology has high energy requirements and GHG emissions associated with on-site drilling. However, administrative requirements should be moderate. It is anticipated that the owner would readily provide access to the property. Permitting requirements would include construction stormwater, air emissions, and underground injection permits. Coordination with utilities regarding relocations would be required. However, since most (if not all) are located on property owned by CRAA, this should not be difficult to arrange.

Since the contaminants remain on-site, land use restrictions would have to be implemented. Acceptance of this technology by regulators, owners, and the public may be reduced by the fact that 1) contaminants are not destroyed, 2) land use restrictions would be required, and 3) the treatment might physically limit site use (e.g., subsurface installation of utilities).

#### **5.3.3.3 Cost**

The cost of ISSM in this area of concern was elevated due to the presence of multiple utility lines, concrete fuel-line anchors, and existing pavement for roads and parking lot. The estimated cost to complete a generic scope of work is \$2,688,000 (Table F-15).

#### **5.3.4 Multi-Phase Extraction**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the permeability of the subsurface, the depth of the water table, the volumes of materials to be removed, and susceptibility of the contaminants to biodegradation. The use of MPE is not suggested for sites with very high permeability and is better suited for soils with low to moderate permeability to reduce the risk of short-circuiting. It is also not recommended for use in soils with very low permeability because of a lack of secondary flow paths. When used at sites with

low to moderate permeability, this system can potentially create a large radius of influence causing greater capture of the contaminant plume and reducing the need for extra wells.

In order for MPE to work efficiently and cost effectively, the location needs to have hydraulic conductivity between  $1.8 \times 10^{-4}$  and  $5.3 \times 10^{-3}$  cm/s and a water table depth of less than 30 ft to the surface (the total fluids configuration requires an even shallower depth to water). The goal of this technology is to remove contaminant mass while promoting bioremediation and ultimately allowing natural attenuation to take over once the MPE system can no longer cost effectively remove contaminants.

#### **5.3.4.1 Effectiveness**

Hydraulic conductivity, depth to groundwater, and thickness of LNAPL at the site all appear to be within recommended ranges. However, the LNAPL appears to be present within disconnected sand lenses in a highly heterogenous soil environment. Identifying preferred pathways for extraction may prove impossible, and a large number of extraction wells equipped with pumps would be required. Effectively locating extraction wells to avoid existing infrastructure would inevitably involve compromise and may prove impractical. Even if these constraints are overcome, the time to achieve RAOs can be expected to be longer than in a more favorable setting. In addition, the LNAPL characteristics discussed in Section 5.3.1.1 would likely limit the effectiveness of bioremediation and natural attenuation in reducing contaminant concentrations over time. The time to achieve the RAOs with respect to reduction of free phase liquid to <0.01 ft is estimated to be three to eight years, but it is likely that concentrations of COCs in soil and groundwater within the free product area may remain above RAOs for some time.

During implementation there would be some potential for exposure to workers and the public to contaminated media. Extracted product, groundwater, and vapors would have to be treated on site or disposed of off site. Exposure to the contaminated material would be minimized by the use of appropriate worker personal protective equipment and engineering controls (e.g., treatment of air emissions, if required).

#### **5.3.4.2 Implementability**

The physical implementation of this alternative is very feasible, as there are few technical or regulatory barriers to hinder its design, installation, or operation. The technology requires drilling, sampling, chemical analysis, disposal of small quantities of contaminated soil, and extraction and treatment of groundwater and vapors. Facilities, equipment, and labor necessary to implement these activities are available and have been implemented at multiple sites. The site is accessible, and although there are more surface and subsurface structures, utilities, and piping at AOC 11 than at either of the other two AOCs, drilling can be planned around these obstacles. Minimal site restoration would be required after wells have been sealed.

Energy requirements and GHG emissions for treatment and compressors would be moderate. Permits would likely be required for air emissions and treated water discharges, and land use restrictions might be required if soil and groundwater RAOs are not met. Due to noise and air



emissions, acceptability to regulators and the public would be contingent on the effectiveness of the technology in achieving RAOs within a reasonable time.

#### **5.3.4.3 Cost**

The cost to implement MPE at AOC 11 is anticipated to be \$2,032,000 capital cost and \$2,125,000 present worth cost (Table F-16). The cost estimate assumes that the remedy would be implemented without removing and replacing existing surface and subsurface infrastructure.

#### **5.3.5 Multi-phase Extraction with Heating**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the permeability of the subsurface, the depth of the water table, the volumes of materials to be removed, and susceptibility of the contaminants to biodegradation. The use of MPEH is not suggested for sites with very high permeability and is better suited for soils with low to moderate permeability to reduce the risk of short-circuiting. It is also not recommended for use in soils with very low permeability because of a lack of secondary flow paths. When used at sites with low to moderate permeability, this system can potentially create a large radius of influence causing greater capture of the contaminant plume and reducing the need for extra wells.

In order for MPEH to work efficiently and cost effectively, the location needs to have hydraulic conductivity between  $1.8 \times 10^{-4}$  and  $5.3 \times 10^{-3}$  cm/s, a water table depth of less than 30 ft to the surface (the total fluids configuration requires an even shallower depth to water), and ideally less than 0.5 foot of product. The goal of this technology is to remove contaminant mass while promoting bioremediation and ultimately allowing natural attenuation to take over once the MPE with heating system can no longer cost effectively remove contaminants.

##### **5.3.5.1 Effectiveness**

Hydraulic conductivity, depth to groundwater, and LNAPL thickness at the site appear to be within acceptable ranges. Adding heat to conventional MPE will increase the effectiveness of the process by volatilizing higher molecular weight compounds than traditional MPE, reducing the viscosity of free-phase and residual NAPL, and increasing chemical reaction rates for contaminant breakdown. Although this process would be more effective than traditional MPE, the LNAPL appears to be present within disconnected sand lenses in a highly heterogeneous soil environment. Identifying preferred pathways for extraction may prove impossible, and a large number of extraction/injection wells might be required. Effectively locating extraction wells and heating equipment to avoid existing infrastructure would inevitably involve compromise and might prove impractical. In addition, the LNAPL characteristics discussed in Section 5.3.1.1 would likely limit the effectiveness of bioremediation and natural attenuation in reducing contaminant concentrations over time. Even if these constraints are overcome, the time to achieve RAOs would be expected to be longer than in a more favorable setting. Although the addition of heating to MPE should reduce the time to achieve RAOs over MPE alone, the time to achieve RAOs is still estimated to be two to three years.

