Department of Energy

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JUL 02 2018

Mr. Brian Begley
Federal Facility Agreement Manager
Division of Waste Management
Kentucky Department for Environmental Protection
300 Sower Boulevard, 2nd Floor
Frankfort, Kentucky 40601

PPPO-02-4842399-18A

Ms. Julie Corkran
Federal Facility Agreement Manager
U.S. Environmental Protection Agency, Region 4
61 Forsyth Street
Atlanta, Georgia 30303

Dear Mr. Begley and Ms. Corkran:

REMEDIAL ACTION COMPLETION REPORT FOR THE INTERIM REMEDIAL ACTION FOR THE GROUNDWATER OPERABLE UNIT FOR THE VOLATILE ORGANIC COMPOUND CONTAMINATION AT THE C-400 CLEANING BUILDING AT THE PADUCAH GASEOUS DIFFUSION PLANT, PADUCAH, KENTUCKY, DOE/LX/07-2417&D2

References:

1. Letter from A. Webb to T. Duncan, "Submittal of Comments to the Remedial Action Completion Report for the Interim Remedial Action for the Groundwater Operable Unit for the Volatile Organic Contamination at the C-400 Cleaning Building (DOE/LX/07-2417&D1)," dated May 7, 2018
2. Letter from J. Corkran to T. Duncan, "EPA Comments: Remedial Action Completion Report for the Interim Remedial Action for the Groundwater Operable Unit for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky (DOE/LX/07-2417&D1), Primary Document, transmittal dated February 6, 2018 (PPP0-02-4472864-18C) [*sic*]," dated April 27, 2018

Enclosed for review and approval is the certified *Remedial Action Completion Report for the Interim Remedial Action for the Groundwater Operable Unit for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-2417&D2 (RACR). This RACR documents implementation of the interim remedial action, electrical resistance heating, in the Upper Continental Recharge System and Regional Gravel Aquifer at the C-400 Cleaning Building, as documented in the

Record of Decision signed by the Federal Facility Agreement (FFA) parties in 2005. This version of the RACR addresses comments received from the U.S. Environmental Protection Agency (EPA) and Kentucky Department for Environmental Protection (KDEP) on April 27, 2018, and May 7, 2018, respectively. This RACR was developed consistent with the *Federal Facility Agreement for the Paducah Gaseous Diffusion Plant,* DOE/OR/07-1707, and as set forth in the *Memorandum of Agreement on the C-400 Complex under the Federal Facility Agreement for the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* signed August 8, 2017, and the *Memorandum of Agreement for Resolution of Formal Dispute Regarding the Non-Concurrence by EPA and KDEP on the DOE Milestone Modification Request for Submittal of the Revised Proposed Plan for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, DOE/LX/07-2407&D1,* signed September 28, 2017.

In addition to a clean version of the RACR, a redline version of the RACR that identifies changes made to the D1, a signed certification page, and comment response summaries are provided to assist with review. In accordance with Section XX.G.2 of the FFA, there is a 30-day review period for this RACR.

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

Sincerely,

Tracey Duncan
Federal Facility Agreement Manager
Portsmouth/Paducah Project Office

Enclosures:
1. Certification Page
2. C-400 Remedial Action Completion Report, DOE/LX/07-2417&D2—Clean
3. C-400 Remedial Action Completion Report, DOE/LX/07-2417&D2—Redline
4. Comment Response Summary—EPA Comments
5. Comment Response Summary—KDEP Comments

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CERTIFICATION

Document Identification: ***Remedial Action Completion Report for the Interim Remedial Action for the Groundwater Operable Unit for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-2417&D2, dated July 2018**

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.

Four Rivers Nuclear Partnership, LLC

Myrna E. Redfield
Deputy Program Manager

7/2/18
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

7/2/18
Date Signed

DOE/LX/07-2417&D2
Primary Document

Remedial Action Completion Report for the Interim Remedial Action for the Groundwater Operable Unit for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

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DOE/LX/07-2417&D2
Primary Document

Remedial Action Completion Report for the Interim Remedial Action for the Groundwater Operable Unit for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

Date Issued—July 2018

U.S. DEPARTMENT OF ENERGY
Office of Environmental Management

Prepared by
FOUR RIVERS NUCLEAR PARTNERSHIP, LLC,
managing the
Deactivation and Remediation Project at the
Paducah Gaseous Diffusion Plant
under Contract DE-EM0004895

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PREFACE

This *Remedial Action Completion Report for the Interim Remedial Action for the Groundwater Operable Unit for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-2417&D2, (RACR) was prepared in accordance with requirements under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); 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) (FFA). This report documents implementation of electrical resistance heating (ERH) in both Upper Continental Recharge System (UCRS) and Regional Gravel Aquifer (RGA) soils to remove trichloroethene (TCE) and other volatile organic compounds in those soils associated with the C-400 Cleaning Building and documented in a CERCLA record of decision signed by the FFA parties in 2005. Prior to implementation of the interim remedial action (IRA) and consistent with decisions made by the FFA parties, the implementation approach was changed to a phased approach. This report documents attainment of the remedial action goals for the IRA in treating the UCRS and Upper RGA soils, and that implementation of the IRA successfully removed 535 gal (Phase I) and 1,137 gal (Phase IIa) of TCE from the UCRS and Upper RGA during Phase I and Phase IIa operations. The RACR also documents the technical limitations for ERH to achieve remediation goals in the lower RGA soils. The information included in this document is intended to fulfill the requirements of both a remedial action completion report and a postconstruction report for the C-400 IRA.

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CONTENTS

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FIGURES

TABLES

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ACRONYMS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSM	conceptual site model
digiPAM™	digital pressure sensor
digiTAM™	digital temperature sensor
DNAPL	dense nonaqueous-phase liquid
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ERH	electrical resistance heating
FFA	Federal Facility Agreement
HU	hydrogeologic unit
IRA	interim remedial action
ITR	independent technical review
KAR	*Kentucky Administrative Regulations*
KDEP	Kentucky Department for Environmental Protection
KDOW	Kentucky Division of Water
LATA Kentucky	LATA Environmental Services of Kentucky, LLC
LUCIP	Land Use Control Implementation Plan
MIP	membrane interface probe
MOA	memorandum of agreement
O&M	operations and maintenance
OU	operable unit
PGDP	Paducah Gaseous Diffusion Plant
POE	point of exposure
PRS	Paducah Remediation Services, LLC
QA	quality assurance
QAPP	quality assurance program plan
QC	quality control
RACR	remedial action completion report
RAO	remedial action objective
RAWP	remedial action work plan
RDR	remedial design report
RDSI	remedial design support investigation
RDWP	remedial design work plan
RGA	Regional Gravel Aquifer
ROD	record of decision
ROI	radius of influence
SAP	sampling and analysis plan
SME	subject matter expert
SVE	soil vapor extraction
SVGTS	soil vapor and groundwater treatment system
SWMU	solid waste management unit
TS	treatability study
UCRS	Upper Continental Recharge System
VOC	volatile organic compound
WAG	waste area group

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EXECUTIVE SUMMARY

This *Remedial Action Completion Report for the Interim Remedial Action for the Groundwater Operable Unit for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-2417&D2, (RACR) has been prepared in support of U.S. Department of Energy's (DOE's) environmental remediation efforts at the Paducah Gaseous Diffusion Plant (PGDP) in Paducah, Kentucky. The report provides a summary of activities, results, and observations compiled from implementing the C-400 Interim Remedial Action (IRA). Electrical resistance heating (ERH) was implemented as the C-400 IRA remedy to remove volatile organic compound (VOC) contamination, primarily trichloroethene (TCE), from Upper Continental Recharge System (UCRS) and Regional Gravel Aquifer (RGA) subsurface soils in the vicinity of the C-400 Cleaning Building. This decision for the IRA was documented in a record of decision (ROD) signed in August 2005 (DOE 2005). Prior to implementation of the IRA, the Federal Facility Agreement (FFA) parties agreed to perform the action in a phased approach due to risks/uncertainties associated with implementation of ERH. Figure ES.1 shows the areas to be addressed by the IRA following the remedial design support investigation. Phase I was implemented in the Southwest and East Treatment Areas with Phase II to be treatment of the Southeast Area; however, due to technical limitations of ERH in the RGA in Phase I, Phase II was further split into Phase IIa and Phase IIb. Phase IIa was implemented successfully in the Southeast Area in the UCRS and Upper RGA. Phase IIb, was to implement treatment in the lower RGA in the Southeast Treatment Area. The FFA parties agreed to perform a steam treatability study in the southwest corner (upgradient edge) of the Phase IIb Treatment Area to determine the efficacy of steam heating in the RGA. In August 2017, the FFA parties agreed to address the Phase IIb action in the newly formed C-400 Complex Operable Unit (OU). Figure ES.2 provides a graphical presentation of the phased approach used for the IRA implementation. This RACR closes out the 2005 Interim ROD for the volatile organic compound (VOC) contamination at the C-400 Cleaning Building because the remedial action objectives have been met.

PHASE I

The C-400 IRA was implemented in phases to mitigate the risks/uncertainties associated with full-scale deployment of such a complex remedy at the C-400 Cleaning Building area. Phase I implemented the ERH design presented in the Remedial Design Report (DOE 2008a) in the UCRS soils of the Southwest and East Treatment Areas of the C-400 Cleaning Building area. In addition to removing VOCs from these areas, Phase I evaluated the heating performance of the design through the RGA down to the contact with the McNairy Formation in the Southwest Treatment Area. In addition to evaluating heating performance in the RGA, operation of Phase I also provided the opportunity to evaluate the radius of influence of the vapor recovery system, assess hydraulic containment, and optimize the aboveground vapor/liquid treatment system. Treatment in the East Treatment Area addressed only the UCRS.

The project site was immediately adjacent to the C-400 Cleaning Building located in the central portion of the PGDP industrial complex. Phase I construction began in December 2008 and was complete in December 2009. The construction included both subsurface and aboveground construction. Installation of the subsurface ERH equipment involved rotosonic drilling of borings within which the electrodes, multiphase extraction wells, temperature monitoring strings, vacuum piezometers, and water level monitoring instruments were installed. The soil vapor and groundwater treatment system (SVGTS) was designed to remove the contaminants from the soil vapor and groundwater extracted and was constructed on the east side of the C-400 Cleaning Building. The subsurface and aboveground construction is detailed further in Section 4.

