Department of Energy

Portsmouth/Paducah Project Office
1017 Majestic Drive, Suite 200
Lexington, Kentucky 40513
(859) 219-4000

JUN 06 2012

PPPO-02-1440658-12B

Mr. Todd Mullins, FFA Manager
Kentucky Department for Environmental Protection
Division of Waste Management
200 Fair Oaks Lane, 2nd Floor
Frankfort, Kentucky 40601

Ms. Jennifer Tufts
Remedial Project Manager
U.S. Environmental Protection Agency, Region 4
61 Forsyth Street
Atlanta, Georgia 30303

Dear Mr. Mullins and Ms. Tufts:

TRANSMITTAL OF THE 30% REMEDIAL DESIGN REPORT *IN SITU* TREATMENT USING DEEP SOIL MIXING FOR THE SOUTHWEST GROUNDWATER PLUME VOLATILE ORGANIC COMPOUND SOURCE AT THE C-747-C OIL LANDFARM (SOLID WASTE MANAGEMENT UNIT 1) AT THE PADUCAH GASEOUS DIFFUSION PLANT, PADUCAH, KENTUCKY (DOE/LX/07-1276&D1)

Please find enclosed the *30% Remedial Design Report In Situ Source Treatment Using Deep Soil Mixing for the Southwest Groundwater Plume Volatile Organic Compound Source at the C-747-C Oil Landfarm (Solid Waste Management Unit 1) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-1267&D1, for your review.

Per discussions with Federal Facility Agreement (FFA) Managers on May 17, 2012, the Southwest Plume Remedial Action will be bifurcated to support remedy selection. The 30% Remedial Design Report submitted under cover of this letter presents the conceptual design for *in situ* source treatment using deep soil mixing with interim land use controls at the C-747 Oil Landfarm [Solid Waste Management Unit (SWMU) 1]. As agreed to by the FFA managers, a subsequent remedial design report will be submitted upon completion of the D1 Remedial Design Support Investigation Report that presents the conceptual design for the remedy selected for the northeast and southeast C-720 areas (SWMUs 211-A and 211-B).

Section XX.G.2 of the FFA allows for a 90-day review cycle for a secondary document; however, to accommodate the current project schedule for submittal of the 60% Remedial Design Report on September 5, 2012, the U.S. Department of Energy requests a 30-day review cycle. Receipt of regulatory comments within 30 days will allow adequate time for resolution and incorporation of comments prior to transmittal of the 60% Remedial Design Report.

If you have any questions or require additional information, please contact David Dollins at (270) 441-6819.

Sincerely,

Reinhard Knerr
Paducah Site Lead
Portsmouth/Paducah Project Office

Enclosure:
30% RDR in Situ Source Treatment for the SW Groundwater Plume at C-747-C Oil Landfarm

e-copy w/enclosure:
alicia.scott@lataky.com, LATA/Kevil
ballard.turpin@epamail.epa.gov, EPA/Atlanta
brandy.mitchell@lataky.com, LATA/Kevil
christie.lamb@lataky.com, LATA/Kevil
craig.jones@lataky.com, LATA/Kevil
david.dollins@lex.doe.gov, PPPO/PAD
gaye.brewer@ky.gov, KDEP/PAD
jeff.carman@lataky.com, LATA/Kevil
jeffrey.gibson@ky.gov, KDEP/Frankfort
jennifer.woodard@lex.doe.gov, PPPO/PAD
leo.williamson@ky.gov, KDEP/Frankfort
mark.duff@lataky.com, LATA/Kevil
pad.dmc@swiftstaley.com, SST/Kevil
reinhard.knerr@lex.doe.gov, PPPO/PAD
rob.seifert@lex.doe.gov, PPPO/PAD
todd.mullins@ky.gov, KDEP/Frankfort
tufts.jennifer@epamail.epa.gov, EPA/Atlanta

DOE/LX/07-1276&D1
Secondary Document

30% Remedial Design Report *In Situ* Source Treatment Using Deep Soil Mixing for the Southwest Groundwater Plume Volatile Organic Compound Source at the C-747-C Oil Landfarm (Solid Waste Management Unit 1) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

CLEARED FOR PUBLIC RELEASE

DOE/LX/07-1276&D1
Secondary Document

30% Remedial Design Report *In Situ* Source Treatment Using Deep Soil Mixing for the Southwest Groundwater Plume Volatile Organic Compound Source at the C-747-C Oil Landfarm (Solid Waste Management Unit 1) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

Date Issued—June 2012

U.S. DEPARTMENT OF ENERGY
Office of Environmental Management

Prepared by
LATA ENVIRONMENTAL SERVICES OF KENTUCKY, LLC
managing the
Environmental Remediation Activities at the
Paducah Gaseous Diffusion Plant
under contract DE-AC30-10CC40020

CLEARED FOR PUBLIC RELEASE

THIS PAGE INTENTIONALLY LEFT BLANK

CONTENTS

FIGURES

TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

ACRONYMS

ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
DOE	U.S. Department of Energy
E/PP	excavation/penetration permit
FFS	focused feasibility study
FID	flame ionization detector
GAC	granular activated carbon
GC	gas chromatograph
HU	hydrogeologic unit
KO	knock-out tank
LDA	large diameter auger
LUC	land use control
OU	operable unit
PCB	polychlorinated biphenyl
PGDP	Paducah Gaseous Diffusion Plant
PID	photoionization detector
RA	Remedial Action
RAO	remedial action objective
RAWP	remedial action work plan
RDR	remedial design report
RDSI	remedial design support investigation
RDWP	remedial design work plan
RG	remediation goal
RGA	Regional Gravel Aquifer
RI	remedial investigation
ROD	record of decision
SI	site investigation
SPT	standard penetration test
SWMU	solid waste management unit
TCE	trichloroethene
UCRS	Upper Continental Recharge System
VCS	vapor conditioning system
VOC	volatile organic compound
WAG	waste area grouping
ZVI	zero-valent iron

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

This Remedial Design Report has been prepared for the *In Situ* Source Treatment Using Deep Soil Mixing with Interim Land Use Controls (LUCs) Remedial Action (RA) for the Southwest Plume volatile organic compound (VOC) source area, Solid Waste Management Unit 1 at the Paducah Gaseous Diffusion Plant (PGDP) in Paducah, Kentucky. This remedial design report was prepared in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act, and is the response action selected in the *Record of Decision for Solid Waste Management Units 1, 211-A, 211-B, and Part of 102 Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-0365&D2/R1 (ROD) (DOE 2012a).

The response action for VOCs selected in the ROD is required to address the release of hazardous substances into the environment that are sources of groundwater contamination and present unacceptable risk from direct exposure to residual VOCs and non-VOCs. Removal of VOCs, like trichloroethene, from the soils in the Southwest Plume Source areas will contribute to the final cleanup of the Groundwater Operable Unit at PGDP.

The ROD specified an *in situ* source treatment using deep soil mixing with interim LUCs. The RA also will include the implementation of interim LUCs consisting of the Excavation/Penetration Permit Program and the posting of warning signs at the source areas.

This report contains information regarding the preliminary design of the remediation system, including discussions of the following:

- Mixing of soil using large diameter augers
- Injection of hot air and steam to volatize targeted contaminants
- Injection of zero-valent iron as a polishing step for treating residual VOCs
- Treatment of recovered vapor through a vapor conditioning/treatment system
- Data collection and monitoring

THIS PAGE INTENTIONALLY LEFT BLANK

1. INTRODUCTION

This Remedial Design Report (RDR) presents the 30% conceptual design for the remedial action (RA) to be implemented at the Southwest Groundwater Plume source area at PGDP at Solid Waste Management Unit (SWMU) 1. The remedy planned for SWMU 1 is documented in the *Record of Decision for Solid Waste Management Units 1, 211-A, 211-B, and Part of 102 Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-0365&D2 (ROD) (DOE 2012a). The overall design process is described in the *Remedial Design Work Plan for Solid Waste Management Units 1, 211-A, and 211-B Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-1268&D2/R1 (DOE 2012b).