During implementation there would be some potential for exposure to workers and the public to contaminated media. Extracted product, groundwater, and vapors would have to be treated on

site or disposed of off site. Exposure to the contaminated material would be minimized by the use of appropriate worker personal protective equipment and engineering controls (e.g., treatment of air emissions, if required).

#### **5.3.5.2 Implementability**

The physical implementation of this alternative at AOC 11 would be difficult given existing surface and subsurface infrastructure in the vicinity of the contamination. The technology requires drilling, sampling, chemical analysis, disposal of small quantities of contaminated soil, and extraction and treatment of groundwater and vapors. Facilities, equipment, and labor necessary to implement these activities are available and have been implemented at other sites. Availability of power for heating needs further assessment based on the heating technology selected, but should be implementable at this site. The site is accessible, but installation of wells and associated equipment would require careful selection of locations to minimize the effect on existing infrastructure and ongoing operations.

Energy requirements and GHG emissions for treatment and compressors would be moderate, if waste heat were used for the heating component. Permits would likely be required for air emissions, underground injection, and treated water discharges, and land use restrictions might be required, if soil and groundwater RAOs are not met. Due to noise and potential air emissions, acceptability to regulators and the public would be contingent on the effectiveness of the technology in achieving RAOs within a reasonable time. Minimal site restoration would be required after wells have been sealed.

#### **5.3.5.3 Cost**

The cost to remediate this AOC utilizing MPE supplemented with low temperature in-situ thermal desorption is approximately \$2,631,000 capital cost and \$2,683,000 present worth cost (Table F-17). The cost estimate assumes that the remedy would be implemented without removing and replacing existing surface and subsurface infrastructure. (This assumes that waste heat from the MPE process will be injected to enhance VOC mass removal, leading to lower operational costs. The source of heat is essentially free, and the rate of remediation is accelerated, so the time to achieve RAOs is shorter and costs are lower than MPE alone.)

### **5.3.6 In-Situ Chemical Oxidation**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the permeability of the subsurface, mass of contaminants to be treated, and the physical condition of the contaminant (i.e., dissolved, adsorbed, or free phase). ISCO is best implemented in relatively homogeneous soils with higher conductivities, and at sites where the target contaminant (in this case, weathered JP-4) is present in the dissolved phase.

#### **5.3.6.1 Effectiveness**

As described in the preceding section, the conditions necessary for successful implementation of ISCO do not appear to exist at AOC 11. The discontinuity of the granular lenses and the low permeability of the remaining soil are not favorable to distribution of the oxidant. In addition, the free product is the target contamination, and dissolution of the weathered JP-4 LNAPL is

occurring at a very slow rate based on the absence of dissolved contaminants outside the free product area. The hydrogeological conditions and contaminant characteristics are both limiting factors in achieving adequate contact between the oxidant and the dissolved contaminant compounds.

On the basis of this analysis, it does not appear that ISCO would be effective in achieving the RAOs due to the limitations of the heterogeneous subsurface conditions and the presence of relatively large quantities of free phase product and contaminants adsorbed to the soil matrix.

#### **5.3.6.2 Implementability**

Equipment and facilities necessary to implement this technology are available and could be installed at the site. The technology requires drilling, sampling, chemical analysis, disposal of small quantities of contaminated soil and groundwater, and the mixing and injection of the ISCO solution. The site is accessible, and drilling can be planned around existing underground utilities. However, there are more underground structures and utilities in close proximity to the free product area at AOC 11 than at either AOC 3 or AOC 9. These structures and utilities might have to be protected or relocated to prevent adverse impacts from the oxidizing compound.

Energy requirements and GHG emissions associated with this technology would be relatively low, but a permit for underground injection would be required. Injection of oxidizing chemicals into the subsurface might not be acceptable to regulators or the public. Minimal site restoration would be required after wells have been sealed.

#### **5.3.6.3 Cost**

Oxidant demand is the controlling factor with respect to cost for ISCO. However, the mass of contamination is smaller at AOC 11 than at AOC 3, so it will require a proportionally smaller mass of oxidant. The total oxidant demand is the sum of the contaminant oxidant demand and the natural oxidant demand (also referred to as the soil oxidant demand). The contaminant demand represents the stoichiometric mass of oxidant required to oxidize the target contaminant.

The contaminant oxidant demand for potassium permanganate is 19.7 pounds per pound of contaminant, assuming naphthalene as a surrogate for JP-4. Using this value, the stoichiometric mass of potassium permanganate required to oxidize the assumed volume of free product at AOC 11 (6,400 gallons, or 44,800 pounds of JP-4 at 7 pounds per gallon) is 882,560 pounds. At a unit cost of \$1.80 per pound, the cost of the oxidant alone would be \$1.6 million (Ref. 30). However, due to the challenges associated with achieving direct contact between the oxidant and the contaminants in in-situ applications, as well as the presence of naturally occurring organics, the actual mass of permanganate that must be injected is typically greater than this stoichiometric requirement based on the contaminant mass alone. This cost also does not include the costs associated with construction of injection points and the mixing/injection of the oxidant solution, or any costs associated with effectiveness monitoring and reporting.

#### **5.3.6.4 Surfactant Enhanced LNAPL Removal**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the permeability of the subsurface, groundwater flow conditions, the volume of contaminants to be removed and their physical condition (i.e., dissolved, adsorbed, or free phase). SELR is best implemented over small free product areas and in relatively homogeneous soils with hydraulic conductivities of  $10^{-3}$  cm/s or higher. The fluctuating groundwater table will likely reduce effectiveness by limiting contact between the surfactant and flushing fluid and the contaminants. As noted previously, this technology will only address contaminants present below the water table.