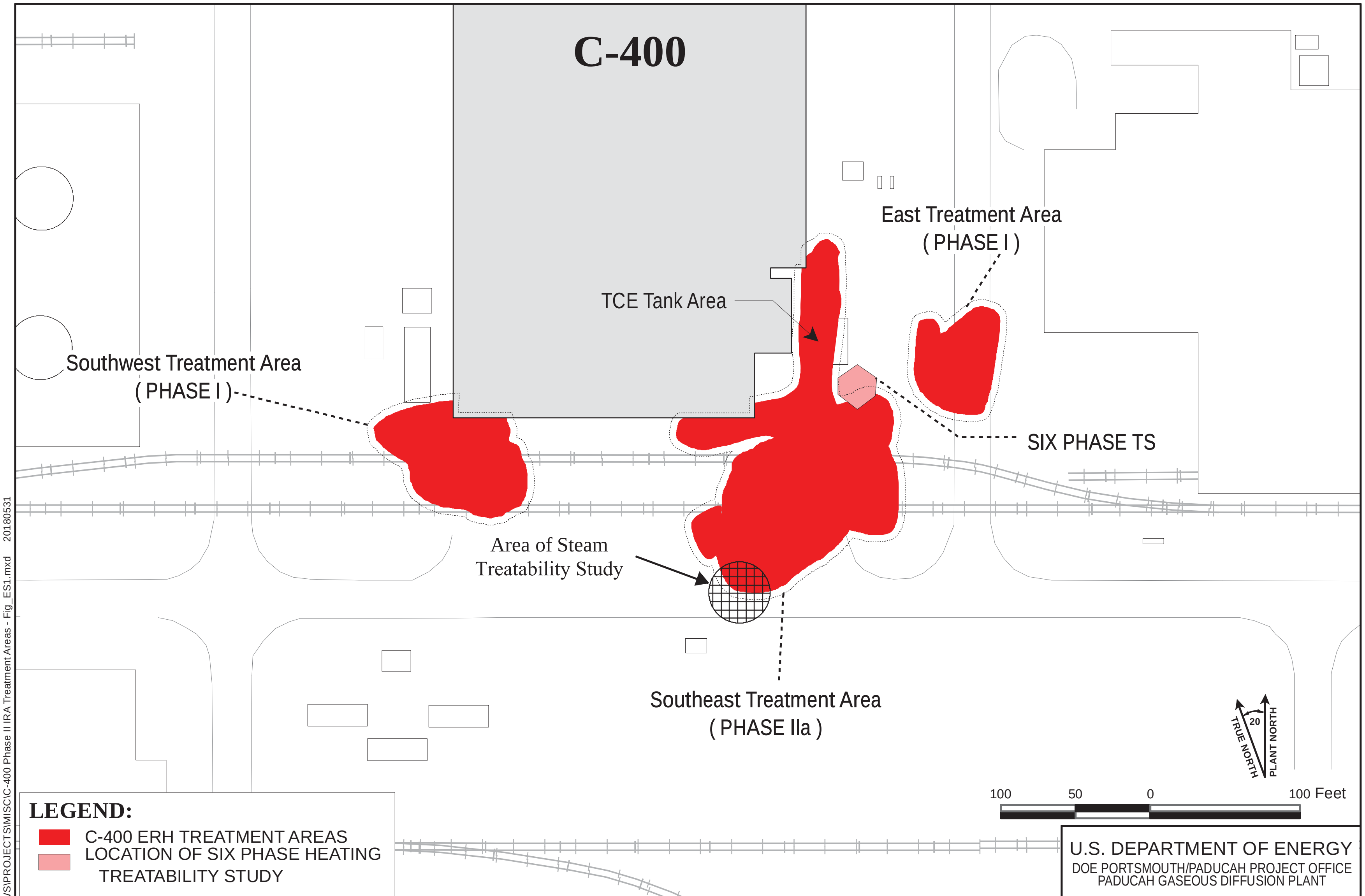

Figure ES.1. ERH Treatment Areas

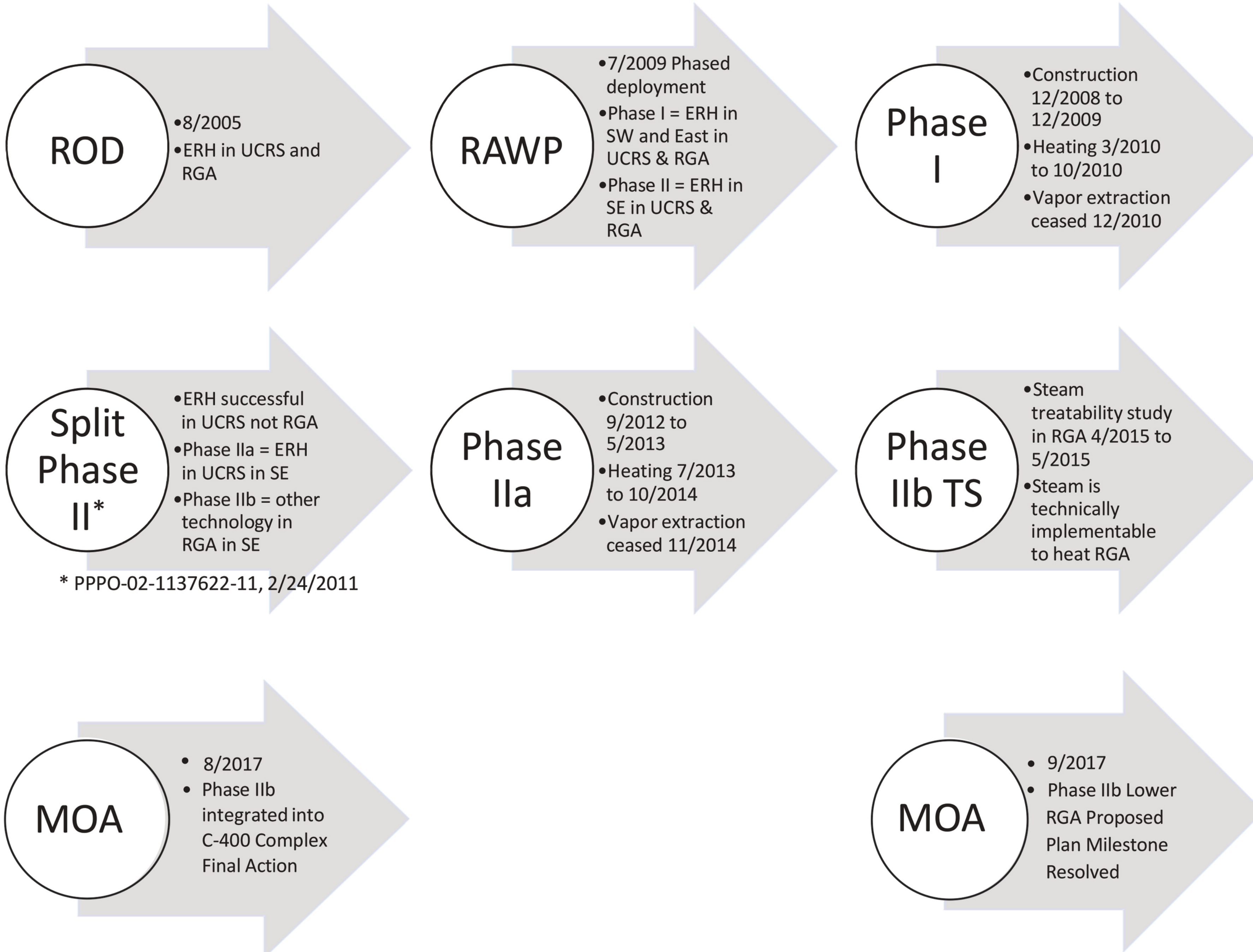

Figure ES.2. ERH Phased Implementation

Following completion of construction, start up and shakedown testing began. Testing was complete, and operations commenced at the end of March 2010. Heating operations ceased (soil vapor extraction continued) at the end of October 2010.

Phase I preoperational and postoperational soil sample results show average percent reductions in TCE concentrations of 95% and 99% in the East and Southwest Treatment Areas, respectively. Groundwater analytical results from postoperational samples showed average reductions of 76% and 99% in the East and Southwest Treatment Areas, respectively. Target temperatures were attained in treatment areas at depths targeted for VOC removal, which indicated that the ERH design was adequate for thermal treatment of UCRS soils. Phase I operations removed an estimated 535 gal of VOCs (primarily TCE).

Target temperatures were not attained in the Lower RGA in the Phase I Southwest Treatment Area, but heating was effective to about 60 ft below ground surface (bgs) or about 10 ft into the Upper RGA. Key factors that affected nonattainment of target temperature in the RGA include groundwater flow velocity, high formation electrical resistivity, and heat loss due to convective flow. Observed maximum formation temperatures attained during Phase I operations in the Lower RGA fell short of target temperature. Contingency thermal engineering techniques identified in the remedial action work plan to boost formation heating were implemented during Phase I in attempts to attain target temperatures. These techniques included injection of saline solutions and maximizing the delivery of electrical power to the electrodes in the Lower RGA. Phase I operating experience in the Southwest Treatment Area and subsequent modeling results using a groundwater velocity of 3 ft per day indicated that, in order to achieve target temperatures in the RGA, the ERH configuration developed for Phase I would require application of significant additional resources.

Based on the experience gained from the Phase I activities, the approach to Phase IIa was to deploy ERH only in the UCRS and Upper RGA soils of the Southeast Treatment Area. It was further identified and recommended that alternate technologies, or combinations of technologies, be evaluated to take advantage of increased knowledge of RGA characteristics to develop a refined technical strategy for remedial action in the Phase II area. The following are the lessons learned during Phase I activities relative to the RGA heating:

- The range of groundwater flow velocity in the formation was a substantial contributing factor in the inability to attain target temperature in the RGA;

- Utility and building operations avoidance posed more significant coordination challenges than originally assumed, and additional logistical challenges would be posed as part of Phase II based on the greater boring density that would be necessary for heating the RGA; and

- RGA formation electrical resistivity characteristics are high, leading to difficulty in attaining target temperatures and requiring contingency actions such as additional power and salt injection to improve conductivity/reduce resistivity.

PHASE IIa

As a result of the technical limitations of ERH technology to successfully heat the Lower RGA, Phase II of the project was further divided into a Phase IIa and Phase IIb. Phase IIa of the IRA targeted the UCRS and Upper RGA soils from 20 ft to 60 ft in the Southeast Treatment Area. Phase IIa construction commenced in September 2012 and was complete in May 2013. Heating operations were initiated on the Southeast Treatment Zone on July 30, 2013. Target temperatures in the treatment zone were reached by June 2014. Subsurface temperatures in the target treatment zone were judged sufficient to allow mass removal to reach asymptotic conditions in July 2014. Pulsed operations commenced on July 28, 2014, and continued through September 9, 2014; at that time, the FFA parties reached consensus that asymptotic conditions had been achieved in the treatment zone. Asymptotic condition, which was a remediation goal documented the C-400 IRA ROD (DOE 2005), was to operate the ERH system until monitoring indicates that heating has stabilized in the subsurface and that recovery of TCE, as measured in the recovered vapor, diminishes to a point at which further recovery is at a constant rate (i.e., recovery is asymptotic). Subsurface electrode heating was discontinued on October 9, 2014, while the vacuum and treatment system continued to operate until November 5, 2014; at that time, Phase IIa was determined to be complete.

Phase IIa operations removed approximately 1,137 gal of VOCs (primarily TCE). The average of soil TCE concentration reductions in collocated preoperational versus postoperational samples collected in the Southeast Treatment Area was 99.8%. The average of groundwater TCE concentration reductions in preoperational versus postoperational samples collected in the Southeast Treatment Area was 99%.

MEMORANDA OF AGREEMENT

The FFA parties signed two dispute resolution agreements (October 28, 2013, and September 28, 2017) and one FFA senior managers agreement (August 8, 2017) that closed issues associated with the implementation of the C-400 IRA.

The Memorandum of Agreement (MOA) signed in October 2013, was titled *Memorandum of Agreement for Resolution of Informal Dispute for the D2 Revised Proposed Plan for Volatile Organic Compound Contamination in the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-1263&D2. The resolution contained in the MOA resulted in DOE implementing a treatability study for steam enhanced extraction prior to amended remedy selection at C-400 Cleaning Building and established a trigger for DOE submittal of the revised proposed plan for the Middle and Lower RGA contamination not addressed by Phase I or Phase IIa.

The FFA senior managers signed, in August 2017, the *Memorandum of Agreement on the C-400 Complex under the Federal Facility Agreement for the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 2017a). The memorandum describes a new C-400 Complex OU that accelerates the investigation and cleanup of the C-400 Cleaning Building area for all sources of contamination in all media associated with the "city block" and underlying the C-400 Cleaning Building and integrates the Phase IIb source area into the final action for the C-400 Complex OU.

The MOA signed in September 2017 was titled *Memorandum of Agreement for Resolution of Formal Dispute Regarding the Non-Concurrence by EPA and KDEP on the DOE Milestone Modification Request for Submittal of the Revised Proposed Plan for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-2407&D1 (DOE 2017b). The FFA parties agreed in the MOA that remediation work under the 2005 C-400 Cleaning Building Interim Action ROD was complete, and a new enforceable milestone for the D1 Revised Proposed Plan is unnecessary because the C-400 Phase IIb source area is being integrated into the final remedial action for the C-400 Complex OU. This agreement also identifies a timetable for submittal of this RACR to close out the 2005 ROD for the Phase I and Phase IIa interim actions.

