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Ms. Julie Corkran
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Dear Mr. Begley and Ms. Corkran:

TRANSMITTAL OF THE REMEDIAL ACTION COMPLETION REPORT FOR *IN SITU* SOURCE TREATMENT BY DEEP SOIL MIXING OF THE SOUTHWEST GROUNDWATER PLUME VOLATILE ORGANIC SOURCE AT THE C-747-C OIL LANDFARM (SOLID WASTE MANAGEMENT UNIT 1), AT THE PADUCAH GASEOUS DIFFUSION PLANT, PADUCAH, KENTUCKY, DOE/LX/07-2405&D1

Enclosed for your review and approval is the certified *Remedial Action Completion Report for In Situ Source Treatment by Deep Soil Mixing of the Southwest Groundwater Plume Volatile Organic Source at the C-747-C Oil Landfarm (Solid Waste Management Unit 1) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, DOE/LX/07-2405&D1*. This report documents the successful completion of remediation of the volatile organic source in the subsurface soils by deep soil mixing.

In accordance with Section XX.G.2, Appendix F of the Federal Facility Agreement, there is a 90-day review/comment period for this document.

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

Sincerely,

A handwritten signature in black ink, appearing to read "Tracey Duncan", is written over a horizontal line.

Tracey Duncan
Federal Facility Agreement Manager
Portsmouth/Paducah Project Office

Enclosures:

1. Certification Page
2. SWMU 1 Remedial Action Completion Report, DOE/LX/07-2405&D1

e-copy w/enclosures:


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CERTIFICATION

Document Identification: *Remedial Action Completion Report for In Situ Source Treatment by Deep Soil Mixing of the Southwest Groundwater Plume Volatile Organic Source at the C-747-C Oil Landfarm (Solid Waste Management Unit 1) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, DOE/LX/07-2405&D1*

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to ensure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Fluor Federal Services, Inc.




Myrna E. Redfield, Director
Environmental Management



Date Signed

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to ensure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

U.S. Department of Energy



Jennifer Woodard, Paducah Site Lead
Portsmouth/Paducah Project Office



Date Signed

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



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

Date Issued—September 2016

U.S. DEPARTMENT OF ENERGY
Office of Environmental Management

Prepared by
FLUOR FEDERAL SERVICES, INC.,
Paducah Deactivation Project
managing the
Deactivation Project at the
Paducah Gaseous Diffusion Plant
under Task Order DE-DT0007774

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PREFACE

This *Remedial Action Completion Report for In Situ Source Treatment by Deep Soil Mixing of the Southwest Groundwater Plume Volatile Organic Source at the C-747-C Oil Landfarm* (Solid Waste Management Unit 1), DOE/LX/07-2405&D1, was prepared in accordance with requirements under the Comprehensive Environmental Response, Compensation, and Liability Act; Resource Conservation and Recovery Act; KRS 224.46-530; and the Federal Facility Agreement for the Paducah Gaseous Diffusion Plant, DOE/OR/07-1707 (EPA 1998). This report documents the implementation of the *in situ* deep soil mixing and interim land use controls remedial action (RA) at SWMU 1, as required by the 2012 record of decision (ROD) (DOE 2012). The active portions of the RA were completed in October 2015. Supplemental activities associated with the action were completed in 2016. The zero-valent iron portion of the RA continues to operate passively to attain remedial action objective 3, as stated in the ROD (DOE 2012).

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ACRONYMS

ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
<i>CFR</i>	<i>Code of Federal Regulations</i>
COC	contaminant of concern
DOE	U.S. Department of Energy
DPT	direct push technology
EM-38	Electromagnetics-38
EPA	U.S. Environmental Protection Agency
FFA	Federal Facility Agreement
FID	flame ionization detector
GAC	granular activated carbon
GC	gas chromatograph
HU	hydrogeologic unit
KDEP	Kentucky Department for Environmental Protection
KO	knockout
<i>KRS</i>	<i>Kentucky Revised Statutes</i>
LATA Kentucky	LATA Environmental Services of Kentucky, LLC
LDA	large diameter auger
LSRS	LATA-Sharp Remediation Services, LLC
LUC	land use control
MCL	maximum contaminant level
PAA	photo-acoustic analyzer
PGDP	Paducah Gaseous Diffusion Plant
PID	photoionization detector
QA	quality assurance
QAPP	quality assurance project plan
RA	remedial action
RACR	remedial action completion report
RAO	remedial action objective
RAWP	remedial action work plan
RDR	remedial design report
RDSI	remedial design support investigation
RG	remediation goal
RGA	Regional Gravel Aquifer
ROD	record of decision
SI	site investigation
SWMU	solid waste management unit
UCRS	Upper Continental Recharge System
VCS	vapor conditioning system
VFD	variable frequency drive
VOC	volatile organic compound
WAG	waste area grouping
ZVI	zero-valent iron

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EXECUTIVE SUMMARY

The Paducah Gaseous Diffusion Plant (PGDP) is an inactive uranium enrichment facility owned by the U.S. Department of Energy (DOE) and formerly operated by the United States Enrichment Corporation until 2014. DOE is conducting environmental remediation activities at PGDP in compliance with identified applicable or relevant and appropriate requirements. PGDP was placed on the National Priorities List in 1994, and DOE, EPA, and the Commonwealth of Kentucky entered into a Federal Facility Agreement (FFA) in 1998 (EPA 1998). On-site Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) actions are not required to comply with administrative requirements. This Remedial Action Completion Report (RACR) has been prepared for completion of the selected remedial action (RA), *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 (SWMU 1)]. The RA was chosen in accordance with CERCLA and is the response action selected in the signed *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/OR/07-0365&D2/R1 (DOE 2012). Under the Site Management Plan, there will be a separate remedial action completion report for SWMUs 211-A and 211-B. The outline and information used to prepare the RACR is consistent with Appendix D, Document Outlines of the FFA.

The SWMU 1 area has been investigated several times in support of remedy selection and development of RA, including the Phase II Site Investigation (SI) (CH2M HILL 1991); Waste Area Grouping (WAG) 27 Remedial Investigation (DOE 1999); WAG 23 (DOE 1998); Southwest Plume SI (DOE 2007); and the remedial design support investigation, which was conducted in 2012 (DOE 2013a).

The RACR addresses the completion in 2015 of *in situ* source treatment by deep soil mixing of 258 soil columns (8-ft in diameter) supplemented by hot air/steam injection with vapor extraction and vapor-phase treatment, followed by zero-valent iron (ZVI) and guar gum injection. Contaminants treated as part of the RA included trichloroethene (TCE), *cis*-1,2-dichloroethene (DCE), *trans*-1,2-DCE, 1,1-DCE, and vinyl chloride. The RA recovered an estimated 24 ± 12 gal of solvents total with a 95% confidence interval. In addition to that quantity recovered, the action left ZVI (estimated at 958,395 lb) in place to continue to provide passive treatment for any remaining volatile organic compound (VOC) contamination. The recovered VOC contamination was captured on approximately 20,000 lb of activated carbon that was regenerated for reuse. Lime soil stabilization, grading and restoration of the excavated site, management and disposition of accrued waste, and post-remedial field sampling were performed following soil mixing. The post-treatment sampling included 11 soil borings that were sampled for VOCs at 5-ft intervals. Six monitoring wells also were constructed adjacent to the treatment area to provide long-term monitoring to determine the effectiveness of the remedy.

The SWMU 1 RA also includes interim land use controls (LUCs) that consist of the excavation/penetration permit program and placement of warning signs to provide notice and warning of environmental contamination.

Activities that continue after submittal of this RACR include the following:

- Sampling of associated monitoring wells to determine the effectiveness of the remedy; and
- Continuing implementation and annual inspection of interim LUCs of SWMU 1, which are reported in a FFA Semiannual Report.

Post-treatment soil sampling supplied TCE contaminant data to support the following observations:

- Average post-treatment TCE soil contaminant concentrations were reduced by approximately 99% in the eight locations in the mixing area. compared to pre-mixing TCE contaminant concentrations.
- Average post-treatment TCE concentrations in those eight soil borings in the mixing area all were below the Upper Continental Recharge System soil TCE cleanup level of 73 ppb.
- Average TCE concentrations in the three soil borings drilled outside the soil mixing area showed that reductions in TCE contamination occurred; therefore, it is concluded that the soil mixing did not cause TCE contaminant migration outside of the mixing area.

The following are the RAOs for this remedial action, as contained in the ROD (DOE 2012):

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 Operable Unit and the Groundwater Operable Unit.
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 MCLs in the underlying RGA groundwater.

The soil mixing and placement of ZVI were completed consistent with the RD, the RAWP, and associated discussions with the FFA parties (RAO 1). The remedy was successful at removing VOCs from the treatment area, as described in Section 4.2.2, “Volatile Organic Compounds Removed.” Additionally, the ZVI portion of the remedy will passively continue destroying remaining residual VOCs. The interim LUCs are in place and operational (RAOs 2a and 2b). Monitoring wells have been installed as required in the RAWP. The purpose of the groundwater sampling will be to ascertain when RAO 3 of this action is attained.

1. INTRODUCTION

This Remedial Action Completion Report (RACR) has been prepared for completing implementation of the selected remedial action (RA), *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 (SWMU) 1]. The RA was chosen in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and is the response action selected and 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/OR/07-0365&D2/R1 (ROD) (DOE 2012). Under the Site Management Plan, there will be a separate remedial action completion report (RACR) for SWMUs 211-A and 211-B.

The Southwest Groundwater Plume refers to an area of groundwater contamination at Paducah Gaseous Diffusion Plant (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 in 1998 (DOE 1999). The U.S. Department of Energy (DOE) conducted a site investigation (SI) of the Southwest Plume and selected four potential source areas from 2004 [*Site Investigation Report for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 2007)] for RA. Of the four areas investigated, the SI identified SWMU 1 as one probable contributor to trichloroethene (TCE) groundwater contamination in the Southwest Plume. The RA consisted of implementing *in situ* source treatment by deep soil mixing supplemented by hot air/steam injection with vapor extraction and vapor-phase treatment, followed by zero-valent iron (ZVI) and guar gum injection. As a result of site conditions during RA implementation, a lime stabilization process was implemented following soil mixing to address soil stability concerns, but was not an active treatment component of the RA. Grading and restoration of the deep soil mixing site, management and disposition of accrued waste, and subsequent post-remedial field sampling were performed following the soil mixing field activity. Contaminants treated as part of the RA include TCE and degradation products. The entire SWMU 1 also has interim land use controls (LUCs) that consist of the excavation/penetration permit program and placement of warning signs to provide notice and warning of environmental contamination.

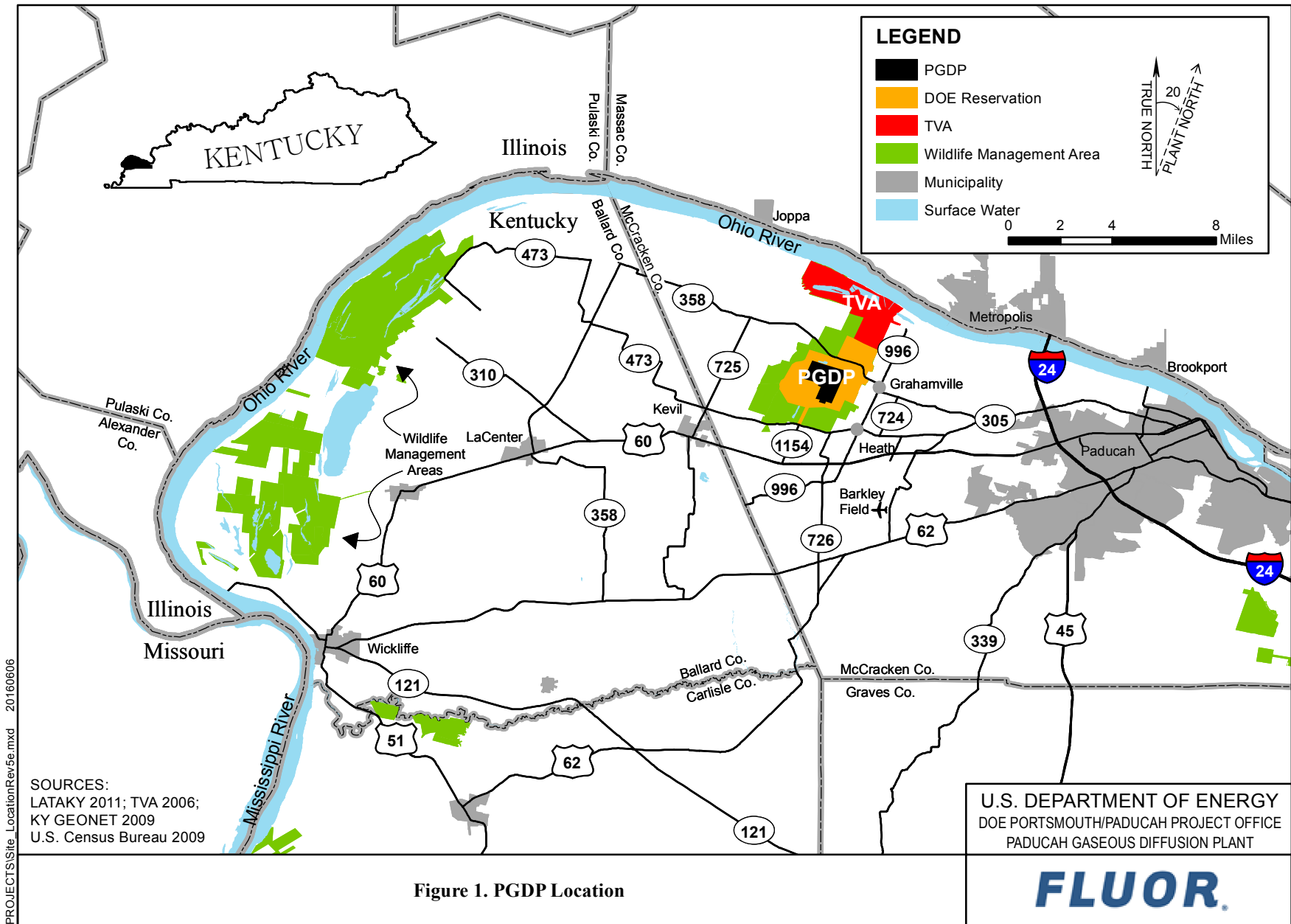
1.1 GENERAL DESCRIPTION OF SITE

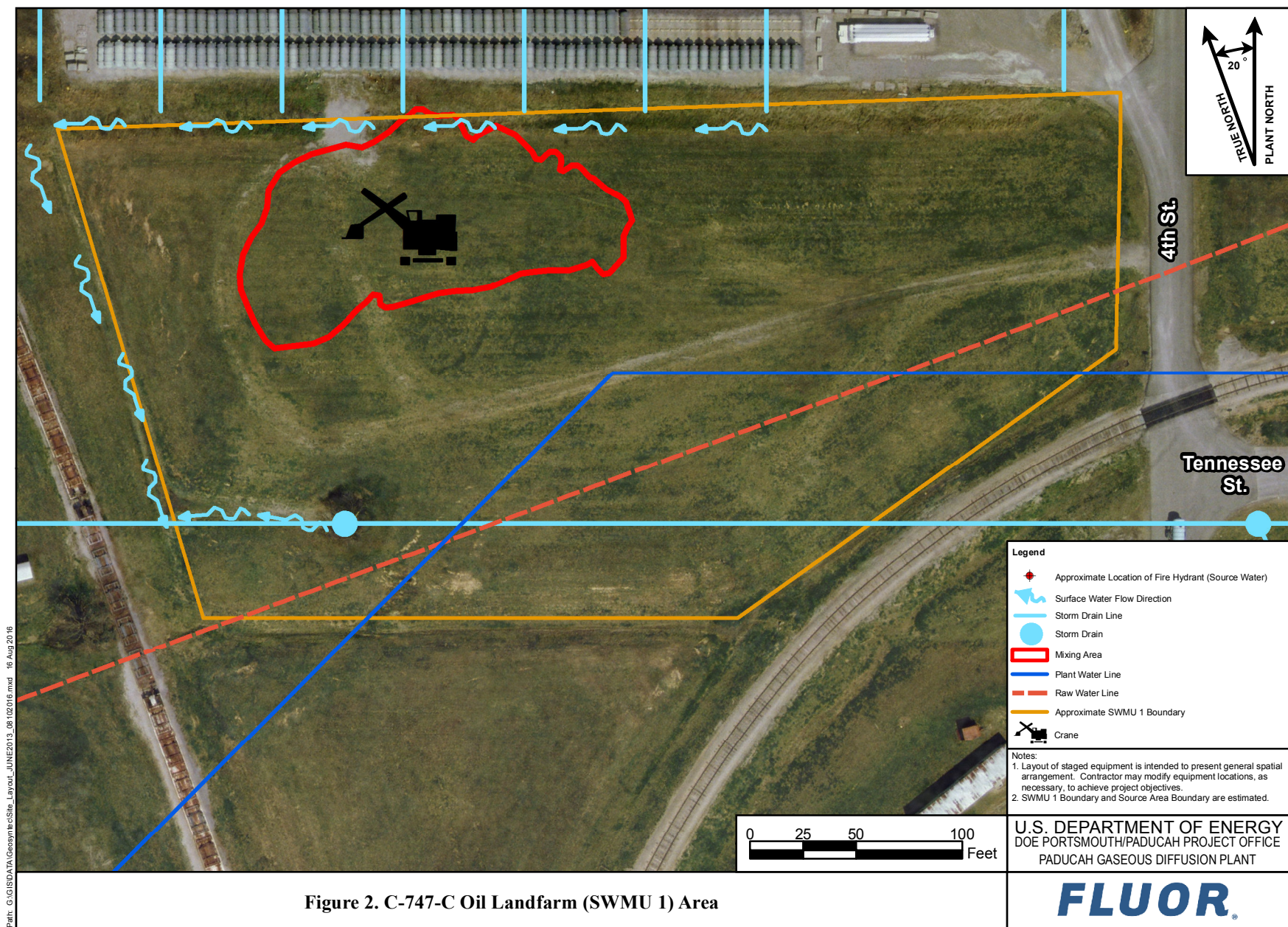
1.1.1 Site Location

PGDP is located approximately 10 miles west of Paducah, Kentucky, and 3.5 miles south of the Ohio River in the western part of McCracken County (Figure 1). The plant is located on a DOE-owned site; approximately 650 acres are within a fenced security area, approximately 800 acres are located outside the security fence, and the remaining 1,986 acres are licensed to Commonwealth of Kentucky as part of the West Kentucky Wildlife Management Area.

1.1.2 Description

The C-747-C Oil Landfarm, SWMU 1, is a facility located inside the plant limited access area, near the west fence of the industrial section of PGDP. The facility is bound on the north by the C 745-A Cylinder Yard and by railroad tracks on the east, west, and south. The nearest plant streets are the intersection of Tennessee Avenue and 4th Street, which lies southeast of SWMU 1 (Figure 2).





Between 1973 and 1979, the landfarm consisted of two (approximately 1,125 ft²) plots that were plowed to a depth of 1 to 2 ft for landfarming (mixing waste oils with soil to aid biodegradation of the oil in an area that prevents runoff) waste oils primarily contaminated with TCE, uranium, polychlorinated biphenyls (PCBs), and 1,1,1-trichloroethane. These waste oils are believed to have been derived from a variety of PGDP processes. Waste oils were spread on the surface every three to four months; then the area was limed and fertilized. The volatile organic compound (VOC) contamination in the soils at C-747-C was from the waste oils that were landfarmed.

1.1.3 Early Environmental Actions

Early investigations of the oil landfarm included the Phase I and Phase II SI (CH2M HILL 1991; CH2M HILL 1992), additional sampling performed to support the WAG 23 Feasibility Study and a resulting removal action (DOE 1998), and the *Remedial Investigation Report for Waste Area Grouping 27 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 1999). These investigations and actions identified the presence of VOCs, PCBs, dioxins, semivolatile organic compounds, heavy metals, and radionuclides as contaminants of concern (COCs). As part of the WAG 23 Removal Action, 17.58 m³ (23 yd³) of dioxin-contaminated soil was excavated and removed from the unit. The removal action area was roped-off to prevent equipment access during the implementation of the soil mixing process.

A remedial design site investigation (RDSI) was conducted in 2012 to gather supplemental data necessary for the design and implementation of the *in situ* source treatment deep soil mixing RA selected for SWMU 1. Data collected from 22 soil borings during the RDSI allowed for a more refined delineation of the size and shape of the overall treatment area for this RA. The completion of this analysis was documented in the *Remedial Design Report In Situ Source Treatment Using Deep Soil Mixing for Southwest Groundwater Plume Volatile Organic Source at the C-747-C Oil Landfarm at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-1276, (RDR) (DOE 2013a) and is shown in Figure 3.

1.2 GENERAL DESCRIPTION OF REMEDY

The RA for the Southwest Groundwater Plume Volatile Organic Source at the C-747-C Oil Landfarm, SWMU 1, included the design, installation, and operation of deep soil mixing with interim LUCs. The soil mixing was supplemented by steam/hot air injection with vapor extraction and ZVI injection, as required by the RDR (DOE 2013a). Following the soil mixing portion of the RA, soils were sampled, and monitoring wells were installed for long-term monitoring to examine contaminant trends after remedy implementation and to assess progress toward achieving cleanup objectives as prescribed in the ROD (DOE 2012).

1.2.1 Components of the Remedy

The remedy was selected and documented under a CERCLA ROD signed in 2012 is *In Situ* Source Treatment Using Deep Soil Mixing with Interim LUCs.

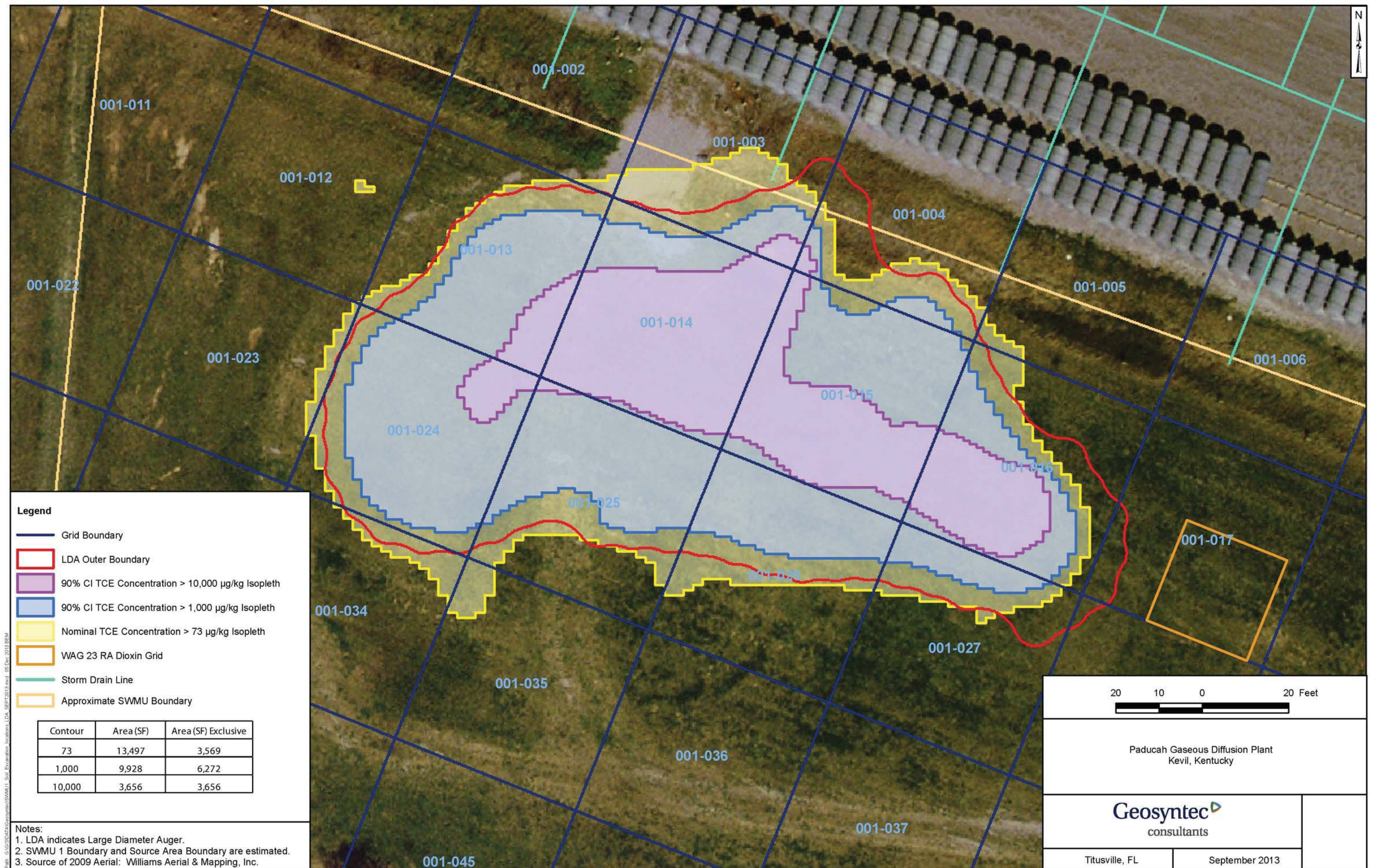


Figure 3. SWMU 1 Area to be Soil Mixed (LDA Outer Boundary)

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Warning signs to provide notice and warning of environmental contamination have been placed at SWMU 1. The warning signs indicate the following:

WARNING: CONTAMINATED AREA

Hazardous Substances in Soil and Groundwater

Authorized Access Only

Contact: [Insert Phone Number]

SWMU 1 continues to require use of a trenching/excavation/penetration permit consistent with CP3-EN-0227.

The remedy was designed and documented in the RDR. Additional information concerning the implementing of the soil mixing RA also was documented in the *Remedial Action Work Plan for In Situ Source Treatment by Deep Soil Mixing of the Southwest Groundwater Plume Volatile Organic Source at the C-747-C Oil Landfarm (Solid Waste Management Unit 1) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, DOE/LX/1287&D2 (RAWP) (DOE 2013b).*

The soil mixing RA includes seven major components:

1. Procurement of Subcontractors,
2. Site Preparation and Soil Excavation,
3. Mobilization and Setup,
4. Soil Mixing and Test-Column Soil Sampling,
5. Demobilization and Site Breakdown,
6. Surface Restoration, and
7. Post-Treatment Soil Sampling and Monitoring Well Installation.

Procurement of Subcontractors. The implementation of the RA, except for components 2 and 6, required the procurement of two specialty subcontractors: one contractor was to perform the soil sampling and monitoring well installation, and a second contractor was to perform the actual soil mixing operations. Chase Environmental Group, West Paducah, Kentucky, was selected to perform the soil sampling and monitoring well installation. FECC, Inc., Orlando, Florida, was selected to perform the *in situ* soil mixing portion of the RA.

Subtasks 2 and 6 involved excavation/replacement of soil, placement of drainage structures, placement of gravel equipment pads, and removal of waste soils and were performed by LATA Environmental Services of Kentucky, LLC (LATA Kentucky) and LATA-Sharp Remediation Services, LLC, (LSRS) internal staff. Other general support activities such as radiological control, utilities, and security also were supplied by PGDP site resources.

Site Preparation and Soil Excavation. The site preparation subtask was performed during the summer of 2014 and into early 2015. It included modifying the SWMU 1 area to that shown in Figure 4 and the following explanation:

- Excavated the area to be soil mixed to approximately 4 ft below ground surface (bgs) to remove identified alumina particles (trap-mix) that were present at SWMU 1 and located inside the soil mixing area;



Figure 4. SWMU 1 after Site Preparation and Soil Excavation

- Replaced approximately 2 ft of soil in the 4-ft deep excavation to make a less than 1% sloping surface for the soil mixing crane to operate on the soil mixing area. Constructed a 1% sloped pathway over SWMU 1 from 4th Street west to the soil mixing area, placed an aggregate base on access pathway for crane stability, and performed gamma radiological walkover survey;
- Installed drainage culverts for conveying storm water around the soil mixing area; and
- Constructed a storm water containment pond to catch and convey storm water to a drainage ditch leading to Outfall 008.

Mobilization and Setup. The mobilization and setup subtask involved bringing the necessary pieces of the soil mixing and treatment equipment, as well as other supporting equipment, to the SWMU 1 area and setting up, calibrating, and testing the equipment during initiation of soil mixing. Mobilization and setup included the following:

- Placed aggregate over areas in which equipment trailers, treatment equipment, etc., were located to facilitate the soil mixing action and the movement of equipment;
- Delivered and inspected soil mixing equipment, including crane, mixing bits and Kelly bar, and drill platform;
- Delivered and inspected hot air/steam generation and delivery system including boilers, water pumps, and softeners;
- Delivered and inspected off-gas extraction and vapor conditioning system, including major items such as vacuum shroud, blower, water knockout, and chiller and reheater;
- Delivered and inspected liquid treatment system, including fractionation storage tanks and activated carbon liquid-phase treatment canisters;
- Delivered and inspected vapor treatment system, including activated carbon canisters;
- Delivered and inspected ZVI mixing and delivery system, including material hoppers, mixing tanks, and pumps; and
- Delivered and inspected data collection and monitoring system, including gas chromatographs (GCs); flame ionization detector (FID) system; Labview[®] control and operating system; and temperature, pressure, and flow sensors.

Soil Mixing and Test-Column Soil Sampling. The subtask included the soil mixing and placement of ZVI into each of the 258 completed soil columns. This subtask also included the post-mixing soil sampling of the three identified test columns (62, 116, and 224), which initially were mixed and then rapidly soil sampled and analyzed.

Demobilization and Site Breakdown. This subtask followed completion of the soil mixing subtask and included disassembling all mixing and treatment equipment and shipping it off-site.

Site Closure and Soil Replacement. During this subtask, the stockpile of excavated soil was relocated to the mixing treatment area, graded to a natural contour, and seeded for erosion control. Graveled areas were excavated and stockpiled or respread to provide temporary roadways for the installation of

monitoring wells that followed. This subtask also included implementing the soil stabilization activities by mixing quicklime into the treated soil.