#### **5.3.6.5 Effectiveness**

As described in the preceding section, the site characteristics necessary for successful implementation of this technology do not exist at AOC 11 and surfactant enhanced LNAPL removal should be considered an ineffective option for this site.

#### **5.3.6.6 Implementability**

Equipment and facilities necessary to implement this technology are available, and the technology could be readily installed and implemented at the site. The technology requires conventional activities including drilling, sampling, chemical analysis, injection of surfactant, extraction and separation/treatment of surfactant and contaminated groundwater, and disposal of contaminated soil and discharge of treated groundwater/vapors. Although there are more underground structures and utilities in close proximity to the free product area at AOC 11 than at either AOC 3 or AOC 9, drilling could probably be planned around these obstacles.

Energy requirements and GHG emissions would be low, but permits would likely be required for treated wastewater discharge, underground injection, and possibly air emissions. Injection of surfactant chemicals into the subsurface might not be acceptable to regulators or the public, due to the potential for increased contaminant migration. Minimal site restoration would be required after wells have been sealed.

Overall, the hydrogeologic conditions and large area of free product at AOC 11 are not conducive for implementation of this remediation method. This method should not be considered further for remediation of the site.

#### **5.3.6.7 Cost**

Because the site does not exhibit hydrogeologic and geologic conditions conducive to the application of this remediation technology, costs have not been estimated as part of this effort.

#### **5.3.7 Electrical Resistance Heating**

The critical issues in evaluating the effectiveness, implementability, and cost of this technology are the volume of LNAPL present and the chemical composition of the contaminants. Overall, ERH has been shown to be an effective but costly technology.

### **5.3.7.1 Effectiveness**

Remediation projects using thermally enhanced vapor generation and recovery are highly dependent upon the specific soil and chemical properties of the contaminated media. ERH is most effective on VOCs with boiling points at or below that of water (100°C). Of the contaminants targeted for remediation at this site, benzene and TPH-GRO are easily removed with ERH. Less volatile contaminants, including xylenes and TPH-DRO, can be remediated with ERH, but more energy will be required to volatilize those chemicals. Installing a MPE system alongside ERH would help in recovering the less volatile contaminants.

ERH can be effective for all soil types, but soil that has a high moisture content or is tight will have a lower permeability to air, requiring more energy input to increase temperature and vacuum. Lower operating costs are associated with using ERH in more permeable soils. Additionally, soils with high organic content will respond less favorably to ERH due to the soil's high VOC-sorption capacity.

Compared to other remediation technologies, the time to achieve RAOs with ERH is low. ERH usually takes three to six months to complete treatment under ideal conditions. At this AOC, the time to achieve RAOs is not expected to exceed nine months, with a post-completion monitoring period. Assuming that ERH could cost effectively achieve RAOs at AOC 3, the long-term effectiveness of ERH is high. The contaminants would be volatilized from the subsurface and treated, leaving residual concentrations that would be protective of human health and the environment.

The highest exposure risk would occur during process implementation. Workers and the public could risk exposure to contaminants through inhalation of volatilized contaminants, and the electrical equipment and steam generated represent safety hazards, particularly with respect to fuel storage, piping, and dispensing. These potential short-term risks would be minimized by monitoring and controls during the ERH process. Workers would use appropriate personal protective equipment and safety precautions, fugitive emissions would be minimized by the vapor collection and treatment system, and air monitoring would be conducted.

### **5.3.7.2 Implementability**

Facilities, equipment, and labor necessary to implement this technology are significant and intensive, but available. Site accessibility for further investigation and installation is challenging. Although electrodes and vapor recovery wells could be located around existing underground utilities, safety considerations might require removal of some piping and storage units and suspension of fueling operations. Additional information on preferential vapor flow pathways would need to be considered in design. Other conditions at the site are conducive to implementing ERH technology, including slow groundwater movement and low hydraulic gradient. These favorable conditions could potentially lower the cost to implement ERH at AOC 11. Minimal site restoration would be required after equipment has been moved off site and wells have been sealed.

The energy costs for this technology are high, but off-set by the relatively short duration of treatment. Permits may be required for air emissions and underground injection of water, which

may be required to maintain the electric current. Because of the short treatment time and the effectiveness of the technology, acceptance by regulators and the public is anticipated to be high.

### **5.3.7.3 Cost**

If safety concerns can be managed and ERH considered further at AOC 11, the cost of implementation is anticipated to be \$3,323,000 (Table F-18). This cost estimate does not account for the removal and replacement of existing infrastructure as part of the remedy.

## 6.0 SUMMARY AND CONCLUSIONS

Tables 4 through 6 present a summary of the technology evaluations by AOC, as presented in Section 5.0. Because of the similarity of the conditions, particularly the hydrogeology, at each of the AOCs, the evaluations of the technologies at each location are relatively similar. Therefore, the text of this section is organized by technology to present a qualitative summary of the highlights of the evaluations, with limited reference to unique conditions at each of the AOCs.

### 6.1 SUMMARY EVALUATION OF NSZD

NSZD involves monitoring the physical and biological transformation of LNAPL over time. Since the technology only requires drilling and sampling, implementability at all the AOCs is high, and costs are relatively low. However, this technology would not be effective in achieving RAOs within a reasonable time due to slow dissolution of weathered LNAPL under heterogeneous subsurface conditions.

### 6.2 SUMMARY EVALUATION OF EXCAVATION

Excavation involves removal and disposal of contaminated soil to the maximum depth of the free product smear zone. This technology is implementable at all the AOCs, but costs would be higher at AOCs 3 and 11, because of the presence of above and below ground structures, utilities, and piping. Costs would generally be moderate to high, and would increase if significant water management were required. The effectiveness of this technology would be moderate to high, because free product and contaminated soil would be permanently removed from the AOCs.

### 6.3 SUMMARY EVALUATION OF ISSM

ISSM involves in place mixing of soil with water and grout to the maximum depth of the free product smear zone. This technology is implementable at all the AOCs, but costs would be higher at AOCs 3 and 11, because of the presence of above and below ground structures, utilities, and piping that would have to be removed and relocated. Costs would generally be high. The effectiveness of this technology would be moderate. Although free product and contaminated soil would be homogenized and solidified to minimize potential exposure and migration, contaminants would be left in place on the site and future land use would be restricted.