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1. INTRODUCTION

1.1 GENERAL DESCRIPTION OF SITE

1.1.1 Site Location

Paducah Gaseous Diffusion Plant (PGDP) is located approximately 10 miles west of Paducah, KY, and 3.5 miles south of the Ohio River in the western part of McCracken County (Figure 1.1). The plant is located on a 3,556-acre U.S. Department of Energy (DOE)-owned site that is comprised of the following: approximately 628 acres are within a fenced security area, approximately 809 acres are located outside the security fence, 133 acres of acquired easements, and the remaining 1,986 acres are licensed to the Commonwealth of Kentucky as part of the West Kentucky Wildlife Management Area.

1.1.2 Description

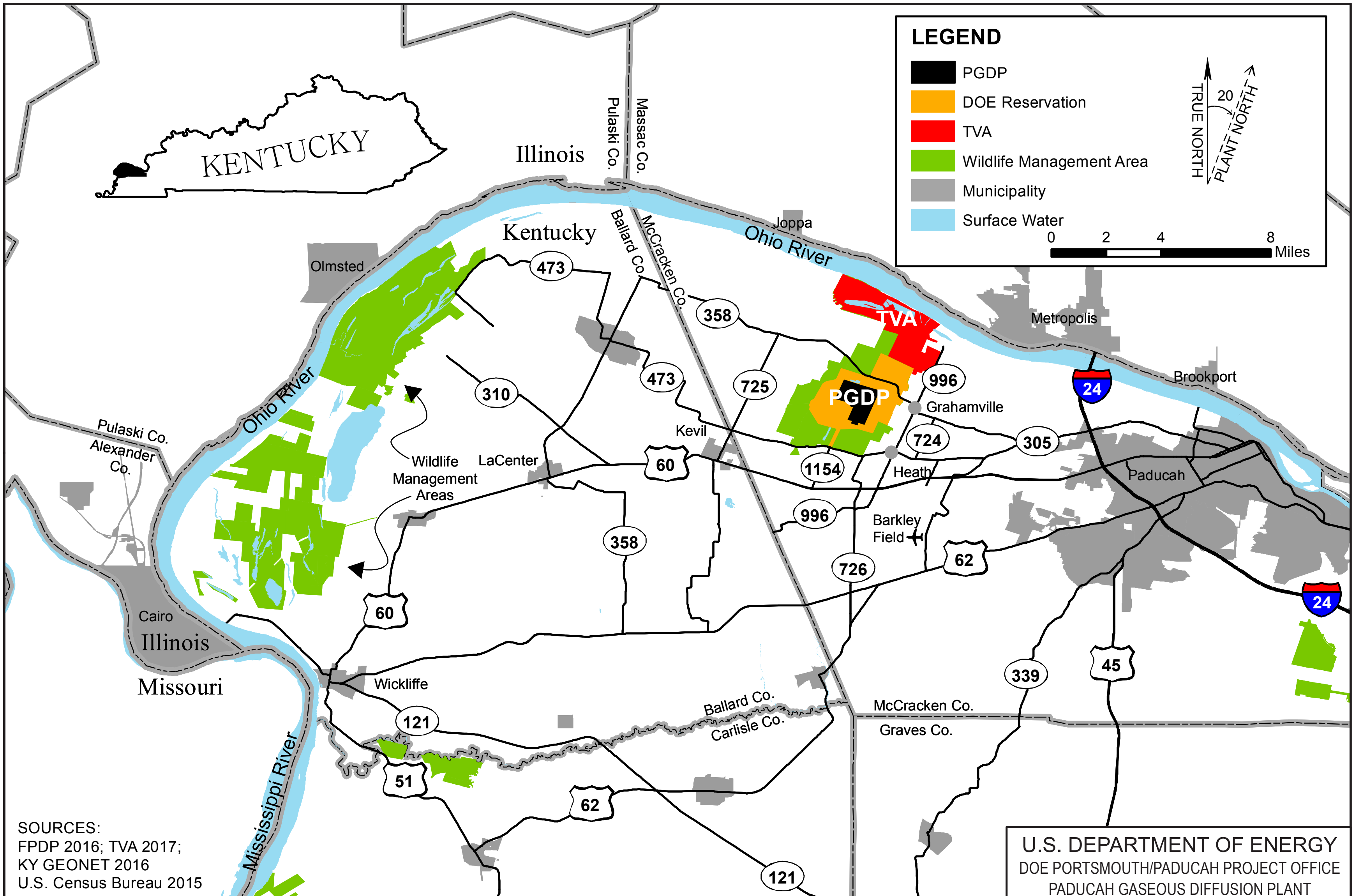
The C-400 Cleaning Building is located inside the plant secured area, near the center of the industrial section of PGDP. The building is bound by 10th and 11th Streets to the west and east, respectively, and by Virginia and Tennessee Avenues to the north and south, respectively. A figure depicting the location of C-400 Cleaning Building in relation to the plant site can be found in Figure 1.2.

1.1.3 Site Geology/Lithology

In the immediate vicinity of PGDP, Coastal Plain deposits unconformably overlie Mississippian carbonate bedrock. The full Coastal Plain stratigraphic sequence to the immediate south of PGDP consists of the following three units (from bottom to top): sands and clays of the Clayton/McNairy Formations; the Porters Creek Clay; and Eocene sand and clay deposits (undivided Jackson, Claiborne, and Wilcox Formations). Continental Deposits unconformably overlie the Coastal Plain deposits, which are, in turn, covered by loess and/or alluvium. Both the loess and alluvium typically are composed of clayey silt.

In the central and northern part of the PGDP site, including the area of the C-400 Cleaning Building, the Coastal Plain sediments are composed exclusively of unconsolidated, interbedded, fine-grained sand, silt, and clay of the Upper Cretaceous-aged McNairy Formation. The thickness of the McNairy Formation at C-400 Cleaning Building is approximately 250 ft. The McNairy in this location is overlain by approximately 100 ft of Continental Deposits.

A principal geologic feature in the PGDP area is the buried fore slope of the Porters Creek Clay Terrace, a subsurface boundary that trends approximately east to west across the southern portion of the plant. The fore slope of the Porters Creek Clay Terrace represents the southern limit of erosion or scouring of the ancestral Tennessee River. In the area north of the subsurface terrace fore slope, including the C-400 Cleaning Building area, Continental Deposits directly overlie the McNairy Formation. Thicker sequences of Continental Deposits, as found underlying most of PGDP, represent valley fill deposits and can be divided informally into a lower unit (gravel facies) and an upper unit (silt facies). The Lower Continental Deposits is a Pliocene to Pleistocene-aged gravel facies consisting of fine-to-coarse chert gravel in a matrix of very fine-to-medium sand and silt. These gravels rest on an erosional surface representing the beginning of the valley fill sequence beneath PGDP. In total, the gravel units commonly average approximately 30-ft thick. The Upper Continental Deposits overlie the Lower Continental Deposits and are approximately 50-ft thick.



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

Figure 1.1. PGDP Location

FOUR RIVERS
NUCLEAR PARTNERSHIP, LLC

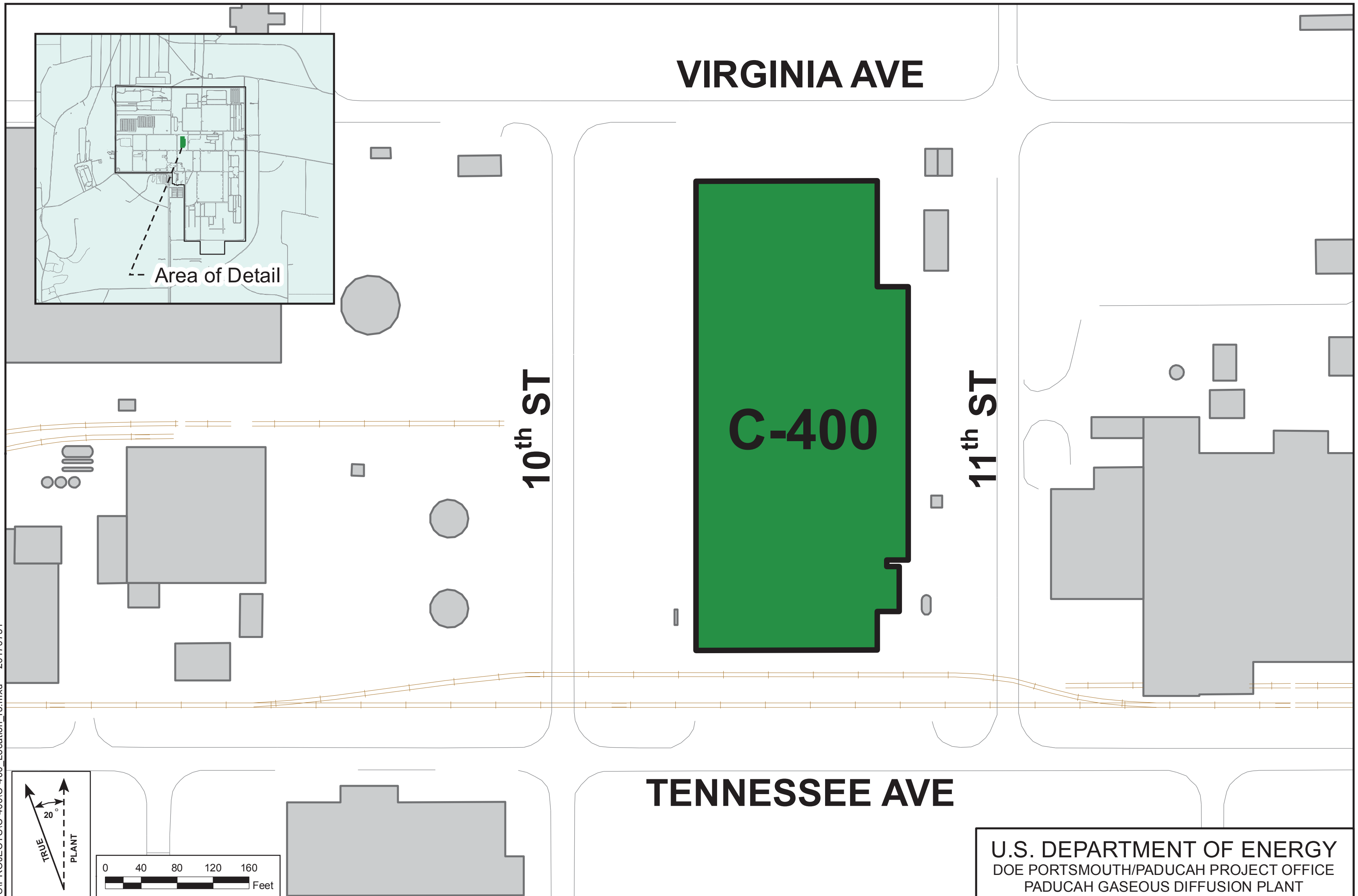


Figure 1.2. Location of C-400 Cleaning Building

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1.1.4 Site Hydrogeology

The main hydrogeologic units (HUs) in the C-400 Cleaning Building area are the Upper Continental Recharge System (UCRS), the Regional Gravel Aquifer (RGA), and the McNairy Formation. In the study area, the RGA and the first major sand of the upper McNairy Formation are separated by an approximately 9-ft thick lens of McNairy silts, sands, and clays, which act as an aquitard. Approximately 56 ft of silt and clay (UCRS), with horizons of sand and gravel lenses, overlies the RGA.

In the area of C-400 Cleaning Building, the UCRS is mostly unsaturated. The RGA, the uppermost aquifer in the C-400 Cleaning Building area, consists of the lowermost sand interval of the Upper Continental Deposits and the underlying sand and gravels of the Lower Continental Deposits to the top of the McNairy Formation. The RGA potentiometric surface is encountered at a depth of approximately 50 ft below ground surface (bgs). Groundwater flow in the RGA generally is to the north, eventually discharging into the Ohio River, although some flow diverges to the east and to the west. The sand and gravel of the RGA are highly permeable, and pore velocity is thought to be on the order of 1 ft to 3 ft per day. The vertical anisotropy of the RGA is thought to be low.