Post-Treatment Soil Sampling and Monitoring Well Installation. This subtask, the final component of the RA, was implemented to perform post-soil sampling and monitoring well installation. The monitoring wells will provide the data to support long-term evaluation of meeting the overall cleanup objectives for the Upper Continental Recharge System (UCRS) soils and volatile organic contaminants and to determine the effectiveness of the remedy.

The RDR and the RAWP provide additional detail concerning the composition of the components of the *In Situ* Source Treatment Using Deep Soil Mixing RA.

1.2.2 Contaminants Treated

The C-747-C Oil Landfarm was used for landfarming of waste oils contaminated primarily with TCE, uranium, PCBs, and 1,1,1-trichloroethane between 1973 and 1979. These waste oils are believed to have been derived from a variety of plant processes. Sample analyses from the Southwest Plume SI and previous investigations indicated that the primary site-related VOCs in subsurface soil in the Groundwater Operable Unit source zones were TCE and its breakdown products [*cis*-1,2-dichloroethene (*cis*-1,2-DCE), *trans*-1,2-DCE, and vinyl chloride].

The selected RA for the oil landfarm sought to achieve Remedial Action Objectives (RAOs) by removing significant amounts of TCE and VOCs in the subsurface soils using deep soil mixing treatment. The following are RAOs for this action, as contained in the ROD (DOE 2012):

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,¹ and SWMU 211-B¹) pending remedy selection as part of the Soils Operable Unit and the Groundwater Operable Unit.
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 MCLs in the underlying RGA groundwater.

The selected RA for the oil landfarm would achieve RAOs by removing significant amounts of TCE and VOCs in the subsurface soils by treatment using deep soil mixing and *in situ* chemical treatment.

¹ The remedial action presented in the ROD for SWMUs 211-A and 211-B have separate documentation and schedule under the Site Management Plan and is not discussed further in this report.

The treatment zone of the soil mixing RA targeted the soils directly below and within the area of the C-747-C Oil Landfarm, as identified in the RDR. The RDR contained completion criteria required for determining when soil column mixing was complete. Groundwater protection remediation goals (RGs) for UCRS soil, as shown in Table 1, are VOC concentrations in subsurface soils in the treatment area that would not result in exceedance of the maximum contaminant levels (MCLs) in the RGA and, therefore, would meet RAO 3 with no other controls necessary for the SWMU 1 treatment area. The cleanup levels were calculated for TCE half-lives in UCRS soils ranging from 5 years to 50 years to assess the effects of high to low rates of degradation on overall remedy time frames (50 years essentially representing no observable degradation).

Table 1. UCRS Soil Cleanup Levels for VOCs for Groundwater Protection at the Oil Landfarm Source Areas

VOC	Half-Life (yr)	Primary MCL (mg/L)	UCRS Soil RG (mg/kg)*
Oil Landfarm			
TCE	5	5.00E-03	8.50E-02
TCE	25	5.00E-03	8.00E-02
TCE	50	5.00E-03	7.30E-02
1,1-DCE	infinite	7.00E-03	1.30E-01
<i>cis</i> -1,2-DCE	infinite	7.00E-02	6.00E-01
<i>trans</i> -1,2-DCE	infinite	1.00E-01	1.08E+00
VC	infinite	2.00E-03	3.40E-02

*Based on a dilution attenuation factor of 59.

The soil mixing success at achieving the needed cleanup levels is discussed in Section 4, Construction Activities.

1.2.3 Field Changes

The remedial design (DOE 2013a) included flexibility to make adjustments to treatment protocols, with approval of the Federal Facility Agreement (FFA) parties based upon results of field implementation, with an objective to improving performance and enhancing mass reduction. During the mobilization and soil mixing fieldwork phase of the RA at the C-747-C Oil Landfarm, field changes to the remedy were identified, approved, and implemented (DOE 2013b; DOE 2014). These field changes were made in an effort to improve safety of the workforce, improve operational reliability and environmental protection, and/or improve productivity. The reason behind each field change is stated in the following subsections.

The field changes included the following:

- Switching method of air discharge monitoring from a photo-acoustic analyzer (PAA) to a combination of FID and GC (This measurement was taken after carbon treatment immediately prior to vapor phase discharge);
- Adjustments to address excessive energy release during mixing, (which included implementing “slurrying” of columns), adjustment of steam flow rates, and equipment modifications such as vacuum hood attachment method;
- Utilization of GC to evaluate shroud off-gas concentrations when FID appeared to have interferences from non-target VOC compounds (this measurement was taken immediately upon vapor extraction

from the soil and prior to carbon treatment and was used to determine thermal treatment completion of the soil column);

- Adjustment of completion criteria for low concentration treatment columns;
- Modification of mixing sequence from completing entire perimeter first and working inward to a west to east sequencing;
- Implementation of lime stabilization of wet soils;
- Elimination of treatment of four columns located in an area of transuranic contaminated soils;
- Identification of soil columns not completed due to refusal (see Section 4.5.1, Columns Encountering Refusal); and
- Revision of test soil columns to be mixed first.

Each of these changes was discussed and concurred upon with the U.S. Environmental Protection Agency (EPA) and Kentucky Department for Environmental Protection (KDEP) during routine weekly updates or as a part of specific project discussions.

1.2.3.1 Switching air discharge monitoring from PAA to FID/GC

The RDR specified the use of a PAA to monitor gas discharge to the environment from the deep soil mixing project. Specifically, an Innova 1412 or equivalent PAA was defined for performing exhaust stack monitoring.

The PAA had been used during C-400 remedial activities. Operational conditions of the C-400 treatment system resulted in a substantial quantity of moisture in the sampled vapor stream. The moisture present in the sampled stream created operational problems (shutdowns) for the PAA. Discussions with the PAA manufacturer confirmed that the PAA incurs operational issues (e.g., requires shutdown and drying) when used in vapor streams with high levels of moisture present.

During deep soil mixing, the steam injection operation produces a vapor stream containing a substantial quantity of moisture. The moisture continues to be present in the vapor stream during ZVI injection (after steam treatment stops), due to the high temperature of the treated soil and continued operation of the shroud vacuum during iron injection. The project team had concerns the PAA would stop operation during mixing, resulting in lack of monitoring capability until mixing operations could be shut down. Further, mixing operations could not be resumed until the PAA could be brought back online, resulting in delaying mixing progress.

To provide a more reliable monitoring process, the deep soil mixing subcontractor recommended using the same system currently being used to monitor off-gas during soil mixing operations at other sites. The proposed system used a combination GC and FID monitoring approach. The specific proposed instruments were an SRI Model 8610 GC paired with a VIG Industries Model 20 FID. The GC/FID provides monitoring capability during soil mixing operations that is not impacted by moisture in the gas stream and provides similar detection limits for the target contaminants as the PAA. The soil mixing operation at Paducah was designed to include use of the FIDs and multiple GCs as process support equipment for measuring concentrations in the shroud, between carbon columns, and at other locations prior to the discharge stack (see Section 4.4.1.5 of the RDR).

The project team discussed utilizing the GC/FID combination with the EPA and Commonwealth of Kentucky, and provided a letter to document the request (DOE 2015a).

EPA approved this request via letter on March 13, 2015, (EPA 2015) and KDEP approved via letter on March 3, 2015 (KDEP 2015). Soil mixing operations were performed using the GC/FID combination for monitoring exhaust stack emissions.

1.2.3.2 Adjustments to address excessive energy release during mixing

The approach used for performance of deep soil mixing operations is soil type and lithology dependent. During mixing of the first 12 or so columns at the SWMU 1 site, different combinations of mixing strategies were attempted to determine the best mixing approach. Columns were tried with use of no water or drilling fluid (directly injecting steam on the first pass); use of drilling water only during first pass to varying depths; and use of drilling mud during the first pass to varying depths. During mixing of the first 12 columns, rapid returns of energy to the surface, or “burps,” were encountered. The cause of the burps was determined to be related to the energy (steam and compressed air) being injected into the ground building up in the subsurface, and then returning to the surface in a rapid burst. When these bursts of energy return to the surface, they result in a pressure build up in the containment shroud, which is greater than can be removed by the vapor extraction system. The resulting pressure then exerts an upward force on the shroud and drilling platform.

On April 20, 2015, while working on Column 53, the subcontractor crane operator paused work due to safety concerns based on encountering a very strong burp while mixing this column. The upward force generated by this burp was strong enough to physically lift the shroud and drilling platform off the ground, generating slack in the static cable lines that support the platform from the crane mast. After the upward push, gravity then pulled the shroud/platform back down. The result of this lifting and resultant downward travel of the shroud and platform resulted in enough downward force that the crane boom and supporting static cables received a “shock load.” Shock loading a crane boom or static cables creates an unsafe situation that is outside operating parameters for the crane. The mixing subcontractor observed burps on other sites, although not to the extent nor the frequency observed on this project.

During this work pause, the team evaluated this situation to determine what operational changes or equipment modifications could be made to control the rapid release of energy. Initially, a column was mixed by injecting water during the first mixing pass, rather than steam, so as to loosen and soften the dense soils. Turning the material into a slurry provided an opportunity for the injected energy to return to the surface in a smoother, more uniform fashion. Up to 40 gal per minute of potable water, along with compressed air, was injected into a column during the first pass. Further, in some columns, based on crane operator experience and soil conditions, the mixing tool was advanced partially downward into the column, retracted approximately 5 ft, followed by advancing 10 ft downward. This process was repeated until target depth was reached to increase the blending of water and soil into a slurry. Upon completion of creating the slurry in the column to be treated, water injection stopped, and steam injection was performed. The water and steam were not injected simultaneously to prevent a potentially dangerous “water hammer” in the equipment. Water hammer is the momentary increase in pressure, which occurs in a fluid or fluid/gas system when there is a sudden change in direction or velocity of the fluid.

Additionally, efforts to control burping included allowing the soil mixing operator to reduce the steam injection rate (specified at a minimum of 8,000 lb per hour in the RDR). Steam flow rates were generally maintained at a minimum of 8,000 lb per hour, but occasionally were reduced in an effort to minimize the soil burps based on observance of critical elevated shroud offgas temperature (approaching 190°F to 200°F) and/or unacceptable behavior of the shroud (movement or vibration). The overall end-point

criterion for thermal treatment was either achieving 100 ppm VOC concentrations in the offgas stream or 80% reduction of first pass offgas contaminant measurements throughout the final thermal pass.

The combination of these changes did not alleviate the burping issue completely; therefore, a physical modification to the equipment was implemented. This modification included fabricating and installing a “shock absorber” between the shroud and the drilling platform. The shock absorber consisted of telescoping tubes allowing the shroud to move and absorb energy from a burp without transferring the energy to the drill platform and crane. The combination of these modifications provided adequate control and/or mitigation of the burping such that mixing could continue safely.

These field modifications to address soil burping and safety concerns with soil mixing operations were discussed with the remedial project team in real time during routine weekly conference calls. The discussions were documented in a record of conversation (DOE 2015b).

1.2.3.3 Utilization of GC to evaluate shroud off-gas VOC concentrations when FID indicated interference

The vapor stream extracted from the soil mixing operations was monitored by a FID and two GCs that were online at all times during mixing. A third GC was present that was operated at the discretion of the operator. The FID monitored total organic material, including methane, in the off-gas stream exiting the shroud, before entering the carbon vessels for treatment. The FID provided data on a continuous, real time basis. The two GCs collected a discrete sample from the vacuum stream prior to entering the off-gas conditioning equipment approximately every 6 minutes, on an alternating basis such that a sample was collected approximately every 3 minutes. The GC provided specific analysis for methane, VC, 1-1-DCE, *trans*-1,2-DCE, *cis*-1,2-DCE, and TCE.

During mixing operations, on certain treatment columns the results from the FID indicated levels of organic material in the off-gas in excess of the combined target chlorinated volatile organics and methane, as measured by the GC. Comparison of the data from the FID and the GC data did not indicate substantial swings or spikes in the FID data between discrete GC sampling points. This indicates target VOCs in excess of the amounts being measured by the GC were not being extracted during the time frame between the GC discrete sampling points. Further, the operator-controlled third GC was used on occasion to collect discrete samples at other nonuniform (not 3 minute interval) times. There was no indication of target VOC extraction being missed by the GCs.

Considering that SWMU 1 had been used for degradation of oils, it is reasonable that hydrocarbons or compounds other than the five, identified target VOC were present. An FID will detect organic materials other than the specific target contaminant VOC. Because removal of these hydrocarbons was not included in the RA objectives as target VOC contaminants, the sum of the specific contaminant concentrations, as reported by the GCs, was used to determine achievement of the thermal treatment completion criteria of 100 ppm or less when necessary. The sum of GC measured target contaminant concentrations of VC, 1-1-DCE, *trans*-1,2-DCE, *cis*-1,2-DCE, and TCE was compared to the 100 ppm objective to determine completion of thermal treatment. The use of this alternate approach of determining that target contaminant concentrations met the 100 ppm completion criteria was discussed in the weekly FFA conference call updates on June 18, 2015, and July 1, 2015.

1.2.3.4 Adjustment of thermal treatment completion criteria for low concentration columns

One of the completion criteria for thermal treatment in Figure 7 of the RDR for soil mixing at SWMU 1, required achieving maximum of 100 ppm FID readings (adjusted for methane) and 160°F vapor shroud temperature during an entire final thermal pass.

Typically, multiple thermal passes were required to achieve a temperature of 160°F. Additionally, based on prior soil mixing experience and confirmed during initial mixing at SWMU 1, the first steam heating pass through a soil column produced the highest concentrations of target contaminants for that column, without regard to vapor shroud temperature during the treatment pass. In cases where the first steam treatment pass through the column resulted in a FID reading (or total VOC reading) of less than 100 ppm, each subsequent steam pass would result in lower contaminant concentrations in the shroud.

For the columns where the first steam treatment pass through the column resulted in a FID reading (or total VOC reading) of less than 100 ppm, the thermal treatment completion goal of a shroud gas temperature of 160°F was considered to be met on the first steam pass, regardless of temperature achieved. Additional thermal passes increase the probability of generating soil burps. In soil columns which achieved a FID reading (or total VOC reading) less than 100 ppm on the first thermal pass, subsequent passes did not result in removal of significant additional contaminant mass. Following discussions with EPA and KDEP, the requirement was eliminated for reaching 160°F shroud vapor temperature for columns where the first thermal pass exhibited less than 100 ppm of VOCs.

The removal of the 160°F temperature requirement only impacted columns with low concentrations of VOCs on the first thermal pass. The change did not alter the thermal treatment of columns that produced higher than 100 ppm VOC contaminant levels on the first steam pass. Further, all columns received ZVI in accordance with the RDR following completion of thermal treatment.

This change in treatment protocol for low concentration columns (those that produced less than 100 ppm FID response or sum of GC measured target contaminant concentration on first steam pass) was discussed with EPA and KDEP during routine project update calls prior to implementation. The conversations regarding this topic were documented in a record of conversation (DOE 2015b).

1.2.3.5 Modifying mixing sequence from completing entire perimeter to a west to east sequencing

The RAWP and RDR defined a soil mixing sequence in which three test columns would be mixed, then a perimeter “ring” of soil columns, followed by completion of mixing in the inside of the perimeter. Columns inside the perimeter would be completed in concentric circles, generally moving inward from lower to higher concentration areas. The intent of this sequencing was to establish a barrier of ZVI treated soils around the treatment zone to control any VOCs that could migrate outward as a result of the soil mixing in higher concentration areas.

Upon initial discussions with soil mixing subcontractors during the procurement process, the bidding subcontractors expressed concerns regarding the defined mixing sequence. This sequencing would require both crane and support equipment to be placed on previously mixed soils. The subcontractors were concerned that the unstable nature of mixed soils would impact stability of the crane. Further, due to the presence of the uranium hexafluoride cylinder storage yards located immediately north of SWMU 1 and potential consequences if the crane were to fail and strike the cylinders, an evaluation of crane operations was performed by an outside risk management consultant and geotechnical engineer. One of the recommendations from this evaluation to assure crane stability was to avoid operating the crane on previously mixed soils.

To keep the crane on unmixed soils, a revision to the mixing sequence was proposed in an addendum to the RAWP (DOE 2014). The revised sequence, depicted in Figure 5, provided for completing the test columns followed by a perimeter of columns, with the exception of a line of unmixed columns along the southeastern side of the mixed area. Mixing would proceed from the perimeter columns toward the line of unmixed columns, with the last columns mixed as the crane and support equipment backed out of the area. This sequence was accepted by KDEP and EPA upon approval of the RAWP Addendum.

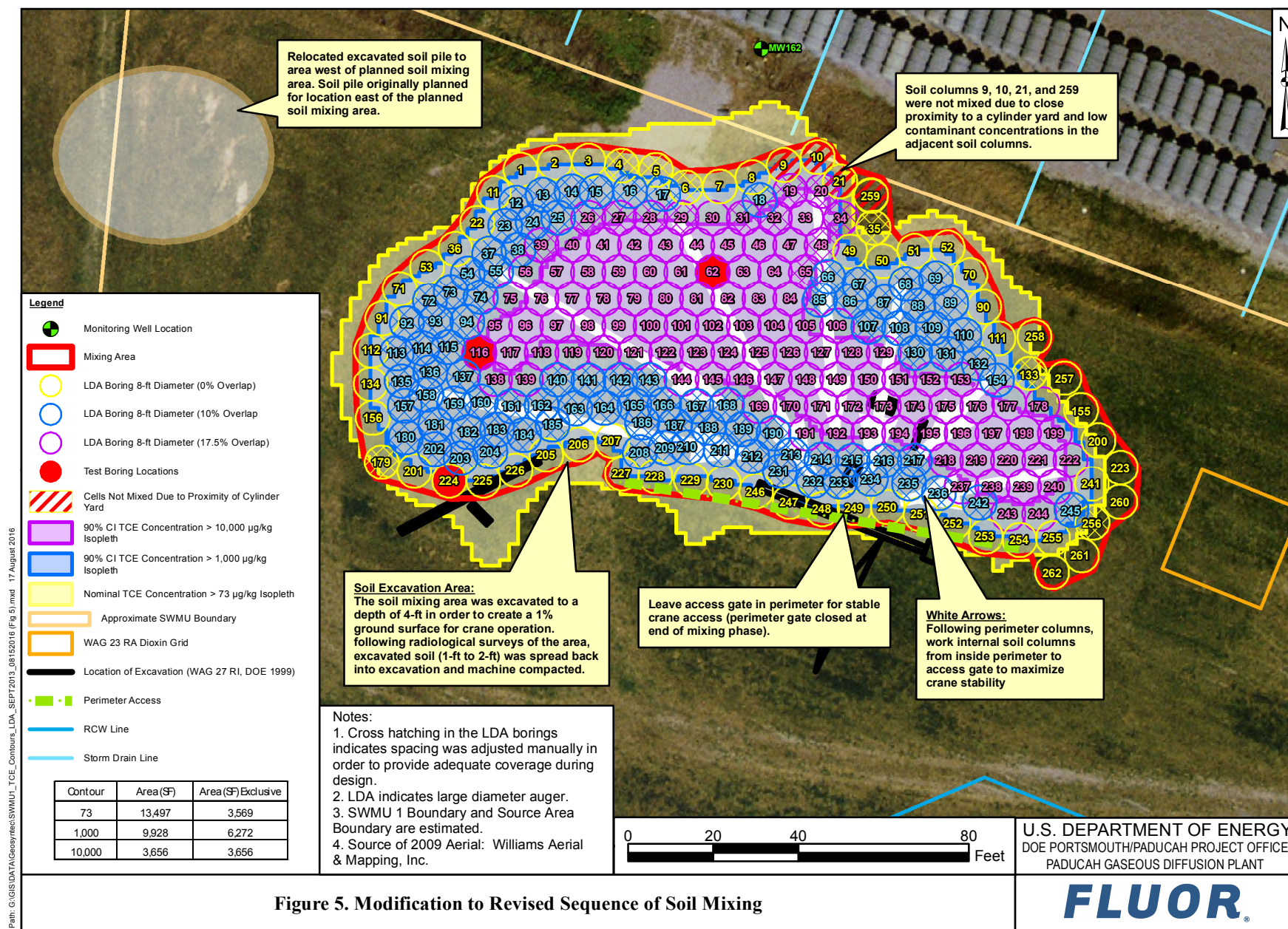


Figure 5. Modification to Revised Sequence of Soil Mixing

Further modification of this sequencing was required based on field conditions encountered during implementation of soil mixing. Water injection during the first mixing pass to create a slurry to control soil burps resulted in swelling (bulking) of the mixed soils. Generally, the excess soils physically were moved from the mixing area to the west to keep excess soils away from the mixing operations. Because mixing operations were initiated toward the western end of SWMU 1, this resulted in a somewhat dry work area from the crane toward the east, a very wet area of unstable mixed soils, and the wet excess soils toward the west of the crane. As mixing operations progressed, it became apparent that completing a perimeter ring was unworkable, with the unstable soils and the excess soils surrounding the equipment.

Based on these field conditions, the field team proposed further modification to the mixing sequence. The revised sequence provided for a boundary of thermally treated mixed and ZVI treated columns on three sides (north, west, and south), with mixing progressing toward the east, as shown in Figure 6. After completing the test columns, mixing was initiated on the western perimeter columns. For the newly proposed sequence, columns on the north and south perimeters connected to the already mixed western perimeter columns were completed first, leaving a concave middle section. The columns in the middle section, bounded by completed columns on north, south, and west, then were mixed. After treatment of the center section, operations were moved toward the east; additional columns were completed on the northern and southern perimeters, followed by treatment of the center section, again with completed columns to the north, south, and west. Repeating this approach allowed for mixing operations to continue toward the eastern edge of the mixing zone.

This change in treatment sequence was discussed with EPA and KDEP during routine project update calls prior to implementation (DOE 2015b).

1.2.3.6 Lime stabilization of soils

The implementation of the soil mixing generates a loose saturated soil that exhibits little bearing strength. The implementation of water injection and creation of slurry in treatment columns to control soil burping exacerbated the loose saturated soil conditions. These soils were very wet and unstable. While no specific geotechnical or stability analysis tests were performed, the soils would not support equipment or personnel; and an excavator operator could “push” the excavator bucket into the treated soils to the maximum reach of the excavator, encountering little to no resistance. During mixing operations, access to the unstable area was controlled for personnel safety. It was unknown if or when the soils would stabilize adequately to allow for post-remediation sampling and/or site restoration. Further, some degree of soil swelling/bulking was occurring, and managing the excess soils generated was providing a challenge to allow continued soil mixing progress.

The project team determined some type of dewatering or stabilization should be implemented for safety reasons and to allow better management of the loose wet soils. Soil stabilization using anhydrous lime was implemented. Granular lime was brought to the area in supersacks (nominally 3,000 lb bags, although some varying sizes were used), and placed into the area with an excavator. A second excavator, equipped with a rotating agitator, blended the lime into the unstable soils. Soils were stabilized across the soil mixing area to a depth of approximately 6 ft to provide a stable surface to allow replacement of soil excavated during preparation for soil mixing. Lime addition in an area generally continued until the area being treated could support the excavator. Approximately 278,000 lb of lime was used during the soil stabilization. The approach of lime stabilization of the upper few ft of mixed soils was discussed with the FFA parties during several weekly conference calls in August and September 2015.

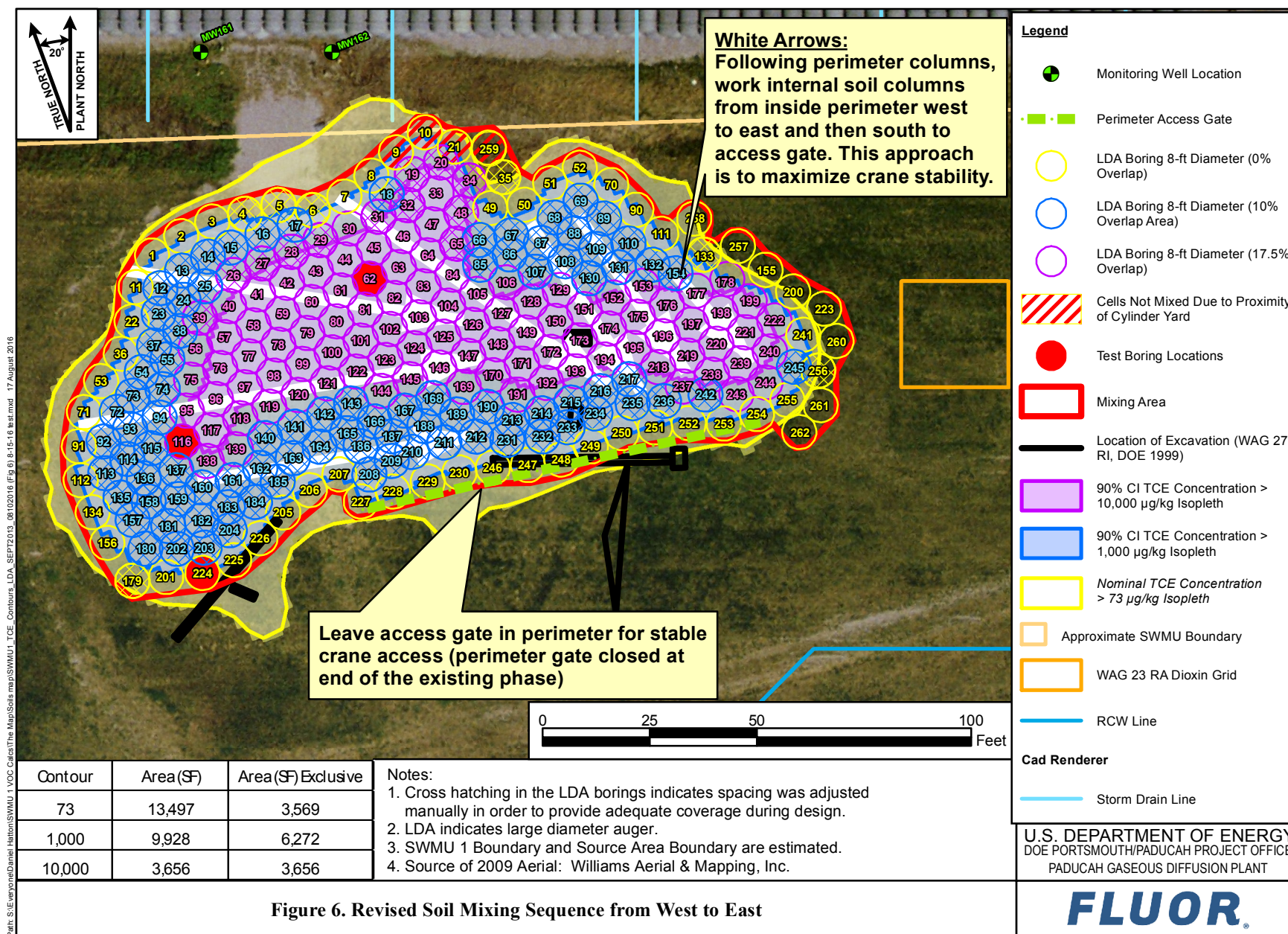


Figure 6. Revised Soil Mixing Sequence from West to East

Implementing the lime stabilization and the presence of the unstable soils at depth also resulted in determination to return excavated soils to the area prior to collection of post-remediation samples. The RDR indicates post-remediation soil sampling will be performed prior to return of the excavated soils.

The mixed soils were unstable and provided a safety concern for personnel and equipment. Following lime stabilization, the excavated soils were returned to the mixing area prior to performing the post-remediation sampling. Soils were returned in fairly thick lifts, with dozer operations taking place only on the replaced soils. No vibratory consolidation of the replaced soil was performed. This approach provided additional thickness of known quality soil on the area prior to accessing for sampling and well installation. Lime stabilization activities were not a portion of the active (steam) or passive (ZVI) RA and are not expected to increase or decrease the ultimate reduction in levels of target contaminants.

1.2.3.7 Elimination of four soil columns near transuranic contaminated ditch

Four columns along the northern perimeter of the mixing area (Columns 9, 10, 21, and 259—see Figure 5) were located within the boundaries of a drainage ditch contaminated with transuranic materials. The presence of these materials is unrelated to activities at SWMU 1. Additionally, these columns are very close to the uranium hexafluoride cylinder yard located north of SWMU 1 (Soil mix Column 10 is within 20 ft of a uranium storage cylinder). Although no specific minimum distance was determined for the soil mixing equipment, a 20-ft offset was considered to be the lowest limit to separate the soil mixing equipment from the cylinders.

The deep soil mixing technology provides capability to monitor the relative quantity of VOCs removed from a column in real time. Observations from this treatment system had indicated that a minimum of two rows of columns on the northern perimeter of the mixed area contained low contaminant concentrations such that they exhibited 100 ppm or less VOC contamination in the shroud off gas during the first thermal pass. These columns met the cleanup criteria for treatment on the first thermal pass.

Based on these observations, the project team proposed an approach to potentially eliminate mixing of the four columns located in the transuranic contaminated drainage ditch. Under this approach, the columns located immediately south or “inside” of the four columns in the drainage ditch were mixed first, and served as indicator columns. If these indicator columns, specifically Columns 18, 19, 20, 34, and 35, met the thermal treatment criteria of less than 100 ppm VOCs on the first thermal pass, then Columns 9, 10, 21, and 259 would not be mixed. The probability of significant VOC presence in columns 9, 10, 21, and 259 is very low if columns to the south exhibited low levels of contamination. Additionally, there were operational and safety benefits to eliminating the columns in the ditch, which included avoiding exposure of personnel to transuranics, reduced possibility of equipment contamination, and the ability to keep mixing operations further away from the uranium hexafluoride cylinder yard.

This approach was discussed with the EPA and KDEP on August 19, 2015. Based on ability to perform real time monitoring of contaminant removal; the low probability of finding contamination in Columns 9, 10, 21, and 259 if the indicator columns did not show contamination; and in consideration of the benefits, EPA and KDEP agreed to this proposal. The discussion was documented in a record of conversation (DOE 2015c).