### 6.4 SUMMARY EVALUATION OF MPE

MPE combines free product recovery, groundwater extraction, and soil vapor extraction to remove LNAPL, contaminants dissolved in the groundwater, and volatile compounds trapped in the soil. Since the technology only requires drilling, extraction, and treatment, implementability and costs at all the AOCs are moderate. However, effectiveness is uncertain. Although free product reduction would probably meet RAOs within a reasonable period of time, residual soil

and groundwater contamination might remain because of the heterogeneous subsurface conditions and the presence of less soluble and volatile constituents in the weathered LNAPL.

## 6.5 SUMMARY EVALUATION OF MPEH

MPEH adds heating to MPE to increase the rate and recovery and/or range of contaminants that can be extracted. Installation of heating equipment increases the complexity of implementation over MPE. Depending on the heating method, surface and subsurface obstructions and hazards at AOC 11 may require removal, relocation, and/or suspension of fueling operations. Costs are relatively high and may be very high for AOC 11. Effectiveness is likely to be high, since heating will help to overcome the limitations associated with MPE alone.

## 6.6 SUMMARY EVALUATION OF ISCO

ISCO involves injection of chemicals into the subsurface to oxidize dissolved-phase organic contaminants. This technology was eliminated from consideration at all the AOCs, because it is unlikely to be effective because of the slow dissolution of the weathered LNAPL and the difficulties of achieving contact between the oxidant and the contaminants under the heterogeneous subsurface conditions.

## 6.7 SUMMARY EVALUATION OF SELR

SELR involves injection of a surfactant into the subsurface to mobilize contaminants in free phase product and adsorbed to the soil matrix. The mobilized contaminants are then extracted with the groundwater. This technology was eliminated from consideration, because it is unlikely that the surfactant could be distributed effectively under the heterogeneous subsurface conditions.

## 6.8 SUMMARY EVALUATION OF ERH

ERH uses arrays of electrodes to create a concentrated flow of current that creates heat as a result of the resistance to the flow of electricity in the soil. The heat volatilizes the contaminants, which are captured by vacuum extraction and piped to condenser. Implementation is somewhat complicated and energy requirements are high, resulting in high costs for this technology. Surface and subsurface obstructions and hazards at AOC 11 may require removal, relocation, and/or suspension of fueling operations at that AOC. The effectiveness of this technology is high. It is anticipated that it can achieve all RAOs in less than a year.



Table 4. AOC 3 Technology Comparison

Alternative	Description	Criteria		
		Effectiveness	Implementability	Cost
Natural Source Zone Depletion	Natural processes act to (a) physically redistribute LNAPL components to the aqueous or gaseous phase and (b) biologically break down these source zone components. Requires monitoring well installation and long-term monitoring.	Very Low. Not likely to achieve RAOs within a reasonable period of time due to slow dissolution and evaporation of weathered LNAPL under heterogeneous subsurface conditions.	Moderate to High. Requires only conventional, short-term, and demonstrated activities (drilling, sampling, disposal). Facilities, equipment, and labor are readily available. The site is accessible, and drilling can be planned around existing underground utilities. Minimal site restoration required. However, requires long term monitoring, and public and regulatory acceptance might be low, because of time to reach RAOs.	Low. Capital: \$234,000 Present Worth: \$418,000
Excavation	Contaminated soil would be excavated to the maximum depth of the free product smear zone and hauled to a landfill for disposal as a special waste. Clean overburden soil would be stockpiled and used in backfilling the excavation, along with additional clean soil from an off-site source. Water entering the excavation would be treated on site and discharged to the sanitary sewer.	Moderate to High. Free product and contaminated soil would be permanently removed from the site, which should achieve all RAOs. Although contaminants would not be destroyed, potential exposure would be minimized through containment within a properly constructed off-site landfill. Potential short term worker and public exposure would be minimized through use of appropriate personal protective equipment and environmental controls.	Moderate to High. Requires only conventional construction equipment and services and site is readily accessible. Although labor-intensive in the short-term, long-term monitoring should not be required. Depending on the haul distance, public and regulatory acceptance of transporting a large volume of contaminated soil off site might be low. Would require relocation of utilities.	Moderate. Capital: \$3,627,000

Table 4. AOC 3 Technology Comparison

Alternative	Description	Criteria		
		Effectiveness	Implementability	Cost
<b>In Situ Soil Mixing</b>	Contaminated soil would be mixed in place with water and grout to the maximum depth of the free product smear zone. Mixing would be achieved using augers and mixing paddles to drill and inject material. Soil, groundwater, and free product within the mixing zone would be homogenized, stabilized, and solidified.	Moderate. Free product would be eliminated through the mixing process. Although contaminants would not be removed from the site, homogenization and solidification would minimize potential exposure to and migration of contaminants. Potential short term worker and public exposure would be minimized through use of appropriate personal protective equipment and environmental controls.	Moderate. Requires somewhat specialized drilling equipment, but several contractors are available. Although labor-intensive in the short-term, long-term monitoring should not be required. Public and regulatory acceptance might be reduced by the contaminants remaining on the site and by associated administrative and physical land use constraints. Would require relocation of utilities.	High Capital: \$6,932,000
<b>Multi-phase Extraction</b>	Multi-phase extraction combines free product recovery, groundwater extraction, and soil vapor extraction. The water table is lowered in order to dewater the saturated zone so that volatile organic compounds can be stripped from the exposed soil. The lowering of the water table also increases the flow of residual product from the now unsaturated soil pore spaces, while the air flow enhances aerobic bioremediation.	Low to Moderate. Effectiveness somewhat uncertain because of limiting factors, including discontinuous granular lenses and weathered LNAPL. It is likely that free product reduction would meet RAOs in 3-8 years, but residual soil contamination would likely remain. Potential short term worker and public exposure would be minimized through use of appropriate personal protective equipment and environmental controls.	Moderate. Requires only conventional, short-term, and demonstrated activities (drilling, pumping, SVE, onsite treatment). Facilities, equipment, and labor are readily available. The site is accessible, and drilling can be planned around existing underground utilities. However, site conditions would require close well spacing, and operation, maintenance, and monitoring up to 8 years. Minimal site restoration would be required. Public and regulatory acceptance contingent on ability to achieve RAOs in a reasonable period of time. Land use restrictions might be required for residual soil contamination.	High Capital: \$4,036,000 Present Worth: \$4,129,000