Below the RGA is the McNairy Formation. The uppermost portion of the McNairy Formation typically contains a significant proportion of clay or silty clay. The hydraulic potential (water level) of the uppermost McNairy Formation is slightly less than that of the RGA. The clayey, uppermost McNairy functions as an aquitard restricting groundwater flow between the RGA and lower McNairy Flow System. The McNairy topographic surface in the immediate area of the C-400 Cleaning Building is a topographic high, while the McNairy surface in the location of the C-400 Interim Remedial Action (IRA) slopes to the south.

1.1.5 History and Early Environmental Actions

The C-400 Cleaning Building was built in 1953. The primary activities associated with the C-400 Cleaning Building were cleaning machinery parts, decontaminating the interiors of used uranium hexafluoride cylinders, disassembling and testing cascade components, and laundering plant clothes. The building also housed various other processes and activities, including recovery of precious metals and treatment of radiological waste streams.

In June 1986, a routine construction excavation along the 11th Street storm sewer revealed trichloroethene (TCE) soil contamination. The cause of the contamination was determined to be a leak in a drain line from the C-400 Cleaning Building's basement sump to the storm sewer. The area of contamination became known as the C-400 TCE Leak Site and was given the designation of Solid Waste Management Unit (SWMU) 11. As a result of the leak, approximately 310 ft^3 of TCE-contaminated soil was excavated and dispositioned. The excavation hole was backfilled with clean fill soil and a 1-ft thick clay layer. After the initial discovery of contamination, SWMU 11 and the C-400 Cleaning Building area have been the subject of several investigations, including the Phase II Site Investigation, Waste Area Group (WAG) 6 Remedial Investigation (DOE 1999), and the C-400 Remedial Design Site Investigation (RDSI), as reported on in Section 1.3 of the C-400 Remedial Design Report (Phase I RDR) (DOE 2008a).

Significant concentrations of TCE were detected during the WAG 6 Remedial Investigation. TCE was identified in the UCRS and the RGA. In the vicinity of the C-400 Cleaning Building, the UCRS extends from surface to an average depth of 51 ft. The RGA extends from the bottom of the UCRS to an approximate bottom depth of 91 ft bgs.

Two previous actions have remediated some of the soil contamination near the southeast corner of C-400 Cleaning Building. After the discovery of the C-400 TCE Leak Site in June 1986, some of the soils were excavated in an attempt to reduce the contamination in the area. Approximately 310 ft^3 of TCE-contaminated soil was drummed for off-site disposal. The excavation was backfilled with clean soil, and the area was capped with a layer of clay. A 2003 Six-Phase Heating Treatability Study (TS) removed approximately 1,900 gal of TCE from the subsurface of a 43-ft diameter treatment area near the southeast corner of the area near the C-400 Cleaning Building (see Figure ES.1).

This remedial action completion report (RACR) documents Phase I and Phase IIa electrical resistance heating (ERH). Additionally, the FFA parties agreed to perform a steam TS in a portion of the Phase IIb Treatment Area to determine the efficacy of steam heating in the RGA. The Steam Injection TS is not a component of the IRA being documented herein. The IRA is part of the *Record of Decision for Interim Remedial Action for the Groundwater Operable Unit for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-2150&D2/R2, (ROD) (DOE 2005) that was signed in August 2005.

1.2 GENERAL DESCRIPTION OF REMEDY

1.2.1 Components of the Remedy

The C-400 IRA included the installation and operation of a three-phase ERH system to heat the subsurface, volatilize volatile organic compounds (VOCs), and remove them by way of a vapor recovery system. The three-phase ERH system consisted primarily of a network of inground electrodes, vapor extraction wells, vacuum monitoring piezometers (also referred to as vacuum monitoring wells), and temperature probes distributed throughout the treatment areas. The locations of the electrodes are placed in triangular spacing because of the three-phase electrical power utilized by ERH. Controlled spacing of the electrodes is required to ensure that uniform heating and recovery are achieved. The controlled spacing sometimes results in electrodes being constructed outside the planned treatment area to honor the geometric requirements. The three dense nonaqueous-phase liquid (DNAPL) source areas targeted are depicted in Figure ES.1. Electrical power for the electrodes was supplied to the ERH system by an existing electrical feeder from the PGDP C-531-1 electrical switchyard. ERH heats the groundwater, and steam is generated, which facilitates the stripping of VOCs (primarily TCE and its breakdown products) from the treatment area.

A phased deployment of ERH was implemented. Phase I was implemented in the Southwest and East Treatment Areas. Phase I also evaluated the heating performance of the base design through the RGA down to the McNairy interface in the Southwest Treatment Area. Treatment in the East Treatment Area during Phase I involved only the UCRS. Phase I also provided the opportunity to evaluate the radius of influence of the vapor recovery system, assess hydraulic containment, and optimize the aboveground vapor/liquid treatment system.

Phase II was segmented into two phases, Phase IIa and Phase IIb, because the results of Phase I activities identified that ERH did not achieve the target temperatures in the lower portions of the RGA. Phase IIa used ERH in the Southeast Treatment Area in the UCRS and Upper RGA based on findings from Phase I. The Federal Facility Agreement (FFA) parties agreed to integrate the Phase IIb source area into a final remedial action for the C-400 Complex Operable Unit (OU).

1.2.2 Contaminants Treated

The C-400 Cleaning Building Treatment Area contaminants treated were TCE and its breakdown products [*cis*-1,2-dichloroethene (*cis*-1,2-DCE), *trans*-1,2-DCE, vinyl chloride, and 1,1-DCE].

The following are remedial action objectives (RAOs) for this action, as contained in the ROD (DOE 2005):

1. Prevent exposure to contaminated groundwater by on-site industrial workers through institutional controls (e.g., excavation/penetration permit program);

2. Reduce VOC contamination (primarily TCE and its breakdown products) in UCRS soil at the C-400 Cleaning Building area to minimize the migration of these contaminants to RGA groundwater and to off-site points of exposure (POEs); and

3. Reduce the extent and mass of the VOC source (primarily TCE and its breakdown products) in the RGA in the C-400 Cleaning Building area to reduce the migration of the VOC contaminants to off-site POEs.

The selected IRA was designed to meet the RAOs.

The treatment zone of the C-400 IRA targeted the soils in the areas of the C-400 Cleaning Building, as identified in the RDRs (DOE 2008a; DOE 2012).

1.2.3 Design Changes

The RDRs included flexibility to make adjustments to treatment protocols, with approval of the FFA parties based upon results of field implementation, with an objective to improving performance and enhancing mass reduction (DOE 2008a). The following information provides a summary of critical design changes that were incorporated during implementation of Phases I and Phase IIa ERH.

1.2.3.1 Phase I to Phase IIa ERH remedial design changes

The Phase I ERH implementation design was documented in the Phase I RDR (DOE 2008a). During the implementation of the Phase I activities, a number of improvements were identified and incorporated into the Phase IIa design and planned operations. Among the improvements were the following:

- Modifying the vapor phase treatment equipment to allow for higher flow and higher vacuum,

- Increasing vapor extraction vacuum and density of soil vapor extraction wells allowing enhanced overall extraction,

- Redesigning groundwater extraction well screens and sand packs to reduce fine sand migration into the treatment system, and

- Incorporating condensation collection and purging equipment in vapor header pipes to minimize impacts to vapor extraction.

These improvements were identified during Phase I and were incorporated into Phase IIa. A detailed discussion is presented in the *Remedial Design Report, Certified for Construction Design Drawings and Technical Specifications Package, for the Groundwater Operable Unit for the Phase IIa Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-1272&D2/R1 (DOE 2012).

2. CHRONOLOGY OF EVENTS AT C-400 CLEANING BUILDING

The following provides a summary of the chronology of events associated with the IRA beginning with signing of the ROD to development of this RACR.

August 9, 2005—ROD signed for IRA for the VOC contamination at C-400 Cleaning Building

September 5, 2006—Agreement of Change signed to modify C-400 ROD to reflect the *Land Use Control Implementation Plan: Interim Remedial Action for the Groundwater Operable Unit for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant*, *Paducah*, *Kentucky*, DOE/OR/07-2151&D2/R2

September 15, 2006—Approval of the *Remedial Design Work Plan for the Interim Remedial Action for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant*, *Paducah*, *Kentucky*, DOE/OR/07-2214&D2 (RDWP) (DOE 2006)

July 16, 2008—Approval of the D2 RDR for Phase I

October 23, 2008—Approval of the *Remedial Action Work Plan for the Interim Remedial Action for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-0004&D2/R2/A1/R2 (Phase I RAWP)

November 7, 2008—Approval of the *Construction Quality Control Plan for the Interim Remedial Action for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-0031&D2/R1

December 2008—Construction on Phase I began

July 28, 2009—Approval of *Operations and Maintenance Plan for the Interim Remedial Action for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-0187&D2 (Phase I O&M)

December 2009—Phase I construction complete

March 29, 2010—Phase I system testing complete and startup of Phase I operations

September 2010—Pulsed operations initiated for Phase I to maximize removal of the remaining contaminants

October 10, 2010—Phase I heating operations ceased

October 29, 2010—DOE letter notification, PPPO-02-1034068-11, "Remedial Goals Met in the East and Southwest Treatment Areas for Phase I of the C-400 Interim Remedial Action," Indicating Goals Achieved on September 10, 2010

February 24, 2011—Phase II separated into two phases (Phase IIa and IIb) by FFA managers decision made on January 20, 2011, and documented in DOE letter, "C-400 Phase II Implementation Path Forward for the Interim Remedial Action for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky," PPPO-02-1137622-11

March 14, 2011—Approval of the Field Sampling Plan for DNAPL in Southeast Treatment Area of C-400 Cleaning Building

September 18, 2012—Approval of the *Remedial Action Work Plan for Phase IIa of the Interim Remedial Action for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-1271&D2/R1 (Phase IIa RAWP)

September 27, 2012—Phase IIa construction starts

May 30, 2013—Phase IIa construction complete

June 4, 2013—Informal Dispute initiated on the D2 *Revised Proposed Plan for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-1263&D2

June 21, 2013—Approval of the *Operations and Maintenance Plan for Phase IIa of the Interim Remedial Action for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-1285&D2 (Phase IIa O&M)

July 22, 2013—Phase IIa heating operations started

October 28, 2013—Signed Memorandum of Agreement (MOA) of Resolution of Informal Dispute for the D2 *Revised Proposed Plan for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-1263&D2

July 28, 2014—Pulsed operations for Phase IIa initiated to maximize removal of the remaining contaminants

September 9, 2014—Phase IIa pulsed operations complete

October 9, 2014—Phase IIa heating operations complete

November 5, 2014—Phase IIa operations completed

May 27, 2016—Kentucky Department for Environmental Protection (KDEP) approved the *Treatability Study Report for the C-400 Interim Remedial Action Phase IIb Steam Injection Treatability Study at Paducah Gaseous Diffusion Plant,* DOE/LX-07-2202&D2

June 9, 2016—The U.S. Environmental Protection Agency (EPA) approved the *Treatability Study Report for the C-400 Interim Remedial Action Phase IIb Steam Injection Treatability Study at Paducah Gaseous Diffusion Plant*, DOE/LX-07-2202&D2, triggering the milestone date for DOE submittal of the D1 revised Proposal Plan

June 20, 2016—DOE provides "Paducah Site Cleanup Priorities, FFA Senior Managers Discussion" PowerPoint proposal to KDEP and EPA senior managers to realign PGDP sitewide priorities. This proposal includes a new strategy to achieve final cleanup of the C-400 Complex rather than interim cleanup of Phase IIb Lower RGA TCE source area

June 22, 2016—DOE provides "C-400 Remediation Strategy" PowerPoint to EPA and KDEP FFA managers

September 6, 2016—DOE issues "Milestone Modification Request for Submittal of the D1 Revised Proposed Plan for the Volatile Organic Compound Contamination at the C-400 Cleaning Building," PPPO-02-3751665-16

October 7, 2016—Milestone date for DOE submittal of the D1 Revised Proposed Plan

October 11, 2016—DOE issues "Notification of Invocation of Informal Dispute Resolution Concerning Receipt of Nonconcurrence Regarding the Milestone Modification Request for Submittal of the Revised Proposed Plan for the Volatile Organic Compound Contamination at the C-400 Cleaning Building," PPPO-02-3808684-17

November 30, 2016—DOE issues, "Written Statement Initiating Formal Dispute Resolution on the Nonconcurrence Regarding the Milestone Modification Request for Submittal of the Revised Proposed Plan for the Volatile Organic Compound Contamination at the C-400 Cleaning Building," PPPO-02-3894945-17

August 8, 2017—Signed *Memorandum of Agreement on the C-400 Complex under the Federal Facility Agreement for the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*

September 28, 2017—Signed *Memorandum of Agreement for Resolution of Formal Dispute Regarding the Non-concurrence by EPA and KDEP on the DOE Milestone Modification Request for Submittal of the Revised Proposed Plan for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-2407&D1

February 6, 2018—DOE submitted the D1 *Remedial Action Completion Report for the Interim Remedial Action for the Groundwater Operable Unit for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-2417&D1

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3. PERFORMANCE STANDARDS AND CONSTRUCTION QUALITY CONTROL

3.1 STANDARDS

The DOE prime contractor was responsible for the overall management of the ERH and Soil Vapor and Groundwater Treatment System (SVGTS) system installations, including quality assurance (QA), quality control (QC), radiological protection and health and safety activities, as outlined in the Construction Quality Control Plan (DOE 2008b). The DOE prime contractor confirmed that the referenced subcontractors were capable of meeting applicable quality requirements, as documented in the following project documents: Phase I RAWP (DOE 2011a) and Phase IIa RAWP (DOE 2013a); Phase I RDR (DOE 2008a) and Phase IIa RDR Certified for Construction (DOE 2012).