Thermal treatment and ZVI placement in columns 18, 19, 20, 34, and 35 were completed between August 22, 2015, and August 25, 2015. The maximum VOC levels in these columns were less than 100 ppm during the first thermal pass. Based on these results, columns 9, 10, 21, and 259 were not treated. As a result of eliminating these columns, the total number of columns to be mixed changed from 262 to 258.

1.2.3.8 Revision of test soil columns to be mixed first

The RDR included three soil columns that were to be the first three columns to be soil mixed during initiation of mixing operations. The locations for the three columns were established during the design with one in the high TCE contamination area (62), one in the medium-level TCE contamination level (116), and one in the low contamination level area (5). The locations were documented as the test columns in the RDR and the RAWP. The intent of the test soil columns was to assist in identifying modifications to the mixing process that could be implemented on the remaining soil columns. Due to the close proximity of soil column (5) to the cylinder yard, however, it was determined that an alternate soil column should be used as the low contamination level location. Soil column (224) was the chosen replacement column. This adjustment was documented in an addendum to the RAWP. This sequence was accepted by KDEP and EPA upon approval of the RAWP Addendum (DOE 2014).

2. CHRONOLOGY OF EVENTS

The following provides a concise summary of the chronology of events associated with the RA beginning with the signing of the ROD to the completion of this RACR.

SWMU 1 CHRONOLOGY OF EVENTS

October 7, 2011–November 16, 2011—Public Review Period for associated Proposed Plan, DOE/LX/07-0363&D2/R2

March 20, 2012—ROD signed for SWMUs 1, 211-A, 211-B, and Part of 102

July 2012—Warning signs posted, and ROD provided to Engineering Program

September 23, 2013—RDR issue date (Approval September 26, 2013, by KDEP and October 21, 2013, by EPA)

November 2013—Deep Soil Mixing Contract awarded

December 19, 2013—RAWP issued (Approval January 21, 2014, by KDEP and January 23, 2013, by EPA)

July 15, 2014—Excavation of soil at SWMU 1 begins

July 23, 2014—Addendum to the RAWP issue date

August 28, 2014—Soil samples taken from borings at anomaly identified from historical aerial photographs

September 4, 2014—Completed site preparation for mixing

October 21, 2014—United States Enrichment Corporation returns PGDP to DOE

November 1, 2014–January 30, 2015—Fabrication and delivery of 90-ft Kelly bar

December 3–4, 2014—Mixing contractor personnel made first visit to site

January–February 2015—Work control planning and development

March 9, 2015—Subcontractor crew arrived on-site

March 10, 2015—Crane and treatment equipment arrives on-site

March 13, 2015—Crane assembly complete

April 1, 2015—Installed drill platform and Kelly bar

April 3, 2015—Installed shroud and mixing tool

April 8, 2015—Setup of treatment system completed

April 10, 2015—Mixed first soil column

April 14, 2015—Instituted water into soil mixing to slurry columns in order to address energy releases

April 20, 2015—Crane operator initiates work pause due to soil energy release (burping) concerns

April 21–22, 2015—Performed temperature and conductivity logging and collected soil samples from test columns 224, 116, and 062 (See Figure 5)

April 25, 2015—Modification to shroud to absorb energy releases in soil

April 29, 2015—Push-rod in drilling platform engine broke resulting in engine failure

May 7, 2015—Installed new engine on drill platform, but found leak in transmission. Further inspection identified transmission damaged

May 18, 2015—Installed new transmission on drill platform

May 21, 2015—Reached agreement with regulators on adjustments to protocols (to address energy releases)

July 16, 2015—Deep soil mixing paused due to transition from LATA Kentucky to Fluor Federal Services, Inc.

July 27– August 7, 2015—Revised work control and procedures in preparation to resume mixing

August 10, 2015—Resumed deep soil mixing activities

August 26, 2015—First bags of lime mixed with treated soils for stabilization

October 8, 2015—100% of columns completed; decontamination and disassembly of equipment began

November 3, 2015—Disassembly of crane body started

November 4, 2015—Completed disassembly of crane body; crane left site

November 13, 2015—Finished soil stabilization

November 16, 2015—All mixing subcontractor personnel left site

December 17, 2015—Initiated backfilling soil in mixed area

January 13, 2016—Shipped subcontractor carbon vessels for reclaiming carbon

January 13, 2016—Completed all subcontractor equipment demobilization

January 19, 2016—Completed restoration of area to natural contours

February 15, 2016—Initiated post-remediation soil sampling

February 18, 2016—Completed temperature and soil conductivity measurements

March 21, 2016—Completed post-remediation soil sampling

March 22, 2016—Initiated groundwater monitoring well installation

April 19, 2016—Completed groundwater monitoring well installation

May 4, 2016—Completed well development and pad/post installation

May 4, 2016—Demobilized post-remediation sampling and well installation subcontractor

August 19, 2016—Completed disposition of waste

September 2, 2016—Issued RACR

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3. PERFORMANCE STANDARDS AND CONSTRUCTION QUALITY CONTROL

3.1 STANDARDS

LATA Kentucky and LSRS were responsible for determining if FECC soil mixing subcontractor was capable of meeting applicable quality requirements, as documented in the Remedial Action Work Plan and Remedial Design Report. A quality assurance (QA) assessment was completed successfully to confirm the FECC subcontractor met quality requirements regarding calibration capabilities and used standards traceable to national standards such as National Institute of Standards and Testing. Calibration services assessed were limited to these:

- Calibration of Celesco Unit (depth indicator),
- Calibration of Omega Resistance Temperature Detectors (measured temperature),
- Start-up and calibration of GCs,
- Start-up and calibration FIDs, and
- Calibration of the Rosemount Pressure Transmitter (measured steam and flow rate).

FECC implemented LATA Kentucky and LSRS quality program controls supporting the measurement and testing of equipment. LATA Kentucky engineering and QA reviewed the calibration instructions supporting the five specific processes.

3.2 RESULTS OF FIELD SAMPLING

The results of field sampling from post-soil mixing soil borings are contained in Section 4.1.4.

3.3 LOCATION AND FREQUENCY OF TESTS

During RA implementation, active data collection and review were performed by the project team to confirm that treatment requirements were achieved for each soil column mixed. A more detailed explanation of this process is included in Section 3.4.

3.3.1 Post-Treatment Soil Sampling and Logging

Following the cessation of active remedial operations with *in situ* soil mixing with hot air/steam and ZVI injection, monitoring was conducted to assess the near-term performance of the RA.

Post-treatment sampling and analysis is intended to achieve three main goals:

1. Assessment of the heating of the subsurface,
2. Assessment of the placement of ZVI for continued VOC reduction, and
3. Assessment of the success of deep soil mixing to achieve the primary project goal of reduction of VOC concentrations to the RA cleanup levels in the treated source zone.

In addition, post-treatment actions included the installation of upper RGA wells at the perimeter of the treated source zone to monitor the progress of contaminant reduction in the RGA groundwater following

the soil mixing. It is expected that a reduction in the VOC contaminant concentrations in the RGA groundwater over time after the RA will be indicative of supporting Goal 3.

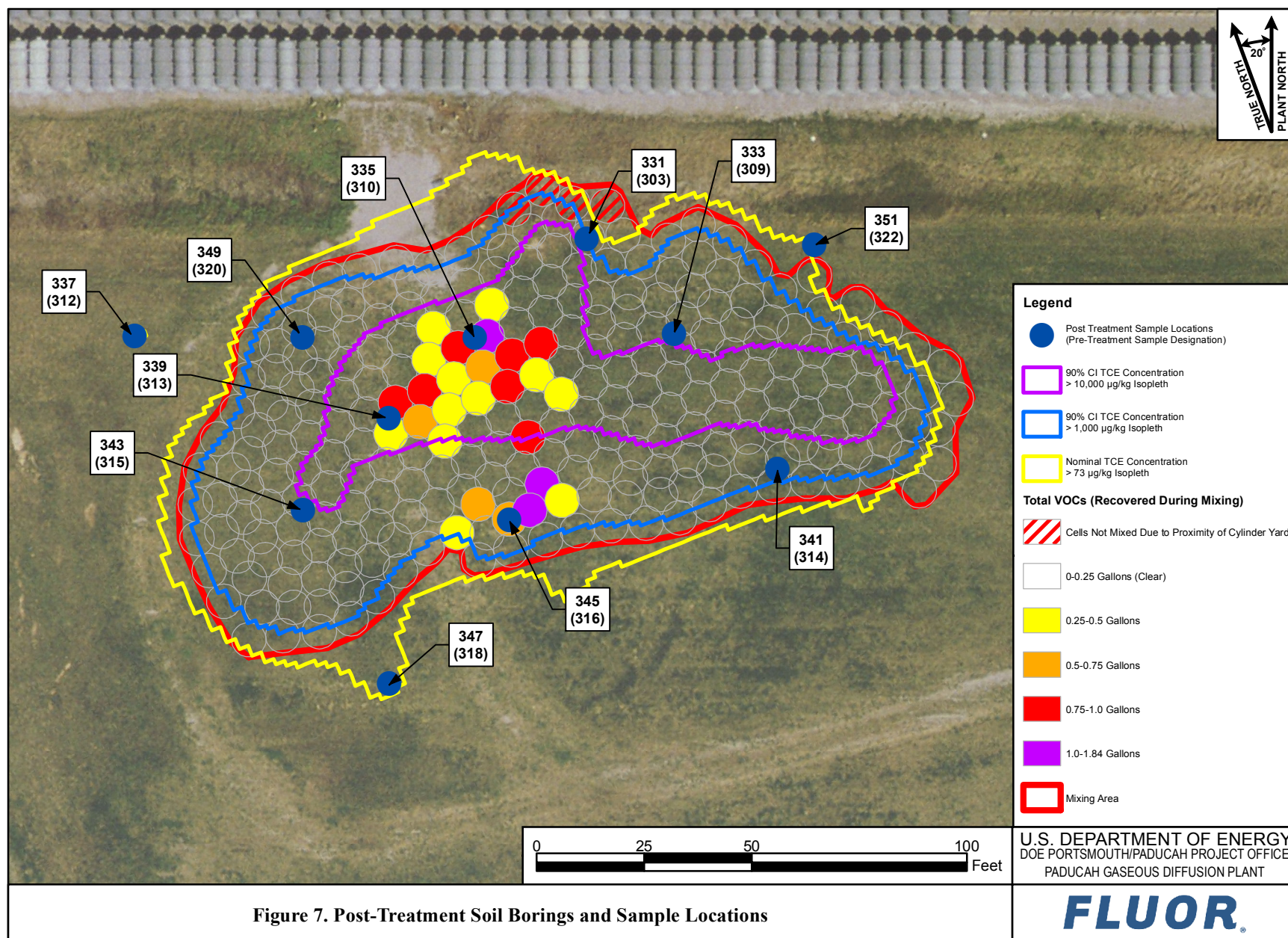
The post-treatment characterization fieldwork duplicated the collection of RDSI VOC contaminant concentrations in the UCRS soils by twinning the RDSI boring locations and collecting samples. The samples were collected using the same approach used in the RDSI. The post-treatment characterization fieldwork included continuous logging of soil conductivity and temperature and sampling of soil borings to the total depth of mixing in 11 of the original RDSI soil boring locations (Figure 7). Eight of the soil borings were located within the treated source zone, and 3 of the soil borings were located on the perimeter. The final soil boring locations were assessed by the FFA parties using results and data collected during implementation of the RA, and no soil boring locations were adjusted.

A direct push technology (DPT) rig equipped with an electrical conductivity probe and a thermocouple provided continuous logs of electrical conductivity and temperature of the soil column throughout the depth of the treated source zone with the exception of one boring located outside soil mixing area where refusal was met at a depth of 18 ft. These logs were used to assess the vertical distribution of ZVI and the residual heat in the treated source zone for health and safety concerns during the drilling of the soil borings and monitoring wells.

As during the RDSI field characterization, post-treatment characterization soil samples were collected consistent with CP4-ER-1020, *Collection of Soil Samples with Direct Push Technology Sampling*. For this field characterization effort, the DPT rig used a dual tube sampling system. The system collected the soil core for sample collection within an acetate liner/sleeves liner. It was planned to utilize thin-walled stainless steel sample tubes because of elevated subsurface temperatures. However, the maximum temperature encountered during the post-treatment temperature survey was 133°F. Because the subsurface temperatures did not exceed 140°F, acetate core sleeves were utilized. The conductivity/temperature logging boreholes were located approximately 2 ft removed from VOC/ZVI soil sample borings.

The following steps for high temperature soil sampling were used to supplement contractor sampling procedures. Because the areas drilled had been steamed during the soil mixing process, the subsurface soils temperatures were elevated and required special health and safety precautions for handling. The field crew collected samples (plus quality control samples) for laboratory analysis in 5-ft increments to approximately 60-65 ft, depending on RGA depth (RGA hit at 60 ft would yield 12 samples; 13 samples were collected when depth of RGA exceeded 60 ft). The field crew capped and sealed the ends of the acetate liners containing the soil cores and submerged them in an ice bath for 30 minutes to lower the soil temperature and minimize the off-gassing of VOCs. After cooling the core and polyvinyl chloride sleeve, each sleeve and each core were punctured proportionally every 6 inches² and scanned with a ppb RAE 3000™ or equivalent photoionization detector (PID) to identify the soil sample with highest VOC levels from the 5-ft interval. The PID readings were used for directing subsampling for laboratory analysis. After identifying the VOC levels in the sample locations, the acetate liner was removed by slicing. Where the highest PID response was earlier detected, a soil subsample was collected for VOC analysis using an En Core® sampler. If no elevated PID response was measured, the soil subsample was collected based on observations of greater sand content, if present and apparent. If no sandy zones were obvious, the soil subsample for VOC analysis was collected from the middle point of the length of the soil core.

² Although the soil core was collected in 5-ft depth increments, the retrieved core, in some instances, may have been longer or shorter than 5.0 ft, depending upon swelling, compaction, or loss of soil core. Where swelling or compaction accounts for a discrepancy in the core length, the sample points were adjusted to represent 0.5-ft depth intervals in the subsurface. Where it is apparent that soil has been lost in the sampling process, the samplers noted the lost core interval in the field logbooks and identified the sample locations to represent the remaining 0.5-ft depth intervals in the subsurface.



After the field sample crew collected the subsample(s) for VOC analysis in each 5-ft interval of soil, an additional sample was collected from the soil core adjacent to the depth of the VOC sample(s) for a qualitative measurement of weight percent ZVI (not corrected for moisture content). These analyses were performed by a fixed-base laboratory. Each of these samples, collected by the field team, consisted of an approximately 0.33-ft length of soil core that was containerized in a separate, sealed plastic bag until analysis. In the laboratory, each sample was weighed on a portable laboratory scale and the weight recorded in a laboratory project logbook. Sample preparation consisted of placing the sample (each with an approximate volume of 0.1 liters) along with approximately 0.3 liters of potable water in a 0.5-liter, sealed, wide-mouth plastic sample jar and shook vigorously to disassociate the soil sample. A strong magnet placed on the top of the bottle was used to separate the ZVI content from the soil slurry and the mass of the ZVI was weighed on the portable laboratory scale; the weight was recorded in the project logbook. The weight percent ZVI (as a decimal fraction) for each sample was determined by dividing the weight of the ZVI by the initial mass of the soil sample.

3.3.2 RGA Monitoring Wells

To provide for a broader and continuing assessment of future dissolved VOC levels in the area of the treated source zone, six monitoring wells were installed in the top of the Hydrogeologic Unit (HU) 5 gravel interval of the RGA as part of the post-treatment field sampling efforts as indicated in Figure 8 and Table 2. The FFA parties approved the placement of the monitoring wells similar to the soil boring locations discussed earlier. Screen levels were selected by the field geologist based on subsurface conditions and the lithologic cores collected from the well location. To assess the potential near-term decline in VOC levels in the monitoring wells, groundwater samples will be collected for VOC analysis on a quarterly basis for a one-year term following construction of the monitoring wells and will be collected semiannually during the second year. Subsequent sampling frequencies and requirements of the SWMU 1 monitoring wells will be incorporated into the Environmental Monitoring Plan, as agreed to by the FFA parties for the SWMU 1 CERCLA selected remedy. Trends in dissolved VOC levels in MW161 (existing well) and the six new wells will provide data for future assessment of this SWMU 1 RA. Long-term monitoring will assess effectiveness of the implemented remedy.

3.4 BASIS FOR DETERMINATION THAT STANDARDS WERE MET

LATA Kentucky and LSRS had employees in the field during mixing activities to check and verify that all treatment criteria were met for each column treated. The field crew consisted of a field superintendent and a scientist or engineer who observed the treatment of each soil column as it occurred and monitor the same control/monitoring (Labview®) screen that the FECC site superintendent would view. Following the steam treatment and soil mixing, a member of the field team reviewed the live electronic data with FECC prior to approving the column to be subsequently treated with the ZVI. The field engineer or superintendent observed mixing field operations to ensure operating parameters (advance rate of auger, steam injection rates, air injection rates, etc.) were maintained during mixing operations. Additionally, the output from the FID and GCs, as well as shroud temperature measurements, were observed in real time to validate thermal treatment was complete in accordance with Figure 7 of the RDR and (as amended and documented in Section 1.2.3.4) prior to implementation of ZVI injection. The engineer or superintendent verified via observation that the subcontractor determined percentage of ZVI to be applied to each column, in accordance with Figure 7 of the RDR, and that ZVI injection was completed.

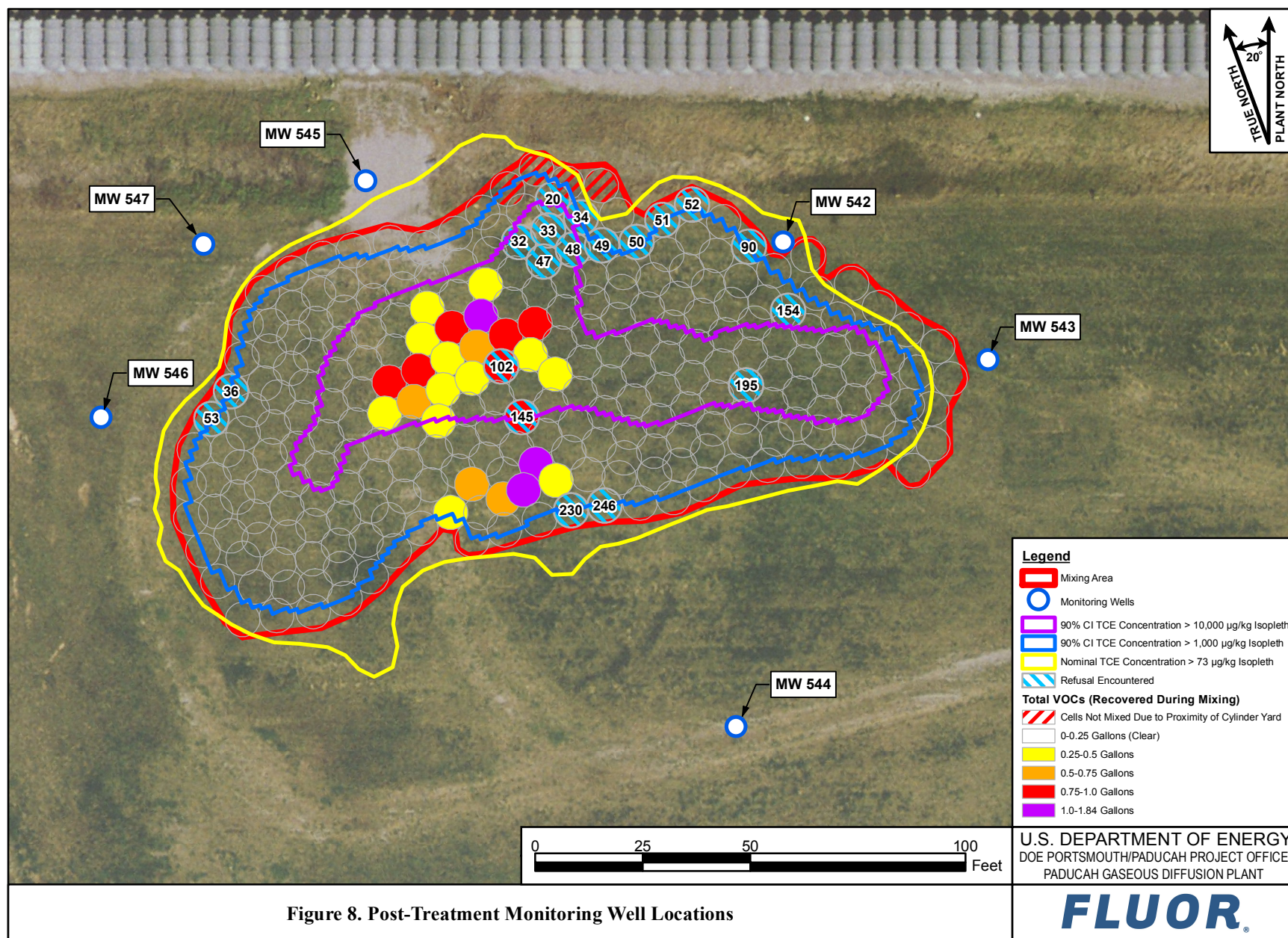


Table 2. SWMU 1 Post-Remedial Monitoring Wells

Monitoring Well Number	Screen Interval, ft bgs	Date Installed
542	62.75–67.75	2016
543	66.25–71.25	2016
544	62.25–67.25	2016
545	58.25–63.25	2016
546	65.0–70.0	2016
547	63.75–68.75	2016
161 (Existing)	78–83	1990

The soil mixing treatment system was interfaced with control/monitoring software known as Labview®. Labview® provides a graphic indicating the depth of the soil mixing tool and the flame ionization detector VOC readings on a continuous basis versus time (see Figure 9). The vapor stream is also analyzed by two GCs, which pull live vapor samples offset by 3 minutes. The GCs analyze the vapor for the concentrations present of the target VOC compounds in the untreated vapor stream extracted from the soil column and prior to processing by the vapor conditioning system. Labview® also collects and assimilates the data from sensors on the steam generation and treatment system. This assimilation process allows the operators to determine on an instantaneous basis how the system is performing. Figure 10 presents a portion of the Labview®-collected performance shown in Microsoft Excel format output from the soil mixing of soil column 123. The explanation of information captured in the output is contained in Table 3. The system performance data in a Microsoft Excel format for all columns treated is included in Appendix A. The system performance data from the treatment of each column also is supplied in a graphical format captured in a Microsoft Word file format from the Labview® system. This information in electronic format also is included in Appendix A. Figure 11 presents a portion of the GC results collected from the treatment of soil column 123. The explanation of information captured in the output is contained in Table 4.

Appendix A has each of the 258 columns labeled according to how many times the mixing unit was set up over the column for treatment. For instance, column 186 required coming back for further treatment which required naming the next treatment as 186A. The items that could lead to naming a column with multiple names include, but it not limited to, the following:

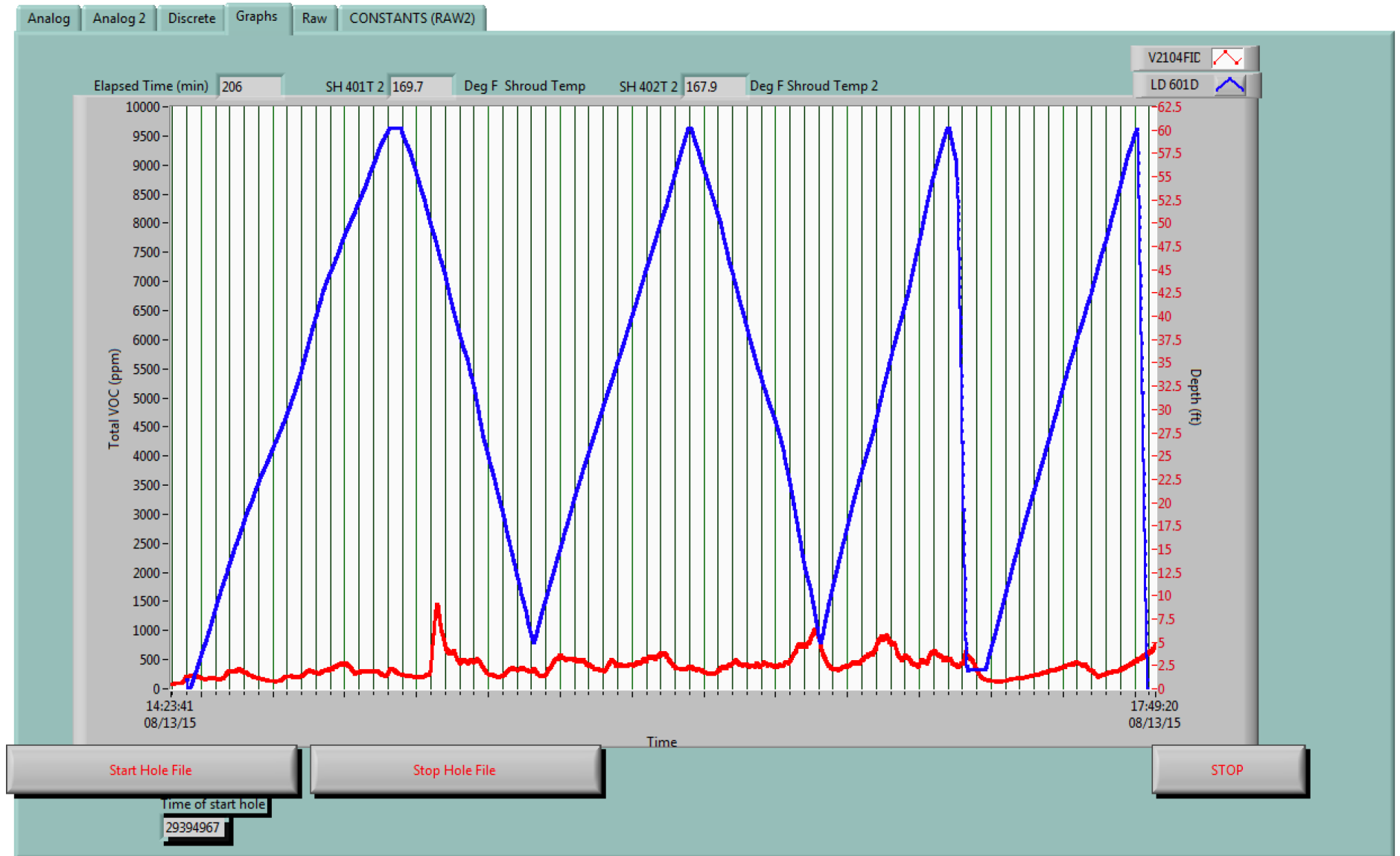
- Treatment of the column occurring across two or more work shifts;
- Mechanical issues of various kinds that may occur before mixing is complete and require return to the same column after restarting Labview® Program; and
- In order to control “soil burping” and heat control, a column is allowed to rest for a time period and then retreated for an additional length of time.

Each time an area is remixed after the control system is restarted requires an additional ordered file name formatted such as 186, 186A, 186B, etc.

Confirmation soil borings were drilled and sampled and analyzed consistent with RAWP requirements. Those results are discussed in Section 4.1.4, Post-Remedial Soil Sampling and Monitoring Well Installation. The combination of data from the soil borings and monitoring well installations will be used in the future to assist in determining the continued attainment of the RAOs.

Florida Environmental Compliance Corporation

Data Acquisition Display



V1 V2 Agree

Note: - Blue line indicates mixing tool depth, ft (BGS)
- Red line indicates flame ionization detector readings at the corresponding time.