Table 4. AOC 3 Technology Comparison

Alternative	Description	Criteria		
		Effectiveness	Implementability	Cost
<b>Multi-phase Extraction with Heating</b>	Heating is added to conventional multi-phase extraction to increase the rate of recovery and/or the range of contaminants that can be treated. Heating will volatilize higher weight compounds, reduce viscosity of LNAPL, and speed up chemical reactions. Steam injection, electrical resistance heating, or other methods may be used.	Moderate. Heating will help to overcome limiting factors, including discontinuous granular lenses and weathered LNAPL. It is likely that free product reduction would meet RAOs in 2-3 years, and residual soil contamination is less likely. Potential short term worker and public exposure would be minimized through use of appropriate personal protective equipment and environmental controls.	Low to Moderate. Installation of heating equipment increases complexity of multi-phase extraction implementation. Facilities, equipment, and labor are readily available. The site is accessible; however, relocation of utilities may be required. Site conditions would require close well spacing, and operation, maintenance, and monitoring up to 3 years. Minimal site restoration would be required. Public and regulatory acceptance contingent on ability to achieve RAOs in a reasonable period of time.	High Capital: \$3,633,000 Present Worth: \$3,685,000
<b>In Situ Chemical Oxidation</b>	Chemical oxidants are injected into the subsurface to react with and destroy dissolved-phase organic contaminants. Common oxidants include hydrogen peroxide, ozone, permanganate, and persulfate.	Very Low. Process will be limited by the rate of dissolution of free product, which will be slow for weathered LNAPL. Contact of the oxidant with dissolved compounds will be limited by the heterogeneous subsurface conditions.	Low to Moderate. Requires only conventional, short-term, and demonstrated activities (drilling, chemical mixing and injection, sampling, disposal). Facilities, equipment, and labor are readily available. Oxidants are hazardous to human health and require careful handling by trained workers using appropriate protective equipment. This could reduce public and regulatory acceptance. Utilities might have to be relocated because of damaging effects of oxidants. Minimal site restoration and no long term monitoring would be required.	Very High. Cost of oxidant alone based on LNAPL volume at the site: \$8,700,000. Costs of installing and operating mixing and injection system and additional oxidant required for naturally occurring organic compounds were not calculated.

Table 4. AOC 3 Technology Comparison

Alternative	Description	Criteria		
		Effectiveness	Implementability	Cost
<b>Surfactant-Enhanced LNAPL Removal</b>	Injection of low viscosity surfactant solution into the subsurface to mobilize contaminants in free phase product and adsorbed to the soil matrix into the aqueous phase.	Very Low. Subsurface is too heterogeneous and has too low a hydraulic conductivity for this technology to be effective.	Low to Moderate. Requires only conventional, short-term, and demonstrated activities (drilling, mixing and injection, sampling, disposal). Facilities, equipment, and labor are readily available. However, implementation is unlikely to achieve adequate distribution of the surfactant, and control of the injected material might be difficult under site conditions.	Not calculated.
<b>Electrical Resistance Heating</b>	Uses arrays of electrodes installed around a central neutral electrode to create a concentrated flow of current toward the central point. Soil resistance to the flow of electricity creates heat above 100° C, which is used to evaporate contaminants from soil and groundwater. Steam and volatilized contaminants are captured by vacuum extraction wells and piped to a condenser.	High. This technology can achieve RAOs in less than a year. However, more heat is required to achieve complete remediation of contaminants with higher boiling points, especially in tight soils with high organic content.	Low to moderate. Installation and operation is relatively complicated, but equipment and contractors are available. Although labor-intensive in the short-term, long-term monitoring should not be required. Public and regulatory acceptance would likely be high, because contaminants are permanently destroyed in a relatively short period of time. Utilities would likely have to be relocated.	High. Capital: \$7,400,000

Table 5. AOC 8 & 9 Technology Comparison

Alternative	Description	Criteria		
		Effectiveness	Implementability	Cost
Natural Source Zone Depletion	Natural processes act to (a) physically redistribute LNAPL components to the aqueous or gaseous phase and (b) biologically break down these source zone components. Requires monitoring well installation and long-term monitoring.	Low. Not likely to achieve RAOs within a reasonable period of time due to slow dissolution and evaporation of weathered LNAPL under heterogeneous subsurface conditions. However, more likely to be effective at this AOC than on larger areas of free product at AOC 3 and 11.	Moderate to High. Requires only conventional, short-term, and demonstrated activities (drilling, sampling, disposal). Facilities, equipment, and labor are readily available. The site is accessible, and drilling can be planned around existing underground utilities. Energy requirements and GHG emissions would be low. However, requires land use restrictions and long term monitoring, and public and regulatory acceptance might be low, because of time to reach RAOs. Minimal site restoration required.	Low. Capital: \$235,000 Present Worth: \$419,000
Excavation	Contaminated soil would be excavated to the maximum depth of the free product smear zone and hauled to a landfill for disposal as a special waste. Clean overburden soil would be stockpiled and used in backfilling the excavation, along with additional clean soil from an off-site source. Water entering the excavation would be treated on site and discharged to the sanitary sewer.	Moderate to High. Free product and contaminated soil would be permanently removed from the site, which should achieve all RAOs. Although contaminants would not be destroyed, potential exposure would be minimized through containment within a properly constructed off-site landfill. Potential short-term worker and public exposure would be minimized through use of appropriate personal protective equipment and environmental controls.	Moderate to High. Requires only conventional construction equipment and services, site is readily accessible, and disposal facilities are available. Although labor-intensive in the short-term, long-term monitoring should not be required. High energy and GHG emissions, and stormwater and wastewater discharge permits would be required. Since contamination above RAOs would be removed from the site, public and regulatory acceptance should be high.	Moderate. Capital: \$551,000