3.2 RESULTS OF FIELD SAMPLING

The results of field sampling from postoperational groundwater and soil sampling are discussed in Section 4.2 for Phase I and Section 5.2 for Phase IIa.

3.3 LOCATION AND FREQUENCY OF TESTS

During IRA implementation, active data collection and review were performed by the project team to confirm that treatment requirements were achieved for each treatment area (i.e., East, Southwest, and Southeast Areas).

3.3.1 Baseline, Operational, and Postoperational Sampling

Three distinct phases of sampling and analysis occurred as a part of the C-400 Phase I and IIa IRA: baseline, operational, and postoperational. Baseline sampling and postoperational sampling were conducted as a means to determine the percent reduction in VOC contamination in the treatment area. The sampling plan for baseline and postoperational sampling activities are presented in Section 8 of both the Phase I RAWP (DOE 2011a) and Phase IIa RAWP (DOE 2013a).

Operational sampling and analysis data were collected to measure progress and determine when criteria for ceasing operations were met. Additional discussions on operational sampling can be found in Section 8.2 of both the Phase I RAWP (DOE 2011a) and the Phase IIa RAWP (DOE 2013a). A sampling and analysis (SAP) for operational sampling was included in Section 5.2 of both the Phase I O&M Plan (DOE 2009) and the Phase IIa O&M Plan (DOE 2013b). Section 8.3 of both the Phase I RAWP (DOE 2011a) and the Phase IIa RAWP (DOE 2013a) address waste characterization sampling and analysis.

Phase I and Phase IIa baseline operational and postoperational soil and groundwater samples were collected to support analysis of the efficiency of removal of TCE by the ERH remedial action. The difference in soil baseline and postoperational TCE (and TCE breakdown products) levels was intended to be a direct measure of the percent reduction of TCE. Soil samples were collected during installation of the ERH wells [electrode, digital temperature sensor (digiTAM™), and extraction well borings], along with locations between electrodes and extraction wells in order to characterize pretreatment soil TCE levels. Postoperational samples were collected from locations adjacent to baseline soil borings to characterize residual TCE levels subsequent to the operation of the ERH electrodes. Due to high subsurface temperatures in the treatment areas, a cool down period was required to allow the subsurface to cool down sufficiently, in order to safely collect and handle post operational samples (approximately 2–4 months). Collection and analysis of the collocated soil samples allowed the direct comparison of baseline and postoperational TCE levels in a discrete volume.

Extraction well groundwater samples were collected to characterize TCE levels in groundwater before, during, and after operation of the ERH system in an effort to observe the effect of Phase I and Phase IIa operations on groundwater TCE concentrations in the RGA. Groundwater samples are more indicative of average conditions in the vicinity of the sample pump. All groundwater and soil analyses were performed by a fixed-base laboratory.

Analytical data collected during Phase I & IIa further provides an indication that RAOs, as documented in the ROD, were achieved for the UCRS and upper RGA in the Phase I and Phase IIa Treatment Areas.

The following tables review the project data that was collected and/or monitored during Phase I and Phase IIa.

Tables 3.1 and 3.2 outline the SVGTS sampling schedules used in Phase I and Phase IIa operations, respectively.

Tables 3.3 and 3.4 outline the Phase I soil and groundwater sampling plans followed to collect baseline/postoperations sample data in order to evaluate remediation results.

Tables 3.5 and 3.6 outline the Phase IIa soil and groundwater sampling plans followed to collect baseline/postoperations sample data in order to evaluate remediation results.

3.4 BASIS FOR DETERMINATION THAT STANDARDS WERE MET

RAOs were established in the 2005 ROD for the C-400 IRA and apply to both Phase I and Phase IIa projects. The RAOs and the criteria for ceasing IRA system operations are summarized in the following sections (DOE 2005).

3.5 INTERIM ACTION REMEDIAL OBJECTIVES FOR EAST, SOUTHWEST, AND SOUTHEAST TREATMENT AREAS

The RAOs for the C-400 IRA, as documented in Section 2.8 of the C-400 ROD (DOE 2005), are as follows:

1. Prevent exposure to contaminated groundwater by on-site industrial workers through institutional controls (e.g., excavation/penetration permit program);

2. Reduce VOC contamination (primarily TCE and it breakdown products) in UCRS soil at the C-400 Cleaning Building area to minimize the migration of these contaminants to RGA groundwater and to off-site POEs; and

3. Reduce the extent and mass of the VOC source (primarily TCE and its breakdown products) in the RGA in the C-400 Cleaning Building area to reduce the migration of the VOC contamination to off-site POEs.

RAO 1 above is addressed in the Land Use Control Implementation Plan (LUCIP) for the C-400 IRA (DOE 2008c).

Table 3.1. Phase I Operational Sampling[1]

Sample Type	Location	No. of Sample Points	Frequency	Parameters
Water	Groundwater Extraction Wells	9	Monthly	VOCs, Tc-99
	Air Stripper Feed Tank	1	Monthly	TCE, Tc-99
	Air Stripper Effluent	1	Monthly	TCE, Tc-99
	Lead Ion Exchange Effluent	1	Monthly	Tc-99
	Lead Liquid Carbon Column Effluent	1	Monthly	TCE
	Water Treatment System Effluent	1	Weekly	VOCs, Tc-99, total suspended solid (TSS)
	Start-up—System Effluent	1	Daily	VOCs, Tc-99
	On-Request	2	Biweekly	Various
Air (Summa)	Vapor Extraction Wells	9	Biweekly	VOCs
	Southwest Treatment Area Vapor Header	1	Monthly	VOCs
	East Treatment Area Vapor Header	1	Monthly	VOCs
	Lead Vapor Carbon Column Effluent	1	Monthly	TCE
	Vapor Treatment System Discharge Stack	1	Monthly	VOCs
	Start-up—Stack	1	Once	VOCs
Vapor (Photoacoustic Analyzer)	Combined Outlet of Vapor Treatment Skids	1	1/hour	TCE (and breakdown products)
	Lead Vapor Phase Carbon Vessel Discharge	1	1/hour	TCE (and breakdown products)
	Lead Vapor Phase Zeolite Vessel Discharge	1	1/hour	TCE (and breakdown products)
	Treatment System Discharge Stack	1	~ 30/hour	TCE (and breakdown products)
	Vapor Headers	2	Daily	TCE (and breakdown products)
	Grab Samples from Wellfield (extraction wells, vacuum piezometers, and vapor headers)	Multiple	As needed	TCE (and breakdown products)

[1] Sampling occurred on normal business days, which is a modification from the Phase I O&M Plan, DOE/LX/07-0187&D2 (DOE 2009).
Table modified from O&M Plan, DOE/LX/07-0187&D2 (DOE 2009).

Table 3.2. Phase IIa Operational Sampling[1]

Sample Type	Location	No. of Sample Points	Frequency	Parameters[2]
Water	Multiphase Extraction Wells	22	monthly	VOCs, Tc-99
	Air Stripper Feed Tank	1	monthly	TCE, Tc-99
	Air Stripper Effluent	1	monthly	TCE, Tc-99
	Lead Ion Exchange Column Effluent	1	monthly	Tc-99
	Lead Liquid Carbon Column Effluent	1	monthly	TCE
	Water Treatment System Effluent	1	weekly	VOCs, Tc-99, TSS, Chlorine
	Start-up—System Effluent[2]	1	daily	VOCs, Tc-99
Vapor (Summa)	Multiphase Extraction Wells	22	biweekly	VOCs
	Extraction/Electrode (XE) Wells	39	biweekly	VOCs
	Vapor Extraction Wells	11	biweekly	VOCs
	Southeast Treatment Area Vapor Header	1	monthly	VOCs
	Lead Vapor Carbon Column Effluent	1	monthly	TCE
	Vapor Treatment System Discharge Stack	1	monthly	VOCs
	Start-up—Stack	1	N/A	VOCs
Vapor (Photoacoustic Analyzer)	Combined Outlet of Vapor Treatment Skids	1	1/hour	TCE (and breakdown products)
	Lead Vapor Phase Carbon Vessel Discharge	1	1/hour	TCE (and breakdown products)
	Lead Vapor Phase Zeolite Vessel Discharge	1	1/hour	TCE (and breakdown products)
	Treatment System Discharge Stack	1	~ 30/hour	TCE (and breakdown products)
	Vapor Header	1	daily	TCE (and breakdown products)
	Grab Samples from Wellfield (extraction wells, vacuum monitors, and vapor headers)	Multiple	As needed (portable photoacoustic analyzer inoperable), pulsed operations	TCE (and breakdown products)
Vapor (Infrared Gas Monitor)	Lead Steam Regenerated Carbon Adsorber Vessel Effluent	3 (1 at each adsorber vessel)	7 seconds	VOCs
	Steam regenerated Carbon Adsorption System Effluent	1	7 seconds	VOCs

[1] Sampling occurred on normal business days.
[2] Rapid turnaround time (7 days) required during start-up period.
Table modified from Phase IIa O&M Plan, DOE/LX/07-1285&D2 (DOE 2013b).

Table 3.3. Phase I East and Southwest Treatment Areas Soil Sampling Plan

Location ID	Area	Adjacent MIP Borings	Sample Depth Interval					
			UCRS			RGA		McNairy
			Shallow	Middle	Deep	Shallow	Deep	Shallow
E003	Southwest	MIP-08	X	X	-	-	-	-
E006	Southwest	-	X	X	X	X	X	X
E007	Southwest	-	X	X	X	X	X	X
E009	Southwest	MIP-03	X	X	-	-	-	-
E010	Southwest	-	X	X	X	X	X	X
E011	Southwest	MIP-04	X	X	X	X	X	X
E012	Southwest	-	X	X	X	X	X	X
E013	Southwest	-	X	X	-	-	-	-
E016	Southwest	-	X	X	-	-	-	-
E017	Southwest	-	X	X	X	X	X	X
E018	Southwest	-	X	X	X	X	X	X
E019	Southwest	MIP-07	X	X	X	-	-	-
E020	Southwest	-	X	X	-	-	-	-
E026	Southwest	-	X	X	-	-	-	-
X06	Southwest	-	X	X	X	X	X	X
E095	East	-	X	X	X	X	-	-
E097	East	-	-	X	-	-	-	-
E098	East	-	X	X	-	-	-	-
E099	East	-	-	X	-	-	-	-
E100	East	-	X	X	-	-	-	-
E102	East	-	X	X	-	-	-	-
E103	East	MIP-28	X	X	X	-	-	-
E104	East	-	X	X	-	-	-	-
E105	East	-	-	X	-	-	-	-
E106	East	-	X	X	-	-	-	-
E107	East	-	-	X	-	-	-	-
E110	East	MIP-27	X	X	X	-	-	-

Table 3.4. Phase I East and Southwest Treatment Areas Groundwater Sampling Plan

Well	Area	Adjacent MIP Boring	RGA		
			Shallow	Middle	Deep
X01	Southwest	-	X	X	X
X02	Southwest	-	X	X	X
X03	Southwest	-	X	-	-
X04	Southwest	-	X	X	X
X26	East	-	X	-	-
X27	East	MIP-41	X	-	-
X28	East	-	X	-	-
MW155	East	-	-	-	X
MW156	East	-	X	-	-

Tables 3.3 and 3.4 adapted from Phase I RAWP, DOE/LX/07-0004&D2/R2/A1/R2 (DOE 2011a).