Figure 9. Soil Column 123 Labview® Graphic

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	HOLE ID	Date	Time	LD601	FID1	FID2	SH401T	SH402T	SH401P	SH402P	SO501P	VFD101S	SO501DP	SG201DP	SG201F	SG201T	SG201P	AC101DP	AC101T	AC101F	AC101P	SO501T	SO502DP	SO502F	SO503T	SO501F
2	123	8/13/2015	2:23:52 PM	0.956	73.26	41.245	104	96	-4.479	0	-9.07	53.084	0.193	0	0	360.4	119.267	0.147	111.4	97.264	121.941	115.7	0	1	90.5	660.594
3	123	8/13/2015	2:24:04 PM	0.956	75.702	41.294	105	98.6	-4.322	0	-9.265	53.055	0.173	0	0	354.3	119.231	0.183	112.9	108.745	121.612	109.8	0	1	89.9	626.253
4	123	8/13/2015	2:24:16 PM	0	80.586	40.342	104.6	100.6	-3.927	0	-9.748	53.084	0.193	0	0	361.9	119.048	0.147	111.7	97.264	121.429	112.2	0	1	95.9	660.594
5	123	8/13/2015	2:24:28 PM	0	85.47	40.024	104.7	99.8	-4.728	0	-9.162	53.084	0.181	0	0	351.9	118.974	0.073	104.4	68.776	121.172	112.9	0	1	93.6	639.347
6	123	8/13/2015	2:24:39 PM	0	90.354	41.05	104.9	100.2	-5.475	0	-9.705	53.084	0.107	0	0	358.8	118.864	0.147	104.9	97.264	121.026	111.9	0	1	92	493
7	123	8/13/2015	2:24:51 PM	0.224	92.796	41.099	105.9	100.9	-5.822	0	-10.457	53.07	0.183	0	0	359.2	118.938	0.073	109.5	68.776	120.879	113	0	1	94.5	643.653
8	123	8/13/2015	2:25:03 PM	0.509	90.354	41.392	106.2	100.7	0	0	-10.799	53.084	0.19	0	0	354.5	118.864	0.147	110.5	97.264	120.916	112.8	0	1	89	656.399
9	123	8/13/2015	2:25:15 PM	0.753	97.68	41.563	106.2	101.5	0	0	-10.559	53.084	0.161	0	0	357.3	118.791	0.256	106.8	128.669	121.758	111.9	0	1	91.3	603.8
10	123	8/13/2015	2:25:27 PM	1.078	92.796	42.051	105.9	98.4	-5.275	0	-9.929	53.084	0.151	0	0	358.6	118.791	0.073	111.4	68.776	123.187	116.4	0	1	96.2	585.217
11	123	8/13/2015	2:25:38 PM	1.343	92.796	43.223	106	101.5	-5.88	0	-10.349	53.07	0.227	0	0	358.4	118.718	0.183	107.7	108.745	124.469	114.5	0	1	91.8	716.741
12	123	8/13/2015	2:25:50 PM	1.648	97.68	43.297	106.4	100	-5.695	0	-11.165	53.084	0.222	0	0	355.7	118.608	0.22	110.2	119.124	124.322	114.8	0	1	92.5	708.992
13	123	8/13/2015	2:26:02 PM	1.932	102.564	44.737	106.4	99.9	0	0	-10.886	53.07	0.132	0	0	358.3	118.608	0.11	112.4	84.233	123.773	116.3	0	1	98.2	546.157
14	123	8/13/2015	2:26:14 PM	2.258	112.332	45.079	106.2	100.9	0	0	-11.111	53.07	0.156	0	0	359	118.535	0.11	107.1	84.233	123.223	115.2	0	1	96.7	594.581
15	123	8/13/2015	2:26:26 PM	2.563	136.752	46.203	106.4	102.7	-7.272	0	-11.502	53.07	0.159	0	0	357.4	118.388	0.147	109.6	97.264	122.821	116.6	0	1	94.6	599.208
16	123	8/13/2015	2:26:37 PM	2.868	170.94	47.717	106.8	101.7	-6.559	0	-10.901	53.055	0.198	0	0	357.3	118.352	0.11	109.4	84.233	122.418	113.8	0	1	93.7	668.903
17	123	8/13/2015	2:26:49 PM	3.173	192.918	50.159	106.5	101.2	-6.11	0	-10.994	53.084	0.19	0	0	355.5	118.315	0.073	107.3	68.776	121.941	113.9	0	1	92.9	656.399
18	123	8/13/2015	2:27:01 PM	3.499	214.896	52.381	106.3	101.2	-6.73	0	-10.711	53.084	0.176	0	0	358	118.242	0.11	108.7	84.233	121.648	114	0	1	91.1	630.648
19	123	8/13/2015	2:27:13 PM	3.824	214.896	53.675	106.3	100.8	0	0	-10.73	53.084	0.098	0	0	358.7	118.132	0.183	109.8	108.745	121.355	115	0	1	93	470.057
20	123	8/13/2015	2:27:25 PM	4.129	214.896	55.629	105.7	99.9	0	0	-11.214	53.04	0.188	0	0	355.7	118.059	0.147	108.4	97.264	121.245	112.7	0	1	95.6	652.178
21	123	8/13/2015	2:27:36 PM	4.374	205.128	58.193	106.3	98.6	0	0	-10.642	53.055	0.071	0	0	355.9	117.949	0.22	107.4	119.124	121.026	112.7	0	1	93.7	400.239
22	123	8/13/2015	2:27:48 PM	4.577	224.664	59.194	107	99.3	0	0	-10.393	53.026	0.181	0	0	356.6	117.985	0.147	108.8	97.264	120.916	112.9	0	1	92.6	639.347
23	123	8/13/2015	2:28:00 PM	4.923	234.432	62.93	106	101.9	-6.032	0	-10.017	53.055	0.156	0	0	362.8	117.949	0.073	111.5	68.776	120.659	114.5	0	1	102.4	594.581
24	123	8/13/2015	2:28:12 PM	5.248	239.316	64.64	106.1	100.6	-5.099	0	-10.061	53.04	0.147	0	0	353.4	117.875	0.073	109.2	68.776	121.282	110.6	0	1	98.1	575.7
25	123	8/13/2015	2:28:24 PM	5.574	234.432	68.449	106.6	100.5	-5.084	0	-10.193	53.04	0.171	0	0	355.6	117.692	0.22	107.7	119.124	122.674	112.6	0	1	95.8	621.827
26	123	8/13/2015	2:28:35 PM	5.879	229.548	73.382	106	100.3	-5.661	0	-10.525	53.07	0.137	0	0	352.8	117.766	0.11	103.8	84.233	124.359	110.8	0	1	91	556.179
27	123	8/13/2015	2:28:47 PM	6.204	234.432	79.316	106.4	99.6	0	0	-10.305	53.084	0.171	0	0	357	117.729	0.147	111	97.264	124.359	114.2	0	1	91.5	621.827
28	123	8/13/2015	2:28:59 PM	6.53	231.99	84.957	105.4	99.5	0	0	-11.111	53.07	0.161	0	0	354.6	117.656	0.147	107.8	97.264	123.919	111.8	0	1	93	603.8
29	123	8/13/2015	2:29:11 PM	6.896	227.106	92.821	105.8	100.2	-5.817	0	-10.691	53.055	0.071	0	0	353.7	117.582	0.256	110.5	128.669	123.59	113.8	0	1	92.2	400.239
30	123	8/13/2015	2:29:23 PM	7.242	217.338	100	105.6	99.3	-5.592	0	-10.12	53.07	0.215	0	0	357.9	117.546	0.147	109.8	97.264	123.15	114.3	0	1	88.8	697.208
31	123	8/13/2015	2:29:34 PM	7.588	205.128	100	106	99.9	-2.774	0	-8.376	53.07	0.186	0	0	358.5	117.436	0.183	109.9	108.745	122.784	113.9	0	1	96.3	647.929
32	123	8/13/2015	2:29:46 PM	7.933	192.918	100	105.6	104.4	-3.819	0	-9.167	53.07	0.225	0	0	356.9	117.436	0.183	106.7	108.745	122.381	113.7	0	1	96.2	712.877
33	123	8/13/2015	2:29:58 PM	8.279	188.034	100	105.9	99.4	-3.126	0	-9.031	53.04	0.151	0	0	358.8	117.363	0.183	107.4	108.745	122.125	110.7	0	1	89.2	585.217
34	123	8/13/2015	2:30:10 PM	8.625	175.824	100	105.7	99.3	-5.534	0	-9.519	53.084	0.107	0	0	354.9	117.326	0.22	108.4	119.124	121.905	108.9	0	1	98.9	493
35	123	8/13/2015	2:30:22 PM	8.991	180.708	100	105.7	98.6	-4.952	0	-9.607	53.084	0.161	0	0	359.1	117.326	0.11	113.8	84.233	121.685	113.1	0	1	95.8	603.8
36	123	8/13/2015	2:30:33 PM	9.337	173.382	100	105.2	99.2	-3.253	0	-8.205	53.084	0.193	0	0	358.2	117.179	0.22	109.3	119.124	121.429	112	0	1	87.8	660.594
37	123	8/13/2015	2:30:45 PM	9.662	173.382	100	104.8	99	-1.177	0	-8.239	53.084	0.176	0	0	358.6	117.07	0.22	106	119.124	121.355	112.7	0	1	92.6	630.648
38	123	8/13/2015	2:30:57 PM	9.947	173.382	100	104.8	98.6	-3.512	0	-9.504	53.084	0.193	0	0	357.3	116.996	0.073	109.2	68.776	121.172	117.5	0	1	94.5	660.594

Figure 10. Performance Data Collected and Assimilated by Labview® for Soil Column 123

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Table 3. Labview® Microsoft Excel Column Heading Explanation

Column	Column Heading Title	Heading Explanation
A	Hole ID	Identifies the soil column number.
B	Date	The date or dates when the soil column underwent treatment.
C	Time	The system time for the collection of the specific row/time step of data collected.
D	LD601	The depth (ft) of the soil mixing bit relative to the ground surface when mixing started for that column and for the time step shown.
E	FID1	FID reading for vapors extracted from the soil column and prior to processing by the vapor conditioning system to remove the target contaminant compounds (Influent), parts per million.
F	FID2	FID reading for vapors extracted from the soil column and processed by the vapor conditioning system including activated carbon to remove the target contaminant compounds (Effluent), parts per million.
G	SH401T	Shroud air temperature, sensor 1, degrees Fahrenheit.
H	SH402T	Shroud air temperature, sensor 2, degrees Fahrenheit.
I	SH401P	Shroud pressure/vacuum, inches/water column.
J	SH402P	Not used.
K	SO501P	Vapor Conditioning System Duct Pressure, inches/water column.
L	VFD101S	Speed of variable frequency driver/blower on VCS trailer, hertz.
M	SO501DP	VCS trailer delta (change in pressure through treatment equipment), inches/water column.
N	SG201DP	Steam generator delta pressure, pounds per square inch.
O	SG201F	Steam generator flow, pounds per hour.
P	SG201T	Steam generator temperature, degrees Fahrenheit.
Q	SG201P	Steam generator output pressure, pounds per square inch.
R	AC101DP	Compressed air delta pressure, inches/water column.
S	AC101T	Compressed air temperature, degrees Fahrenheit.
T	AC101F	Compressed air flow, ft ³ per minute.
U	AC101P	Compressed air pressure, pounds per square inch gauge.
V	SO501T	VCS duct temperature, degrees Fahrenheit.
W	SO502DP	Not used.
X	SO502F	Not used.
Y	SO503T	Blower output temperature, degrees Fahrenheit.
Z	SO501F	VCS duct flow rate, ft ³ per minute.

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	Contaminant	Date	Time	Contaminant	Concentration	Units	Contaminant	Concentration	Units	Contaminant	Concentration	Units	Contaminant	Concentration	Units	Contaminant	Concentration	Units	Contaminant	Concentration	Units
2	GC112301.CHR	8/13/2015	14:24:50	CH4	27.5719	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	0	ppm	TCE	0	ppm
3	GC112302.CHR	8/13/2015	14:30:50	CH4	50.478	ppm	Vinyl Chloride	2.7447	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	9.1013	ppm	TCE	3.1074	ppm
4	GC112303.CHR	8/13/2015	14:36:50	CH4	47.0366	ppm	Vinyl Chloride	2.8464	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	13.765	ppm	TCE	40.5685	ppm
5	GC112304.CHR	8/13/2015	14:42:50	CH4	42.0869	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	8.7916	ppm	TCE	14.973	ppm
6	GC112305.CHR	8/13/2015	14:48:50	CH4	76.6788	ppm	Vinyl Chloride	4.0914	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	13.8536	ppm	TCE	26.4855	ppm
7	GC112306.CHR	8/13/2015	14:54:50	CH4	94.0406	ppm	Vinyl Chloride	3.382	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	12.6433	ppm	TCE	50.4707	ppm
8	GC112307.CHR	8/13/2015	15:00:50	CH4	115.1424	ppm	Vinyl Chloride	2.9251	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	13.596	ppm	TCE	127.8626	ppm
9	GC112308.CHR	8/13/2015	15:06:50	CH4	148.3278	ppm	Vinyl Chloride	3.0045	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	6.1666	ppm	TCE	36.4361	ppm
10	GC112309.CHR	8/13/2015	15:12:50	CH4	93.3041	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	7.353	ppm	TCE	30.8351	ppm
11	GC112310.CHR	8/13/2015	15:18:50	CH4	863.8218	ppm	Vinyl Chloride	3.3531	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	8.6717	ppm	TCE	42.1196	ppm
12	GC112311.CHR	8/13/2015	15:24:50	CH4	252.77	ppm	Vinyl Chloride	3.8965	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	18.5686	ppm	TCE	61.491	ppm
13	GC112312.CHR	8/13/2015	15:30:50	CH4	94.6895	ppm	Vinyl Chloride	2.7667	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	13.3895	ppm	TCE	22.4068	ppm
14	GC112313.CHR	8/13/2015	15:36:50	CH4	100.1686	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	7.5364	ppm	TCE	18.0024	ppm
15	GC112314.CHR	8/13/2015	15:42:51	CH4	147.702	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	3.8762	ppm	TCE	9.1421	ppm
16	GC112315.CHR	8/13/2015	15:48:51	CH4	84.8214	ppm	Vinyl Chloride	2.7894	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	14.98	ppm	TCE	32.1257	ppm
17	GC112316.CHR	8/13/2015	15:54:51	CH4	112.3852	ppm	Vinyl Chloride	4.6825	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	21.5245	ppm	TCE	32.5795	ppm
18	GC112317.CHR	8/13/2015	16:00:51	CH4	135.4053	ppm	Vinyl Chloride	4.9225	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	26.5255	ppm	TCE	71.6585	ppm
19	GC112318.CHR	8/13/2015	16:06:51	CH4	223.2784	ppm	Vinyl Chloride	4.0279	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	20.8448	ppm	TCE	135.5786	ppm
20	GC112319.CHR	8/13/2015	16:12:51	CH4	95.7137	ppm	Vinyl Chloride	4.6688	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	14.2219	ppm	TCE	65.6623	ppm
21	GC112320.CHR	8/13/2015	16:18:51	CH4	185.5723	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	5.8204	ppm	TCE	31.0735	ppm
22	GC112321.CHR	8/13/2015	16:24:51	CH4	190.4623	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	7.7204	ppm	TCE	28.1575	ppm
23	GC112322.CHR	8/13/2015	16:30:51	CH4	223.7997	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	5.5243	ppm	TCE	10.814	ppm
24	GC112323.CHR	8/13/2015	16:36:51	CH4	339.1675	ppm	Vinyl Chloride	3.8381	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	12.1847	ppm	TCE	15.567	ppm
25	GC112324.CHR	8/13/2015	16:42:51	CH4	74.2467	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	5.7022	ppm	TCE	5.4376	ppm
26	GC112325.CHR	8/13/2015	16:48:51	CH4	299.3049	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	4.4609	ppm	TCE	6.1831	ppm
27	GC112326.CHR	8/13/2015	16:54:51	CH4	434.4536	ppm	Vinyl Chloride	4.8885	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	13.369	ppm	TCE	20.0236	ppm
28	GC112327.CHR	8/13/2015	17:00:52	CH4	206.3314	ppm	Vinyl Chloride	3.7306	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	11.8644	ppm	TCE	45.442	ppm
29	GC112328.CHR	8/13/2015	17:06:52	CH4	147.8113	ppm	Vinyl Chloride	6.5669	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	11.3696	ppm	TCE	51.3628	ppm
30	GC112329.CHR	8/13/2015	17:12:52	CH4	40.3248	ppm	Vinyl Chloride	2.7952	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	4.2469	ppm	TCE	9.2544	ppm
31	GC112330.CHR	8/13/2015	17:18:52	CH4	25.911	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	0	ppm	TCE	3.2246	ppm
32	GC112331.CHR	8/13/2015	17:24:52	CH4	66.8962	ppm	Vinyl Chloride	3.6411	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	4.0053	ppm	TCE	4.6022	ppm
33	GC112332.CHR	8/13/2015	17:30:52	CH4	148.7758	ppm	Vinyl Chloride	6.3338	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	5.5925	ppm	TCE	5.9693	ppm
34	GC112333.CHR	8/13/2015	17:36:52	CH4	74.7904	ppm	Vinyl Chloride	3.2878	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	2.6196	ppm	TCE	3.4171	ppm
35	GC112334.CHR	8/13/2015	17:42:52	CH4	157.5164	ppm	Vinyl Chloride	6.3583	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	4.9175	ppm	TCE	7.6689	ppm
36																					
37	GC212301.CHR	8/13/2015	14:27:49	CH4	131.5331	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	3.9081	ppm	TCE	0	ppm
38	GC212302.CHR	8/13/2015	14:33:49	CH4	42.0901	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	5.5498	ppm	TCE	9.7575	ppm
39	GC212303.CHR	8/13/2015	14:39:49	CH4	47.8358	ppm	Vinyl Chloride	4.0007	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	16.8531	ppm	TCE	35.5778	ppm
40	GC212304.CHR	8/13/2015	14:45:49	CH4	26.3792	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	8.0238	ppm	TCE	11.2872	ppm
41	GC212305.CHR	8/13/2015	14:51:49	CH4	77.7131	ppm	Vinyl Chloride	4.3015	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	17.7328	ppm	TCE	55.0349	ppm
42	GC212306.CHR	8/13/2015	14:57:49	CH4	172.3592	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	12.4886	ppm	TCE	63.767	ppm
43	GC212307.CHR	8/13/2015	15:03:49	CH4	143.0531	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	6.6561	ppm	TCE	44.208	ppm
44	GC212308.CHR	8/13/2015	15:09:49	CH4	183.628	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	7.6614	ppm	TCE	35.4066	ppm
45	GC212309.CHR	8/13/2015	15:15:49	CH4	72.7036	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	6.9483	ppm	TCE	27.5111	ppm
46	GC212310.CHR	8/13/2015	15:21:49	CH4	362.3229	ppm	Vinyl Chloride	3.2513	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	17.642	ppm	TCE	83.4874	ppm
47	GC212311.CHR	8/13/2015	15:27:49	CH4	303.342	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	15.2303	ppm	TCE	33.3533	ppm
48	GC212312.CHR	8/13/2015	15:33:50	CH4	37.1015	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	15.0574	ppm	TCE	30.2151	ppm
49	GC212313.CHR	8/13/2015	15:39:50	CH4	87.0657	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	7.5777	ppm	TCE	6.2617	ppm
50	GC212314.CHR	8/13/2015	15:45:50	CH4	226.3096	ppm	Vinyl Chloride	0	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	7.3423	ppm	TCE	21.3	ppm
51	GC212315.CHR	8/13/2015	15:51:50	CH4	86.0311	ppm	Vinyl Chloride	4.0764	ppm	1_1-DCE	0	ppm	trans-1_2-DCE	0	ppm	cis-1_2-DCE	22.6982	ppm	TCE	31.086	ppm

Figure 11. Gas Chromatography File Detail for Soil Column 123 (Partial)

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Table 4. Gas Chromatograph Microsoft Excel Column Heading Explanation

Column	Column Heading Title	Heading Explanation
A	Contaminant	GC, soil column, and sample number information: <ul style="list-style-type: none"> • First 3 values provide the GC number—GC1 • Values 4 to 6 provide the soil column number—123 • Values 7 and 8 provide the GC sample number for that run
B	Date	The date when the GC analyzed the vapor sample.
C	Time	The system time (24 hour) for the collection of the specific time when sample analyzed.
D	Contaminant	The name of the contaminant being analyzed—CH ₄ (methane).
E	Concentration	Amount or concentration of contaminant contained in analyzed sample.
F	Units	Abbreviation for the units of measured concentration of contaminant [parts per million (ppm)].
G	Contaminant	The name of the contaminant being analyzed—vinyl chloride.
H	Concentration	Amount or concentration of contaminant contained in analyzed sample.
I	Units	Abbreviation for the units of measured concentration of contaminant—ppm.
J	Contaminant	The name of the contaminant being analyzed—1_1-DCE (1,1-dichloroethene).
K	Concentration	Amount or concentration of contaminant contained in analyzed sample.
L	Units	Abbreviation for the units of measured concentration of contaminant—ppm.
M	Contaminant	The name of the contaminant being analyzed— <i>trans</i> -1_2-DCE (<i>trans</i> -1,2-dichloroethene).
N	Concentration	Amount or concentration of contaminant contained in analyzed sample.
O	Units	Abbreviation for the units of measured concentration of contaminant—ppm.
P	Contaminant	The name of the contaminant being analyzed— <i>cis</i> -1_2-DCE (<i>cis</i> -1,2-dichloroethene).
Q	Concentration	Amount or concentration of contaminant contained in analyzed sample.
R	Units	Abbreviation for the Units of measured concentration of contaminant—ppm.
S	Contaminant	The name of the contaminant being analyzed—TCE (trichloroethene).
T	Concentration	Amount or concentration of contaminant contained in analyzed sample.
U	Units	Abbreviation for the units of measured concentration of contaminant—ppm.

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4. CONSTRUCTION ACTIVITIES

4.1 NARRATIVE DESCRIPTION

The construction phase of implementing the RA was initiated in July 2014 with the completion of the internal field review and approval of management to initiate work. The following subsections describe the work performed to implement the RA.

4.1.1 Site Preparation

Soil Excavation and Debris Removal

The excavation of soils was performed between July 15, 2014, and September 4, 2014. Prior to initiating excavation of the planned excavation area and additional area for staging equipment and excavated soils, all nearby utilities were located and potential subsurface anomalies were identified and documented in an excavation/penetration permit. The work area had sediment control fencing installed in drainage areas as well as sediment control equipment (i.e., straw bales, geotextile, and sediment control logs) in drainage ditches and areas where high flow is expected. Each potential subsurface anomaly area was investigated closely with an excavator in an attempt to identify potential subsurface obstructions. Any obstruction identified was removed. The debris included items such as crushed buckets and lids, drum lids, crushed concrete culvert, rags, and rubber hose. These items were collected, containerized, and disposed of as appropriate. The debris and obstructions were located throughout the 4-ft depth of the excavation and aurally across the excavation. No specific depth was correlated to the debris identified.

The excavation of the 4 ft of soil had multiple benefits, which included the following:

- Facilitate deeper soil mixing allowing the HU4 and HU5 contact (approximately 62 ft) to be mixed as planned,
- Protect the aboveground treatment system from potential PCB contamination and increase worker protection, and
- Segregate and properly dispose of potentially contaminated alumina metal particles (trap mix) in the upper 2 ft and other wastes.

Removing approximately the originally planned 2 ft of soil from the area to be mixed allowed the targeted 60-ft thick zone to be mixed. The soil mixing equipment available at the time of the remedial design development had a mechanically limited depth of 60 ft bgs. The design target depth of the soil mixing was the interface between the UCRS soils (HU4) and the RGA (HU5) gravels which is a geologic contact. In some areas of the mixing zone planned, this contact lay at a subsurface depth of up to approximately 62 ft. Removal of the originally planned 2 ft of surface soil allowed the depth limitation to be overcome and be able to mix to 62-ft deep when needed.

Previous soil investigations had identified surface soils (< 1 ft) located in the planned area of soil mixing that were contaminated with PCBs. These contaminants were located in two 45 ft by 45 ft grids in the area that was to be mixed. The level of contamination is discussed in the RDR and was determined that it needed to be removed from the area to prevent volatilization and contamination of the aboveground treatment equipment used in the soil mixing process. Rather than attempting to segregate the upper 1 ft from the lower 3 ft, each of the two grids had precharacterization sampling performed to allow the soil down to 4 ft to be disposed of upon excavation. The soils were excavated with a trackhoe excavator and

loaded into roll-off bins. The soil contained in the two soil grids was excavated to a depth of 4 ft, containerized, and disposed of in the C-746-U Solid Waste Landfill. A total of 62 roll-off bins (averaging 13 yd³ each) of excavated soil were removed from SWMU 1 grids 014 and 028.

In previous investigations of the SWMU 1 area, quantities of alumina particles had been identified in both the shallow subsurface and also on or near the ground surface. The source of the alumina particles is unclear, but was expected to have originated from several locations in PGDP, as documented in the RDR. The alumina was documented in some cases to be radiologically contaminated (DOE 1999). The maximum expected depth for the alumina was up to 4 ft. Consistent with the RDR and RAWP, an additional 2 ft of soil was excavated making the total excavated depth 4 ft. The alumina, as it was encountered, was excavated and placed in intermodal containers. Following characterization the intermixed soils alumina was disposed of in the C-746-U Landfill.

Excavation of the general area to be soil mixed was initiated in specific areas that an Electromagnetics 38 (EM-38) survey had identified potential subsurface anomalies. The EM-38 survey was performed to assist in identifying potential subsurface obstructions that could damage the soil mixing equipment. Some buried debris was identified in these anomaly areas as well as during the general excavation. The types of debris that were identified, collected, and disposed of included 25 drum lids and closure rings, poly drum covers, a crushed 16-gal drum, two 30-gal crushed drums, and a large quantity of alumina trap mix. Due to the quantity of the trap-mix and the small size of the individual pellets, the pellets along with associated soil was excavated and placed into intermodals for characterization and disposal. All other waste materials were containerized in intermodals for disposal after characterization. The remaining non-waste soils were excavated using a tractor and yardpan, bulldozer, and trackhoe excavator. These soils were carried to the western portion of the SWMU and stockpiled (Figure 12).

A buried obstruction that was encountered during the excavation process was a vertical approximately 4-inch steel pipe. The steel pipe was not identified on any utility drawings or maps of the SWMU 1/Oil Landfarm area. Using location coordinates, it was determined the pipe was likely an isolation casing installed for a soil boring H-009 that was drilled in the Oil Landfarm area as part of Phase I SI in January 1990 (CH2M HILL 1991). In August 2014, a hollow-stem drilling rig was used to overdrill the isolation casing to a total depth of approximately 30 ft bgs. The casing was removed and the resulting hole was filled with grout.

Monitoring wells 508/509/510 were installed during the RDSI to provide information to support the RA. The wells were completed variably in the UCRS down to approximately 32 ft. During procurement of FECC, the specialty soil mixing contractor, it was identified the crane supporting the drilling mixing assembly required a maximum of a 1% slope surface for movement and from which to support mixing activity. It was determined the presence of the well cluster would severely impede movement of the crane and construction. To that end, the three wells were plugged and abandoned during this phase to afford a more open crane access to the planned mixing area.

Radiological Analysis

Upon completing the removal of the 4 ft of soil from the general soil mixing area, the area was gridded in 45 ft by 45 ft areas. Radiological control technicians then used field instrumentation to scan the ground surface of each grid for elevated radiation, as prescribed in Section 12.2.8 of the RDR (Figures 13 and 14). Areas with elevated radiological readings were then marked for additional investigation to determine if a waste material was present (Figure 15). The additional radiological investigation did not identify additional waste materials to be containerized.



Figure 12. SWMU 1 Excavated Soil Stockpile



Figure 13. SWMU 1 Grids for Radiological Scanning



Figure 14. Radiological Control Technicians Scanning Grids for Elevated Radiological Readings



Figure 15. Radiological Control Technicians Marking Areas for Further Scanning

Soil Replacement/Soil Mixing Surface

The final portion of the excavation of soils subtask was to replace approximately 2 ft of soil back into the 4 ft deep excavation, compact the soil, and finish the replaced soil to a less than 1% slope. Soil was replaced using a bulldozer with a Caterpillar AccuGrade™ Grade Control System to control surface elevation and provide the needed 1% grade (Figure 16). During replacement, the soil was compacted with a vibratory roller. The final grade of the replaced soil provided the surface from which the soil mixing process took place. Additionally, a storm water basin with overflow piping was excavated at the western end of the SWMU 1 to allow control of storm water. For stability control of the soil mixing crane, a 30-ft driveway from the soil mixing area east to 4th Street provided the soil mixing equipment access. As with the slope of the soil mixing area, the driveway was excavated with a less than 1% slope. The driveway then was covered with approximately 1 ft of #3 stone, which was underlain with a geotextile (see Figure 17). The stone was vibration compacted to assist in achieving a suitable slope and better density for the crane and equipment to travel over. The entire soil exposed area was covered with hydromulch and seeded for erosion control until soil mixing operations began (see Figures 18 and 19). Sediment control materials and equipment were maintained during the soil excavation period and the initiation of the soil mixing. The SWMU 1 area, following the completion of the soil excavation phase and the planned layout of soil mixing columns and support equipment, is shown in Figure 20.

Additional Drilling of Potential Waste Areas

Following completion of the excavation, the FFA parties agreed that a limited quantity of drilling and sampling would be performed to the area east of the planned soil mixing area. The purpose of this additional sampling was to provide data to determine if additional contamination existed in the area. The area was shown to exhibit a dark shadow on historical aerial photographs taken of the Oil Landfarm during the expected years of operation. Four soil borings were drilled and soil samples were obtained from each 5-ft section of core using a photoionization detector to bias the sampling toward the presence of contamination. The data collected from the additional drilling did not support the presence of contaminant source material located outside the planned mixing area that was identified in the design. The average TCE contaminant concentration of all the soil samples (48) was 5.4 ppb, and the maximum TCE concentration in all the results was 54 ppb. The discussion of the additional drilling is contained in DOE Memorandum, PPPO-02-2635172-15. The additional drilling work did not impact completion of the RA.

4.1.2 Soil Mixing

The initial field activity that occurred in the soil mixing phase took place in late 2014 with the placement of gravel in the staging area located south of the soil mixing area. Road-base stone was placed over the area and compacted, and the stone was underlain by a geotextile fabric. The combination of the stone and geotextile was required to protect two plant utility lines that ran under the staging area, and it provided additional geotechnical support to the equipment trailers and improved field working conditions around the equipment trailers. The first piece of construction equipment delivered to the site was the 90-ft Kelly bar on January 30, 2015. Due to its length, it was shipped directly from the manufacturer Stephen Haine, Inc., Garland, Texas. The new Kelly bar was purchased by FECC, Inc., to allow additional depth flexibility (mechanical mixing of depths greater than 60 ft) for the soil mixing equipment. The first field crew arrived at PGDP on Monday, March 9, 2015, and began training. A second crew arrived on March 23, 2015, and initiated their project training.



Figure 16. Bulldozer Mounted with AccuGrade™ System



Figure 17. Construction of Crane Access Driveway



Figure 18. Soil Staging Pile after Hydromulching



Figure 19. SWMU 1 Vegetation after Two Months of Vegetative Growth

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A large amount of equipment that comprised the soil mixing and treatment system, as well as appurtenant equipment and material, began arriving on March 10, 2015. The crews began field locating and assembling the treatment equipment, drilling platform, support crane, and other support equipment/facilities/temporary structures (Figures 21 and 22). Along with assembly of the equipment, the FECC crews also loaded fuel tanks and hoppers, initiated testing of motors, and performed initial equipment calibration and testing of the GCs, iron scales, flow meters, FIDs, steam piping, and operational warning lights. The start-up portion of soil mixing was completed April 8, 2015.