Conceptual design information provided in this report includes the following:

- Site description
- Technology description
- Remedial action objectives
- Design requirements
- Other construction and operational requirements to be included in the Remedial Action Work Plan (RAWP).

PGDP, located approximately 10 miles west of Paducah, Kentucky, and 3.5 miles south of the Ohio River in the western part of McCracken County, is an active uranium enrichment facility owned by the U.S. Department of Energy (DOE) (Figure 1). Bordering PGDP to the northeast, between the plant and the Ohio River, is the Tennessee Valley Authority Shawnee Fossil Plant.

The Southwest Groundwater Plume refers to an area of groundwater contamination at PGDP in the Regional Gravel Aquifer (RGA), which is south of the Northwest Groundwater Plume and west of the C-400 Building (also known as the C-400 Cleaning Building). The plume was identified during the Waste Area Grouping (WAG) 27 Remedial Investigation (RI) in 1998 (DOE 1999). Additional work to characterize the plume was performed as part of the WAG 3 RI (DOE 2000a) and Data Gaps Investigation (DOE 2000b). As discussed in these reports, the primary groundwater contaminant of concern for the Southwest Groundwater Plume (hereinafter referred to as the Southwest Plume) is trichloroethene (TCE). Other contaminants found in the plume include additional volatile organic compounds (VOCs), metals, and the radionuclide technetium-99 (Tc-99). PGDP is posted government property and trespassing is prohibited. Access to PGDP is controlled by guarded checkpoints, a perimeter fence, and vehicle barriers and is subject to routine patrol and visual inspection by plant protective forces.

DOE conducted a site investigation (SI) in 2004 to address the uncertainties associated with potential source areas to the Southwest Plume that remained after previous investigations. The SI further profiled the current level and distribution of VOCs in the dissolved-phase plume along the west plant boundary. Results of the SI were reported in the *Site Investigation Report for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-2180&D2/R1 (DOE 2007). The Focused Feasibility Study (FFS) (DOE 2010a) is based on the SI (DOE 2007), as well as previous investigations identified here.

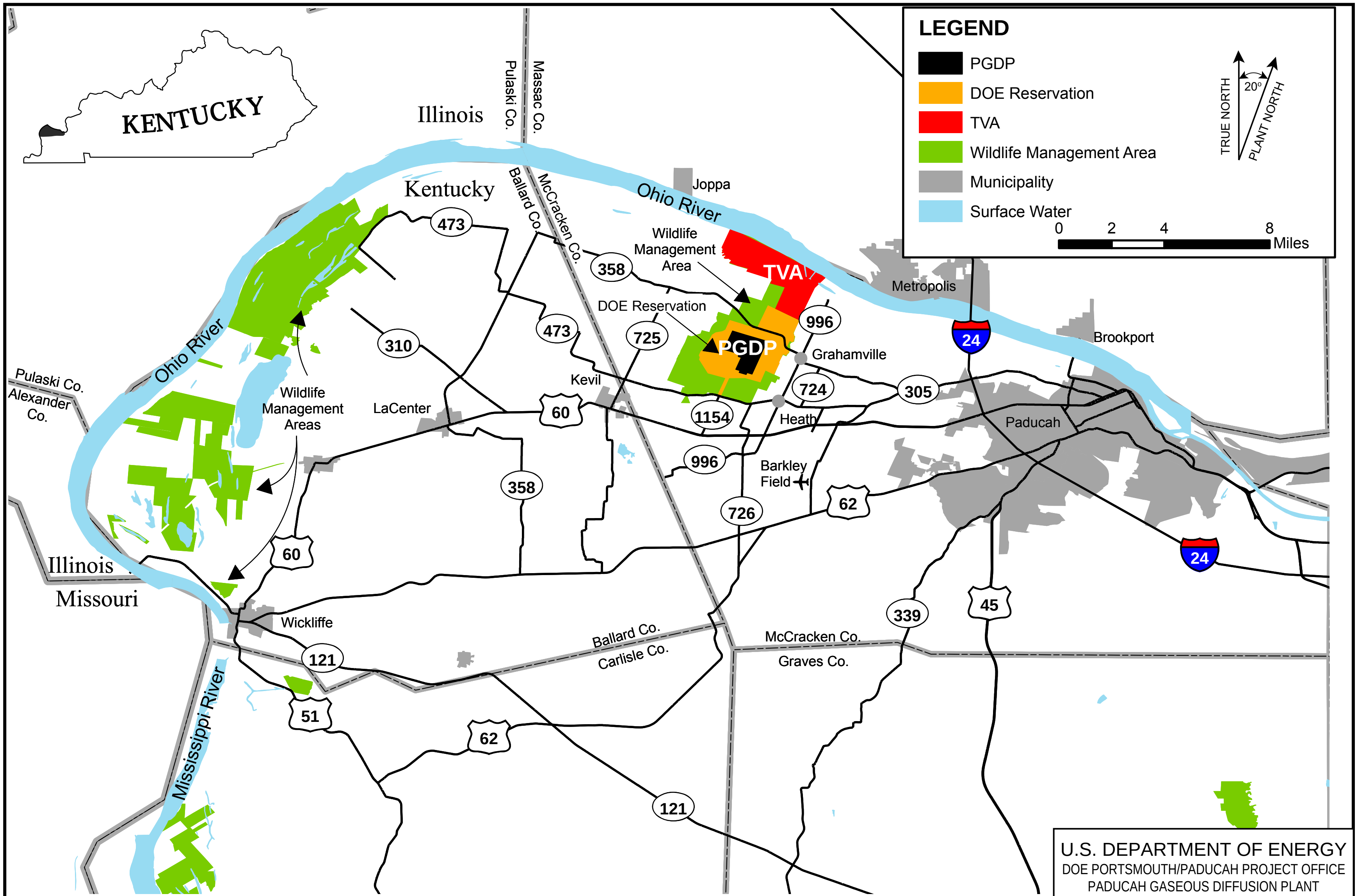

Figure 1. PGDP Site Location

LATA Environmental Services of Kentucky, LLC

The RA includes the implementation of *in situ* soil mixing with large diameter augers (LDAs) combined with the introduction of hot air and steam for thermal volatilization and stripping of VOCs in the soil and groundwater. The RA also includes the implementation of interim land use controls (LUCs) consisting of the Excavation/Penetration Permit Program (E/PP) and the posting of warning signs at the source areas.

A remedial design support investigation (RDSI) is included in the RA. The RDSI will help further delineate areas of high TCE concentration in the Upper Continental Recharge System (UCRS) soils and in the upper RGA [hydrogeologic unit (HU4)] and allow refinement of the remedial design. RDSI results will be available prior to completion of and appropriately included in the D1 (90%) RDR.

This 30% design report supplies information regarding the preliminary design of the remediation system, based on unit processes and activities likely to be included in the selected *in situ* source treatment. These processes and activities are likely to include the following:

- Mixing of soil using LDAs
- Heating of soil *in situ* by application of hot air/steam
- Removal of VOCs and steam from heated subsurface zones by vacuum extraction
- Treatment of recovered vapor off-gas via vapor conditioning/treatment systems
- Injection of a zero-valent iron (ZVI) slurry mixture
- Real-time data collection and monitoring

1.1 REGIONAL GEOLOGY AND HYDROGEOLOGY

PGDP is underlain by a sequence of clay, silt, sand, and gravel layers deposited on limestone bedrock. The sediments above the limestone bedrock are grouped into three major stratigraphic units (loess, continental deposits, and McNairy Formation) and three major HUs (the UCRS, the RGA, and the McNairy Flow System).