Table 3.5. Phase IIa Baseline/Postoperations Soil Sampling Plan

Baseline Sample Location	Area	Postoperations Sample Location	Adjacent MIP Locations	Postoperations Collocated Target Sample Depths					
				UCRS			RGA		
				Shallow (0–10 ft bgs)	Shallow (10–20 ft bgs)	Shallow (20–30 ft bgs)	Middle (30–40 ft bgs)	Deep (40–52 ft bgs)	Upper (52–60 ft bgs)
D206*	Southeast	X		9.9	18	23.5	34.5	51	52.1
D208*	Southeast	X		2.5	18.5	25.5	31.5	50.1	58.5
D213*	Southeast	X		8.5	18.5	21.5	32	51	55.5
D214*	Southeast	X		4	14	20.5	30.5	41	52.5
D216*	Southeast	X		7	10.5	27	31	42.5	59.5
D219*	Southeast	X		6	12.5	22	35.5	46	55.1
D221*	Southeast	X		7.5	18	27	38.5	50.1	55.5
D222*	Southeast	X		3	19	26	39.5	--	--
D225*	Southeast	X		8	15.1	21	36	--	--
E205	Southeast		MIP-17	--	--	--	--	†	†
E207	Southeast		MIP-25	†	†	†	†	†	†
E213	Southeast	X		5.5	16	26	39.1	41	52.5
E217	Southeast		MIP-13	†	†	†	†	†	†
E219	Southeast	X	MIP-16	7.5	17	29.5	34	49	56
E227	Southeast			†	†	†	†	†	†
E229	Southeast	X		4	16	23	36	43.5	55.1
E230	Southeast			†	†	†	†	†	†
E232	Southeast			†	†	†	†	†	†
E237	Southeast	X	MIP-50	6.5	10.5	20.5	30.5	40.1	52.6
E239	Southeast			†	†	†	†	†	†
E247	Southeast			†	†	†	†	--	--
SB63*	Southeast	X		2	16.5	26	35.5	50.5	55.5
SB64*	Southeast	X		7.5	12	29.9	31	43	59.9
SB65*	Southeast	X		4	10.1	27	38	40.5	52.6
SB66*	Southeast	X		8.5	15.5	25.5	38	41	53.5
SB67*	Southeast	X		6	17.5	26.5	36.5	49.5	54.5

Table 3.5 is adapted from the Phase IIa RAWP, DOE/LX/07-1271&D2/R3 (DOE 2013a).
* Sample locations centered between electrodes.
X Denotes sample locations where postoperations samples were collected.
-- Denotes baseline and postoperations samples were not planned to be collected.
† Denotes baseline sample collected but postoperations samples were not planned to be collected.

Table 3.6. Phase IIa Baseline/Postoperations Groundwater Sampling Plan

Location ID	Area	Sample Interval (Upper RGA)*
X206	Southeast	X
X209	Southeast	X
X210	Southeast	X
X211	Southeast	X
X213	Southeast	X
X214	Southeast	X
X215	Southeast	X
X216	Southeast	X
X218	Southeast	X
X221	Southeast	X

*Groundwater pump set in the Upper RGA.
Locations based on Figure 7 from Phase IIa RAWP, DOE/LX/07-1271&D2/R3 (DOE 2013a).

3.6 CRITERIA FOR CEASING IRA SYSTEM OPERATIONS

The criteria for ceasing IRA system operations are summarized in Table 3.7. Sections 4.2 and 5.2 provide documentation that criteria for ceasing IRA system operations were achieved in both Phase I and Phase IIa projects.

Table 3.7. Criteria for Ceasing IRA System Operations

Performance Assessment Model Parameters (P)	Performance Metrics (PM)	Potential Deviation from Performance Assessment Model	Contingencies
P 1: Heating has stabilized in the subsurface.	**PM 1:** Monitor/record temperature readings from temperature sensors installed in the treatment zones to the required depth of heating. Phase I and IIa stable heating goal: • Temperatures in the soil above the potentiometric surface of the RGA (approximately 53 ft bgs) reach 194°F (90°C). The boiling point of free-phase TCE is 189°F (87°C) at sea level pressure conditions. • Temperatures below the potentiometric surface reach the boiling point of the free-phase TCE at the depth of treatment [e.g., approximately 189ºF (87°C) at the potentiometric surface and approximately 239ºF (115°C) at 98 ft bgs]. Refer to Figure 4.8. • The target temperatures presented in bullets one and two are maintained for the period of time necessary to attain Performance Metric 2 below. • At least 90% of the temperature sensors installed at each depth interval verify that target temperatures have been achieved.	The temperature does not reach required levels in a treatment zone within 60 days after the estimated 90 days necessary to heat the zone.* The target temperature is attained and then declines before asymptosis in TCE recovery is achieved. In treatment volumes above the potentiometric surface, unintentional and extended (seven days or more) temperature excursions below the boiling point of TCE would be considered problematic. In the treatment volumes below the potentiometric surface, unintentional and extended (seven days or more) temperature excursions excess of 10% below the target temperature would be considered problematic.	If temperatures specified in **PM 1** are not achieved in a treatment zone within the estimated time required to heat the zone,* operations personnel will attempt to determine the reason for the deviation. If there is a problem with temperature sensing equipment, it will be replaced. If the electrodes are operating normally, then additional energy will be applied to the electrodes in zones that have not achieved or fail to maintain the required temperature in an attempt to increase temperatures. If electrode failure is the cause, attempts will be made to restore functionality to the electrode. If functionality cannot be restored, additional energy will be applied to electrodes in the vicinity of the failed electrode in an effort to compensate for the failed electrode. For Phase I and IIa operations, if contingency measures are unsuccessful and the temperature targets are still not achieved, then DOE will evaluate, in consultation with regulators, the cost/benefit of continuing ERH operations in the treatment zone.

Table 3.7. Criteria for Ceasing IRA System Operations (Continued)

Performance Assessment Model Parameters (P)	Performance Metrics (PM)	Potential Deviation from Performance Assessment Model	Contingencies
P 2: Recovery of TCE, as measured in the recovered vapor, diminishes to a point at which further recovery is at a constant rate (i.e., recovery is asymptotic). Asymptotic recovery is anticipated to occur within 180 days* unless VOC levels in recovered vapors exceed the capacity of the vapor treatment system requiring changes to the rate of heating and/or vapor extraction, in which case up to 240 days may be required.	**PM 2:** Assuming that stable target temperatures have been achieved (see PM 1 above), asymptotic conditions will be identified based on visual inspection of data plots showing TCE mass removal rate and TCE vapor concentration versus time for individual vapor recovery wells. Once the slope of the curves presented in these data plots approaches zero at a slow rate of change, the curves will be understood to be asymptotic. At asymptosis, the rate of TCE recovery is constant. The body of evidence, consisting of data plots of TCE mass removal rate and TCE vapor concentration versus time, and statistical analyses results will be used by DOE to identify when asymptosis has been reached.	TCE vapor concentrations and mass removal rate, plotted across time do not exhibit asymptosis within the estimated 180 days* required to treat the zone.	The treatment period may be extended beyond 180 days if VOC levels exceed the capacity of the vapor treatment system requiring changes to the rate of heating and/or vapor extraction. If asymptosis has not been achieved after 240 days of ERH operations, then DOE will evaluate, in consultation with regulators, the cost/benefit of continuing ERH operations in the treatment zone.

*Time estimates for achieving required temperature levels and for treating treatment zones are based on the results of numerical simulations conducted by McMillan-McGee Corporation.
Adapted from Phase I RDR, DOE/LX/07-0005&D2/R1 (DOE 2008a), and Phase IIa RDR, DOE/LX/07-1272&D2/R1 (DOE 2012).

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4. PHASE I ACTIVITIES

4.1 NARRATIVE DESCRIPTION

The construction Phase I of implementing the ERH IRA was initiated in December 2008 and was complete in December 2009. The following subsections describe the work performed to implement the IRA.

Information presented in this Phase I Construction Activities Section came from a number of sources, including many of the documents referenced herein, C-400 project team members, subject matter experts (SMEs) from DOE contractors, teaming partners, and subcontractors who collected much of the information presented in this report.

The Phase I RDR (DOE 2008a) and Phase I RAWP (DOE 2011a) describe the Phase I design and implementation strategy. In 2007, DOE commissioned an independent technical review (ITR) of the C-400 90% Phase I RDR (ITR 2007). The 2007 ITR team observations and recommendations helped formulate the Phase I design and led to the phased deployment strategy. The report *Technical Performance Evaluation for Phase I of the C-400 Interim Remedial Action at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-1260&D1, (DOE 2011b) largely was adapted and presented in this section, which summarizes the completion of implementing the Phase I IRA for the Southwest and East Treatment Areas of the C-400 Cleaning Building.

4.1.1 Site Preparation

4.1.1.1 Removal of existing miscellaneous equipment

As part of the site preparation efforts, these pieces of equipment and infrastructure were removed and disposed of. The specific equipment and infrastructure removed included the following:

- TCE storage tank (approximately 10,800 gal), tank saddles, diking and subsurface catch-basin, and associated piping;
- TCE truck unloading and building transfer pumps and associated piping and electrical equipment;
- Fence; and
- Rail-mounted mobile overhead lifting crane.

Figure 4.1 shows the locations of the equipment removed to prepare the area for the remedial action.

In addition to removing some existing equipment, it was necessary to construct some new foundations and pads for IRA equipment, including electrical power transformers, tanks and other required equipment (see Figure 4.2.). As-built drawing M7DC40000A002, Rev. 7, “Groundwater/Vapor Treatment System Treatment Area Equipment Layout,” included in Appendix A, provides a complete plan view of the treatment equipment layout.