Table 5. AOC 8 & 9 Technology Comparison

Alternative	Description	Criteria		
		Effectiveness	Implementability	Cost
<b>In Situ Soil Mixing</b>	Contaminated soil would be mixed in place with water and grout to the maximum depth of the free product smear zone. Mixing would be achieved using augers and mixing paddles to drill and inject material. Soil, groundwater, and free product within the mixing zone would be homogenized, stabilized, and solidified.	Moderate. Free product would be eliminated through the mixing process. Although contaminants would not be removed from the site, homogenization and solidification would minimize potential exposure to and migration of contaminants. Potential short-term worker and public exposure would be minimized through use of appropriate personal protective equipment and environmental controls.	Moderate. Requires somewhat specialized drilling equipment, but several contractors are available. Although labor-intensive in the short-term, long-term monitoring should not be required. Energy requirements and GHG emissions would be high during operation, and underground injections and air emissions permits would be required. Public and regulatory acceptance might be reduced by the contaminants remaining on the site and by associated administrative and physical land use constraints.	Moderate. Capital: \$746,000
<b>Multi-phase Extraction</b>	Multi-phase extraction combines free product recovery, groundwater extraction, and soil vapor extraction. The water table is lowered in order to dewater the saturated zone, so that volatile organic compounds can be stripped from the exposed soil. The lowering of the water table also increases the flow of residual product from the unsaturated soil pore spaces, while the air flow enhances aerobic bioremediation.	Moderate. Effectiveness somewhat uncertain because of limiting factors, including discontinuous granular lenses and weathered LNAPL. It is likely that free product reduction would meet RAOs in 3-8 years, but residual soil contamination would likely remain. Potential short-term worker and public exposure would be minimized through use of appropriate personal protective equipment and environmental controls.	Moderate. Requires only conventional, short-term, and demonstrated activities (drilling, pumping, SVE, on-site treatment). Facilities, equipment, and labor are readily available. The site is accessible, but site conditions would require close well spacing. Land use restrictions and monitoring might be required for an extended period, if soil and groundwater RAOs are not met. Energy requirements and GHG emission would be moderate. Public and regulatory acceptance contingent on ability to achieve RAOs in a reasonable period of time. Minimal site restoration required.	High Capital: \$1,226,000 Present Worth: \$ 1,319,000

Table 5. AOC 8 & 9 Technology Comparison

Alternative	Description	Criteria		
		Effectiveness	Implementability	Cost
<b>Multi-phase Extraction with Heating</b>	Heating is added to conventional multi-phase extraction to increase the rate of recovery and/or the range of contaminants that can be treated. Heating will volatilize higher weight compounds, reduce viscosity of LNAPL, and speed up chemical reactions. Steam or hot air injection, electrical resistance heating, or other methods may be used.	Moderate. Heating will help to overcome limiting factors, including discontinuous granular lenses and weathered LNAPL. It is likely that RAOs would be met in 2-3 years. Potential short-term worker and public exposure would be minimized through use of appropriate personal protective equipment and environmental controls.	Moderate. Installation of heating equipment increases complexity of multiphase extraction implementation. Facilities, equipment, and labor are readily available. The site is accessible, but site conditions would require close well spacing. Land use restrictions and long-term monitoring less likely to be required than for MPE alone. Energy requirements and GHG emission would be moderate. Permits required for air emissions and wastewater discharge. Minimal site restoration required. Public and regulatory acceptance contingent on ability to achieve RAOs in a reasonable period of time.	High Capital: \$ 1,118,000 Present Worth: \$ 1,170,000
<b>In Situ Chemical Oxidation</b>	Chemical oxidants are injected into the subsurface to react with and destroy dissolved-phase organic contaminants. Common oxidants include hydrogen peroxide, ozone, permanganate, and persulfate.	Low. Process limited by the rate of dissolution of free product, which will be slow for weathered LNAPL. Contact of the oxidant with dissolved compounds limited by the heterogeneous subsurface conditions. Short-term risks due to hazards posed by oxidizing chemicals would be reduced by implementing appropriate safety procedures.	Moderate. Requires only conventional, short-term, and demonstrated activities (drilling, chemical mixing and injection, sampling, disposal). Facilities, equipment, and labor are readily available. Permit required for underground injection, which might not be acceptable to regulators and the public. Low energy requirements, low GHG emissions, minimal site restoration, and no long-term monitoring.	High to very high. Cost of oxidant alone based on LNAPL volume at the site: \$446,800. Costs of installing and operating mixing and injection system and additional oxidant required for naturally occurring organic compounds were not calculated.

Table 5. AOC 8 & 9 Technology Comparison

Alternative	Description	Criteria		
		Effectiveness	Implementability	Cost
<b>Surfactant-Enhanced LNAPL Removal</b>	Injection of low viscosity surfactant solution into the subsurface to mobilize contaminants in free phase product and adsorbed to the soil matrix into the aqueous phase.	Low. Subsurface is too heterogeneous and has too low a hydraulic conductivity for this technology to be effective.	Moderate. Requires only conventional, short-term, and demonstrated activities (drilling, mixing and injection, sampling, disposal). Facilities, equipment, and labor are readily available. Energy requirements and GHG emissions low, but permits required for treated wastewater discharge, underground injection, and air emissions. Implementation is unlikely to achieve adequate distribution of the surfactant, and control of the injected material might be difficult under site conditions, so public and regulatory acceptance may be low.	Not calculated.
<b>Electrical Resistance Heating</b>	Uses arrays of electrodes installed around a central neutral electrode to create a concentrated flow of current toward the central point. Soil resistance to the flow of electricity creates heat above 100° C, which is used to evaporate contaminants from soil and groundwater. Steam captured by vacuum extraction wells and piped to a condenser.	High. Site conditions at AOC 8/9 are favorable, and this technology can achieve RAOs in less than a year. However, more heat is required to achieve complete remediation of contaminants with higher boiling points, especially in tight soils with high organic content. Use of proper protective equipment and engineering controls would reduce potential short-term exposure risks and safety hazards during implementation.	Moderate. Installation and operation are relatively complicated, but equipment and contractors are available. Although labor-intensive in the short-term, long-term monitoring should not be required. Energy requirements are high, but duration is short. Permits required for underground injection and air emissions. Public and regulatory acceptance would likely be high, because contaminants are permanently destroyed in a relatively short period of time.	High. Capital: \$1,358,000