The upper-most stratigraphic unit consists of fill and a layer of wind-deposited, silty clay, or loess, extending from the surface to a depth of approximately 20 ft below ground surface (bgs). Beneath the loess, the upper continental deposits, a subunit of the continental deposits consisting of discontinuous sand and gravel layers interbedded with silt and clay, extend to an average depth of 55 ft bgs. These deposits comprise the local hydrostratigraphic unit known as the UCRS. The lower continental deposits, also a subunit of the continental deposits, is a highly permeable layer of gravelly sand or chert gravel, typically extending from approximately 55 to 92 ft bgs. These deposits comprise the local hydrostratigraphic unit known as the RGA. Below the continental deposits is the McNairy Formation, a sequence of silts, clays, and fine sands that extends from approximately 92 to 350 ft bgs. These deposits comprise the local hydrostratigraphic unit known as the McNairy Flow System.

The UCRS is subdivided into the HU1, HU2, and HU3 units and consists of the loess (HU1) and the underlying upper continental deposits (HU2 and HU3). The sand and gravel lenses of the HU2 unit are separated from the underlying RGA by a 12- to 18-ft-thick silty or sandy clay interval designated as the HU3 aquitard. The aquitard reduces the vertical flow of groundwater from the sands and gravels of the HU2 unit to the gravels of the RGA. The RGA is the uppermost aquifer in the Southwest Plume source areas and consists of the lower continental deposits stratigraphic unit. Below the RGA is the McNairy Flow System, which corresponds to the McNairy Formation. The uppermost portion of the McNairy Flow System typically is a clay or silty clay, which acts as an aquitard restricting groundwater flow between the RGA and McNairy Flow System.

The depth of the water table within the UCRS varies considerably across PGDP, but generally is encountered at depths of approximately 40 to 50 ft bgs. Water within the UCRS tends to flow downward to the RGA. Groundwater flow in the RGA generally is to the northwest, although there is evidence for some divergent flow to the east and to the west as part of the Northeast and Southwest Plumes, respectively. Divergent flow is limited primarily to the area of the PGDP site and is influenced mainly by anthropogenic recharge due to loss of water from plant piping systems for raw, sanitary, cooling, and fire water and focused infiltration from engineered runoff controls, such as paved areas, building roofs, lagoons, and ditches.

1.2 TREATMENT SITE LOCATION

The potential source areas investigated in the SI included the C-747-C Oil Landfarm (Oil Landfarm) (SWMU 1); C-720 Building Area near the northeast and southeast corners of the building [C-720 Northeast Site (SWMU 211A) and C-720 Southeast Site (SWMU 211B)]; and the storm sewer system between the south side of Building C-400 and Outfall 008 (Storm Sewer) (part of SWMU 102) (DOE 2007). As a result of the Southwest Plume SI sampling, the storm sewer subsequently was excluded as a potential VOC source to the Southwest Plume. Respective SWMU numbers for each potential source area investigated in the SI are provided in Table 1. The location of the SWMU 1 source area (Oil Landfarm) is shown in Figure 2.

Table 1. Potential Source Areas Investigated in 2007 SI

Potential Source Area	SWMU No.
C-747-C Oil Landfarm	1
C-720 TCE Spill Sites Northeast and Southeast	211 A and B

1.3 REMEDIAL DESIGN SUPPORT INVESTIGATION

The RDSI will be conducted to gather supplemental data to improve the design and implementation of the *in situ* source treatment deep soil mixing remedial action for SWMU 1. Furthermore, this RDSI field effort also will support the collection of contaminant and engineering data to support the Federal Facility Agreement parties' decision regarding selection and implementation of either enhanced *in situ* bioremediation or long-term monitoring at the C-720 SWMUs and the subsequent remedial design. The design and implementation of either enhanced *in situ* bioremediation or long-term monitoring remedial action for the C-720 Building will follow the remedial action at SWMU 1 by an estimated two years.

An RDSI Characterization Plan was developed to support the implementation of the selected alternatives for remediation at the Southwest Plume and to resolve data gaps identified through a data quality objectives process (DOE 2010b). Data collected during the RDSI, coupled with data from previous investigations, will allow for a more accurate delineation of high TCE concentrations in the UCRS soils and in the upper RGA (HU4) to better define the size and shape of the overall treatment areas for this remedial action. Data from the RDSI will be available prior to completion of the 90% design (D1 RDR).