Soil mixing was initiated on April 10, 2015. As required by the RAWP and RDR, three test columns were to be completed initially. Those test columns included 62, 116, and 224 (Modified—see Section 1.2.3.8) as shown in Figure 23. Due to the close proximity of soil column 5 to the cylinder yard, it was determined that an alternate soil column should be used as the low contamination level location. Soil column 224 was the chosen replacement column. This adjustment was documented in an addendum to the RAWP. This sequence was accepted by KDEP and EPA upon approval of the RAWP Addendum (DOE 2014). The purpose of the test columns was to provide an initial assessment of operational parameters that the FFA parties specified. The soil mixing on the test columns was performed consistent with the approved RDR and utilized the protocols outlined in RDR, Figure 7, large diameter auger (LDA)/Steam/ZVI Treatment Protocol. The protocol required the columns to be steamed at 8,000 lb per hour until the column attained 160°F throughout, during the last pass. It was identified that with steam injection at 8,000 lb per hour, the soil column in some instances would release energy rapidly to the mixing shroud. This release of energy from SWMU 1 soil was problematic in different ways including these:

- Unexpected ejection of loose soil from the soil column onto the ground surface (Figure 24);
- Violent movement (raising and falling) of the steam shroud, drilling assembly, and crane cables;
- Excess pressure on the vapor vacuum hose resulting in hose disconnection and vacuum loss; and
- Creation of steam vapor vents through the adjacent soil or from beneath the bottom edge of the shroud.

A number of methods were attempted to reduce the occurrence of the “soil burping.” Ultimately, three actions mitigated the impacts of the soil burping:

- Adjusted treatment protocols to allow variable quantities of steam to be injected in the soil column to be able to control the heat contained in each soil column, but still attain the 160°F (excluding columns where the first thermal pass exhibited less than 100 ppm VOCs), as stipulated by the treatment protocols.
- Mixed, initially, each soil column with water from surface to depth in a process known as slurring to fluidize the soil, allowing the steam to move more easily through the column.
- Modified the method of connecting the shroud and the drilling assembly, changing it from a rigid connection to a chain connection that allowed for limited movement of the shroud with respect to the drill assembly. This modification allowed the shroud to absorb the shock of the soil burp without the energy propagating through the drilling assembly and shock-loading the suspension cables.



Figure 21. Satellite View of Soil Mixing and Support Equipment (Imagery 2015 Google[®])



Figure 22. View of Soil Mixing and Support Equipment from Crane Access Driveway

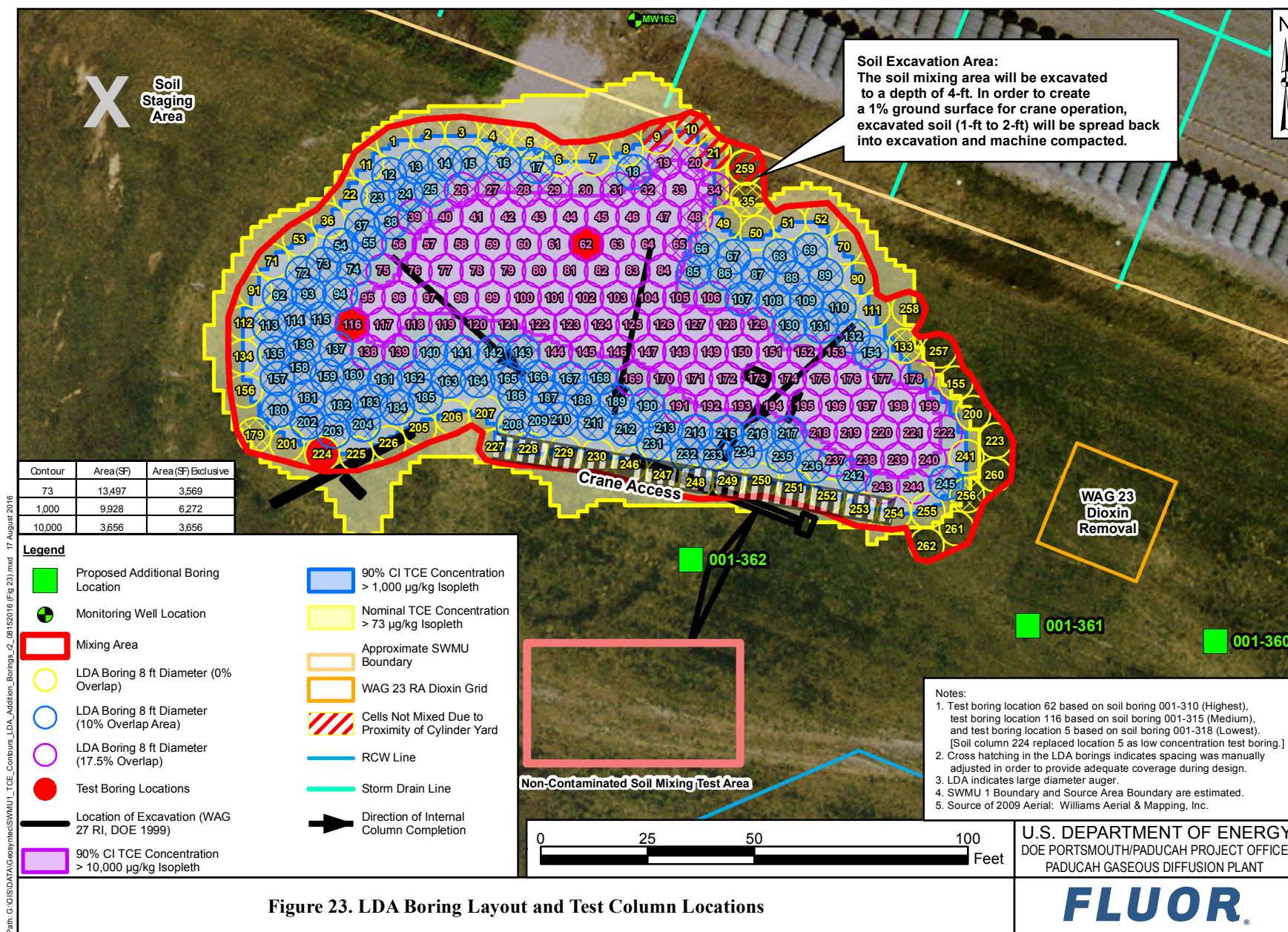


Figure 23. LDA Boring Layout and Test Column Locations



Figure 24. Ejection of Soil Column Resulting from Release of Energy (Soil Burp)

Following the soil mixing and steaming of each column, the appropriate weight of ZVI, guar gum, and water was combined and injected into the soil column as the auger mixed the soil column from surface to depth. The three test columns were mixed (4/10/2015–4/14/2015), and then soil samples were collected (4/19/2015), with temperature and conductivity being logged. The collection of the test column soil samples and temperature/conductivity data did not impact the continued soil mixing activities because they were sampled over a weekend.

Mixing of the soil columns continued after the three test columns. The RDR provided that exterior soil columns would be completed around the mixing area to provide a ZVI treated soil buffer to remediate potentially migrating contaminants. A required safety stipulation to decrease the potential for crane instability was that the soil mixing support crane was only to work on top of undisturbed soil and wood crane mats. The crane was not allowed to traverse any areas that previously had been soil mixed. It was identified that this requirement would, at times, be at odds with the RDR requirement for completing the exterior columns first because the crane would need to traverse across a mixed soil column at some point. Therefore, a modification to the completion sequence was made. The mixing of soil columns, following the test columns, began on the western edge and continued to the eastern side of the mixing area (see Section 1.2.3.5). This approach, which is similar to painting the floor of a room, allowed the crane to stay on unmixed soil throughout all mixing operations.

A total of 258 soil columns were mixed during the remedial operation. The remedial design included 262 columns. Four of the planned soil columns were located in a drainage ditch located north of SWMU 1 and adjacent to the C-747-A Cylinder Storage Yard (see Figure 5). The soil in the drainage ditch contained elevated levels of transuranic radioactive compounds that might have contaminated the soil mixing equipment and complicated soil mixing work due to potential spread of radioactive contamination. The soil columns adjacent to, but not located in the drainage ditch, were identified as having only minimal levels of VOC contamination. The FFA parties agreed the project would not need to mix the four columns located directly in the drainage ditch because of limited contamination by target compounds and the potential of negative impacts to the project from transuranics.

A consequence of the soil mixing process was an increase in soil volume (bulking) upon mechanical mixing. The occurrence of soil bulking associated with soil mixing had not been identified by FECC as an issue or a concern. Historically, when FECC had performed soil mixing, the soil collapsed in the soil column which required placing additional soil in the column to backfill it to the original surface; however, soil bulking did occur upon mixing of the UCRS soils. Although the amount of soil volume increase was variable and inconsistent from one soil column to the next, overall, the bulking resulted in the need to handle the extra soils and stockpiling them, once they had dried sufficiently, due south of the storm water basin (as shown in Figure 20). The stockpiled soil was replaced over the mixing area after the completion of the mixing.

The treatment of each individual soil column was unique. The variables included the time to complete treatment, level of difficulty in mixing the soil, presence of soil burps, amount of steam the soils accepted without overheating (burping), percent overlap, etc. In general, the quickest a column could be slurried, soil mixed, and ZVI placed was about 2–3 hours with perfect circumstances; without perfect circumstances, the time frame easily could increase to greater than one work shift. The approach to treating each column utilized the following general steps:

1. Place/rearrange crane mats as needed.
2. Relocate crane and mixing unit to the area of the target soil column.

3. Perform fine location adjustment of the crane and mixing unit using Total Station surveying instrument.
4. Initiate first pass (surface to bottom) mixing soil while injecting potable water to slurry the soil column. The slurring process may have been focused on specific depths if soil mixing conditions were difficult.
5. Initiate first thermal pass with steam injection from bottom of soil column to the top of the treatment zone at about 5 ft bgs to attain the target of less than 100 ppm on flame-ionization detector throughout soil column (or the combination of VOC readings from in-line GC sample analysis was less than 100 ppm throughout the pass).
6. Perform additional thermal passes, if needed, to attain the target of less than 100 ppm on flame-ionization detector throughout soil column (or until the combination of VOC readings from in-line GC sample analysis was less than 100 ppm throughout the pass) and return to surface.
7. Prepare guar gum, water and ZVI mixture consistent with the RDR.
8. Perform placement of ZVI mixture during a descent soil mixing pass from surface to bottom of column.
9. Perform flush/washout of Kelly bar and mixing tool during ascent of final mixing pass to surface.
10. Repeat for next soil column.

The soil mixing treatment system targeted treatment of volatile organic contaminants as documented in the ROD. Specifically, the VOCs targeted were these:

- TCE
- 1,1-DCE
- VC
- *cis*-1,2-DCE
- *trans*-1,2-DCE

The soil mixing system, when combined with the injection of steam, can volatilize other chemicals that could be in the soils and yet not be one of the above targeted VOCs. Section 1.2.3.3, “Utilization of gas chromatograph to evaluate shroud off-gas VOC concentrations when FID indicated interference,” provides a summary of information concerned with encountering non-target compounds during soil mixing operations.

Contamination recovered from the air stream by the vapor conditioning system was treated with activated carbon. Four Vapor-Pac[®] units containing approximately 20,000 lb of activated carbon were used to treat the vapor stream. An FID and GCs were used to check the treated vapors for elevated target compounds.

As a result of the soil mixing, as well as the need to “slurry” the soil columns during treatment, PGDP UCRS soils lost the ability to support any load following treatment. The UCRS soils were very slow in regaining their load-bearing strength following treatment. In order to allow replacement of the previously excavated soils, perform post-treatment soil sampling, and for worker safety, the project treated the upper few feet of the soil columns with quicklime to dry and stabilize the upper few feet of soil. Quicklime was trucked to the site in approximately 3,000-lb industrial synthetic sacks also known as “supersacks.” The supersacks were moved from the truck to the SWMU 1 area or to storage and then were transferred into

the specific area of treatment by a tracked bucket excavator. The bucket excavator and an additional excavator outfitted with an Alpine hydraulic axial mixer were used to mix the quicklime into the upper few feet of soil. The quicklime removed the moisture from the soil as well as increased the workability and bearing strength of the soils.

Demobilization of the soil mixing equipment was initiated following the completion of soil mixing activities on October 8, 2015. The treatment system included support crane, drilling assembly, and other support equipment. Demobilization task included disassembly, decontamination, and loading on trucks for transporting back to FECC, Inc. The support crane was disassembled and removed from PGDP on November 4, 2015. Lime stabilization of the mixed area, which began August 26, 2015, was continued until completion on November 13, 2015, at which time all subcontractor personnel left the PGDP site. The Vapor-Pac[®] activated carbon units utilized for treatment of the extracted vapors were sampled and characterized for reactivation. The estimated 20,000 lb of vapor phase carbon was shipped off-site for reactivation on January 13, 2016.

4.1.3 Replacement of Excavated Soils

After removal of the treatment system equipment, supporting crane, drill assembly, and other supporting equipment, replacement of the previously excavated soils was initiated on December 17, 2015. Prior to the excavated soils being respread, the gravels that had been used to improve the surface conditions of the treatment equipment area and the crane access road were removed. A large portion of this gravel was used to create a temporary road that allowed the drilling rig and other vehicles access to the monitoring well locations. This temporary road was underlain with a geotextile layer to control the gravel-soil contact beneath the road. The remaining volume of gravel was removed from SWMU 1. The area of the soil mixing, storm water control pond, and the crane access road then were filled with the excavated soil. This work was performed using a bulldozer and a bucket excavator. As a result of the bulking or expansion of soils, the grade of the area was estimated to have increased from 1–2 ft once replacement of the previously excavated soils was completed on January 19, 2016. It is not clear at the current time whether the elevated grade will remain or potentially settle over time as would a typical hole refilled with soil. As part of the original excavation, a culvert was used to line a drainage ditch west of the soil mixing area. The culvert was removed as part of the replacement of excavated soils. The soils were replaced in bulk and not placed and compacted in lifts. The SWMU 1 area generally does not receive vehicle traffic other than mowers and sampling equipment. The area that was disturbed by RA implementation was graded to natural draining contours and seeded with a hydromulcher system to assist in controlling erosion. The area was seeded with a mixture of annual rye and fescue.

4.1.4 Post-Remedial Soil Sampling and Monitoring Well Installation

The approved RAWP required the post-remedial soil sampling and well locations to be reviewed by the FFA parties prior to field implementation. Eleven proposed soil sampling locations consistent with the locations in the RAWP were reviewed by the FFA parties. Six monitoring well locations were revised from those in the approved RAWP and also were reviewed by the FFA parties. These locations were discussed in a teleconference on January 19, 2016, and approved by the FFA parties on January 21, 2016. The locations of the soil sampling locations and the monitoring well locations are shown in Section 3 in Figures 7 and 8, respectively. The FFA parties approved the planned locations of the soil sampling and monitoring wells on January 21, 2016.

The soil sampling locations were logged with electrical conductance and temperature geophysical logging instruments on April 19, 2015, and during the week of February 15–20, 2016. The data resulting from those geophysical logging efforts along with the data from the three test locations at soil columns 062, 116, and 224 are contained in Appendix B. All borings exhibited elevated temperatures above the

expected natural ambient soil temperature for the Paducah area of 57–60°F (Earth River Geothermal, Inc. 2014). The time between soil mixing and the temperature logging was variable and depended on the location of the soil boring. Soil mixing was initiated on the western edge in April and completed on the eastern edge in October. The time frame between logging and soil mixing ranged from approximately 9 days for the three test locations and from 4 to approximately 10 months for the remaining locations. As expected, the maximum subsurface (>1 ft bgs) temperatures were collected from the three test columns; this work was performed 9 days after treatment. The three test location temperatures ranged from a low of 62°F to a maximum of 145°F. The post-remediation subsurface temperature values (4 to 10 months after treatment) ranged from 36°F to 133°F. The temperature logs obtained from both the three test columns and the eleven post-mixing soil borings are contained in Appendix B. During performance of conductivity and temperature logging, some locations were met with refusal prior to reaching targeted depth, such as soil boring 351.

Soil borings were drilled using DPT two times during the soil mixing implementation. Fourteen total 14 soil borings were drilled. Three were drilled after completing the first three soil columns and were known as the test columns. The remaining 11 soil borings were drilled after all soil mixing had been completed. Each soil boring was cored in 5-ft increments to approximately 60-65 ft, depending on RGA depth (RGA hit at 60 ft would yield 12 samples, 13 samples were collected when depth of RGA was approximately 65 ft). Each 5-ft soil core was contained in acetate sleeves during the drilling process. Based upon subsurface temperatures expected during drilling to be approximately 140°F, it was determined that 5-ft plastic liners could be utilized rather than the shorter stainless steel liners. Upon extraction, each core tube was capped and cooled in an ice bath for 30 minutes. Following cooling in the ice bath, each core tube was pierced based on the length of core recovered and scanned with a ppb-RAE PID to determine the area of the core with the highest likelihood of VOC contamination. Each core tube was split open, and the area of the soil core having the highest PID readings was sampled using an Encore sampler. Each sample was sent to a fixed-base laboratory for analysis of the VOC target compounds and percent of ZVI present in the soil at that location.

Table 5 provides a summary of the sampling results from the three test columns. The three test columns were selected based on each being located in a low (224), medium (116), or high (062) level of TCE contamination (Figure 23). The test columns were not located adjacent to an earlier planned RDSI boring; therefore, a before-and-after comparison of the test column location is not possible. As a result, N/A is shown in the Pre-Remedial column for all target contaminants. Three of the 34 soil samples collected from the test columns had TCE concentrations that exceeded the 73 ppb cleanup level (Table 5). Of the three samples shown in Table 5 that exceeded the TCE cleanup level, the two highest (2,400 and 1,900 ppb) were located in column 116 (medium contamination). The third highest sample result (100 ppb) that exceeded the TCE cleanup level was located in column 062 (high contamination). None of the samples from the test columns had an analysis that exceed the cleanup levels for the other target contaminant compounds. The following conditions apply to the borings completed at the test column locations:

- Test column sampling occurred within nine days of mixing, and full-effects of the ZVI may not be present;
- No adjacent soil columns had been completed at the time of sampling; therefore, any collateral reductions (secondary treatment of an area due to column overlap) in TCE from adjacent columns were not present; and
- The slurring of the columns to control soil burping had not been initiated at the time of treating the test columns.

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Table 5. Southwest Plume Test Column Characterization Data
Test Column Post-Remedial Soil Analytical Data (SWMU 1 C-747-C Oil Landfarm)

Boring ID	Date of Collection	Depth (bgs)	Pre-Remedial Actual Sample ³ Depth bgs (ft)	Post-Remedial Actual Sample ³ Depth bgs (ft)	TCE (µg/Kg) ¹			<i>cis</i> -1,2-DCE (µg/Kg) ¹			<i>trans</i> -1,2-DCE (µg/Kg) ¹			VC (µg/Kg) ¹			1,1 DCE (µg/Kg) ¹			ZVI
					Pre-Remedial Final ^{3,5}	Post-Remedial Final ^{3,5}	Qual ⁴	Pre-Remedial Final ^{3,5}	Post-Remedial Final ^{3,5}	Qual ⁴	Pre-Remedial Final ^{3,5}	Post-Remedial Final ^{3,5}	Qual ⁴	Pre-Remedial Final ^{3,5}	Post-Remedial Final ^{3,5}	Qual ⁴	Pre-Remedial Final ^{3,5}	Post-Remedial Final ^{3,5}	Qual ⁴	Post-Remedial Zero Valent Iron, %
Oil Landfarm UCRS Soil Cleanup Level (µg/Kg)					73			600			1080			34			130			N/A
001-364 (Test Column 224)	4/21/2015	5	N/A	no recovery	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A
		10	N/A	no recovery	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A
		15	N/A	14.9	N/A	3.6	-/U	N/A	3.6	-/U	N/A	3.6	-/U	N/A	3.6	-/U	N/A	3.6	-/U	0.120
		15D ²	N/A	14.9	N/A	2.8	-/U	N/A	2.8	-/U	N/A	2.8	-/U	N/A	2.8	-/U	N/A	2.8	-/U	0.200
		20	N/A	15.1	N/A	3.1	-/U	N/A	3.1	-/U	N/A	3.1	-/U	N/A	3.1	-/U	N/A	3.1	-/U	0.310
		25	N/A	20.1	N/A	3.4	-/U	N/A	3.4	-/U	N/A	3.4	-/U	N/A	3.4	-/U	N/A	3.4	-/U	0.110
		30	N/A	25.1	N/A	2.8	-/U	N/A	2.8	-/U	N/A	2.8	-/U	N/A	2.8	-/U	N/A	2.8	-/U	0.190
		35	N/A	30.1	N/A	3.5	-/U	N/A	3.5	-/U	N/A	3.5	-/U	N/A	3.5	-/U	N/A	3.5	-/U	0.200
		40	N/A	35.1	N/A	3.0	-/U	N/A	3.0	-/U	N/A	3.0	-/U	N/A	3.0	-/U	N/A	3.0	-/U	0.200
		45	N/A	44.5	N/A	3.8	-/U	N/A	3.8	-/U	N/A	3.8	-/U	N/A	3.8	-/U	N/A	3.8	-/U	0.290
		50	N/A	45.1	N/A	3.3	-/U	N/A	3.3	-/U	N/A	3.3	-/U	N/A	3.3	-/U	N/A	3.3	-/U	0.140
		55	N/A	50.1	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	2.400
		60	N/A	55.1	N/A	38.0	-/-	N/A	8.9	-/-	N/A	2.6	-/U	N/A	2.6	-/U	N/A	2.6	-/U	0.002
		65	N/A	RGA present	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A
Average			N/A	6.7		N/A	3.8		N/A	3.2		N/A	3.2		N/A	3.2		0.396		
001-366 (Test Column 116)	4/21/2015	5	N/A	1.0	N/A	2.7	-/U	N/A	2.7	-/U	N/A	2.7	-/U	N/A	2.7	-/U	N/A	2.7	-/U	0.170
		10	N/A	5.5	N/A	2.5	-/U	N/A	2.5	-/U	N/A	2.5	-/U	N/A	2.5	-/U	N/A	2.5	-/U	0.240
		15	N/A	10.5	N/A	3.1	-/U	N/A	3.1	-/U	N/A	3.1	-/U	N/A	3.1	-/U	N/A	3.1	-/U	0.700
		20	N/A	16.0	N/A	18.0	-/-	N/A	2.4	-/U	N/A	2.4	-/U	N/A	2.4	-/U	N/A	2.4	-/U	0.270
		25	N/A	20.1	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	0.450
		30	N/A	25.1	N/A	2.8	-/U	N/A	2.8	-/U	N/A	2.8	-/U	N/A	2.8	-/U	N/A	2.8	-/U	0.480
		35	N/A	30.1	N/A	3.1	-/U	N/A	3.1	-/U	N/A	3.1	-/U	N/A	3.1	-/U	N/A	3.1	-/U	1.000
		40	N/A	35.1	N/A	2.8	-/U	N/A	2.8	-/U	N/A	2.8	-/U	N/A	2.8	-/U	N/A	2.8	-/U	1.670
		45	N/A	44.9	N/A	1900.0	-/-	N/A	170.0	-/J	N/A	2.4	-/U	N/A	2.4	-/U	N/A	25.0	-/-	0.840
		50	N/A	45.5	N/A	2400.0	-/-	N/A	220.0	-/J	N/A	2.4	-/U	N/A	2.4	-/U	N/A	24.0	-/-	0.001
		55	N/A	50.1	N/A	33.0	-/-	N/A	4.8	-/-	N/A	2.4	-/U	N/A	2.4	-/U	N/A	2.4	-/U	0.005
		60	N/A	RGA present	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A
		65	N/A	RGA present	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A
Average			N/A	397.4		N/A	37.9		N/A	2.7		N/A	2.7		N/A	6.7		0.530		
001-368 (Test Column 62)	4/22/2016	5	N/A	0.5	N/A	3.1	-/U	N/A	3.1	-/U	N/A	3.1	-/U	N/A	3.1	-/U	N/A	3.1	-/U	0.740
		10	N/A	9.0	N/A	3.3	-/U	N/A	3.3	-/U	N/A	3.3	-/U	N/A	3.3	-/U	N/A	3.3	-/U	0.770
		15	N/A	10.1	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	4.200
		20	N/A	17.5	N/A	6.5	-/-	N/A	3.2	-/U	N/A	3.2	-/U	N/A	3.2	-/U	N/A	3.2	-/U	5.300
		25	N/A	no recovery	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A ⁶
		30	N/A	26.5	N/A	3.4	-/U	N/A	3.4	-/U	N/A	3.4	-/U	N/A	3.4	-/U	N/A	3.4	-/U	N/A ⁶
		35	N/A	34.0	N/A	100.0	-/-	N/A	11.0	-/-	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	N/A ⁶
		40	N/A	36.5	N/A	3.6	-/J	N/A	3.1	-/U	N/A	3.1	-/U	N/A	3.1	-/U	N/A	3.1	-/U	2.200
		40D ²	N/A	36.5	N/A	2.8	-/J	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	1.500
		45	N/A	41.5	N/A	3.6	-/U	N/A	3.6	-/U	N/A	3.6	-/U	N/A	3.6	-/U	N/A	3.6	-/U	3.050
		50	N/A	45.1	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	N/A	2.9	-/U	0.500
		55	N/A	50.5	N/A	3.0	-/U	N/A	3.0	-/U	N/A	3.0	-/U	N/A	3.0	-/U	N/A	3.0	-/U	3.500
		60	N/A	56.0	N/A	2.3	-/U	N/A	2.3	-/U	N/A	2.3	-/U	N/A	2.3	-/U	N/A	2.3	-/U	3.400
		65	N/A	RGA present	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A	N/A	-/-	N/A
Average				12.2			3.8			3.1			3.1			3.1		2.6		

Table 5. Southwest Plume Test Column Characterization Data
Test Column Post-Remedial Soil Analytical Data (SWMU 1 C-747-C Oil Landfarm)

Boring ID	Date of Collection	Depth (bgs)	Pre-Remedial Actual Sample ³ Depth bgs (ft)	Post-Remedial Actual Sample ³ Depth bgs (ft)	TCE (µg/Kg) ¹			<i>cis</i> -1,2-DCE (µg/Kg) ¹			<i>trans</i> -1,2-DCE (µg/Kg) ¹			VC (µg/Kg) ¹			1,1 DCE (µg/Kg) ¹			ZVI
					Pre-Remedial Final ^{3,5}	Post-Remedial Final ^{3,5}	Qual ⁴	Pre-Remedial Final ^{3,5}	Post-Remedial Final ^{3,5}	Qual ⁴	Pre-Remedial Final ^{3,5}	Post-Remedial Final ^{3,5}	Qual ⁴	Pre-Remedial Final ^{3,5}	Post-Remedial Final ^{3,5}	Qual ⁴	Pre-Remedial Final ^{3,5}	Post-Remedial Final ^{3,5}	Qual ⁴	Post-Remedial Zero Valent Iron, %
					Oil Landfarm UCRS Soil Cleanup Level (µg/Kg)					73			600			1080			34	

Notes:

¹ For analytical results reported as non-detect (ND) or identified with a U qualifier, a value equal to one half of the reported result is shown in this table and was used to calculate the average borehole soil VOC values which were then rounded to the nearest 0.1 number.

² Denotes duplicate (QA/QC) sample, duplicate samples were not used in the sample VOC averaging calculations. Duplicate (QA/QC) sample is from the post-remedial soil boring. A duplicate from this location was not collected during pre-remedial sampling.

³ N/A: Indicates that soil sample was not collected for the interval due to loss of core, insufficient sample volume, or drilling refusal. N/A indicates that area was not sampled during specific project phase.

⁴ **Qualifier Definitions:** U - Non-detect; J - Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value Dash (-) indicates that qualifiers are not applicable.

⁵ Test columns did not have pre-remedial samples collected during the RDSI

⁶ ZVI samples not available due to low soil core recovery.

Table 6 and 7 contain the analytical results of the samples collected from the post-mixing soil borings. Eleven post-mixing soil borings were drilled with DPT technology in the SWMU. Eight were located within the area that had been soil mixed (Table 6), while 3 were located outside the mixed area (Table 7). Each location of the post-remedial action boring was a twin to a soil boring drilled earlier during the RDSI in 2012. The intent of twinning a historical soil boring is to allow the post-remedial analyses to be compared generally to the analyses taken prior to mixing. It should be noted that for the pre-remedial RDSI laboratory results, the lab reported the results at the method detection limit rather than at the reporting limit. The post-remedial laboratory results were shown with the reporting limit. For the nondetects, the reported results in the post-remedial column are significantly higher than the pre-remedial column because of the difference in the way the results were reported.

Table 6 provides a side-by-side comparison of contaminant levels for each compound targeted by the RA. For analytical results reported as nondetect, a value equal to one-half of the reported result was listed in the table and used to calculate the final average borehole soil VOC values, which then were rounded to the nearest tenth. For the eight post-remedial borings located within the soil mixing area, the 109 soil sample results (including duplicates) for each of the target compounds indicate, on average, greater than 99 plus percent in the reduction of TCE concentrations (excluding duplicates). The overall percent reduction for the mix/treatment area was calculated by averaging the borehole reductions (excluding duplicates). The average percent borehole reduction was calculated with the equation shown below:

$$[(\text{Avg pre-remedial concentration} - \text{avg post-remedial concentration}) / \text{Avg pre-remedial concentration}] * 100 = \text{Average Borehole Reduction}$$

Two post-remedial action samples collected in the treatment zone had detected TCE (8.6 ppb, soil boring 335 at 45 ft bgs and 6.8 ppb, soil boring 331 at 65 ft bgs). The percent reduction for the result from soil boring 335 was over 99%. Because a preremediation action sample was not available for soil boring 331 at 65 ft bgs, percent reduction cannot be derived for this sample. The detected result for both samples is well below the remedial goal for TCE (73 ppb). Each of the other four target VOCs in Table 6 also had 109 soil samples analyzed from the soil mixing area. Of those results, there was a total of 5 detects in post-remedial action samples for *cis*-1,2-DCE. *Trans*-1,2-DCE, vinyl chloride, and 1,1-DCE were not detected. None of the detects exceeded the SWMU 1 cleanup levels. The seven detections for target contaminants in post-remedial samples located inside the treatment area are highlighted within Table 6 with light-red shading.