Table 6. AOC 11 Technology Comparison

Alternative	Description	Criteria		
		Effectiveness	Implementability	Cost
Natural Source Zone Depletion	Natural processes act to (a) physically redistribute LNAPL components to the aqueous or gaseous phase and (b) biologically break down these source zone components. Requires monitoring well installation and long-term monitoring.	Very Low. Not likely to achieve RAOs within a reasonable period of time due to slow dissolution and evaporation of weathered LNAPL under heterogeneous subsurface conditions.	Moderate to High. Requires only conventional, short-term, and demonstrated activities (drilling, sampling, disposal). Facilities, equipment, and labor are readily available. The site is accessible, and drilling can be planned around existing underground utilities. Energy requirements and GHG emissions would be low. However, requires land use restrictions and long-term monitoring, and public and regulatory acceptance might be low, because of time to reach RAOs. Minimal site restoration required.	Low. Capital: \$231,000 Present Worth: \$416,000
Excavation	Contaminated soil would be excavated to the maximum depth of the free product smear zone and hauled to a landfill for disposal as a special waste. Clean overburden soil would be stockpiled and used in backfilling the excavation, along with additional clean soil from an off-site source. Water entering the excavation would be treated on site and discharged to the sanitary sewer.	Moderate to High. Free product and contaminated soil would be permanently removed from the site, which should achieve all RAOs. Although contaminants would not be destroyed, potential exposure would be minimized through containment within a properly constructed off-site landfill. Potential short term worker and public exposure would be minimized through use of appropriate personal protective equipment and environmental controls.	Moderate. Requires only conventional construction equipment and services, site is accessible, and disposal facilities are available. However, more surface and subsurface structures, utilities, and piping requiring relocation are present at AOC 11 than at either of the other AOCs. Although labor-intensive in the short-term, long-term monitoring should not be required. High energy and GHG emissions during implementation, and stormwater and wastewater discharge permits required. Since contamination above RAOs would be removed from the site, public and regulatory acceptance should be high.	Moderate. Capital: \$1,501,000

Table 6. AOC 11 Technology Comparison

Alternative	Description	Criteria		
		Effectiveness	Implementability	Cost
<b>In Situ Soil Mixing</b>	Contaminated soil would be mixed in place with water and grout to the maximum depth of the free product smear zone. Mixing would be achieved using augers and mixing paddles to drill and inject material. Soil, groundwater, and free product within the mixing zone would be homogenized, stabilized, and solidified.	Moderate. Free product would be eliminated through the mixing process. Although contaminants would not be removed from the site, homogenization and solidification would minimize potential exposure to and migration of contaminants. Potential short-term worker and public exposure would be minimized through use of appropriate personal protective equipment and environmental controls.	Moderate. Requires somewhat specialized drilling equipment, but several contractors are available. More surface and subsurface structures, utilities, and piping requiring relocation are present at AOC 11 than at either of the other AOCs. Although labor-intensive in the short-term, long-term monitoring should not be required. Energy requirements and GHG emissions would be high during operation, and underground injection and air emissions permits would be required. Public and regulatory acceptance might be reduced by the contaminants remaining on the site and by land use constraints.	High Capital: \$2,688,000
<b>Multi-phase Extraction</b>	Multi-phase extraction combines free product recovery, groundwater extraction, and soil vapor extraction. The water table is lowered in order to dewater the saturated zone, so that volatile organic compounds can be stripped from the exposed soil. The lowering of the water table also increases the flow of residual product from the unsaturated soil pore spaces, while the air flow enhances aerobic bioremediation.	Moderate. Effectiveness somewhat uncertain because of limiting factors, including discontinuous granular lenses and weathered LNAPL. It is likely that free product reduction would meet RAOs in 3-8 years, but residual soil contamination would likely remain. Potential short-term worker and public exposure would be minimized through use of appropriate personal protective equipment and environmental controls.	Moderate. Requires only conventional, short-term, and demonstrated activities. Facilities, equipment, and labor are readily available. Site conditions would require close well spacing, and more surface and subsurface obstructions are present at AOC 11 than at either of the other AOCs. Land use restrictions and monitoring might be required for an extended period, if soil and groundwater RAOs are not met. Energy requirements and GHG emission would be moderate. Public and regulatory acceptance contingent on ability to achieve RAOs in a reasonable period of time. Minimal site restoration required.	High Capital: \$2,032,000 Present Worth: \$2,125,000

Table 6. AOC 11 Technology Comparison

Alternative	Description	Criteria		
		Effectiveness	Implementability	Cost
<b>Multi-phase Extraction with Heating</b>	Heating is added to conventional multi-phase extraction to increase the rate of recovery and/or the range of contaminants that can be treated. Heating will volatilize higher weight compounds, reduce viscosity of LNAPL, and speed up chemical reactions. Steam or hot air injection, electrical resistance heating, or other methods may be used.	Moderate to high. Heating will help to overcome MPE limiting factors, including discontinuous granular lenses and weathered LNAPL. It is likely that RAOs would be met in 2-3 years. Potential short-term worker and public exposure would be minimized through use of appropriate personal protective equipment and environmental controls.	Low to moderate. Installation of heating equipment increases complexity of MPEH implementation. Facilities, equipment, and labor are readily available. Site conditions would require close well spacing, and surface and subsurface obstructions at AOC 11 may have to be removed. Land use restrictions and long-term monitoring less likely to be required than for MPE alone. Energy requirements and GHG emission would be moderate. Permits required for air emissions and wastewater discharge. Minimal site restoration required. Public and regulatory acceptance contingent on ability to achieve RAOs in a reasonable period of time.	High Capital: \$2,631,000 Present Worth: \$ 2,683,000
<b>In Situ Chemical Oxidation</b>	Chemical oxidants are injected into the subsurface to react with and destroy dissolved-phase organic contaminants. Common oxidants include hydrogen peroxide, ozone, permanganate, and persulfate.	Very Low. Process limited by the rate of dissolution of free product, which will be slow for weathered LNAPL. Contact of the oxidant with dissolved compounds limited by the heterogeneous subsurface conditions. Short-term risks due to hazards posed by oxidizing chemicals would be reduced by implementing appropriate safety procedures.	Moderate. Requires only conventional, short-term, and demonstrated activities. However, more surface and subsurface structures, utilities, and piping possibly requiring relocation are present at AOC 11 than at either of the other AOCs. Facilities, equipment, and labor are readily available. Permit required for underground injection, which might not be acceptable to regulators and the public. Low energy requirements, low GHG emissions, minimal site restoration, and no long term monitoring.	Very High. Cost of oxidant alone based on LNAPL volume at the site: \$1,600,000. Costs of installing and operating mixing and injection system and additional oxidant required for naturally occurring organic compounds were not calculated.