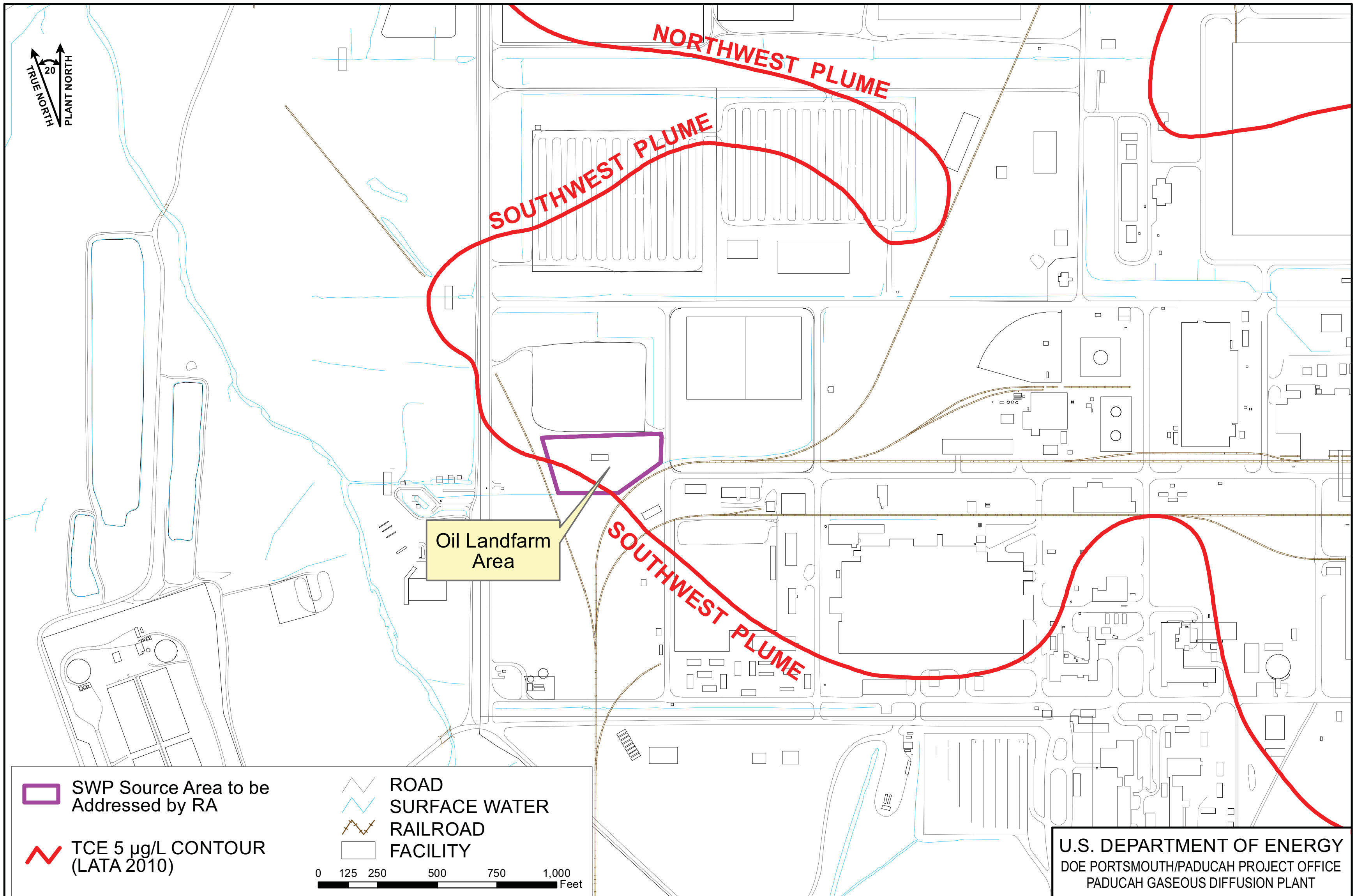

Figure 2. Southwest Plume Source Area Addressed by the Remedial Design

LATA Environmental Services of Kentucky, LLC

G:\GIS\ARCVIEWS\PROJECTS\C5AC90005SK007R6_3.mxd 20120320

1.4 SEQUENCING WITH OTHER REMEDIES

This remedy will be executed in coordination with the Soils Operable Unit (OU) for remediation of polychlorinated biphenyls (PCBs) and other surface soil contaminants, as appropriate. Prior to implementing the deep soil mixing Remedial Action (RA), the collocated portion of SWMU 1 will be excavated to a maximum depth of 10 ft bgs based on existing Soils OU sample results available in the area of LDA mixing. The excavated soil will be stockpiled and covered for anticipated disposition at the C-746-U Landfill. Existing SWMU 1 soil characterization data show some levels of PCB and metal contamination; however, the contamination levels are expected to meet the C-746-U Landfill requirements for disposal. Final waste disposition will be in accordance with the C-746-U waste acceptance criteria. Once all surface contaminants have been removed (from the 0–10 ft level), the excavation will be backfilled with clean soil procured from an off-site source. Excavation and backfilling will occur before the deep soil mixing RA begins.

2. TREATMENT TECHNOLOGY

This RA will implement *in situ* source treatment using deep soil mixing with interim LUCs. This selected remedy consists of a RDSI to refine the extent of VOC contamination in the UCRS and in the upper RGA (HU4) and quantify parameters for selecting and applying the treatment methods.

The selected RA technology involves the utilization of LDAs combined with the introduction of hot air/steam for thermal volatilization and stripping of VOCs in soil and groundwater. Granular ZVI in a guar gum solution also will be delivered to the subsurface via LDA injection as a polishing step to provide treatment of residual VOCs within the source area.

A vapor treatment system will be utilized that includes real-time monitoring for data evaluation. Real-time monitoring will assist in controlling the process parameters to maximize VOC removal and support operation of the LDA and injection systems.

A more detailed description of the treatment technology and process is included in Section 4.

3. TREATMENT SYSTEM OBJECTIVES

For the SWMU 1 site, information required to optimize soil mixing effectiveness and attain remediation goals will be obtained during the RDSI. This information will be used during the design phases of the project to determine the specific parameters of the soil mixing application, including hot air/steam generation and delivery, vapor extraction and conditioning, ZVI mixing and delivery, and vapor treatment.

3.1 RA OBJECTIVES

The following remedial action objectives (RAOs) are defined in the ROD for the Southwest Plume source areas (DOE 2012a).

(1) Treat and/or remove the principal threat waste consistent with the National Contingency Plan.

(2a) Prevent exposure to VOC contamination in the source areas that will cause an unacceptable risk to excavation workers (< 10 ft).

(2b) Prevent exposure to non-VOC contamination and residual VOC contamination through interim LUCs within the Southwest Plume source areas (i.e., SWMU 1, SWMU 211-A, and SWMU 211-B) pending remedy selection as part of the Soils OU and the Groundwater OU.

(3) Reduce VOC migration from contaminated subsurface soils in the treatment areas at the Oil Landfarm and the C-720 Northeast and Southeast Sites so that contaminants migrating from the treatment areas do not result in the exceedance of maximum contaminant levels in the underlying RGA groundwater.

3.2 OPERATIONAL PARAMETERS

The design will allow for operational parameters to be monitored during the treatment period. Operational parameters to be monitored and evaluated may include, but are not limited to, the following:

- Temperature, flow rate, and pressure for
  - Injected steam
  - Compressed/heated air
  - Slurry mixture
- Vapor recovery flow rate, temperature, and pressure
- Extracted VOC concentrations

4. 30% TECHNICAL DESIGN

4.1 TECHNICAL JUSTIFICATION FOR SELECTION OF REMEDIAL TECHNOLOGY

The selected RA technology for the Southwest Plume VOC Oil Landfarm source area involves the utilization of *in situ* soil mixing with LDA combined with the introduction of hot air/steam for thermal volatilization and stripping of VOCs in soil and groundwater. Additionally, granular ZVI in a guar gum solution will be delivered to the subsurface via LDA injection as a polishing step to provide additional treatment.

Prior to selecting the proposed RA, technology permutations considered included: (1) LDA soil mixing with emulsified ZVI delivery; (2) LDA soil mixing with oxidant delivery; and (3) LDA soil mixing with ZVI and clay delivery. Based upon an evaluation of implementation approaches, the *in situ* LDA soil mixing with hot air/steam and ZVI injection offers (1) the highest anticipated level of mass reduction and potential to achieve objectives; (2) an implementation cost that falls within the range of the other technology permutations considered; and (3) demonstrated effectiveness providing treatment of high levels of VOCs. Unique to the *in situ* LDA soil mixing with hot air/steam and ZVI injection technology, the mixing process and treatment application is adapted real-time based upon the monitoring of off-gas VOC concentrations. Accordingly, the selected RA has flexibility and can be actively adapted during individual borehole mixing to spend additional time, providing enhanced treatment to specific depth intervals and/or boreholes with higher levels of VOCs, as appropriate.

4.2 CRITICAL PARAMETERS

Critical parameters for *in situ* LDA soil mixing with hot air/steam and ZVI injection are those operational parameters of the system and the physical and chemical parameters of the media being treated that have the greatest impact on the ability of the technology to meet the performance goals. These critical parameters are as follows:

Soil and Groundwater Temperature. The temperature of soil and groundwater throughout the treated volume must be raised sufficiently to achieve volatilization of the targeted contaminants.

Percentage of Auger Boring Overlap. The LDA borings will be established based upon an overlap spacing ranging from 0% (no overlap) to 17.5% (representing complete overlap with no interstitial space between treatment cells) overlap. A conceptual depiction of LDA boring spacing in the oil landfarm source area based on an assumed 10% overlap (which will be further refined in the 60% RDR) is presented in Figure 3. The overlap spacing may vary depending on the anticipated concentration of TCE at the boring location and/or location within the treatment zone (i.e., increased overlap around the periphery of the treatment cell and reduced overlap internal to the treatment cell).

Soil Properties/Mixing Rate. Soil properties dictate the rate at which the LDA can penetrate the subsurface, appropriate angle of repose for the mixing blade, and considerations regarding the auger blade terminus. In consideration of the soil characteristics and consistency in the Oil Landfarm source area, which includes a hard layer identified in standard penetration test (SPT) borings in the site vicinity, it is anticipated that "rock teeth" will be required on the auger blades. For the *in situ* LDA soil mixing with hot air/steam and ZVI injection technology to be effective, no large boulders and/or large subsurface concrete structures can be present.

Underground utilities are expected in the vicinity of the treatment area; therefore, a geophysical survey will be conducted in the sampling area prior to intrusive sampling for the RDSI. The geophysical survey will assist in identifying utilities and or metal debris that may be present. Any buried material (other than utilities) is anticipated to be transferred to the C-746-U Landfill along with the soil, as described in Section 1.4.

VOC Vapor Extraction Rate. The rate of air/vapor extraction from the vadose zone must be greater than the production of contaminant vapors to prevent vaporized contaminants from escaping to the atmosphere or from condensing in the vadose zone.