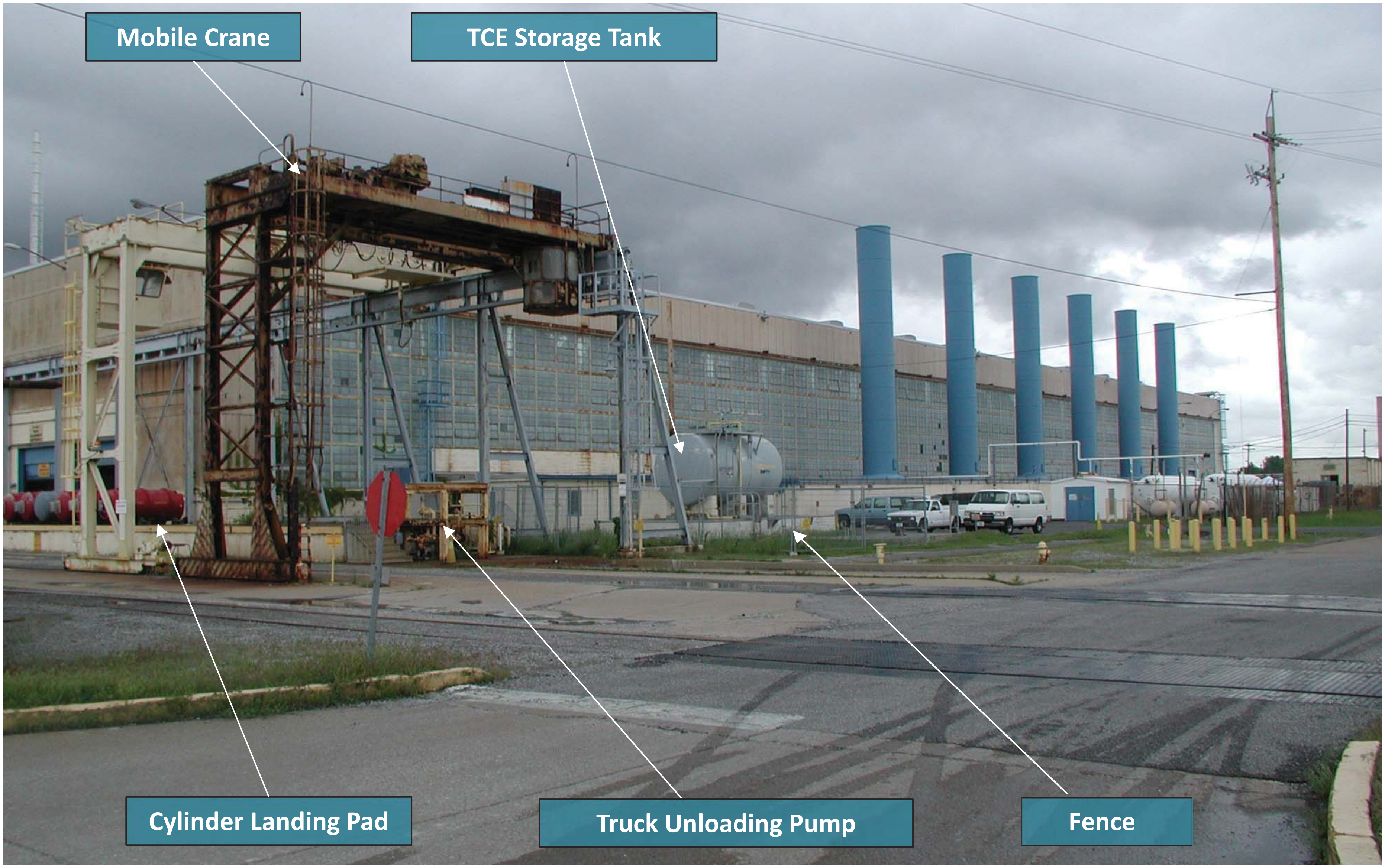

Figure 4.1. Infrastructure Equipment Removal

Photograph Date - Direction: 5/10/2006 - Looking North

Figure 4.2. Foundation Construction for Treatment Equipment

Photograph Date - Direction: 4/27/2009 - Looking North

4.1.1.2 Remedial design support investigation

An RDSI was performed to support implementation of the IRA. A complete discussion of the RDSI results is included in the *Remedial Design Report, Certified for Construction Design Drawings and Technical Specifications Package, for the Groundwater Operable Unit for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-0005&D2/R1 (DOE 2008a). The specific purpose of the RDSI was to support the ERH design and implementation by providing additional information on subsurface conditions and the relative presence of VOC contamination in the UCRS, the RGA, and RGA/McNairy interface. The investigation utilized the innovative membrane interface probe (MIP) technology to complete the RDSI scope of work. MIP technology was implemented with direct-push drilling technology and included utilizing all three of the available capture detectors for identifying VOC contamination. Those detectors included electron capture, flame ionization, and photoionization. During the RDSI, 18 MIP borings were completed through the UCRS soils to a depth of approximately 55 ft and 33 MIP borings were completed through the UCRS to the base of the RGA to a depth of approximately 100 ft. The MIP data was combined with the existing soils data obtained from the WAG 6 Remedial Investigation and utilized to determine the location of potential DNAPL source material (DOE 1999). The location of boreholes and source zones from the WAG 6 Remedial Investigation and the RDSI are shown in Figure 4.3 (DOE 2008a). Table 4.1 provides the name, general location, area, and depths for the DNAPL source areas.

4.1.2 Phase I Electrical Resistance Heating Treatment

The Phase I ERH treatment focused on two specific areas as a result of the FFA parties agreeing to implement the IRA in a phased approach. Phase I Areas were the Southwest Treatment Area and East Treatment Area. The Southwest Treatment Area was expected to contain contaminant in both the UCRS and the RGA horizons (bottom at RGA and McNairy interface), while the East Treatment Area contamination was expected to be located only in the UCRS horizon (DOE 2008a). The ERH design for Phase I, as contained in the 2008 RDR, is identified as the “base design” (DOE 2008a).

4.1.2.1 Subsurface construction

Construction for Phase I activities was initiated in December 2008. The layout of the subsurface components for the Southwest and East Treatment Areas is shown in Figures 4.4 and 4.5. Installation of the subsurface ERH equipment involved rotosonic drilling of borings within which the electrodes, multiphase extraction wells, temperature monitoring strings, vacuum piezometers, and water level monitoring instruments were installed. The system drilled and installed in both the Southwest and East Treatment Areas consisted of the specific components as shown in Table 4.2.

4.1.2.2 Aboveground construction

The SVGTS to remove the contaminants from the soil vapor and groundwater extracted was constructed on the east side of the C-400 Cleaning Building. Figure 4.6 provides a figure showing the arrangement of the aboveground treatment equipment; while Figure 4.7 shows a picture of the aboveground treatment system at the time of Phase I. The major components of the SVGTS included the following:

- Power Delivery System
- Liquid Treatment System
- Vapor Treatment System
- System Controller
- Backup generator

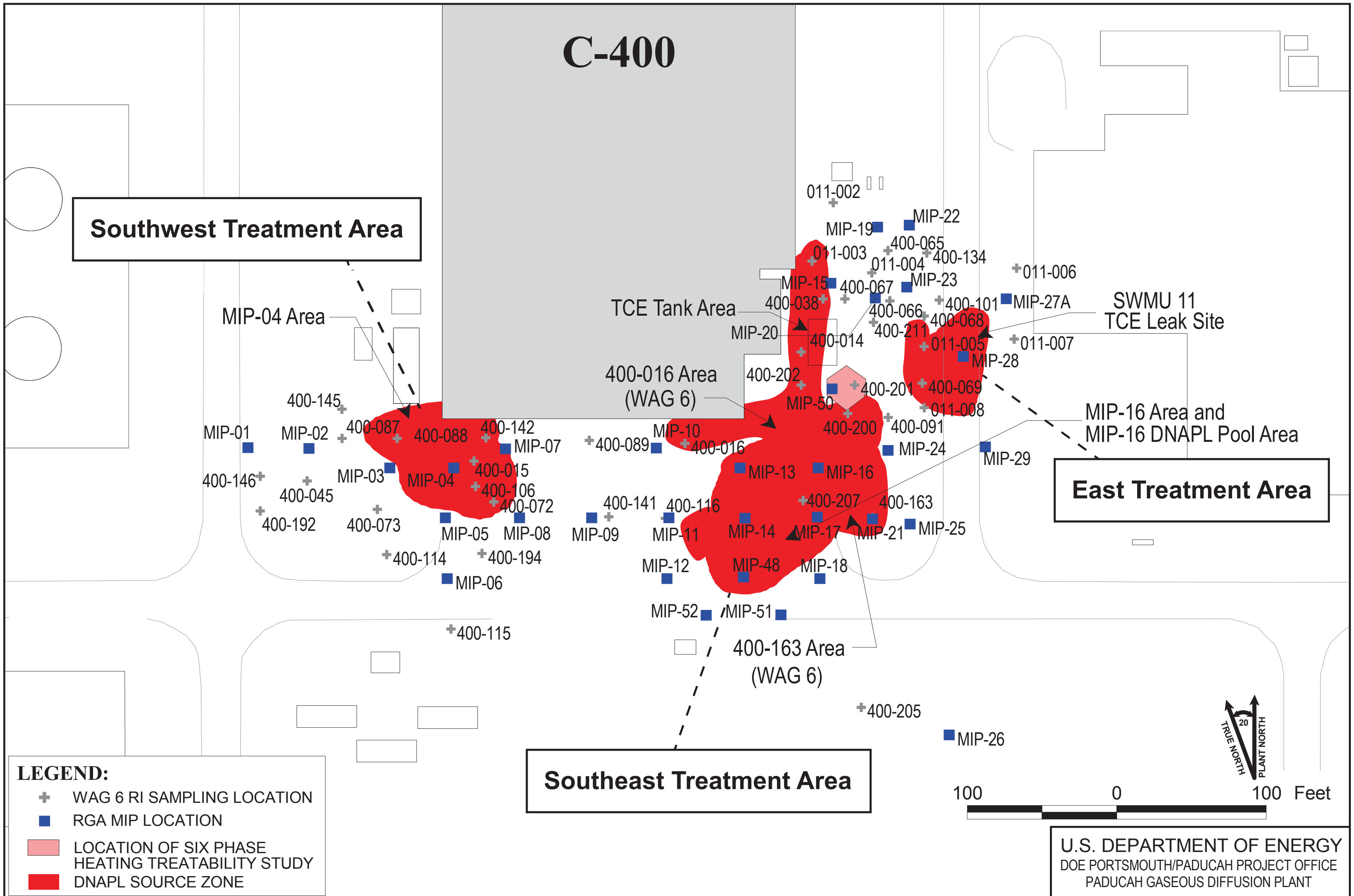

Figure 4.3 Location of Boreholes and DNAPL Source Zone Delineations from RDSI and WAG 6 Results at Completion of RDSI

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Figure No. c5ac90005sk012basemap.apr
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Table 4.1. DNAPL Source Areas*

DNAPL Source Areas (see Figure 4.3)	General Location	Maximum Area (ft^2)	Depth (ft bgs)
MIP-04	Northwest RDSI area (Southwest)	6,000	20–70
MIP-16	East—central RDSI area	5,300	20–80
MIP-16 DNAPL pool	East—central RDSI area	4,800	84–97
SWMU 11 TCE Leak Site	East RDSI area (east)	775	28–32
TCE Tank Area	East side C-400 Cleaning Building	1,700	20–60
400-016 Area	South side C-400 Cleaning Building	2,000	16–34
400-163 Area	Southeast RDSI area	1,400	8–48

*Shading indicates area that was a target of Phase I C-400 IRA treatment (Southwest and East Treatment Areas). Unshaded rows comprise the Southeast Treatment Area.
(Table adapted from DOE 2008a.)