There were 3 post-mix soil borings located outside of the mixed area, 001-337, 001-347, and 001-351, and the resulting soil sample data are contained in Table 7. The purpose of these borings was to assist in determining if the soil mixing process moved contaminant mass outside the mixing area. Of the 41 post-remedial action samples (including duplicates) for each of the target contaminant compounds obtained from these 3 soil borings outside the mixed area, there were 20 TCE detects with the highest being 95 ppb, which is slightly above the TCE cleanup level. Of the 20 TCE detects, 7 were increased over their companion sample obtained from the location prior to soil mixing; however, for the 3 soil borings, on average, there was a 61% decrease in TCE concentration from pre- to post-mixing. The reasons for this reduction in TCE concentrations for soil borings outside the mixing zone have not been identified, but potential possibilities are discussed below. All three of the soil borings provided maximum high temperatures in the 75°F to 85°F range, which was higher than the expected natural subsurface temperature (57–60°F). This increase in temperature may have increased the vaporization of the contaminant allowing it to be extracted by the vacuum system of the soil mixer nearby. Also, increases in subsurface temperatures may have allowed an increase in biological activity, which may have resulted in the slight decrease of TCE concentrations outside the mixed area.

The Commonwealth of Kentucky, during the soil sampling process, obtained split samples for four samples to provide independent analyses. The results obtained from the independent analyses provided similar results to the primary DOE samples.

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Table 6. Southwest Plume RDSI and Post-Remedial Characterization Data
Pre-Remedial and Post-Remedial Soil Analytical Data (SWMU - 1 C-747-C Oil Landfarm)

Boring ID	Date of Collection	Depth (bgs)	Pre-Remedial Actual Sample Depth bgs (ft) ⁶	Post-Remedial Actual Sample Depth, bgs (ft) ⁶	TCE (µg/Kg) ¹				cis -1,2-DCE (µg/Kg) ¹				trans -1,2-DCE (µg/Kg) ¹				VC (µg/Kg) ¹				1,1 DCE (µg/Kg) ¹				ZVI
					Pre Remedial Final ⁷	Post Remedial Final ⁷	Qual ⁷	Average Percentage Concentration Removed (%)	Pre-Remedial Final ⁷	Post-Remedial Final ⁷	Qual ⁷	Percentage Concentration Removed, %	Pre-Remedial Final ⁷	Post-Remedial Final ⁷	Qual ⁷	Percentage Concentration Removed, %	Pre-Remedial Final ⁷	Post-Remedial Final ⁷	Qual ⁷	Percentage Concentration Removed, %	Pre-Remedial Final ⁷	Post-Remedial Final ⁷	Qual ⁷	Percentage Concentration Removed, %	Post-Remedial Zero Valent Iron, %
Oil Landfarm UCRS Soil Cleanup Level (µg/Kg)					73				600				1080				34				130				None
001-310 & 001-335	7/23/2012 & 3/15/2016	5	3.5	4.9	6.3	3.0	J/U/X		0.3	3.0	U/U		0.4	3.0	U/U		0.2	3.0	U/U		0.8	3.0	U/U		0.41
		10	9.9	5.1	1000.0	2.9	-/U		540.0	2.9	-/U		4.0	2.9	U/U		13.5	2.9	U/U		12.0	2.9	U/U		0.39
		15	12.0	12.0	8300.0	3.1	-/U		3000.0	3.1	-/U		3.9	3.1	U/U		13.0	3.1	U/U		11.5	3.1	U/U		0.38
		20	16.0	15.1	960000.0	3.6	-/U		1450.0	3.6	U/U		1100.0	3.6	U/U		3800.0	3.6	U/U		3350.0	3.6	U/U		0.88
		25	20.1	22.0	3300.0	2.9	-/U		280.0	2.9	-/U		3.9	2.9	U/U		13.5	2.9	U/U		11.5	2.9	U/U		0.63
	7/24/2012 & 3/15/2016	30	29.5	25.5	440000.0	5.5	-/U		230.0	5.5	U/U		180.0	5.5	U/U		600.0	5.5	U/U		550.0	5.5	U/U		0.43
		30D ^{2,3}	29.5	25.5	440000.0	7.5	-/U		230.0	7.5	U/U		180.0	7.5	U/U		600.0	7.5	U/U		550.0	7.5	U/U		0.60
		35	31.5	30.1	24000.0	2.8	-/U		960.0	2.8	J/U		16.0	2.8	U/U		55.0	2.8	U/U		47.0	2.8	U/U		0.01
		40	37.0	37.0	28000.0	2.6	-/U		1500.0	2.6	J/U		40.5	2.6	U/U		140.0	2.6	U/U		120.0	2.6	U/U		0.16
		45	44.5	40.1	40000.0	8.6 ⁸	-/J		1800.0	7.0	-/U		21.0	7.0	U/U		70.0	7.0	U/U		65.0	7.0	U/U		N/A ⁴
		50	47.5	45.1	45000.0	2.9	-/U		1600.0	2.9	-/U		20.5	2.9	U/U		70.0	2.9	U/U		60.0	2.9	U/U		N/A ⁴
		55	50.1	51.5	44000.0	2.7	-/U		1800.0	2.7	-/U		20.0	2.7	U/U		70.0	2.7	U/U		60.0	2.7	U/U		0.07
		60	55.1	56.5	2800.0	4.1	-/U		5.5	4.1	U/U		4.3	4.1	U/U		14.5	4.1	U/U		13.0	4.1	U/U		0.92
		65	N/A	61.0	N/A	2.4	-/U		N/A	2.4	-/U		N/A	2.4	-/U		N/A	2.4	-/U		N/A	2.4	-/U		0.40
		Average			133033.9	3.3		100.0	1097.1	3.6		99.7	117.9	3.6		97.0	405.0	3.6		99.1	358.4	3.6		99.0	0.43
001-309 & 001-333	7/24/2012 & 3/7/2016	5 ⁵	4.0	3.5	22.0	2.8	-/U		0.3	2.8	U/U		0.5	2.8	U/U		0.2	2.8	U/U		0.8	2.8	U/U		0.33
		10	7.5	6.0	34.0	2.4	-/U		14.0	0.6 ⁸	-/J		0.5	2.4	U/U		0.2	2.4	U/U		0.8	2.4	U/U		0.49
		15	12.5	12.0	19.0	2.4	-/U		5.9	2.4	J/U		0.5	2.4	U/U		0.2	2.4	U/U		0.8	2.4	U/U		0.70
		20	17.0	16.5	2.9	2.7	J/U		0.7	2.7	J/U		0.5	2.7	U/U		0.2	2.7	U/U		0.9	2.7	U/U		0.80
		25	22.5	24.0	4100.0	2.7	-/U		1900.0	2.7	-/U		3.8	2.7	U/U		13.0	2.7	U/U		11.0	2.7	U/U		0.84
	7/25/2012 & 3/7/2016	30	25.1	25.1	3800.0	2.8	-/U		1700.0	2.8	-/U		3.4	2.8	U/U		11.5	2.8	U/U		10.0	2.8	U/U		1.40
		35	31.5	34.0	3700.0	2.5	-/U		1300.0	2.5	-/U		3.3	2.5	U/U		11.0	2.5	U/U		10.0	2.5	U/U		1.70
		40	35.1	38.0	2600.0	2.6	-/U		820.0	2.6	-/U		3.1	2.6	U/U		10.5	2.6	U/U		9.0	2.6	U/U		2.50
		45	40.5	43.0	2100.0	3.1	-/U		950.0	3.1	-/U		3.2	3.1	U/U		10.5	3.1	U/U		9.5	3.1	U/U		3.10
		50	45.5	46.0	2500.0	2.7	-/U		860.0	2.7	-/U		3.2	2.7	U/U		11.0	2.7	U/U		9.5	2.7	U/U		3.40
		55	52.5	52.0	2500.0	2.5	-/U		440.0	2.5	-/U		3.3	2.5	U/U		11.0	2.5	U/U		10.0	2.5	U/U		0.22
		60	59.5	56.0	2000.0	3.0	-/U		670.0	3.0	-/U		3.4	3.0	U/U		11.5	3.0	U/U		10.0	3.0	U/U		15.00
		65	N/A	62.0	N/A	2.2	-/U		N/A	2.2	-/U		N/A	2.2	-/U		N/A	2.2	-/U		N/A	2.2	-/U		1.90
		Average			1948.2	2.7		99.9	721.7	2.7		99.6	2.4	2.7		-13.9	7.6	2.7		64.6	6.9	2.7		60.9	2.49
		001-315 & 001-343	7/27/2012 & 3/15/2016	5	4.0	3.0	0.2	2.8	U/U		0.3	2.8	U/U		0.5	2.8	U/U		0.2	2.8	U/U		0.9	2.8	U/U
10	7.5			6.0	0.2	2.9	U/U		0.3	2.9	U/U		0.5	2.9	U/U		0.2	2.9	U/U		0.9	2.9	U/U		0.45
15	14.5			12.0	2.2	7.5	J/U		0.3	7.5	U/U		0.4	7.5	U/U		0.2	7.5	U/U		0.8	7.5	U/U		0.26
20	16.5			15.1	12.0	3.6	-/U		0.7	3.6	J/U		0.4	3.6	U/U		0.2	3.6	U/U		0.7	3.6	U/U		0.32
25	23.0			22.0	5000.0	2.4	-/U		310.0	0.8 ⁸	-/J		4.2	2.4	U/U		14.0	2.4	U/U		12.5	2.4	U/U		0.04
30	25.1			25.5	4100.0	2.6	-/U		260.0	3.7 ⁸	-/J		4.0	2.6	U/U		13.5	2.6	U/U		11.5	2.6	U/U		0.04
35	33.5			32.5	4300.0	6.5	-/U		370.0	6.5	-/U		4.3	6.5	U/U		14.5	6.5	U/U		12.5	6.5	U/U		0.23
40	35.5			36.5	2400.0	3.4	-/U		230.0	3.4	-/U		3.7	3.4	U/U		12.5	3.4	U/U		11.0	3.4	U/U		0.25
45	40.1			0.0	5100.0	3.6	-/U		440.0	3.6	-/U		4.2	3.6	U/U		14.0	3.6	U/U		12.5	3.6	U/U		0.22
50	45.1			48.0	4900.0	2.6	-/U		440.0	2.6	-/U		4.2	2.6	U/U		14.0	2.6	U/U		12.5	2.6	U/U		0.07
55	50.1			50.1	3200.0	3.0	-/U		290.0	3.0	-/U		4.7	3.0	U/U		16.0	3.0	U/U		14.0	3.0	U/U		0.07
55D ^{2,3}	50.1			50.1	3200.0	2.5	-/U		290.0	2.5	-/U		4.7	2.5	U/U		16.0	2.5	U/U		14.0	2.5	U/U		0.08
60	59.5			56.0	460.0	2.4	-/U		5.5	2.4	U/U		4.3	2.4	U/U		14.5	2.4	U/U		12.5	2.4	U/U		0.07
65	62.5			61.0	2900.0	2.9	-/U		130.0	2.9	J/U		4.6	2.9	U/U		15.5	2.9	U/U		14.0	2.9	U/U		2.40
Average				2490.4	3.6		99.9	190.6	3.7		98.0	3.1	3.6		-16.4	9.9	3.6		64.3	8.9	3.6		60.2	0.35	
001-316 & 001-345	7/31/2012 & 3/16/2016	5	4.9	2.5	0.2	2.7	U/U		0.3	2.7	U/U		0.4	2.7	U/U		0.2	2.7	U/U		0.7	2.7	U/U		0.20
		10	6.0	7.0	0.2	2.5	U/U		0.3	2.5	U/U		0.4	2.5	U/U		0.2	2.5	U/U		0.7	2.5	U/U		0.20
		15	10.1	10.1	0.2	2.5	U/U		0.3	2.4 ⁸	U/J		0.4	2.5	U/U		0.2	2.5	U/U		0.7	2.5	U/U		0.07
		20	17.0	15.1	0.2	2.9	U/U		4.8	2.9	J/U		0.4	2.9	U/U		1.3	2.9	J/U		0.7	2.9	U/U		0.12
		25	23.0	20.1	320.0	3.7	-/U		430.0	3.7	-/U		3.9	3.7	U/U		13.0	3.7	U/U		11.5	3.7	U/U		0.26
		30																							

Table 6. Southwest Plume RDSI and Post-Remedial Characterization Data
Pre-Remedial and Post-Remedial Soil Analytical Data (SWMU - 1 C-747-C Oil Landfarm)

Boring ID	Date of Collection	Depth (bgs)	Pre-Remedial Actual Sample Depth bgs (ft) ⁶	Post-Remedial Actual Sample Depth, bgs (ft) ⁶	TCE (µg/Kg) ¹				cis -1,2-DCE (µg/Kg) ¹				trans -1,2-DCE (µg/Kg) ¹				VC (µg/Kg) ¹				1,1 DCE (µg/Kg) ¹				ZVI
					Pre Remedial Final ⁷	Post Remedial Final ⁷	Qual ⁷	Average Percentage Concentration Removed (%)	Pre-Remedial Final ⁷	Post-Remedial Final ⁷	Qual ⁷	Percentage Concentration Removed, %	Pre-Remedial Final ⁷	Post-Remedial Final ⁷	Qual ⁷	Percentage Concentration Removed, %	Pre-Remedial Final ⁷	Post-Remedial Final ⁷	Qual ⁷	Percentage Concentration Removed, %	Pre-Remedial Final ⁷	Post-Remedial Final ⁷	Qual ⁷	Percentage Concentration Removed, %	Post-Remedial Zero Valent Iron, %
Oil Landfarm UCRS Soil Cleanup Level (µg/Kg)					73				600				1080				34				130				None
001-314 & 001-341	7/31/2012 & 3/8/2016	5	3.0	3.5	0.2	2.9	U/UX		0.3	2.9	U/UX		0.4	2.9	U/UX		0.2	2.9	U/UX		0.7	2.9	U/UX		0.58
		10	7.0	7.5	1.3	2.9	J/U		0.3	2.9	U/U		0.4	2.9	U/U		0.2	2.9	U/U		0.7	2.9	U/U		0.63
		15	14.0	13.0	1.8	3.0	J/U		0.2	3.0	U/U		0.4	3.0	U/U		0.2	3.0	U/U		0.7	3.0	U/U		0.81
		20	19.0	17.5	0.2	2.6	U/U		0.3	2.6	U/U		0.4	2.6	U/U		0.2	2.6	U/U		0.8	2.6	U/U		0.56
		25	21.5	24.9	13.0	2.6	-/U		8.4	2.6	-/U		0.4	2.6	U/U		0.2	2.6	U/U		0.7	2.6	U/U		0.05
		30	28.5	26.0	200.0	2.9	J/U		110.0	2.9	J/U		4.2	2.9	U/U		14.0	2.9	U/U		12.5	2.9	U/U		0.11
		35	32.0	34.0	220.0	3.0	-/U		120.0	3.0	J/U		3.2	3.0	U/U		11.0	3.0	U/U		9.5	3.0	U/U		1.70
		40	36.5	39.5	270.0	2.7	-/U		4.9	2.7	U/U		3.8	2.7	U/U		13.0	2.7	U/U		11.5	2.7	U/U		1.10
		45	44.0	43.0	950.0	2.9	-/U		640.0	2.9	-/U		4.1	2.9	U/U		14.0	2.9	U/U		12.0	2.9	U/U		0.82
		45D ^{2,3}	44.0	43.0	950.0	2.7	-/U		640.0	2.7	-/U		4.1	2.7	U/U		14.0	2.7	U/U		12.0	2.7	U/U		0.98
		50	49.0	49.5	1000.0	2.6	-/U		700.0	2.6	-/U		4.2	2.6	U/U		14.5	2.6	U/U		12.5	2.6	U/U		0.85
		55 ⁵	50.1	51.5	510.0	2.7	-/U		270.0	2.7	-/U		3.9	2.7	U/U		13.5	2.7	U/U		11.5	2.7	U/U		0.73
		60	57.5	58.0	210.0	2.3	J/U		5.0	2.3	U/U		4.0	2.3	U/U		13.5	2.3	U/U		12.0	2.3	U/U		0.89
		65	60.5	62.5	410.0	2.1	-/U		200.0	2.1	J/U		4.0	2.1	U/U		13.5	2.1	U/U		12.0	2.1	U/U		0.63
Average					291.3	2.7		99.1	158.4	2.7		98.3	2.6	2.7		-5.6	8.3	2.7		67.4	7.5	2.7		63.7	0.73
001-303 & 001-331	8/2/2012 & 3/17/2016	5	4.0	3.0	0.2	2.6	U/UX		0.3	2.6	U/UX		0.5	2.6	U/UX		0.2	2.6	U/UX		0.9	2.6	U/UX		0.29
		10	9.0	6.5	5.2	3.6	J/U		0.3	3.6	U/U		0.5	3.6	U/U		0.2	3.6	U/U		0.8	3.6	U/U		0.23
		15	14.5	11.0	17.0	3.8	-/U		7.5	3.8	J/U		0.4	3.8	U/U		0.2	3.8	U/U		0.7	3.8	U/U		0.77
		15D ^{2,3}	N/A	11.0	17.0	2.9	-/U		7.5	2.9	J/U		0.4	2.9	J/U		0.2	2.9	U/U		0.7	2.9	J/U		0.32
		20	19.5	15.1	0.4	2.8	J/U		0.3	2.8	U/U		0.5	2.8	U/U		0.2	2.8	U/U		0.8	2.8	U/U		0.58
		25	21.0	22.5	0.2	2.3	U/U		0.3	2.3	U/U		0.4	2.3	U/U		0.2	2.3	U/U		0.8	2.3	U/U		1.10
		30	27.5	25.1	3.0	2.5	J/U		1.6	2.5	J/U		0.5	2.5	U/U		0.2	2.5	U/U		0.8	2.5	U/U		0.90
		35	34.5	33.0	0.4	2.8	J/U		1.1	2.8	J/U		0.5	2.8	U/U		0.2	2.8	U/U		0.8	2.8	U/U		1.80
		40	39.9	37.0	340.0	2.4	-/U		210.0	2.4	J/U		4.1	2.4	U/U		14.0	2.4	U/U		12.5	2.4	U/U		1.60
		45	43.5	40.5	340.0	3.7	-/U		220.0	3.7	J/U		4.1	3.7	U/U		14.0	3.7	U/U		12.0	3.7	U/U		1.90
		50	49.5	46.5	510.0	2.2	-/U		280.0	2.2	-/U		4.0	2.2	U/U		13.5	2.2	U/U		12.0	2.2	U/U		1.20
		55	50.1	51.0	29.0	2.4	-/U		23.0	2.4	-/U		0.5	2.4	U/U		0.2	2.4	U/U		0.8	2.4	U/U		1.50
		60	55.1	55.5	9.5	2.4	U/U		5.5	2.4	U/U		4.3	2.4	U/U		14.5	2.4	U/U		13.0	2.4	U/U		2.20
		65	N/A	60.5	N/A	6.8 ⁸	-/-		N/A	3.3 ⁸	-/J		N/A	2.8	-/U		N/A	2.8	-/U		N/A	2.8	-/U		0.01
Average					104.6	2.8		97.3	62.5	2.8		95.5	1.7	2.8		-66.6	4.8	2.8		41.9	4.7	2.8		40.0	1.08
001-313 & 001-339	8/6/2012 & 3/16/2016	5	3.5	0.5	24.0	2.3	-/UX		0.3	2.3	U/U		0.5	2.3	U/U		0.2	2.3	U/U		0.8	2.3	U/U		0.21
		10	7.5	8.0	100.0	2.9	-/U		1.8	2.9	J/U		0.5	2.9	U/U		0.2	2.9	U/U		0.8	2.9	U/U		0.65
		15	10.5	11.0	55.0	3.3	-/U		3.7	3.3	J/U		0.5	3.3	U/U		0.2	3.3	U/U		0.8	3.3	U/U		0.84
		20	19.5	16.0	170.0	2.5	-/U		8.1	2.5	J/U		0.4	2.5	U/U		0.2	2.5	U/U		0.7	2.5	U/U		0.18
		25	21.5	21.5	7.5	2.9	U/U		4.6	2.9	U/U		3.6	2.9	U/U		12.0	2.9	U/U		10.5	2.9	U/U		0.20
		25D ²	21.5	21.5	130.0	3.1	-/U		15.0	3.1	-/U		0.4	3.1	U/U		0.2	3.1	U/U		0.8	3.1	U/U		0.24
		30	28.0	25.1	14000.0	2.8	-/U		1100.0	2.8	-/U		8.0	2.8	U/U		26.5	2.8	U/U		23.0	2.8	U/U		0.13
		35	33.5	30.5	18000.0	2.4	-/U		1200.0	2.4	-/U		20.5	2.4	U/U		70.0	2.4	U/U		60.0	2.4	U/U		0.21
		40	35.1	37.0	14000.0	3.6	-/U		900.0	3.6	-/U		8.0	3.6	U/U		27.0	3.6	U/U		24.0	3.6	U/U		0.65
		45	40.1	42.5	1100.0	2.8	-/U		5.0	2.8	U/U		4.0	2.8	U/U		13.5	2.8	U/U		12.0	2.8	U/U		0.61
		50	45.5	49.9	260.0	3.3	-/U		5.0	3.3	U/U		3.9	3.3	U/U		13.0	3.3	U/U		11.5	3.3	U/U		1.20
		55	52.0	50.1	8.5	4.2	U/U		4.9	4.2	U/U		3.8	4.2	U/U		13.0	4.2	U/U		11.5	4.2	U/U		1.10
		60	55.1	58.5	14.0	2.6	-/U		0.3	2.6	U/U		0.5	2.6	U/U		0.2	2.6	U/U		0.8	2.6	U/U		2.60
		62.5	60.5	61	760.0	2.3	-/U		5.0	2.3	U/U		4.0	2.3	U/U		13.5	2.3	U/U		11.5	2.3	U/U		3.40
Average					3730.7	2.9		99.9	249.1	2.9		98.8	4.5	2.9		34.7	14.6	2.9		80.0	12.9	2.9		77.4	0.87
001-320 & 001-349	8/7/2012 & 3/7/2016	5	4.0	3.5	0.2	2.5	U/UX		0.3	2.5	U/U		0.5	2.5	U/U		0.2	2.5	U/U		0.8	2.5	U/U		0.62
		10	6.5	7.5	0.2	2.7	U/U		0.3	2.7	U/U		0.5	2.7	U/U		0.2	2.7	U/U		0.8	2.7	U/U		1.20
		15	14.9	11.5	180.0	6.0	-/U		9.6	6.0	-/U		0.4	6.0	U/U		0.2	6.0	U/U		0.8	6.0	U/U		0.41
		20	17	18.5	7.0	3.0	J/U		0.3	3.0	U/U		0.4	3.0	U/U		0.2	3.0	U/U		0.8	3.0	U/U		0.32
		25	23	24	130.0	2.9	-/U		6.1	2.9	J/U		0.5	2.9	U/U		0.2	2.9	U/U		0.9	2.9			

Table 6. Southwest Plume RDSI and Post-Remedial Characterization Data
Pre-Remedial and Post-Remedial Soil Analytical Data (SWMU - 1 C-747-C Oil Landfarm)

Boring ID	Date of Collection	Depth (bgs)	Pre-Remedial Actual Sample Depth bgs (ft) ⁶	Post-Remedial Actual Sample Depth, bgs (ft) ⁶	TCE (µg/Kg) ¹				cis -1,2-DCE (µg/Kg) ¹				trans -1,2-DCE (µg/Kg) ¹				VC (µg/Kg) ¹				1,1 DCE (µg/Kg) ¹				ZVI
					Pre Remedial Final ⁷	Post Remedial Final ⁷	Qual ⁷	Average Percentage Concentration Removed (%)	Pre-Remedial Final ⁷	Post-Remedial Final ⁷	Qual ⁷	Percentage Concentration Removed, %	Pre-Remedial Final ⁷	Post-Remedial Final ⁷	Qual ⁷	Percentage Concentration Removed, %	Pre-Remedial Final ⁷	Post-Remedial Final ⁷	Qual ⁷	Percentage Concentration Removed, %	Pre-Remedial Final ⁷	Post-Remedial Final ⁷	Qual ⁷	Percentage Concentration Removed, %	Post-Remedial Zero Valent Iron, %
					Oil Landfarm UCRS Soil Cleanup Level (µg/Kg)				73				600				1080				34				130

Notes:

- ¹ For analytical results reported as non-detect (ND) or identified with a U qualifier, a value equal to one half of the reported result is shown in this table and was used to calculate the average borehole soil VOC values which were then rounded to the nearest 0.1 number.
- ² Denotes duplicate (QA/QC) sample, duplicate samples were not used in the sample VOC averaging calculations. Also only results in which there is both pre- and post- results are included in the averaging calculations.
- ³ Duplicate (QA/QC) sample is from the post-remedial soil boring. A duplicate from this location was not collected during pre-remedial sampling; therefore, the associated primary pre-remedial sample result is provided for comparison.
- ⁴ ZVI samples not available due to low soil core recovery.
- ⁵ Indicates soil sample split with Commonwealth of Kentucky. Following samples split: 001-333-15, 001-337-30, 001-341-55, 001-347-35.
- ⁶ N/A indicates that a soil sample was not collected for the interval due to loss of core, shortage of soil, or drilling refusal.
- ⁷ **Qualifier Definitions:** U - Non-detect; J - Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value; X - Surrogate is outside control limits. Dash (-) indicates that qualifiers are not applicable.
- ⁸ Post soil mixing contaminant detects are highlighted in the table as:
- ⁹ Overall TCE Percent Reduction is derived using the calculated average concentration of Pre-Remedial and Post-Remedial contaminant values for each soil boring set. Borehole Equation: (Average Pre-Remedial - Average Post-Remedial)/ Average Pre-Remedial * 100 = Average Percent Reduction.

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Table 7. Southwest Plume RDSI Pre- and Post-Remedial Characterization Data (Outside Treatment/Soil Mixing Area)
Pre-Remedial and Post-Remedial Soil Analytical Data (SWMU - 1 C-747-C Oil Landfarm)