Concentration of VOCs in Extracted Vapor. The concentration of VOCs in the vapor extraction stream must be monitored and balanced with the aboveground treatment system's ability to treat such concentrations.

ZVI Dosing Concentration. A slurry mixture consisting of granular ZVI, water and guar gum (to facilitate ZVI injection into the soil) will be delivered based upon a percentage by weight application rate, with the higher weight ZVI slurry delivered to the perimeter ring of mixing locations. Field-based decisions based upon monitoring data collected during hot air/steam mixing phase will be used to adjust the ZVI dosing concentration.

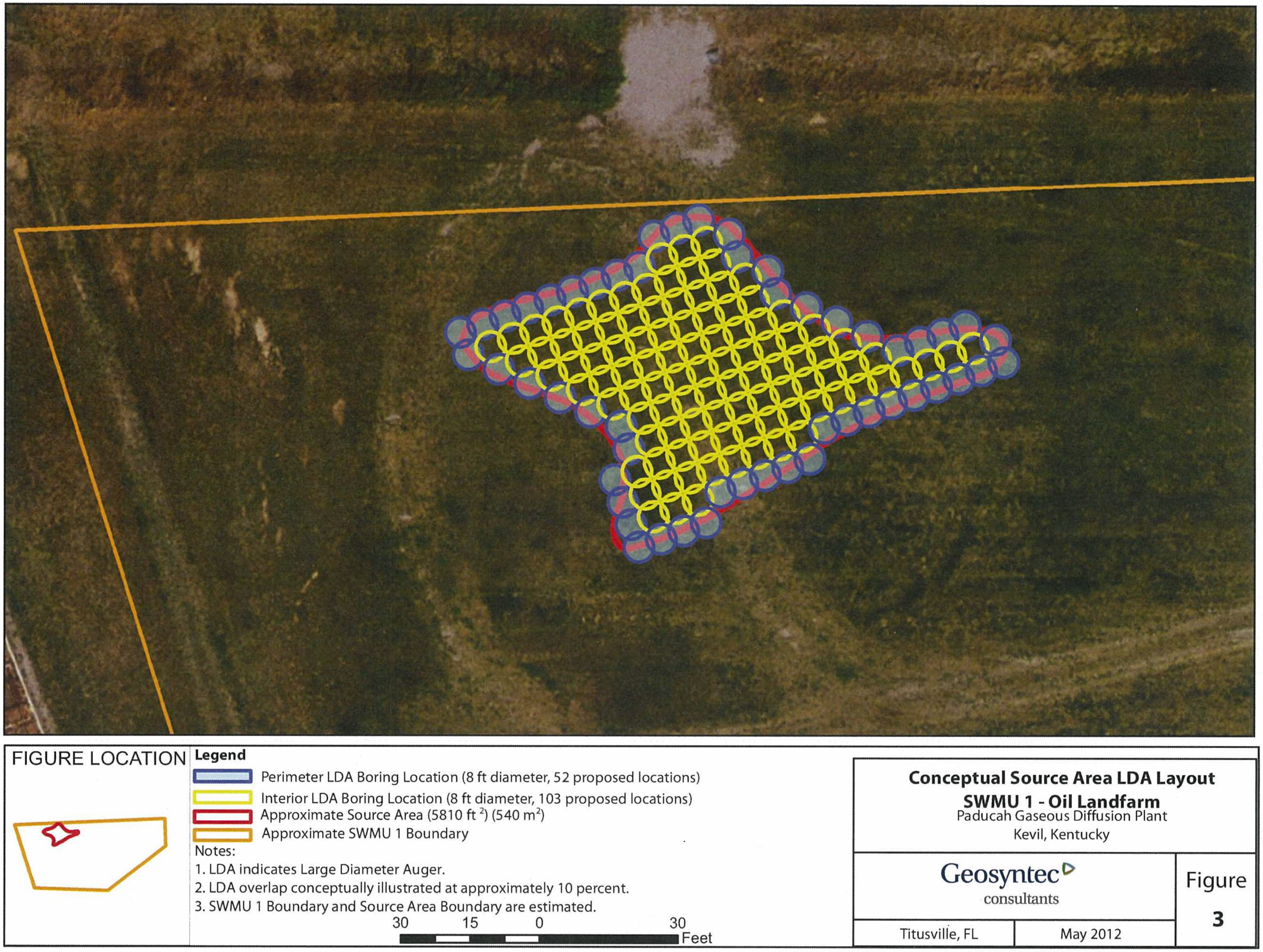

Figure 3. Conceptual Source Area LDA Layout

Impact to Surrounding Structures, Utilities, and Operations. It must be possible to implement the treatment technology at the Oil Landfarm source area and to operate it with limited interference to site personnel and other facility operations.

Contaminants of Concern. The technology is designed specifically for the treatment of VOCs. Unacceptable concentrations of other contaminants such as PCBs or metals in the shallow soils will not be treated by the technology and will be addressed consistent with the detail discussed previously in Section 1.4, Sequencing with Other Remedies.

4.3 DESIGN REQUIREMENTS

The general input requirements for the *in situ* LDA soil mixing with hot air/steam and ZVI injection remediation design include the following:

- Site location and general site logistics, including nearby structures and site activity;
- Buried underground utilities and obstructions;
- Shape and depth of the treatment area;
- Site geology;
- Site hydrogeology, including depth to groundwater and groundwater flow rate;
- Soil chemical characteristics, including percentage of organic carbon content;
- Contaminant-specific remediation goals, defined in the FFS (DOE 2010a) and listed in Table 2;
- Compliance with applicable or relevant and appropriate requirements (ARARs)(ROD DOE 2012a);
- Absence of low-volatility co-contaminants;
- Desired remediation schedule;
- Options for wastewater disposal; and
- Selection of vapor treatment technology.

Table 2. Remediation Goals for the Oil Landfarm Source Area RA

Contaminant of Concern	RG for the Oil Landfarm, mg/kg
TCE	7.30E-02
1,1-DCE	1.30E-01
cis-1,2-DCE	6.00E-01
trans-1,2-DCE	1.08E+00
Vinyl Chloride	3.40E-02

Note: Also see ROD Tables 17 and 18 for the UCRS Soil Cleanup Levels for VOCs (DOE 2012a).

4.4 PROCESS DESCRIPTION FOR *IN SITU* LDA SOIL MIXING WITH HOT AIR/STEAM TREATMENT AND ZVI AMENDMENT

In situ LDA soil mixing with hot air/steam and ZVI treatment technology consists of the following major elements: soil mixing, hot air/steam generation and delivery, vapor extraction and conditioning, recovered-liquid storage and disposal, ZVI mixing and delivery, and vapor treatment. The treatment system includes a monitoring system for real-time data evaluation that assists in controlling the process parameters to maximize VOC removal and supports decision making for operation of the LDA and injection systems.

The mixing system will be equipped with an LDA that shears and mixes the soil as the auger is advanced below the ground surface, while concurrently injecting steam and hot air. This action causes thermal desorption and volatilization of the VOCs from soil particles, groundwater and interstitial spaces. The steam and hot air raises the temperature of the soil mass, increases the vapor pressure of the contaminants, volatilizes the compounds from the soil particles (through heat and air stripping), and allows them to be transported to the surface via the injected hot air/steam where they are collected in a shroud maintained under vacuum, covering the active treatment area. The shroud provides the ability to capture off-gases beyond the auger blades. The vapors are then transported from the shroud through the vapor conditioning system (VCS) to the VOC treatment system by a blower. VOC removal and treatment will then be enhanced via the placement of ZVI in the mixed soil column and aquifer material to enhance abiotic degradation of residual VOCs.