Table 6. AOC 11 Technology Comparison

Alternative	Description	Criteria		
		Effectiveness	Implementability	Cost
Surfactant-Enhanced LNAPL Removal	Injection of low viscosity surfactant solution into the subsurface to mobilize contaminants in free phase product and adsorbed to the soil matrix into the aqueous phase.	Very Low. Subsurface is too heterogeneous and has too low a hydraulic conductivity for this technology to be effective.	Moderate. Requires only conventional, short-term, and demonstrated activities (drilling, mixing and injection, sampling, disposal). However, more surface and subsurface obstructions are present at AOC 11 than at either of the other AOCs. Facilities, equipment, and labor are readily available. Energy requirements and GHG emissions low, but permits required for treated wastewater discharge, underground injection, and air emissions. Implementation is unlikely to achieve adequate distribution of the surfactant, and control of the injected material might be difficult under site conditions, so public and regulatory acceptance may be low.	Not calculated.

Table 6. AOC 11 Technology Comparison

Alternative	Description	Criteria		
		Effectiveness	Implementability	Cost
<p><b>Electrical Resistance Heating</b></p> <p>Uses arrays of electrodes installed around a central neutral electrode to create a concentrated flow of current toward the central point. Soil resistance to the flow of electricity creates heat above 100° C, which is used to evaporate contaminants from soil and groundwater. Steam and volatilized contaminants are captured by vacuum extraction wells and piped to a condenser.</p>	<p>High. Site conditions at AOC 11 are favorable, and this technology can achieve RAOs in less than a year. However, more heat is required to achieve complete remediation of contaminants with higher boiling points, especially in tight soils with high organic content. Use of proper protective equipment and engineering controls would reduce potential short-term exposure risks and safety hazards during implementation.</p>	<p>Moderate. Installation and operation are relatively complicated, but equipment and contractors are available. However, more surface and subsurface structures, utilities, and piping possibly requiring relocation are present at AOC 11 than at either of the other AOCs. Although labor-intensive in the short-term, long-term monitoring should not be required. Energy requirements are high, but duration is short. Permits required for underground injection and air emissions. Public and regulatory acceptance would likely be high, because contaminants are permanently destroyed in a relatively short period of time.</p>	<p>High. Capital: \$3,323,000</p>	

Table 6. AOC 11 Technology Comparison

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## 8.0 ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AOC	Area of Concern
AST	Above Ground Storage Tank
ATSDR	Agency for Toxic Substances and Disease Registry
AVGAS	Aviation Gasoline
bgs	Below Ground Surface
BTEX	Benzene, Toluene, Ethyl benzene, and Xylenes
BUSTR	Bureau of Underground Storage Tank Regulations
CELRL	Louisville District U.S. Army Corps of Engineers
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm/s	Centimeters per Second
COC	Contaminant of Concern
CRAA	Columbus Regional Airport Authority
CSM	Conceptual Site Model
DNAPL	Dense Nonaqueous Phase Liquid
DO	Dissolved Oxygen
DRO	Diesel Range Organics
EA	Environmental Assessment
EPA	U.S. Environmental Protection Agency
ERH	Electrical Resistance Heating
GHS	Greenhouse Gas Gallons per Minute

gpm

GRO Gasoline Range Organics

Inc Incorporated

ISCO In-Situ Chemical Oxidation

ISSM In-Situ Soil Mixing

LAFB Lockbourne Air Force Base

LLC Limited Liability Company

LNAPL Light Nonaqueous Phase Liquid

MNA Monitored Natural Attenuation Assessment

MPE Multi-Phase Extraction

MPEH Multi-Phase Extraction with Heating

MTBE Methyl Tert-Butyl Ether

NSZD Natural Source Zone Depletion

OAC Ohio Administrative Code

ORP Oxidation/Reduction Potential

OSHA Occupational Safety and Health Administration

PAH Polynuclear Aromatic Hydrocarbon

PID Photo-Ionization Detector

PWS Performance Work Statement

RAFB Rickenbacker Air Force Base

RAO Remedial Action Objective

RAP Remedial Action Plan

RCRA Resource Conservation and Recovery Act

RI	Remedial Investigation
RTE	Remedial Technology Evaluation
S&A	S&A Environmental Consultants, LLC
SCAPS	Site Characterization and Analysis Penetrometer System
SCS	SCS Engineers
SEH	Short Elliot Hendrickson, Inc.
SELR	Surfactant Enhanced LNAPL Removal
SFSS	Site Feature Scoring System
SPT	Standard Penetration Test
SSTLs	Site-Specific Target Levels
SVE	Soil Vapor Extraction
SVOC	Semi-Volatile Organic Compound
SWACO	Solid Waste Authority of Central Ohio
TCLP	Toxicity Characteristic Leaching Procedure
TPH	Total Petroleum Hydrocarbons
USACE	United States Army Corps of Engineers
UST	Underground Storage Tank
VER	Vacuum Enhanced Recovery
VOCs	Volatile Organic Compounds
WIDE	Well Injection Depth Extraction