Boring ID ⁵	Date of Collection	Depth (bgs)	Pre-Remedial Actual Sample Depth bgs (ft) ³	Post-Remedial Actual Sample Depth bgs (ft) ³	TCE (µg/Kg) ¹				cis -1,2-DCE (µg/Kg) ¹				trans -1,2-DCE (µg/Kg) ¹				VC (µg/Kg) ¹				1,1 DCE (µg/Kg) ¹				ZVI
					Pre-Remedial Final ³	Post-Remedial Final ³	Qual ⁴	Average Percentage Concentration Removed %	Pre-Remedial Final ³	Post-Remedial Final ³	Qual ⁴	Percentage Concentration Removed, %	Pre-Remedial Final ³	Post-Remedial Final ³	Qual ⁴	Percentage Concentration Removed, %	Pre-Remedial Final ³	Post-Remedial Final ³	Qual ⁴	Percentage Concentration Removed, %	Pre-Remedial Final ³	Post-Remedial Final ³	Qual ⁴	Percentage Concentration Removed, %	Post Remedial Zero Valent Iron, %
Oil Landfarm UCRS Soil Cleanup Level (µg/Kg)					73				600				1080				34				130				N/A
001-312 ³ & 001-337	7/26/2012 & 3/8/2016	5	3.5	2.5	0.2	2.5	U/U		0.4	2.5	U/U		0.6	2.5	U/U		0.3	2.5	U/U		1.0	2.5	U/U		0.011
		5D ²	3.5	2.5	0.2	2.5	U/U		0.4	2.5	U/U		0.6	2.5	U/U		0.3	2.5	U/U		1.0	2.5	U/U		0.340
		10	9.5	8.0	0.2	2.5	U/U		0.3	2.5	U/U		0.5	2.5	U/U		0.2	2.5	U/U		0.8	2.5	U/U		0.067
		15	12.5	11.0	0.9	2.5	J/U		0.3	2.5	U/U		0.5	2.5	U/U		0.2	2.5	U/U		0.8	2.5	U/U		0.019
		20	17.0	16.5	6.2	0.7	J/J		0.9	2.0	J/U		0.4	2.0	U/U		0.2	2.0	U/U		0.8	2.0	U/U		0.011
		25	21.5	22.0	0.2	3.4	U/U		0.3	3.4	U/U		0.5	3.4	U/U		0.2	3.4	U/U		0.9	3.4	U/U		0.007
		30 ⁵	26.5	29.5	11.0	6.4	-/-		2.1	1.6	J/J		0.4	2.4	U/U		0.2	2.4	U/U		0.7	2.4	U/U		0.011
		35	31.5	33.0	80.0	11.0	-/-		15.0	2.4	-/J		0.5	2.4	U/U		0.2	2.4	U/U		4.4	2.4	J/U		0.008
		40	39.0	35.5	95.0	34.0	-/-		16.0	6.4	-/-		0.5	2.3	U/U		0.2	2.3	U/U		5.6	2.3	J/U		0.017
		45	43.0	44.9	38.0	7.2	-/-		7.6	1.6	J/J		0.5	2.3	U/U		0.2	2.3	U/U		2.3	2.3	J/U		0.004
		50	49.9	48.0	5.3	6.2	J/-		1.2	1.0	J/J		0.4	2.4	U/U		0.2	2.4	U/U		0.7	2.4	U/U		0.009
		55	54.5	52.5	69.0	20.0	-/-		13.0	2.0	-/J		0.4	2.4	U/U		0.2	2.4	U/U		3.8	2.4	J/U		0.007
		60	55.5	56.0	65.0	6.9	-/-		12.0	6.7	-/-		0.4	2.4	U/U		0.2	2.4	U/U		3.1	2.4	J/U		0.012
		65	N/A	63.0	N/A	7.0	-/-		N/A	2.7	-/U		N/A	2.7	-/U		N/A	2.7	-/U		N/A	2.7	-/U		0.019
					30.9	8.6		72.2	5.8	2.9		50.0	0.5	2.5		-429.2	0.2	2.5		-1057.2	2.1	2.5		-19.0	0.015
001-318 ³ & 001-347	7/30/2012 & 3/15/2016	5	3.0	3.5	0.2	2.2	U/UX		0.3	2.2	U/U		0.4	2.2	U/U		0.2	2.2	U/UX		0.8	2.2	U/U		0.580
		10	9.0	7.5	0.2	0.9	U/J		0.3	2.4	U/U		0.5	2.4	U/U		0.2	2.4	U/U		0.9	2.4	U/U		0.009
		15	13.0	11.0	0.2	25.0	U/-		0.3	22.0	U/-		0.4	3.0	U/U		0.2	4.9	U/J		0.8	3.0	U/U		0.022
		20	19.0	16.0	0.2	2.3	U/U		0.3	2.3	U/U		0.4	2.3	U/U		0.2	2.3	U/U		0.7	2.3	U/U		0.020
		25	20.5	23.0	0.2	3.9	U/U		0.3	3.9	U/U		0.4	3.9	U/U		0.2	3.9	U/U		0.7	3.9	U/U		0.170
		30	29.0	27.0	65.0	95.0	-/-		47.0	37.0	-/-		0.4	2.6	U/U		0.2	2.6	U/U		2.4	2.6	J/U		0.004
		35 ⁵	34.0	30.5	200.0	90.0	J/-		190.0	39.0	J/-		4.1	2.4	U/U		14.0	2.4	U/U		12.0	2.4	U/U		0.003
		40	35.5	35.5	190.0	46.0	J/-		190.0	34.0	J/-		4.2	2.3	U/U		14.5	2.3	U/U		12.5	2.3	U/U		0.007
		45	41.0	40.1	61.0	91.0	-/-		44.0	67.0	-/-		0.5	2.7	U/U		0.2	2.7	U/U		3.5	3.3	J/J		0.009
		50	46.0	46.5	19.0	29.0	-/-		5.9	7.2	J/-		0.5	2.5	U/U		0.2	2.5	U/U		1.9	2.5	J/J		0.006
		55	50.5	52.5	6.4	27.0	J/-		1.6	36.0	J/-		0.4	2.7	U/U		0.2	2.7	U/U		0.7	2.7	U/U		0.010
		60	56.5	55.1	22.0	18.0	-/-		22.0	49.0	-/-		0.4	2.3	U/U		0.2	2.3	U/U		0.8	2.3	U/U		0.002
		60D ²	56.5	55.1	22.0	12.0	-/-		22.0	11.0	-/-		0.4	2.4	U/U		0.2	2.4	U/U		0.8	2.4	U/U		0.007
		65	N/A	60.1	N/A	30.0	-/-		N/A	170.0	-/-		N/A	2.5	-/U		N/A	2.5	-/U		N/A	2.5	-/U		0.007
					47.0	35.9		23.8	41.8	25.2		39.8	1.1	2.6		-145.9	2.5	2.8		-8.8	3.1	2.7		15.1	0.065
001-322 ³ & 001-351	8/8/2012 & 3/21/2016	5	4.0	2.5	0.2	4.1	U/UX		0.3	4.1	U/U		0.5	4.1	U/U		0.2	4.1	U/U		0.8	4.1	U/U		0.340
		10	9	8	0.2	2.6	U/U		0.3	1.4	U/J		0.5	2.6	U/U		0.2	2.6	U/U		0.8	2.6	U/U		0.160
		15	10.1	11.5	0.2	3.4	U/U		0.3	3.4	U/U		0.4	3.4	U/U		0.2	3.4	U/U		0.8	3.4	U/U		0.180
		20	NA	15.1	N/A	2.4	-/U		N/A	2.4	-/U		N/A	2.4	-/U		N/A	2.4	-/U		N/A	2.4	-/U		0.130
		25	21.5	20.5	0.2	2.7	U/U		0.3	2.7	U/U		0.5	2.7	U/U		0.2	2.7	U/U		0.9	2.7	U/U		0.230
		30	29	26.5	32.0	3.6	-/U		21.0	3.6	-/U		0.5	3.6	U/U		1.4	3.6	J/U		0.9	3.6	U/U		0.120
		35	34.9	32.0	5.8	2.4	J/U		3.9	2.4	J/U		0.5	2.4	U/U		0.2	2.4	U/U		0.8	2.4	U/U		0.410
		40	35.1	36	4.5	2.3	J/U		2.3	2.3	J/U		0.4	2.3	U/U		0.2	2.3	U/U		0.8	2.3	U/U		0.310
		45	44.5	41	100.0	2.6	-/U		50.0	2.6	-/U		0.4	2.6	U/U		0.2	2.6	U/U		0.8	2.6	U/U		0.340
		50	48.5	46.5	80.0	2.4	-/U		46.0	2.4	-/U		0.4	2.4	U/U		0.2	2.4	U/U		0.8	2.4	U/U		0.410
		55	54.9	51.5	53.0	2.3	-/U		34.0	2.3	-/U		0.4	2.3	U/U		0.2	2.3	U/U		0.8	2.3	U/U		0.230
		60	57.5	55.1	3.2	2.8	J/U		3.1	2.8	J/U		0.5	2.8	U/U		0.2	2.8	U/U		0.9	2.8	U/U		0.860
		65	N/A	61.0	N/A	1.0	-/J		N/A	6.9	-/-		N/A	2.2	-/U		N/A	2.2	-/U		N/A	2.2	-/U		0.082
					25.4	2.8		88.8	14.7	2.7		81.4	0.5	2.8		-523.4	0.3	2.8		-796.6	0.8	2.8		-256.6	0.292
		Percent TCE Reduction for Columns Outside Mixed Areas ⁶					61.6																		

Notes:

¹ For analytical results reported as non-detect (ND) or identified with a U qualifier, a value equal to one half of the reported result is shown in this table and was used to calculate the average borehole soil VOC values which were then rounded to the nearest 0.1 number.

² Denotes duplicate (QA/QC) sample, duplicate samples were not used in the sample VOC averaging calculations. Also only results in which there is both pre- and post- results are included in the averaging calculations. Duplicate (QA/QC) sample is from the post-remedial soil boring. A duplicate from this location was not collected during pre-remedial sampling; therefore, the associated primary pre-remedial samp

³ N/A indicates that soil sample was not collected for the interval due to loss of core, insufficient sample volume, or drilling refusal. N/A also indicates that area was not sampled during specific project phase.

⁴ Qualifier Definitions: U - Non-detect; J - Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value; X - Surrogate is outside control limits. Dash (-) indicates that qualifiers are not applicable.

⁵ Indicates soil sample split with Commonwealth of Kentucky. Following samples split: 001-333-15, 001-337-30, 001-341-55, 001-347-35.

⁶ TCE Average Percent Reduction is derived using the calculated average concentration of Pre-Remedial and Post-Remedial contaminant values for each soil boring set. Borehole Equation: (Average Pre-Remedial - Average Post-Remedial)/ Average Pre-Remedial * 100 = Average Percent Reduction.

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Six monitoring wells were installed around SWMU 1 to provide a network to examine contaminant trends after remedy implementation and assess progress toward achieving remediation goals outside of the treatment area (Figure 7). The monitoring wells have screened depths as shown in Table 8, which is in the top of the HU-5 gravel interval. Pumps were installed in the wells on June 15, 2016, and the first sampling event has been performed. As discussed in Section 3.3.2, “RGA Monitoring Wells,” the new monitoring wells and MW161 will be sampled periodically, as described in the RAWP, during the next two years.

Following that time period, FFA managers will determine an agreed to sampling schedule for the outyears.

Table 8. SWMU 1 Post-remediation Monitoring Wells

Well	Plant Coordinate Location		Screen Depth Interval, ft (BGS)
	Northing	Easting	
MW542	-1702.566	-6807.283	62.75–67.75
MW543	-1729.878	-6759.590	66.25–71.25
MW544	-1815.096	-6818.110	62.25–67.25
MW545	-1688.405	-6904.296	58.25–63.25
MW546	-1743.237	-6965.679	65.0–70.0
MW547	-1702.970	-6941.954	63.75–68.75

4.2 TABULAR SUMMARIES

4.2.1 Quantities Excavated (Soil Columns Treated)

The RDR included a total of 262 soil columns to be treated to a depth of 60 ft. Ultimately, soil mixing activities were completed at 258 soil columns. Four soil columns (9, 10, 21, and 259) were not soil mixed due to being located inside a radiological contamination zone. Nineteen soil columns met with refusal to soil mixing for unknown reasons and were terminated above the planned 60-ft treatment depth. A detailed explanation supporting the deletion of the four soil columns from the soil mixing list and soil columns that met with refusal is contained in Section 4.5, “Lessons Learned/Problems Encountered.” The estimated soil volume treated was 26,972 yd³.

4.2.2 Volatile Organic Compounds Removed

Operational data, including VOC concentrations obtained from the online GCs and extracted vapor flow rates obtained from system instrumentation, was collected during the *in situ* LDA soil mixing process and identified for each boring. Given that the GCs only were capable of obtaining VOC concentrations every 2–3 minutes and flow rate readings were recorded every 10 to 15 seconds, a key assumption, used in the calculation, assumes that the VOC concentrations measured by the GCs remained constant during operations until the next set of VOC concentration data was collected. Correlated sets of VOC concentration data and vapor flow rate data were then used to determine quantities of VOCs recovered for a given duration. These values are summed and reported as total volumes for each VOC analyzed by the GCs during mixing a specific boring. Statistical analysis based on error and uncertainty of the instrumentation used to calculate the operational data was assessed and a 95% confidence interval was calculated for the total VOCs removed during operations. See Appendix C for detailed methodology and data used for this analysis. Based on operational data, total VOCs removed as a result of the *in situ* LDA soil mixing process are estimated to be 24 ± 12 gal with a 95% confidence interval.

Analytical data obtained from samples of the vapor carbon indicated loading concentrations of 10,000,000 µg of TCE per kilogram of carbon and 3,500,000 µg of 1,2-DCE per kilogram of carbon, while remaining analytes (1,1-DCE and VC) were below the detection limits. Given that each carbon vessel holds approximately 5,000 lb of carbon and four vessels were installed in the vapor treatment portion of the process, an estimated total quantity of 20,000 lb of carbon was used. Using the analytical data and total quantity of carbon used during operations, mass removal of the specific VOCs was determined to be 200 lb of TCE and 70 lb of 1,2-DCE. Dividing each analyte's weight by its respective liquid densities, a total volume of 23 gal was calculated for both TCE and 1,2-DCE. Quantities calculated based on analytical data fall within the 95% confidence interval previously calculated based on field measured data and supports the 24 ± 12 gal estimate.

4.2.3 Clean-up Levels Achieved

Eight soil borings were drilled in the soil-mixed treatment area to assist in determining attainment of soil cleanup values for the UCRS soils mixed. The TCE cleanup level for the RA is 73 ppb. The TCE concentrations for the 8 pre- and post-mixing borings in the mixed zone show the cleanup level was attained for all of those borings with a 99.3% overall arithmetic average reduction (excluding duplicates) in TCE contamination. Those results are shown graphically in Figure 25 and in Table 6. Figure 26 shows the maximum TCE concentrations pre-treatment versus post-treatment.

4.2.4 Material and Equipment Used

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 27. General unit processes shown include LDA soil mixing; hot air/steam generation and delivery; vapor extraction and conditioning; recovered-liquid storage, liquid treatment, and disposal; ZVI mixing and delivery; and vapor treatment. These are described in the following sections.

Major Equipment and Tools. Major equipment and tools used for soil mixing included a crane, Stephen Haine LDA, Kelly bar, and drill platform. The soil mixing rig was comprised of a crawler-mounted lift crane (Manitowoc 777, 200-ton crane), with a 90-ft long by 13.5 inch diameter hollow drill stem (Kelly bar) driven by a high-torque transmission (Hain drilling platform and turn-table) capable of producing a range of torque of approximately 100,000 to 450,000 ft-lb of torque and capable of achieving a design soil mix depth of 60 ft bgs (62 ft below the original land surface elevation based upon the excavation of the upper 4 ft of soil in the mixing treatment area and placement/recompaction of 2 ft of the excavated soil prior to implementation), Figure 28. A swivel assembly attached to the end of the crane boom cables served as the connection point for the Kelly bar, allowing the bar to rotate freely for drilling. In addition, the swivel served 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 multi-blade rotating mixing/injection tool (auger) with a diameter of 8 ft was 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 and treat VOCs. The mixing tool included injection ports every 8 to 10 inches along the back side of the mixing blade to achieve distribution of hot air/steam and injected ZVI throughout the mixed soil column. The mixing rig operated on wood crane mats that provided stability, maintained vertically plumb mixing, and reduced contamination of drill rig tracks. The mixing rig was capable of reaching outward from the toe of the crawler tracks (crane front) up to two rows of overlapped column locations. The Kelly bar vertical alignment was controlled by adjusting the crane mats, drill platform, or the cables that suspended the turntable and/or by slightly booming up or down as necessary.

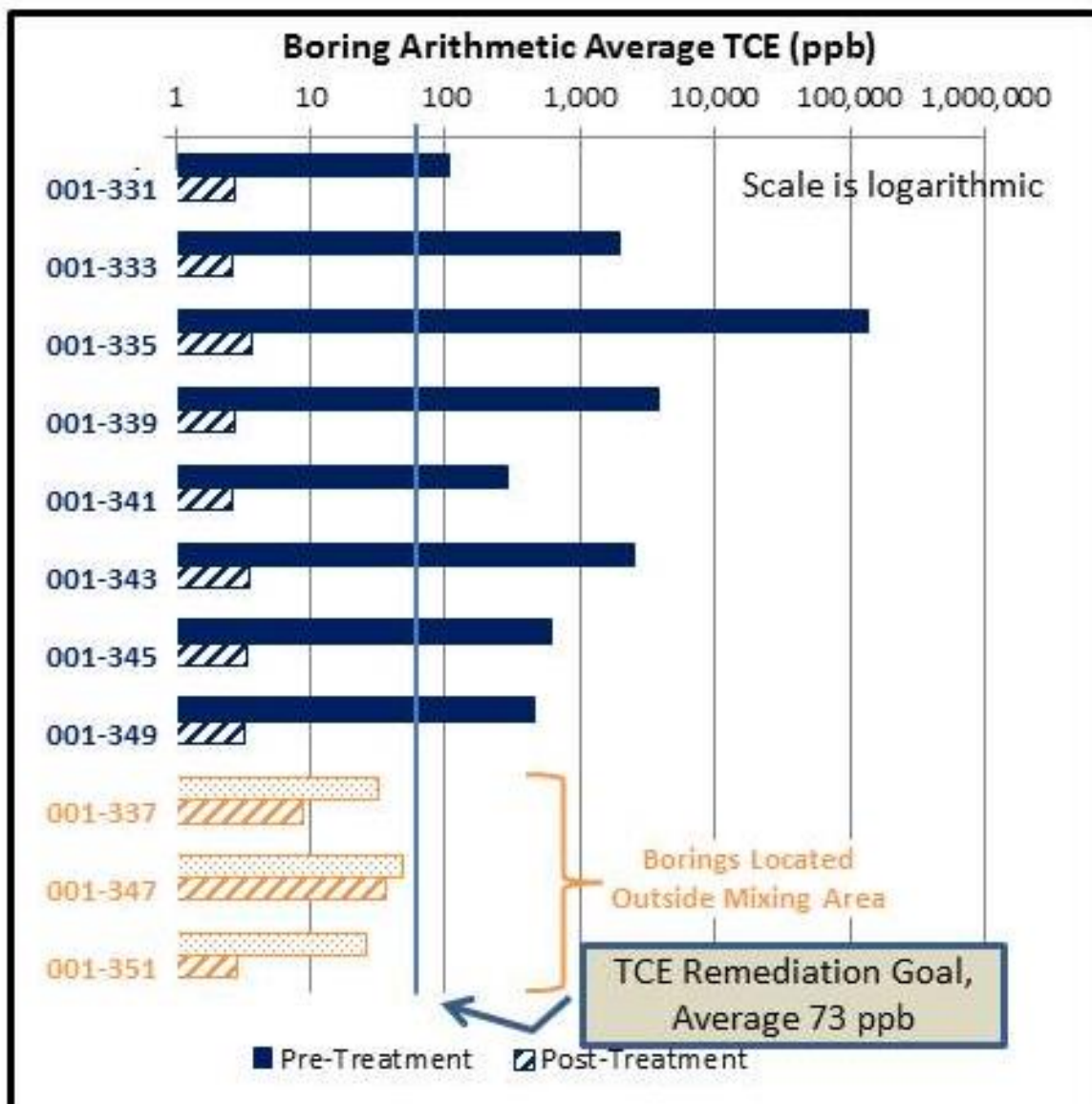


Figure 25. Arithmetic Average TCE Concentrations in Pre- and Post-Mixing Soil Borings

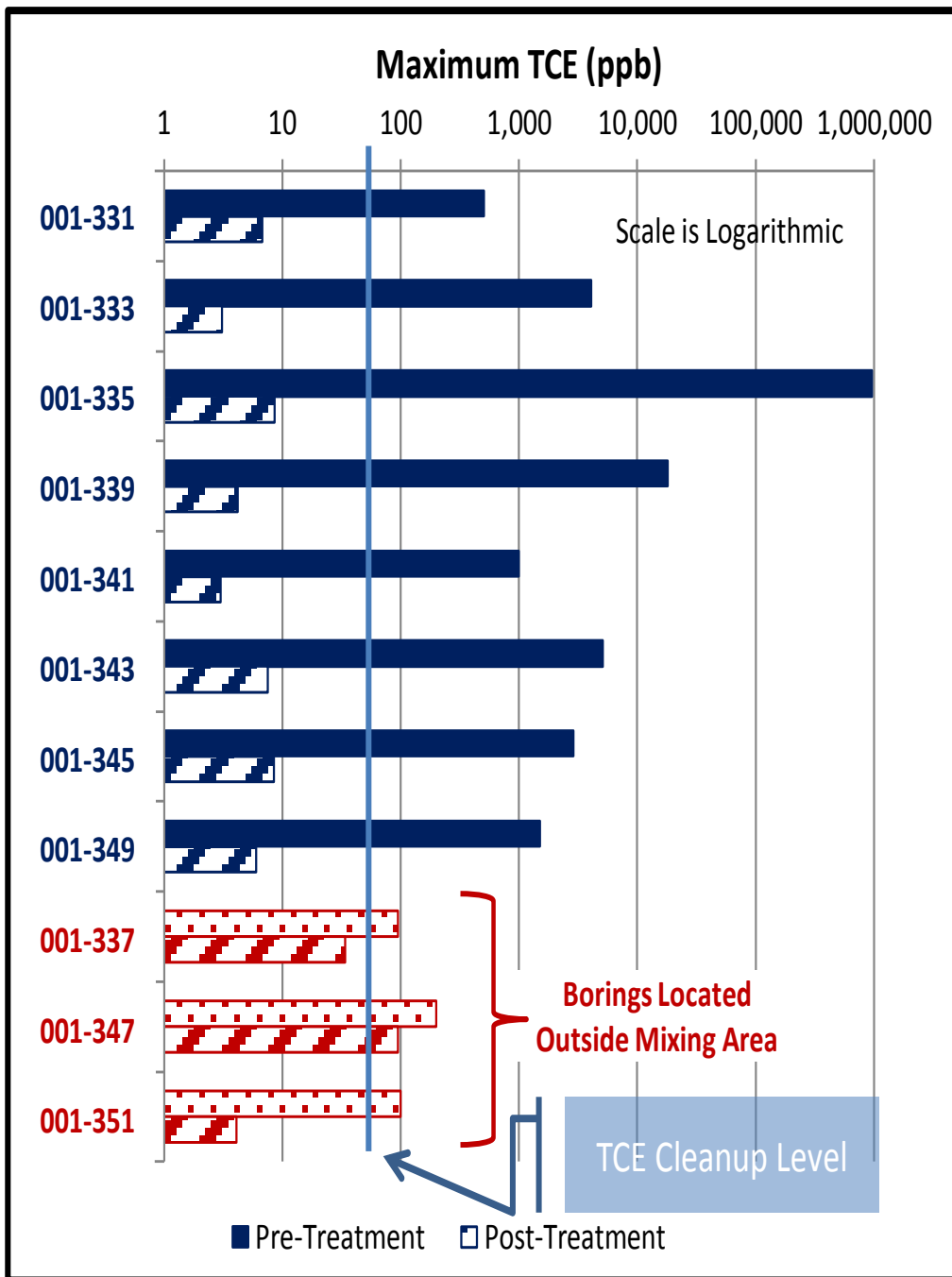
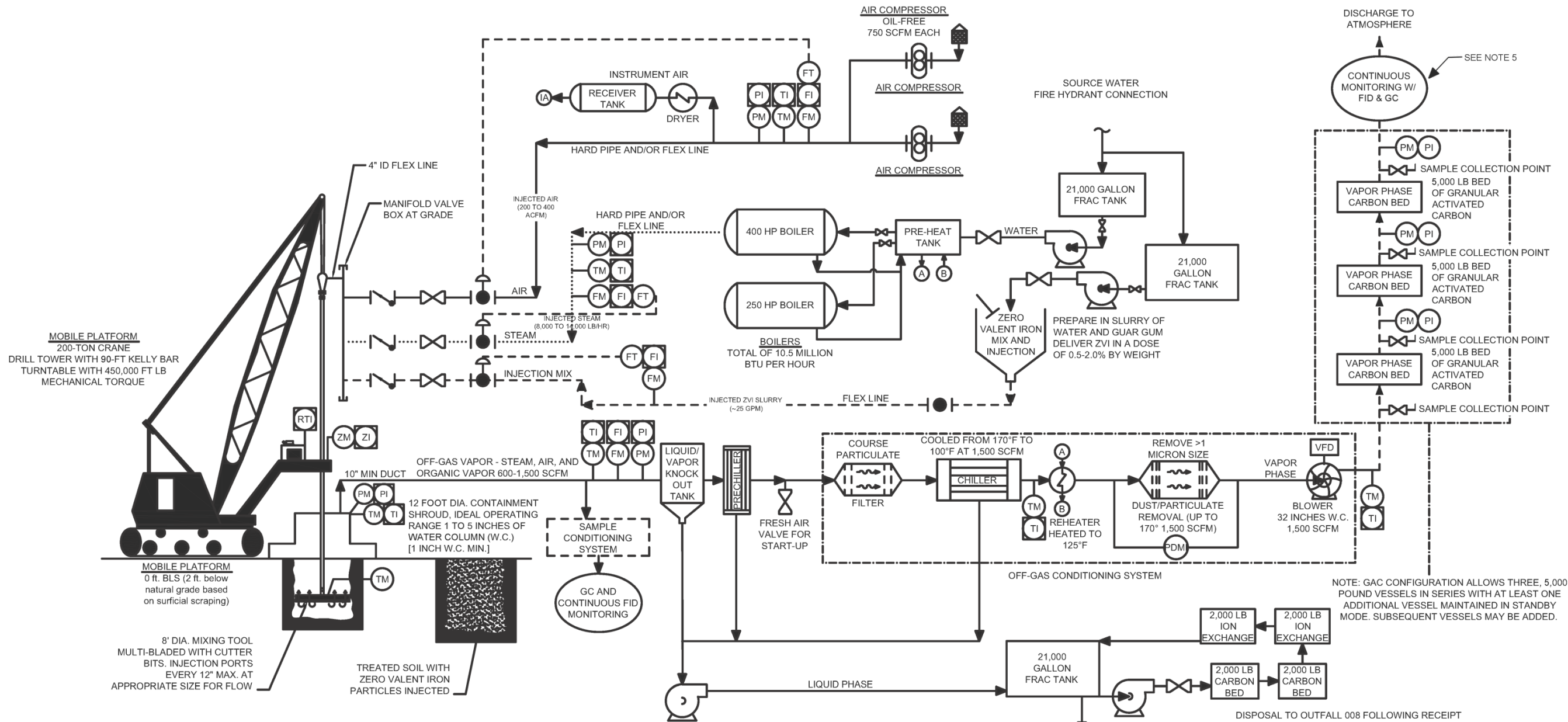


Figure 26. Maximum TCE Concentrations in Pre- and Post-Mixing Soil Borings



NOTES

1. AREA OUTSIDE THE CONTAINMENT SHROUD SHALL BE MONITORED MANUALLY WITH AN ORGANIC VAPOR ANALYZER TO VERIFY THAT OFF-GAS IS CAPTURED BY THE SHROUD.
2. THE CONTRACTOR SHALL PROVIDE AND OPERATE AN INTEGRATED DATA ACQUISITION SYSTEM (DAS) CAPABLE OF CONTINUOUS MONITORING AND RECORDING ALL PROCESS CONTROL PARAMETERS AT A CENTRAL LOCATION.
3. DAS SHALL BE CAPABLE OF PROVIDING DATA, AS INDICATED, IN REAL TIME FOR PROCESS CONTROL.
4. THE STORAGE TANKS SHOULD INCLUDE VENTS CONNECTED TO CARBON FILTERS TO CAPTURE FUGITIVE EMISSIONS.
5. PHOTOACOUSTIC ANALYZER (PAA) TO BE REPLACED WITH FLAME IONIZATION DETECTOR (FID) AND GAS CHROMATOGRAPHS (GC) FOR CONTINUOUS MONITORING OF SYSTEM DISCHARGE.

LEGEND

	BALL VALVE		VARIABLE FREQUENCY DRIVE		FLOW MEASUREMENT		PRESSURE DROP MEASUREMENT/INDICATOR
	BUTTERFLY VALVE		IN-LINE CENTRIFUGAL PUMP		POSITION INDICATOR		RUN TIME INDICATOR
	CHECK VALVE				PRESSURE INDICATOR		INDICATOR ON DAS
	GATE VALVE		POSITION MEASUREMENT		TEMPERATURE INDICATOR		INSTRUMENT AIR
	PNEUMATIC ACTUATED		PRESSURE MEASUREMENT		FLOW INDICATOR		FROM BOILER PRE-HEAT WATER TANK (180°F)
	NORMALLY CLOSED		TEMPERATURE MEASUREMENT		FLOW TRANSMITTER		TO BOILER PRE-HEAT WATER TANK (170°F)
	NORMALLY OPEN						
	SAMPLING PORT						

Figure 27. Remedial Process Flow Diagram

U.S. DEPARTMENT OF ENERGY
DOE PORTSMOUTH/PADUCAH PROJECT OFFICE
PADUCAH GASEOUS DIFFUSION PLANT

FLUOR

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Figure 28. Manitowoc Crane and Soil Mixing Assembly

Hot Air/Steam Generation and Delivery System. Hot air was generated by drawing ambient air through two electrically powered air compressors capable of providing airflow of 750 actual cubic ft per minute (acfm). A filter bank was used in-line to remove entrained oil from the generated air flow. Injection pressure, temperatures, and flows were monitored and controlled during operations by the operational crew utilizing a Labview[®] software system. Hot air was delivered to the subsurface at variable flow rates and at typical temperatures of approximately 385°F at a maximum operating pressure of 150 lb per square inch gauge (psig). Operating parameters were measured and assimilated by a data acquisition system and monitored using the Labview[®] interface.

The steam generating system was comprised of two diesel-powered steam boilers [one 400-horsepower (hp) and one 250 hp] with the capability of producing steam and/or hot air at a minimum temperature of 385°F from a facility-supplied water source that was supplied by the PGDP potable water system. During soil mixing operations, supplied water was softened, converted to steam, and injected at variable flow rates of up to 14,000 lb per hour (pph) at a maximum operating pressure of 135 psig. Braided steel and rubber hoses transferred the steam from the boilers to the manifold and rubber hoses were utilized to connect the manifold to the drill stem (Kelly bar). Steam injection flow rate, pressure, and temperature were collected and monitored through a data acquisition system. The system parameters were controlled by FECC operators during mixing operations.

Off-Gas Extraction and Vapor Conditioning System. As the mixing blade rotated into the subsurface and hot air and steam were injected in the soils, VOCs rose to the surface through the annulus created by the soil mixing process and associated pressure gradient. The contaminants were collected within a 12-ft diameter steel shroud that provided capture of VOCs. The shroud covered the ground surface around the boring location that was penetrated by the rotating Kelly bar providing a minimum 12-ft diameter radius of influence for vapor collection. The shroud was set to penetrate the surface to approximately 1-ft bgs. The shroud provided the ability to capture off-gases beyond the diameter of the 8-ft diameter drilling blades. A blower connected to the shroud provided a vacuum on the shroud for vapor recovery and transfer to the Vapor Conditioning System. The blower connected to the shroud generated a variable air flow rate of 600 to 1,500 standard cubic ft per minute (scfm). An applied shroud vacuum of 1 to 5 inches of water was established prior to soil mixing and maintained throughout soil mixing activities at each boring location. Establishment of the shroud vacuum prior to soil mixing provided a mechanism to confirm that the shroud provided an effective seal around the auger borehole location.

The vapor conditioning system (VCS) consisted of a blower to create the vacuum, liquid-vapor knockout (KO)/demister tank, air filter, chiller, transfer pumps, and reheater/heat exchanger. The vapor entering the shroud from the borehole annulus was highly saturated with water; therefore, the vapors initially flowed through a liquid vapor KO tank to remove large dirt particles and moisture. The vapors then flowed from the KO tank into a chiller unit used to cool the gas (typically to a temperature of less than 90°F). General VCS equipment specifications are included as follows:

- **Blower**—A centrifugal pressure blower rated for 1,800 ft³ per minute at 31 inches total static pressure @ 13.4 BHP using a 15 hp 230-460/3/60 VAC totally enclosed fan cooled premium efficiency motor [for use with a variable frequency drive (VFD)]. National Electrical Manufacturers Association 4-rated VFD motor speed control rated for a 15 hp motor and 460 VAC/3 phase input from a generator.
- **Knockout Tank**—The KO tank consisted of a 44-inch diameter by 72-inch high steel vessel with hose connections for processing air in and out, a sludge drain port with gate valve, and a connection for feeding to a transfer pump. The KO tank included three float switches for pump on/off control and a high water alarm.