The VOC treatment system consists of a VCS and vapor treatment system. Vapor collected in the LDA shroud contains air, water, VOCs, and particulates. The VCS removes water and particulates from the vapor before being processed by the vapor treatment system. The VCS consists of a knockout tank, chiller, re-heater/heat exchanger, and particulate filter. The vapor from the VCS will then be processed in the vapor treatment system, which is anticipated to consist of vapor-phase granular activated carbon (GAC) placed in series to remove VOCs.

Real-time data monitoring is an integral part of the treatment technology because it facilitates real-time decision making to enhance the efficiency of treatment and maximize the results (i.e., additional mixing hot air/steam injection at specific locations and/or discrete depth intervals based upon real-time monitoring results).

4.4.1 Equipment Summary

The general process flow diagram for the *in situ* LDA soil mixing with hot air/steam and ZVI injection system for the Oil Landfarm source area is provided in Figure 4. General unit processes shown in Figure 4, including LDA soil mixing, hot air/steam generation and delivery, vapor extraction and conditioning, recovered-liquid storage and disposal, ZVI mixing and delivery, and vapor treatment, are expected to be part of the final design and are described generally in the following sections. A further refined technology-specific process flow diagram, providing additional process detail, will be included in the 60% RDR.

4.4.1.1 Soil mixing equipment

Major equipment and tools that are to be utilized for soil mixing include a crane, LDA, kelly bar, and drill platform. The soil mixing rig will be comprised of a crawler-mounted lift crane, with a minimum 70-ft long hollow drill stem (kelly bar) driven by a high-torque transmission (capable of producing a range of torque of approximately 100,000 to 450,000 ft-lb of torque) and capable of achieving a soil mix depth of 60 ft bgs. A swivel assembly attached to the end of the crane boom cables serves as the connection point for the kelly bar, allowing the bar to rotate freely while drilling. In addition, the swivel will serve as the injection point of material into the kelly bar from flexible hosing connecting the hot air/steam and ZVI delivery system to the soil mixing equipment. A multibladed rotating mixing/injection tool (auger) with a minimum diameter of 8 ft will be located at the base of the kelly bar, which is capable of injecting the hot air, steam, and ZVI slurry into the soil to volatilize VOCs. The mixing tool will include an adequate number of injection ports along the blades to achieve effective distribution of hot air/steam and injected ZVI throughout the mixed soil column. In consideration of the documented soil consistency [hard (greater than 100 blows per ft) at the approximate 20 to 25 ft below grade depth interval], it is anticipated that "rock teeth" will be required on the mixing tool to facilitate penetration. The mixing rig will operate on mats that will provide stability, maintain vertically plumb mixing, and minimize contamination of drill rig tracks.

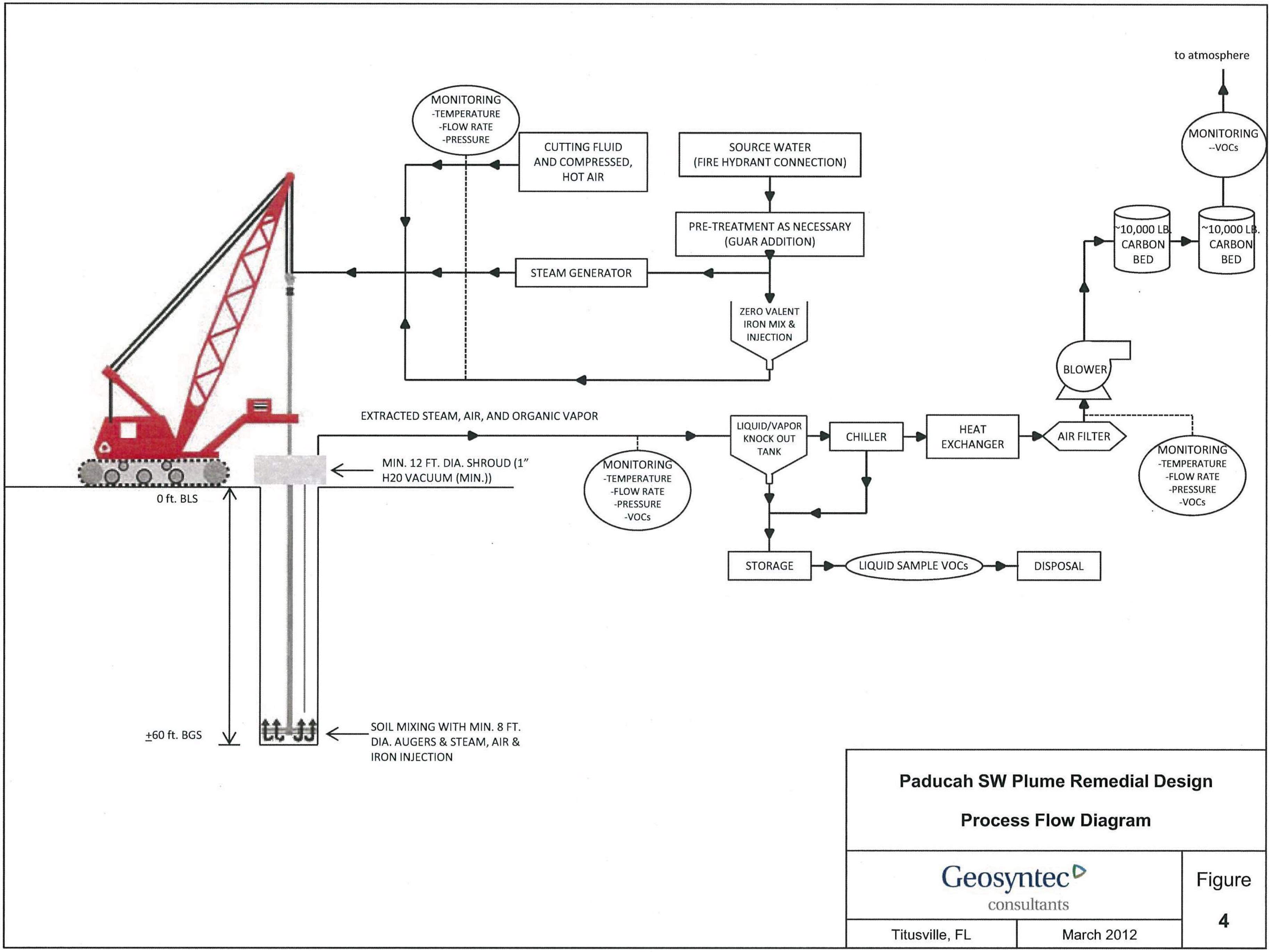

Figure 4. Process Flow Diagram

4.4.1.2 Hot air/steam generation and delivery system

Hot air will be generated by drawing ambient air though air compressors. A filter bank will be utilized in-line to remove entrained oil from the generated air flow. Injection pressure, temperature, and flow will be monitored and controlled during operations.

The steam generating system will be comprised of steam boilers with the capability of producing steam at a minimum temperature of 385°F from a facility-supplied water source. At the maximum operating capacity, the boilers are expected to output a minimum of 10 million British thermal units per hour (MBTU/hr). It is anticipated that a minimum of approximately 10,000 gal of water per day will be converted to steam for injection. Braided steel and rubber hose will transfer the steam from the boilers to the manifold and rubber hose will be utilized to connect the manifold to the drill stem (kelly bar). Steam injection flow rate, pressure, and temperature will be monitored and controlled during operations.

4.4.1.3 Off-gas extraction and vapor conditioning system

As the mixing blade rotates and hot air and steam are injected in the soils, VOCs will rise to the surface through the annulus created by the soil mixing process and associated pressure gradient. The contaminants will be collected within a shroud of sufficient diameter to provide capture of VOCs. The shroud will cover the ground surface around the boring location that is penetrated by the rotating kelly bar. The shroud will provide the ability to capture off-gases beyond the diameter of the drilling blades. A blower connected to the shroud will provide a vacuum on the shroud for vapor recovery and transfer to the VCS.

The VCS will consist of a liquid-vapor knock-out (KO)/demister tank, particle filter, chiller, and reheater/heat exchanger, or equivalent. The vapor entering the shroud from the annulus is expected to be saturated with water; therefore, the vapors initially will flow through a liquid vapor KO tank to remove large dirt particles and moisture. The vapors will then flow from the KO tank into a chiller unit used to cool the gas (typically to a temperature of less than 100°F). Condensate water generated by the KO tank chiller will be transferred and stored in a temporary holding tank for future characterization and proper treatment or disposal. Cooled vapor then will enter a reheater/heat exchanger to raise the off-gas temperature in order to reduce the off-gas relative humidity (thereby increasing the efficiency of the vapor-phase carbon adsorption system). Vapor then will flow through a particle filter to remove fine particulates prior to entering vapor-phase GAC treatment systems. The VCS will be monitored and controlled during operations. Data that will be recorded from monitoring instruments on the VCS include pressure drop over the chiller/heat exchange unit, vapor temperature after chiller, and vapor temperature and relative humidity after the reheater.

4.4.1.4 Vapor Treatment System (Vapor-Phase Carbon Adsorption)

Conditioned vapors exiting the VCS will be treated on-site utilizing two vapor-phase GAC adsorption vessels connected in series. Each GAC vessel will have the capacity for holding in excess of 10,000 lb of vapor-phase GAC. A monitoring system will be put in place, such as the use of a photo-ionization detector (PID) or flame ionization detector (FID) connected to the exhaust stack of the lag carbon vessel to analyze for VOCs in the GAC exhaust.

Based on a conservative estimate of total VOC contaminant mass in the SWMU 1 area of 1,000 lb, and an assumed carbon adsorptive capacity and usage rate of 20% (20 lbs TCE/100 lbs GAC) for an influent GAC relative humidity of 80%, the total mass of vapor-phase carbon to be utilized for off-gas treatment is estimated to be approximately 5,000 lb (indicating that two 10,000 lb or greater vapor-phase GAC vessels in series provides adequate capacity). For design purposes, it is assumed that 100% mass removal will be extracted in the vapor phase.

4.4.1.5 ZVI Mixing and Delivery System

A slurry mixture consisting of granular ZVI, water, and guar gum (to facilitate ZVI injection into the soil) will be prepared on-site and delivered on the final pass of the LDA at each boring location. It is anticipated that granular ZVI particle size will range from approximately 50 micron to 300 micron in diameter. To create this slurry mixture, ZVI will be suspended in the slurry at a rate of approximately 5–7 lbs of ZVI per gal of water, and guar gum will be mixed at a rate of approximately 70 lb per 1,000 gal of water. The actual quantity of guar gum and water may be adjusted during field preparation to adequately suspend the ZVI and achieve optimal pumping viscosity. ZVI preparation and delivery equipment will consist of mixing tanks of a minimum of 500 gal each, a high-shear slurry mixer, a progressive cavity pump and a high viscosity flow meter. It is anticipated that up to approximately 2,000 gal of water per day will be utilized in the preparation of the ZVI/guar slurry.

4.4.1.6 Real-time data collection and monitoring system

The effective application of the *in situ* LDA soil mixing with hot air/steam and ZVI injection system involves real-time data collection and monitoring to allow for field-based decision processes regarding the following:

- Depth and rate and down-hole temperature of LDA soil mixing;
- Injection temperature, pressure and flow rate of hot air and steam;
- Temperature, pressure, flow rate, relative humidity and VOC concentrations in the vapor extraction and conditioning systems;
- Injection temperature, pressure and flow rate of the ZVI slurry injection system; and
- VOC concentration of the vapor-phase treatment system effluent.

Gas samples from the process streams will be collected from the vapor extraction system for analysis by a PID/FID and/or a gas chromatograph (GC). GCs will be used to detect, speciate, and quantify target analytes from the treatment process off-gas. PIDs/FIDs will be used to continuously monitor the vapors produced by the treatment process. Data from the PIDs/FIDs and GCs will be utilized to evaluate VOC trends in depth, concentration, and location of contamination mass requiring focused treatment (i.e., additional mixing time, higher application of ZVI slurry mixture).

4.4.2 Implementation Sequence

The LDA borings will be established based upon an overlap spacing ranging from 0% to 17.5% (representing complete overlap with no interstitial space) overlap. A depiction of LDA boring spacing in the oil landfarm source area based on a 10% overlap is presented in Figure 3. The overlap spacing will be further evaluated in the 60% RDR and may vary depending on the concentration of TCE at the boring location and/or location within the treatment zone (i.e., increased overlap around the periphery of the treatment cell and reduced overlap internal to the treatment cell). The sequencing of soil mixing and treatment locations will be conducted such that the perimeter cells are treated first and subsequent locations will move inward in concentric circles, generally targeting lower concentration areas prior to targeting higher concentration areas and creating a perimeter ZVI slurry enhanced ring, which would provide treatment to any groundwater displaced outward during implementation.

4.4.2.1 Description of soil mixing and hot air/steam delivery procedure

Soil mixing with hot air/steam delivery will be conducted at each cell location in treatment passes (a pass is considered to be one movement of auger through the entire depth of the cell in one direction, up or down). Data collected from off-gas analysis from the PIDs/FIDs and GCs during the first hot air/steam treatment pass will be monitored to aid in the real-time decision making process and to evaluate results against treatment criteria, completion criteria, and iron dosage quantities.

The hot air/steam treatment pass will be initiated when the auger is drilled from the ground surface to the starting thermal treatment depth for the zone of treatment at a typical descent rate of 1 to 3 ft per minute and 6 to 10 revolutions per minute. Additionally, if warranted based on field conditions, a drilling mud may be utilized as a cutting fluid to assist in auger advancement in the formation. The GCs continuously will process samples at a rate of approximately every 2 to 5 minutes for analysis. The PIDs/FIDs continuously will analyze and process the off-gas total VOC concentration. Once the auger reaches the target starting depth (anticipated to be 5 to 6 ft bgs), the steam valve will be opened, steam will enter the treatment column, and the auger will continue descent to the desired finishing depth, which is anticipated to be 60 ft bgs.

The protocol for evaluating the number of treatment passes which will be completed at each treatment cell will be based on the peak TCE concentration in UCRS soils and in the upper RGA (HU4) evaluated by the data collection system during the first treatment pass. Once the peak off-gas VOC values are collected from the first treatment pass, the cell treatment protocol will be characterized into one of three categories, which are described generally as follows (and will be refined further with target quantitative values in the 60% RDR).

(1) Low VOC concentration target threshold—Requires a minimum of one complete thermal pass and monitoring of VOC concentrations to ensure that they are below the established low target threshold.

(2) Greater than the low target on the first treatment pass, but less than the low target treatment threshold on second treatment pass—Requires a minimum of two complete thermal passes and monitoring of VOC concentrations to ensure that they are below the established low target threshold.

(3) Greater than the low target on the first and second treatment passes—Requires a minimum of four complete thermal passes. Depth-focused passes could be implemented after the second pass; however, the final pass must have been completed from finishing treatment depth to top of target treatment interval, and to obtain completion criteria of an FID concentration less than 80% of the highest peak FID value obtained during the first pass, or VOC concentrations less than low target threshold, or reach a maximum established hot air/steam treatment time.