- **Chiller**—The chiller unit consisted of a TRANE 70T [840,000 British thermal units per hour (BTU)/hr] air cooled water chiller. This unit was capable of cooling the gas flow temperature from approximately 160°F to less than 90°F at a flow rate of 1,300 scfm. The chiller was coupled with a heat exchanger. The heat exchanger was an Aerofin Type Rf coil 34.9-inch by 25-inch, six-row with copper fins on 5/8-inch copper tubing with a galvanized steel case. The housing for mounting the coil, inlet filters, inlet and outlet connections was 14 gauge galvanized steel. The drain pan was 304 stainless, 14 gauge, with a 3/4-inch national pipe thread drain connection.
- **Particulate Filter**—Included in the chiller unit housing was a 25-inch by 16-inch by 2-inch stainless steel mesh filter (F-101) for particulates.
- **Condensate Pump and Discharge Pump**—These pumps were commercial off-the-shelf, 1/2-hp water pumps (or approved equivalent) for pumping out the collected water from the knockout tank and chiller condensate to the VOC water holding tank.
- **Reheater**—The reheat unit along with the blower heat of compression raised the temperature and reduced the relative humidity to less than 80%. The coil was housed in the same housing as the chilled water heat exchanger and was designed to produce 150,000 BTU/hr maximum using 180°F water from the boiler preheat tank. A hand valve on the upstream side of the reheater controlled the water flow and subsequent heat capacity.

Condensate water generated by the KO tank chiller was transferred and stored in a frac tank(s) characterized and treated as needed prior to discharge to a PGDP outfall (e.g., Outfall 008), in accordance with applicable or relevant and appropriate requirements (ARARs). Additionally, recovered condensate water from each frac tank for characterization was analyzed for VOCs and nontarget/non-VOC contaminants to establish whether additional treatment measures were necessary prior to discharge. Cooled vapor entered the reheater/heat exchanger to raise the off-gas temperature in order to reduce the off-gas relative humidity to less than 80% (thereby increasing the efficiency of the vapor-phase carbon adsorption system). Vapor then flowed through an air filter to remove fine particulates prior to entering vapor-phase granular activated carbon (GAC) treatment systems. The VCS was monitored with the Labview[®] software system and controlled during operations.

Liquid Treatment System (Liquid-Phase Carbon Adsorption and Ion Exchange). Condensate water generated by the KO tank chiller was transferred and stored in a fractionation tank(s). The frac tanks were enclosed and vents were covered with vapor-phase carbon filters to prevent fugitive VOC emissions. The collected condensate water was treated in a closed-loop recirculation treatment system consisting of 2 liquid-phase GAC connected in series to remove contaminants and sampled prior to discharge to a PGDP outfall (e.g., Outfall 008) (in accordance with ARARs). The liquid-phase carbon vessels were used primarily for removal of VOCs, polyaromatic hydrocarbons, and PCBs, if present in the condensate water. Condensate water was pumped via submersible pump capable of producing a flow rate of 50 gpm placed in the frac tank. Condensate water was recirculated through the treatment system for a minimum of 24 hours (equal to approximately 4 treatment volumes of collected condensate water). Following a 24-hour treatment period and prior to discharge, treated condensate water from each frac tank was analyzed for VOCs and non-target/non-VOC contaminants. Laboratory analysis established whether additional treatment measures were necessary or if discharge could occur. If the treated condensate water met the established treatment criteria for a PGDP outfall (e.g., Outfall 008), the treated effluent was discharged accordingly. While laboratory results were pending, additional condensate water produced by the treatment system was collected in a separate frac tank. The condensate water treatment system was used for treating condensate water collected within other frac tanks while laboratory results were pending. Once the water analysis was complete and the water was approved for release, the water was released through one of the PGDP outfalls.

Vapor Treatment System (Vapor-Phase Carbon Adsorption). Conditioned vapors exiting the VCS were treated on-site utilizing four 5,000-vapor-phase GAC adsorption vessels connected in series. The GAC vessels provided a total holding capacity of 20,000 lb of virgin, vapor-phase GAC and was capable of treating the VCS maximum airflow 1,500 scfm. To monitor the GAC for breakthrough, the effluent from the final GAC vessel was monitored continuously during active operations using FID and GC. The analyzer communicated with the control system to notify operations personnel in the event of an exceedance of discharge criteria. GAC vessel change out was not required during the treatment of SWMU 1. The vapor carbon vessels were returned to the manufacturer along with the used carbon. The carbon was regenerated for reuse.

ZVI Mixing and Delivery System. A slurry mixture consisting of granular ZVI, water, and guar gum (to facilitate ZVI injection into the soil) was prepared on-site and delivered on the final downward pass of the LDA at each boring location. The ZVI used for the action was a Peerless Metals Products, Detroit, Michigan product known as PMP 50D. The quantity of ZVI mixed into each soil column ranged from 0.5% to 2.0%, depending on the level of contamination identified in the soil column or depending on the soil column location. All soil columns within the 10,000 ppb TCE contour of the soil mixing area automatically received 2.0% iron. To create the ZVI slurry mixture, ZVI was suspended in the guar gum slurry at a rate of approximately 5 to 9 lb of ZVI per gal of water, and guar gum was mixed at a rate of approximately 60 to 80 lb per 1,000 gal of water. ZVI preparation and delivery equipment consisted of mixing tanks of a minimum of 500 gal each, a high-shear slurry mixer (5 yd³ High Shear Lightning Mixer), a progressive cavity pump (L-12 Moyno pump), and a high viscosity flow meter. The quantity of materials used in mixing the ZVI and guar gum slurry is discussed in Section 4.2.5.

Vapor Monitoring/Testing System. Operational parameters (frequencies of data collection, monitoring, and associated reporting) of the previously mentioned monitoring protocol were discussed throughout applicable portions of Section 4. Gas samples from the process streams were collected from the vapor extraction system for analysis by a FID, after methane subtraction, and/or a GC. GCs were used to detect, speciate, and quantify target analytes from the treatment process off-gas. FIDs were used to monitor continuously the vapors produced by the treatment process. Data from the FIDs and GCs were utilized to evaluate VOC trends in depth, concentration, and location of contamination mass requiring focused treatment (i.e., additional mixing time, etc.). Real-time monitoring of the point of atmospheric emission was monitored with an FID and GC. This monitoring triggered a notification to the equipment operator as required by the RDR. The operator evaluated the conditions and made the determination that it was appropriate to continue operations. This was a single instance in which the alarm was activated.

The Data Acquisition System consisted of the two SRI GCs 8610, and field instruments served by three Automation Direct 205 programmable logic controllers that provided data input to a personal computer. The data was monitored and recorded in real time. Labview[®] software displayed, in real time, selected parameters and recorded at a selected rate of six times a minute. The recorded data were viewed and saved in a Microsoft Excel spreadsheet.

4.2.5 Material Used for Column Mixing

Total amount of materials used during implementation of the chosen RA was tabulated from operational data captured in field logbooks.

Granular ZVI was used in conjunction with guar gum and water to provide additional treatment to residual VOCs within the source area.

Preparation of the ZVI, guar gum, and water mixture was in accordance with the RDR. ZVI dosing concentration was measured as a percentage mass of ZVI to mass of soil application. ZVI concentration

dosing was based on observed FID data, as outlined in Section 4.2 of the RDR. Based upon the RDR, soil columns within the area greater than 10,000 ppb TCE isoconcentration contour area were treated with a default application of no less than 1.5%, but not greater than 2% ZVI, regardless of FID response. This range of concentration was presented based on practical limitations to injection of 2% ZVI observed at other sites.

Table 9 shows the total amounts of ZVI slurry material used during deep soil mixing of 258 columns at SWMU 1.

Table 9. Material Quantities Used in ZVI Process

Zero-Valent Iron (lb)	Guar Gum Total (lb)	Water Total (gal)	Quicklime for Soil Stabilization (lb)
958,395	17,272	193,435	278,000

4.2.6 Waste Materials Generated

The implementation of the RA resulted in the generation of waste materials. The wastes generated included soil, wastewater, solids, recyclable solids and oils, and general refuse. The soils were generated from the excavation of contaminated soils and alumina trap material. Wastewater was generated from the operation of the vapor conditioning system, decontamination of equipment, and entrained water recovered from the vapor phase. Recyclable solids were generated from the returning of the approximately 20,000 lb of activated carbon for regeneration. Recyclable liquids included the gear lube, off-specification diesel fuel, and transmission fluids that were generated in performing both routine and nonroutine maintenance on equipment. General refuse included materials that were decontaminated as necessary such as hoses, plastic, empty super sacks, pallets, broken wood, wire, cardboard, and paper. Table 10 shown below contains the estimated volumes of the waste materials generated in the implementation of the RA and associated supporting activities. Waste was dispositioned in accordance with ARARs.

Table 10. SWMU 1 Remedial Action Waste Generation

Waste Stream	Volume (Ft³)	Disposition
Drill Cuttings/Soil, PPE, and Sampling Debris	861	Landfill
Carbon	888	Recycle
Wastewater	917	Treated and discharged
Oil	57	Incineration

4.3 NAMES AND ROLES OF REMEDIAL ACTION CONTRACTORS

Fluor Federal Services, Inc./LSRS. Primary contractor to DOE at PGDP from July 27, 2015–present. Provided miscellaneous heavy equipment to support RA fieldwork; executed field excavation and replacement of soils; and provided utilities to SWMU 1 site during implementation of the chosen RA activities. LSRS, teaming partner with Fluor Federal Services, Inc., served as the primary point of contact with DOE for on-site environmental remediation and environmental management activities, including completing the RA at SWMU 1, Oil Landfarm. LSRS personnel oversaw field activities and verified that field operations followed established approved plans and procedures; provided oversight to verify work was completed in accordance with QAPP and data management and implementation plan; coordinated with project QA staff to ensure appropriate level of QA oversight; held responsibility for performance, quality, schedule, and budget of the RA at SWMU 1; and coordinated day-to-day activities of FECC.

LATA Kentucky. Primary contractor to DOE at PGDP from July 2010 to July 2015. LATA Kentucky served as the primary point of contact with DOE for implementation of environmental restoration programs.

FECC, Inc. LDA deep soil mixing specialty subcontractor used for performing the chosen RA at SWMU 1. Supplemental manpower used to support deep soil mixing activities, including material suppliers and equipment vendors, were sourced locally by FECC.

Chase Environmental Group. Drilling subcontractor used for subsurface borings for post-treatment sampling and monitoring well installation. Chase Environmental was supported by Columbia Systems Inc., for the collection of conductivity and temperature logging.

4.4 PARTICIPATION BY OTHER FEDERAL AGENCIES

DOE is the lead agency for the implementation of SWMU 1 RA. EPA was a support agency for the implementation of the RA. EPA, KY, and DOE entered into an FFA in 1998 for the performance of remediation of the PGDP federal facility. EPA had signed the 2012 ROD selecting the RA for SWMU 1.

4.5 LESSONS LEARNED/PROBLEMS ENCOUNTERED

4.5.1 Columns Encountering Refusal

The target soil mixing depth for SWMU 1 mixing was 60 ft below the working grade surface. Of the 258 columns mixed, 19 did not reach this depth. Table 11 provides the column numbers and depths at which refusal was encountered. These columns are marked with light blue hatching and their corresponding column numbers in Figure 8. Soil columns meeting refusal during the previous week of operations were identified to the FFA parties during the weekly conference call. Refusal was reached at the point at which the mixing auger would not advance deeper after multiple attempts of raising the auger a few ft and then advancing downward in an effort to “push” through the problematic zone. This method of lifting and then lowering the auger was required in several columns to advance to total depth. This method was not successful in achieving target depth for the columns listed in Table 11. Also, the soil columns that met refusal were discussed on a weekly basis during the groundwater weekly call with FFA parties.

Repeated lifting and lowering of the mixing auger was also required in some columns where substantial overlap (25% or more) with an adjacent, previously mixed column was present. The auger would attempt to advance into disturbed soil of the previously mixed column, rather than the undisturbed portion of the target column, and would no longer be vertical. The crane operator would lift the auger back to a vertical position, and then allow it to advance slowly maintaining vertical orientation. The process was often repeated several times to allow advancing and maintaining a vertical column. None of the 19 columns encountering refusal were attributed to the overlap; however, production rates were impacted by additional time to complete mixing of columns with substantial overlap.

Table 11. Soil Columns Encountering Refusal

Column Number	Depth Refusal Encountered (ft)	Date	Notes
53	44	4/20/2015	Surrounding columns indicated very little contamination, so low probability of VOCs in area below point of refusal.

Table 11. Soil Columns Encountering Refusal (Continued)

Column Number	Depth Refusal Encountered (ft)	Date	Notes
36	48	5/21/2015	Surrounding columns indicated very little contamination, so low probability of VOCs in area below point of refusal.
230	51	7/13/2015	Columns to the east and west of the 230 column did not indicate significant contamination levels, and one column, Column 211 to the north, required greater than one thermal pass to complete thermal treatment. Considering little contaminant mass present in this column to point of refusal and very little mass present in columns to east and west, the probability is low of presence of substantial contamination in this column below the point of refusal.
246	52	8/12/2015	Surrounding columns indicated very little contamination, so likely low probability of VOCs in area below point of refusal.
145	52	8/15/2015 and 8/17/2015	The column had VOC contamination; however, mixing was able to achieve 52 ft of the 60-ft target depth, or over 80% of the column, indicating a majority of soil mass treated.
102	52	8/14/2015	The column had VOC contamination; however, mixing was able to achieve 52 ft of the 60-ft target depth, or over 86% of the column, indicating a majority of soil mass treated.
47	58.5	8/27/2015	Northern and northeastern portion of mixing treatment area indicates a higher elevation of the HU4/HU5 interface, indicating this column potentially reached that interface. Additionally, surrounding columns/cells indicated very little contamination, so likely low probability of VOCs in area below point of refusal.
32	55	8/26/2015	Northern and northeastern portion of mixing treatment area indicates a higher elevation of the HU4/HU5 interface, indicating this column potentially reached that interface. Additionally, surrounding columns indicated very little contamination, so likely low probability of VOCs in area below point of refusal.
33	58	8/27/2015	Northern and northeastern portion of mixing treatment area indicates a higher elevation of the HU4/HU5 interface, indicating this column potentially reached that interface. Additionally, surrounding columns indicated very little contamination, so likely low probability of VOCs in area below point of refusal.
48	58.5	8/28/2015	Northern and northeastern portion of mixing treatment area indicates a higher elevation of the HU4/HU5 interface, indicating this column potentially reached that interface. Additionally, surrounding columns indicated very little contamination, so likely low probability of VOCs in area below point of refusal.
20	57	8/24/2015	Northern and northeastern portion of mixing treatment area indicates a higher elevation of the HU4/HU5 interface, indicating this column potentially reached that interface. Additionally, surrounding columns indicated very little contamination, so likely low probability of VOCs in area below point of refusal.
34	56.5	8/24/2015	Northern and northeastern portion of mixing treatment area indicates a higher elevation of the HU4/HU5 interface, indicating this column potentially reached that interface. Additionally, surrounding columns indicated very little contamination, so likely low probability of VOCs in area below point of refusal.
49	57.5	8/29/2015	Northern and northeastern portion of mixing treatment area indicates a higher elevation of the HU4/HU5 interface, indicating this column potentially reached that interface. Additionally, surrounding columns

Table 11. Soil Columns Encountering Refusal (Continued)

Column Number	Depth Refusal Encountered (ft)	Date	Notes
			indicated very little contamination, so likely low probability of VOCs in area below point of refusal.
50	52	8/28/2015	Northern and northeastern portion of mixing treatment area indicates a higher elevation of the HU4/HU5 interface, indicating this column potentially reached that interface. Additionally, surrounding column indicated very little contamination, so likely low probability of VOCs in area below point of refusal.
51	58.5	8/27/2015	Northern and northeastern portion of mixing treatment area indicates a higher elevation of the HU4/HU5 interface, indicating this column potentially reached that interface. Additionally, surrounding columns indicated very little contamination, so likely low probability of VOCs in area below point of refusal.
52	52	8/29/2015	Northern and northeastern portion of mixing treatment area indicates a higher elevation of the HU4/HU5 interface, indicating this column potentially reached that interface. Additionally, surrounding columns indicated very little contamination, so likely low probability of VOCs in area below point of refusal.
90	57	9/14/2015	Northern and northeastern portion of mixing treatment area indicates a higher elevation of the HU4/HU5 interface, indicating this column potentially reached that interface. Additionally, surrounding columns indicated very little contamination, so likely low probability of VOCs in area below point of refusal.
154	54.7	9/16/2015	Northern and northeastern portion of mixing treatment area indicates a higher elevation of the HU4/HU5 interface, indicating this column potentially reached that interface. Additionally, surrounding columns indicated very little contamination, so likely low probability of VOCs in area below point of refusal.
195	56	9/28/2015	Northern and northeastern portion of mixing treatment area indicates a higher elevation of the HU4/HU5 interface, indicating this column potentially reached that interface. Additionally, surrounding columns indicated very little contamination, so likely low probability of VOCs in area below point of refusal.

4.5.2 Soil Burping

During soil mixing at SWMU 1, rapid returns of energy to the surface, or “burps” were encountered during soil mixing. The cause of the burps was determined to be related to the energy (steam and compressed air) being injected into the ground building up in the subsurface, and then returning to the surface in a rapid burst. The soil mixing subcontractor had encountered soils of similar grain size on prior projects that had resulted in soil burping. In past operations, however, they were able to control the soil burping with the use of drilling fluid additives and steam flow rate control. The PGDP remedial design anticipated the need for the drilling fluid because it had been included in the approved design. In the case of PGDP soils, the drilling fluid additives and steam flow rate controls were used, but were not effective at controlling the soil burping adequately. FECC reviewed the situation with their geotechnical engineer and identified that hydraulically slurring the column before soil mixing was the next control measure to try. It was found to be effective.

When these bursts of energy return to the surface, they result in a pressure build-up in the containment shroud, which is greater than can be removed by the vapor extraction system. The resulting pressure then exerts an upward force on the shroud and drilling platform. Operational changes were implemented to address and control this issue, including converting columns to a water-soil slurry as the first step of

mixing, implementing modifications to the mixing equipment to mitigate the energy transfer to the drill platform and crane should a burp occur; and providing additional flexibility to the soil mixing operator to adjust steam flow rates during column mixing. Further discussion of this field change is included in Section 1.2.3, “Field Changes.”

Excessive soil burping on seven columns (77, 79, 99, 112, 145, 186, and 209) resulted in the mixing operator pausing thermal treatment of these columns to allow the columns to stabilize. During the pause, mixing operations were relocated to another column. These seven columns required multiple steam passes to complete thermal treatment. Not all multiple pass columns required a pause during thermal treatment. Thermal treatment was completed successfully upon returning to the seven columns. However, additional equipment relocations were required to allow pausing and resuming operations on the seven columns. These columns were thermally treated on more than one day and information on those columns can be found in the operational logs in Appendix A.

4.5.3 Shroud Hose Failure

On April 17, 2015, during mixing operations on Column 134, the shroud vacuum hose failed by coming apart. This is the vacuum hose that pulls offgas from the shroud and conveys the offgas to the vapor conditioning treatment system. Steam injection was stopped, and air injection reduced to a minimum to keep the mixing tool injection ports clear of debris, and the mixing tool was brought back to the surface and secured. Personnel then monitored the area using a hand-held PID to verify no VOCs present, prior to repairing the hose.

Mud build-up under the shroud may have contributed to this breaking of the line. When the shroud was full of mud, there was no space for expansion of steam and air returning to the surface, so it occurred in the hose. To minimize this build up, an adjustment was made to the mixing protocol to bring the auger to the surface, hold until no VOCs were detected under the shroud, and then lift the shroud to allow any mud to evacuate the shroud. Additionally, a more robust shroud vacuum hose was procured and installed, which resolved this issue.

4.5.4 Drill Platform Engine and Transmission Failure

During ZVI treatment of Column 156 on April 29, 2015, the crane operator noticed an oil leak from the drill platform engine. Iron had been placed to a depth of 44 ft at time of the engine problem. The operator quickly stopped ZVI injection and brought the mixing tool to the surface, then shut down the engine. Troubleshooting and leak evaluation indicated a pushrod had failed on the diesel engine that powers the drill platform, resulting in a catastrophic engine failure. The subcontractor evaluated the timeline to complete repair or replacement and determined engine replacement could be achieved in a more timely manner. A compatible series engine was located, tested, and delivered to Paducah, and the external engine accessories (pulleys, water pump, brackets, etc.) necessary to allow installation on the drill platform was swapped from the damaged engine. The replacement engine was installed on May 7, 2015.

During testing of the platform after installation of the replacement engine, a leak in the platform transmission was identified. Troubleshooting of the leak was performed. Upon inspection of the internal component of the transmission, metal shavings were found inside transmission, indicating significant damage had occurred to internal transmission components. It could not be determined how, or if, the transmission failure and engine failure were related.

Both procurement of a replacement transmission and repair of the damaged unit were considered, with primary objective being timely return to mixing operations. Repairs were initiated on the damaged transmission. While assessing the timing to complete the repairs, a compatible replacement transmission

was located. Modifications were made by the manufacturer of the replacement transmission to allow installation into the drill platform, and the unit was transported by air freight for delivery to Paducah. The replacement transmission was installed on May 18, 2015. Testing of the engine and transmission then were conducted to verify appropriate operations. The auger was rotated (out of the ground) to allow a break in of the transmission without being under load, followed by a change of fluids and filters prior to resuming mixing operations.

Soil mixing activities resumed on May 18, 2015, returning to Column 156. The auger was advanced through this column with air and water to ensure proper operation of the engine and drilling platform, and then ZVI treatment of the column was repeated from 2 ft to 60 ft. As treatment of this column had been underway to a depth of 44 ft when the engine failed, the column essentially was treated twice in the 2 ft to 44-ft horizon.

4.5.5 Mechanical Issues during Mixing Operations

During soil mixing operations, as with any construction project, minor equipment corrective maintenance was required throughout the duration of the project. This corrective maintenance was in addition to the routine maintenance on equipment, such as oil and hydraulic fluid changes on crane, drill platform, and support equipment, daily fueling of equipment, GC and FID calibration, and relocating crane mats as mixing locations progressed. Additionally, the swivel located at the top of the Kelley bar required greasing on a daily basis, which required an individual to travel 90 ft up in a manlift to complete this service.

Most of the implemented corrective maintenance resulted in minor (a day or less) loss of mixing time, and, when possible, routine preventative maintenance actions also were performed during corrective maintenance repairs.

Following are examples of the required corrective maintenance during the project.

- Soil burp resulted in mud landing on overhead crane windshield (the windshield on top of cab that allows operator to see the top of crane boom), resulting in crack to windshield. After discussion with safety and the crane manufacturer, mixing operations continued until a replacement windshield was installed a few days later.
- An actuator failed on the crane hoist drum locking pawl. The actuator was taken apart, cleaned, and resumed normal operations. This allowed mixing operations to continue that same day. A replacement actuator was ordered and installed.
- The steam valve would not open and allow steam to flow to the mixing tool. Troubleshooting indicated the programmable logic controller circuit boards required cleaning and reconnection. Mixing resumed the same day.
- Flexible steam hose connecting steel pipe steam line from crane boom out to swivel developed a leak, which required replacement, with mixing resuming the next day.
- Swivel that connects Kelly bar to crane hook developed a steam leak. Mixing operations were temporarily halted and the unit was replaced with the spare.
- Following completion of a column and raising the mixing tool to move to next column, the tool was raised too high and came in contact with the bottom of the shroud. Repairs required disassembly and

straightening the rods that mounted the shroud to the drilling platform. Mixing operations resumed 2.5 days later.

- Following completion of soil mixing, in preparation for crane demobilization, the operator attempted to lower the crane mast while cables used to lift the counterweight tray were attached incorrectly, resulting in damage to the cables. These cables were not the cables used by the crane for normal lifting operations. The crane was inspected by the crane vendor for damage, and found to be in good working order other than the damaged cables. The cables were replaced, connected correctly, and crane demobilization continued.

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5. FINAL INSPECTION

5.1 LIST OF INSPECTIONS ATTENDEES

The implemented RA at SWMU 1 is not of a nature that can be inspected to determine the efficacy of the action. First, most of the active remedial action took place in the subsurface beginning about 5 ft bgs. Secondly, ZVI was placed in the subsurface down to the bottom of the mixed soil column, which also is outside of a visual range. ZVI works in the subsurface in a passive manner to treat TCE. Because of these facts, a visual inspection of the SWMU 1 RA does not provide information on the continued operation of the ZVI to treat TCE passively in the subsurface.

Following completion of the soil mixing of the treatment area and replacement of the excavated surface soils, subsurface soil sampling was performed to determine if TCE contaminant levels are lower by comparative analysis with pre-soil mixing soil samples. Also, installation of wells to monitor the long-term impacts to RGA groundwater (RAO 3) for the SWMU 1 treatment area was completed. This information is discussed in Section 4.1.2, “Post-Remedial Soil Sampling and Monitoring Well Installation.”

At the present time, the surface of the SWMU has been graded to a natural contour to allow drainage and to minimize the ponding of water on the ground surface. The ground surface then was hydromulched to initiate grass growing. The information signs indicating that the interim LUCs that are applicable to SWMU 1 also are in place, as required by the ROD.

5.2 DEFICIENCIES FOUND

No deficiencies in the RA have been identified at this time.

5.3 RESOLUTIONS OF DEFICIENCIES

This section is not applicable at this time.

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6. CERTIFICATION THE REMEDY IS OPERATIONAL AND FUNCTIONAL

6.1 STATEMENT OF WORK WAS PERFORMED WITHIN DESIRED SPECIFICATIONS

The soil mixing and placement of ZVI were completed consistent with the RD, the RAWP, and associated discussions with the FFA parties. The remedy was successful at removing VOCs from the treatment area, as described in Section 4.2.2, “Volatile Organic Compounds Removed.” Additionally, the ZVI portion of the remedy will passively continue destroying remaining residual VOCs. The interim LUC signs are in place and operational. Monitoring wells have been installed as required in the RAWP. The purpose of the groundwater sampling will be to ascertain when RAO 3 of this action is attained. The remedy for SWMU 1, consistent with requirements of Section III, “Purposes of Agreement,” and Section XXX, “Five-Year Review of the Federal Facility Agreement for the Paducah Gaseous Diffusion Plant,” will be subject to CERCLA Five-Year Reviews to evaluate and determine the continued effectiveness of the remedy.

6.2 AFFIRMATION THAT PERFORMANCE STANDARDS HAVE BEEN MET AND THE BASIS FOR DETERMINATION

The RA has been implemented successfully, and the ZVI continues to passively destroy VOC. The discussion of the methods utilized in determining that the RA performance standards have been met is contained in Section 3.4, “Basis for Determination that Standards Were Met.”

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7. OPERATION AND MAINTENANCE

7.1 HIGHLIGHTS OF OPERATION AND MAINTENANCE

The ZVI treatment has been implemented and does not have maintenance requirements. The ZVI, which is passive in nature, will continue to destroy residual VOCs. The remedial action does have two associated items that will be performed consistent with requirements of the ROD. As documented in the ROD (DOE 2012), the estimated time frame for attaining the groundwater protection RG within the SWMU and outside of the treatment area is expected to be approximately 68 years. The following summarizes the scope of the two associated items:

- Monitoring wells have been installed as required in the RAWP. These monitoring wells will provide groundwater samples for examining contaminant trends as the ZVI continues to destroy residual VOCs. The RAWP contains the schedule for the sampling of the monitoring wells for the first two years following construction of the monitoring wells. After two years, the FFA parties will determine the schedule for ongoing sampling, and the schedule will be documented in the PGDP Environmental Monitoring Plan. Groundwater monitoring well sampling will continue until applicable RAOs are attained (Section 1.2.2). The monitoring data will be reported formally in the Five-Year Reviews.
- The ROD requires that the interim LUCS be inspected annually until a final remedy is selected as part of a subsequent OU that addresses the relevant media. The annual monitoring information will be used in preparation of the Five-Year Reviews required for this remedy.

7.2 POTENTIAL PROBLEMS OR CONCERNS

The SWMU 1 area historically has been maintained as a grassy area in which vegetation was mowed on a periodic basis. As a result of the soil expanding/bulking upon soil mixing (see Section 4.2), the soils may, over the long term, consolidate leaving surface holes or depressions that may require filling with additional soil. Because the area is mowed periodically, a walking inspection will be performed in conjunction with the required inspection of the interim LUCs to identify any irregularities in the ground surface (DOE 2012). These surface irregularities, should they occur, will not be detrimental to the passive nature of the ZVI placed at SWMU 1.

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8. SUMMARY OF PROJECT COSTS

8.1 FINAL COSTS

The cost for the design and implementation of the SWMU 1 Oil Landfarm RA was \$13.2 million. This cost includes the efforts to accomplish the following:

- Design the RA,
- Develop the RDWP,
- Develop the RAWP,
- Prepare the site,
- Implement the soil mixing action,
- Procure materials,
- Perform post-treatment evaluation through soil borings and monitoring well installation,
- Manage and dispose of generated wastes,
- Project Management, and
- Prepare the RACR.

8.2 COMPARISON OF FINAL COSTS TO ORIGINAL COST ESTIMATE

The signed ROD estimated the cost of implementing the SWMU 1 RA at \$10.6 million unescalated (DOE 2012). The ROD cost estimate, as indicated in the ROD, is an order-of-magnitude engineering cost estimate that is expected to be within + 50% to -30% of the actual project cost. The actual project costs, as shown in Section 8.1, are within the range of the ROD estimate.

8.3 NEED FOR AND COST OF MODIFICATIONS

Issuance of a cost modification for implementing the remedy is not necessary. As discussed in Section 8.2, Comparison of Final Costs to Original Cost Estimate, the ROD cost estimate identifies the remedy implementation cost is within the required thresholds as identified in Section 8.2.

8.4 SUMMARY OF REGULATORY AGENCY OVERSIGHT COSTS

No text for this section.

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APPENDIX A

SYSTEM PERFORMANCE DATA

**Appendix A Information Included on CD
(see back cover)**

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APPENDIX B

TEMPERATURE LOGS

**Appendix B Information Included on CD
(see back cover)**

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APPENDIX C

VOLATILE ORGANIC COMPOUNDS REMOVED CALCULATION

**Appendix C Information Included on CD
(see back cover)**

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CD DATA

Appendix A: System Performance Data

Appendix B: Temperature Logs

Appendix C: Volatile Organic Compounds Removed Calculation

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