4.4.2.2 Description of ZVI Dosing

The actual quantity of guar gum and water will be adjusted during field preparation to adequately suspend the ZVI and achieve optimal pumping viscosity. The amount of ZVI injected at each location will be determined based upon LDA boring location and also by reading the maximum PID/FID and GC concentration in the treatment cell during operation. The peak VOC concentrations will be subdivided into low, medium, and high VOC concentration thresholds (which will be further refined with target quantitative values in the 60% RDR), and a ZVI slurry injection target concentration of 0.5%, 1.0%, or 1.5% by wt (i.e., percentage mass of ZVI to mass of soil) will be used depending upon the established treatment protocol (delivering higher weight percentage of SVI slurry to locations/depth intervals indicating higher VOC mass). During the LDA ZVI slurry injection pass, the desired quantity of ZVI-guar slurry mixture for each cell will be transferred to the soil mixing auger by a pump. The slurry then will travel down the kelly bar and will be injected into the subsurface through the rotating auger to distribute the iron throughout the column. Water will be used to flush the iron-guar slurry from the injection plumbing into the column during the final pass to ensure that the entire quantity of iron required is injected into the column.

5. CONSTRUCTION REQUIREMENTS

5.1 CONSTRUCTION EQUIPMENT

Construction-type equipment will be required to deliver and stage equipment on-site and to perform *in situ* LDA soil mixing with hot air/steam and ZVI soil mixing and treatment activities. These will likely include, but not be limited to, these items.

- Crawler crane
- Flatbed truck
- Storage units (e.g., conex boxes/Sealand containers)
- Drill turntable
- Excavator
- Loader
- High reach manlift
- Frac tank(s) for KO vessel water storage
- Telescopic forklift

The mixing rig will be mobilized to the site with multiple tractor-trailer components. A crane will be required to unload the tractor-trailers and place the component parts of the mixing rig in the site staging area for rig assembly.

5.2 *IN SITU* DEEP SOIL MIXING WITH HOT AIR AND STEAM TREATMENT AND ZVI AMENDMENT SYSTEM EQUIPMENT

Required equipment for the selected *in situ* LDA soil mixing with hot air/steam and ZVI injection will be finalized in the 60% RDR. Following is a list of typical equipment required for the extraction and treatment systems.

- Mixer
- Liquid mixing tanks
- Liquid transfer pumps
- Hollow kelly bar (70 ft long) and swivel
- 8-ft auger
- Containment shroud
- Chiller unit
- Process knockout tank
- Heat exchanger
- Blower

- Vapor-phase carbon adsorption vessels
- Boilers/steam generators
- Power generators

5.3 ELECTRICAL REQUIREMENTS

Electrical components needed for the i*n situ* soil mixing and treatment system will require 3-phase power for the operation of air compressor, pumps and blowers, mixing equipment, instrument panels and controls, electronic instruments, and thermocouples, etc. It is anticipated that approximately 750 kilovolt amperes (kVA) will be required to operate the *in situ* LDA soil mixing with hot air/steam and ZVI injection system, which will be obtained through a facility power connection or an on-site generator. Electrical requirements for the selected treatment system will be finalized in the 60% RDR.

5.4 WATER REQUIREMENTS

It is anticipated that at least 12,000 gal of water will be utilized by the *in situ* soil mixing and treatment system per day of operation. Water will be utilized for the generation of steam (approximately 10,000 gal per day) and for mixing the ZVI slurry (approximately 2,000 gal per day). Water entering steam boiler units may require conditioning using water softening ion exchange units to prevent scaling of the units. The water supply source and pretreatment requirement will be further evaluated in the 60% RDR.

5.5 SITE PREPARATION

Site preparation also may include the siting of an operations trailer, site surveying, utility locating, well abandonment, clearing and grubbing, grading, and leveling. Additional considerations for site preparations may include, but are not limited to, excavation activities to address unacceptable concentrations of other contaminants (such as PCBs or metals) that may be present in the shallow soils. These contaminants will not be treated by the technology and will be addressed consistent with the approach discussed previously in Section 1.4, Sequencing with Other Remedies.

5.6 PERMITTING

It is anticipated that site-specific permits may be required for the implementation of the RA utilizing the selected *in situ* soil mixing and treatment system. Applicable site-specific permits may include, but are not limited to, the following:

- Excavation/penetration permits
- Lockout/tagout permits
- Hot work permits

Site permitting requirements for the selected *in situ* soil mixing and treatment system will be finalized in the 60% RDR.

6. SAMPLING AND MONITORING

6.1 SAMPLING AND MONITORING DURING SOIL MIXING

During operation, on-site personnel will monitor the soil mixing and treatment system activities to assess the performance and progress of the remedial action. Sampling and monitoring requirements for the selected *in situ* soil mixing with hot air/steam and ZVI injection will be finalized in the 60% RDR. Systems will be designed to accommodate operational sampling and real-time monitoring for parameters, such as the following:

- Subsurface temperatures;
- VOC concentrations in recovered vapor;
- VOC concentrations in the worker breathing zone;
- Shroud extraction vacuum, temperature, and flow rate;
- Hot air/steam delivery pressure, temperature and flow rate;
- ZVI injection temperature, pressure, and flow rate;
- Effluent discharge flow rate and VOC concentration;
- VOC concentration in condensed liquids from the vapor stream; and
- Heat exchanger air temperatures and relative humidity.

6.2 SAMPLING AND MONITORING POSTREMEDIAL ACTION

Following the cessation of active remedial operations with *in situ* soil mixing with hot air/steam and ZVI injection, postremedial performance monitoring and sampling will be conducted to evaluate remedial performance against the established objectives. Postremedial sampling and monitoring requirements will be finalized in the 60% RDR, but generally will include the following:

- Postremedial soil and groundwater sampling for VOCs;
- Postremedial soil temperature evaluation; and
- Postremedial evaluation of soil homogeneity and ZVI distribution.

7. DATA MANAGEMENT

A project-specific data management and implementation plan will be included in the RAWP.

8. HEALTH AND SAFETY

A project-specific health and safety plan will be included in the RAWP.

9. WASTE MANAGEMENT

The sitewide Waste Management Plan (PAD-PLA-ENV-001) will be the basis for all waste management activities. Any deviations from this sitewide plan will be documented in the project-specific RAWP.

10. REFERENCES

DOE (U.S. Department of Energy) 1999. *Remedial Investigation Report for Waste Area Grouping 27 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-1777&D2, U.S. Department of Energy, Paducah, KY, June.

DOE 2000a. *Remedial Investigation Report for Waste Area Grouping 3 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-1895&D1, U.S. Department of Energy, Paducah, KY, September.

DOE 2000b. *Data Report for the Sitewide Remedial Evaluation for Source Areas Contributing to Off-Site Groundwater Contamination at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-1845/D1 (also known as Data Gaps document), U.S. Department of Energy, January.

DOE 2007. *Site Investigation Report for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-2180&D2/R1, U.S. Department of Energy, Paducah, KY, June.

DOE 2010a. *Focused Feasibility Study for the Southwest Groundwater Plume Volatile Organic Compound Sources (C-747-C Oil Landfarm and C-720 Northeast and Southeast Sites) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07/0186&D2/R1, U.S. Department of Energy, Paducah, KY, June.

DOE 2010b. *Remedial Design Support Investigation Characterization Plan for the C-747-C Oil Landfarm and C-720 Northeast and Southeast Sites at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (Draft in Progress), U.S. Department of Energy, Paducah, KY, July.

DOE 2012a. *Record of Decision for Solid Waste Management Units 1, 211-A, 211-B, and Part of 102 Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-0365&D2/R1, U.S. Department of Energy, Paducah, KY, March.

DOE 2012b. *Remedial Design Work Plan for Solid Waste Management Units 1, 211-A, and 211-B Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-1268&D2/R1, U.S. Department of Energy, Paducah, KY, April.

THIS PAGE INTENTIONALLY LEFT BLANK