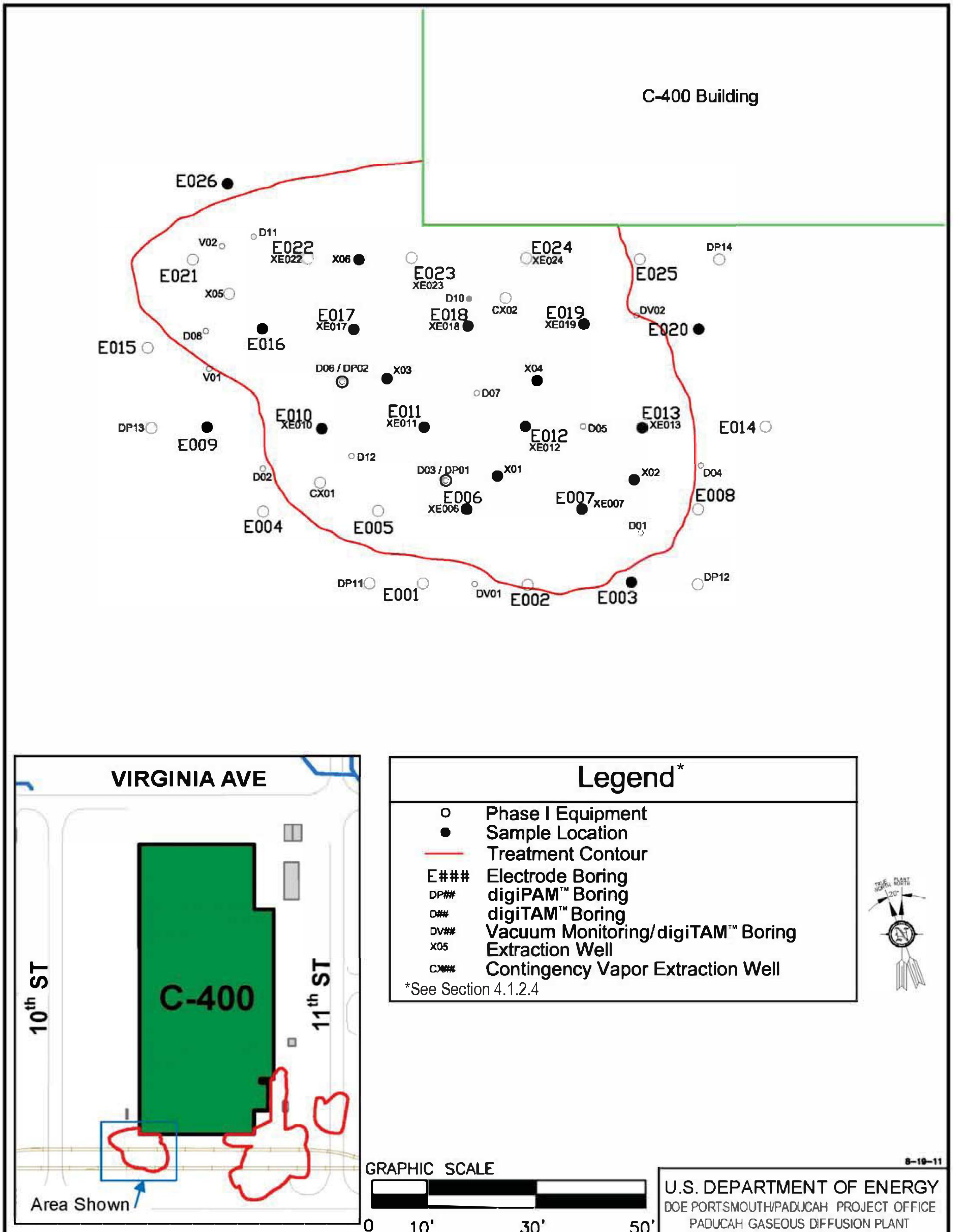

Figure 4.4. Southwest Treatment Area Subsurface Equipment Layout

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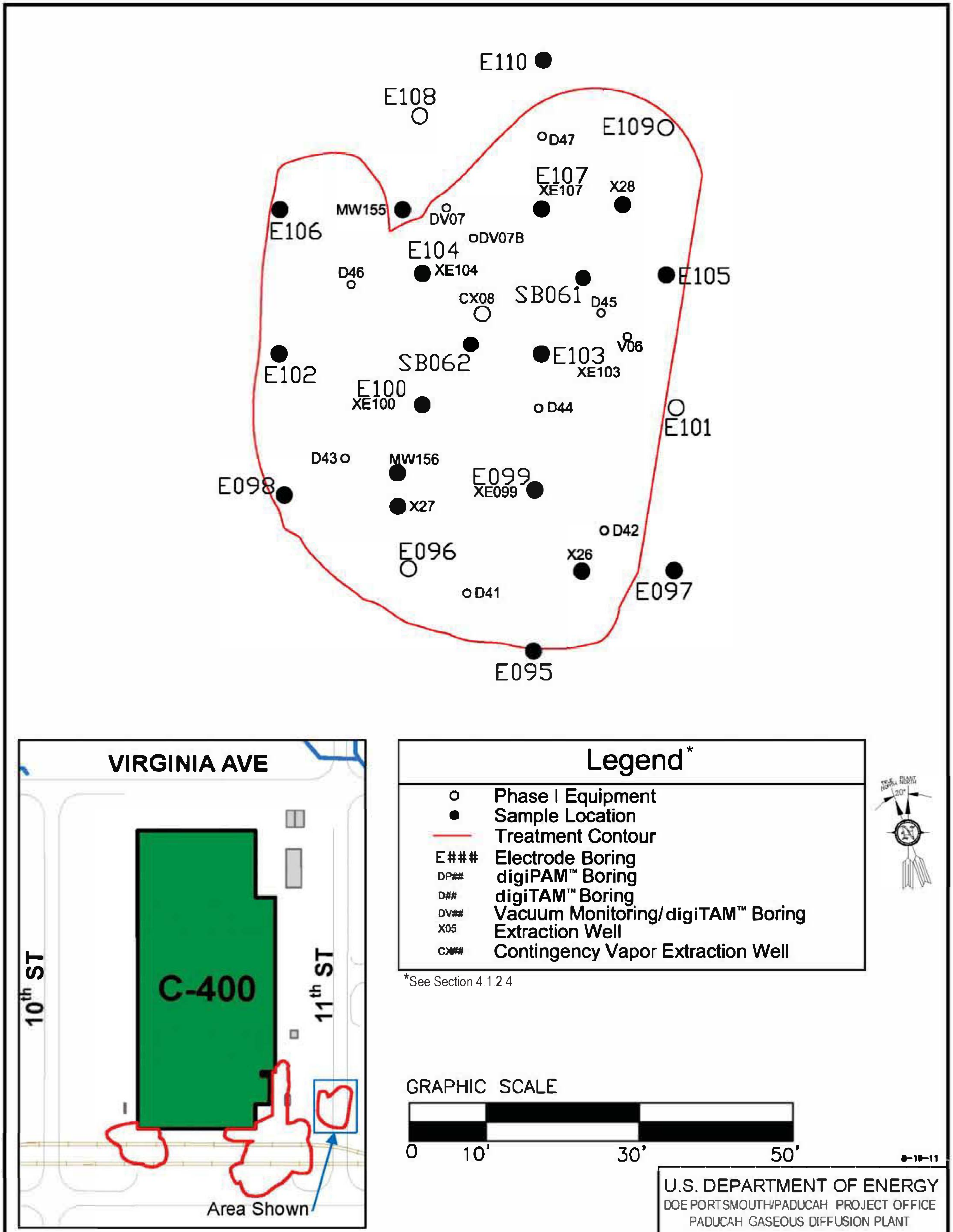

Figure 4.5. East Treatment Area Subsurface Equipment Layout

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Table 4.2. ERH Subsurface Components

ERH Component	Southwest Treatment Area	East Treatment Area
Electrode	26	16
digiPAM™	6	0
digiTAM™	11	7
Vacuum Monitoring/digiTAM™	4	3
Multiphase Extraction Well	18	3
Contingency Vapor Extraction Well	2	1

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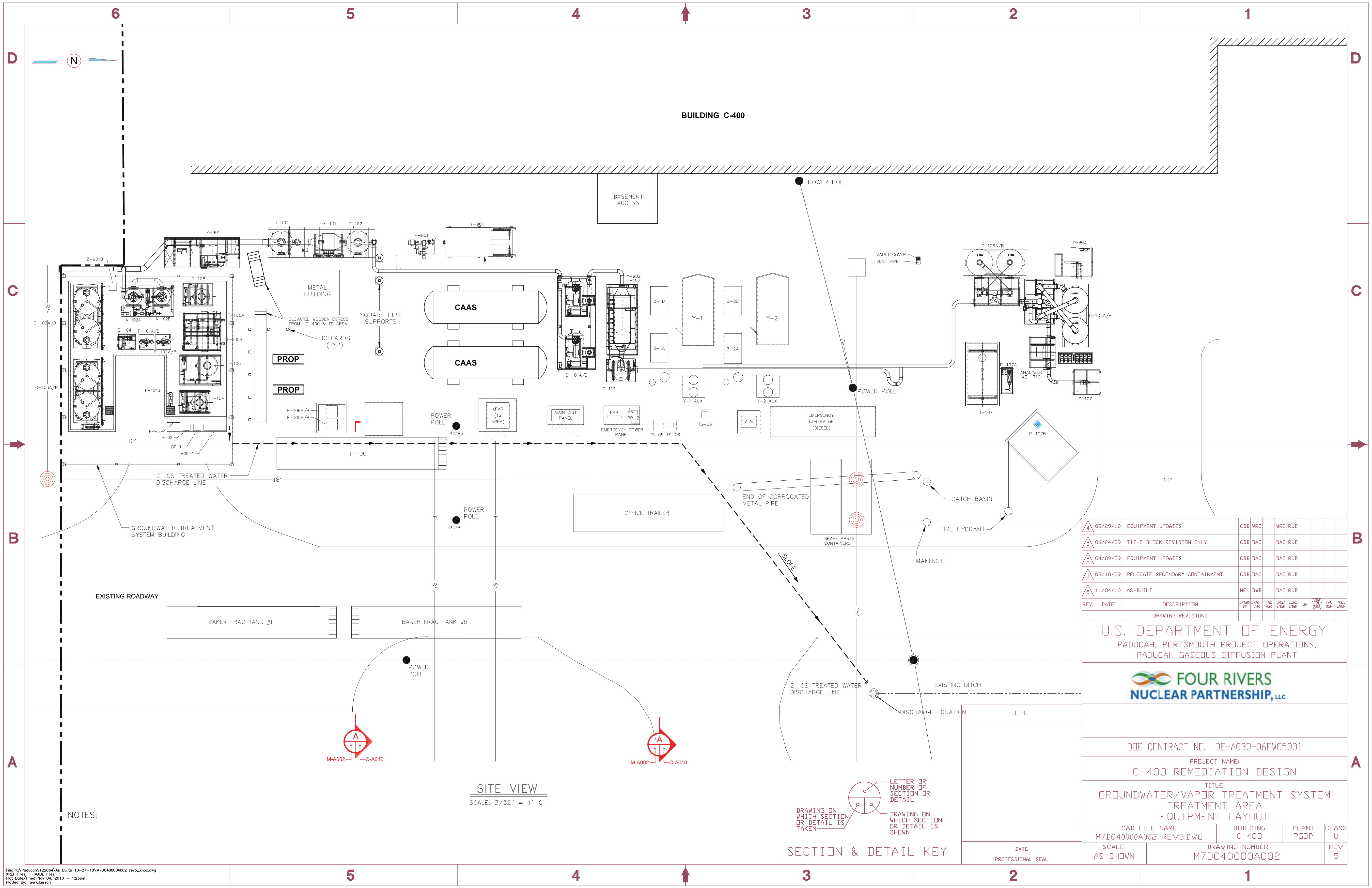

Figure 4.6. Groundwater/Vapor Treatment System Equipment Layout

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Figure 4.7. Picture of Groundwater/Vapor Treatment System Area

Photograph Date - Direction: 3/29/2010 - Looking Northwest

Figure 4.8 shows a portion of the treatment system that was located inside of a tent for weather protection. The aboveground construction included the installation of utilities and support lines including power supply, water lines, compressed air, and vapor transfer lines. Engineering drawings for the ERH system are included electronically in Appendix A. Because the C-400 Cleaning Building was an operating facility at that time and area was constricted in the Southwest Treatment Area, some equipment had to be located remotely to provide for continued building door access. These included recessing pipes in subsurface trenches and on walls and locating process lines and communication lines in the recessed pipes or wall-mounted pipes.

4.1.2.3 Operations

Following construction, commissioning and testing began with testing the SVGTS using ambient air and potable water in a logical sequence to ensure that the subsystems worked correctly. Batch treatment operations then were performed to ensure VOC removal by the SVGTS met design criteria.

Prior to commencing normal operations, extensive step and touch electrical voltage potential testing was implemented in and around the energized wellfields to identify and eliminate induced voltages greater than 15 volts (based on the National Electric Code) on conductive surfaces. Numerous measurements were taken revealing only minor excursions of 3.8–4.4 volts on a section of header pipe and on monitoring well bollards and riser pipe in the east wellfield. These conductive surfaces were covered by insulating material to eliminate the electrical hazard. Subsequent step and touch potential readings at these locations were approximately 0.2 volts after installing insulation. In addition to the step and touch potential testing performed by the project team, PGDP personnel performed independent step and touch potential testing inside the C-400 Cleaning Building. The threshold criterion used for PGDP facilities was a 1-volt limit. No problematic areas were identified during PGDP testing.

System testing was concluded in March 2010 and normal remedial operations were initiated. Operations continued through September 2010 when TCE concentrations in recovered vapor had dropped to asymptotic levels. Pulsed operations were initiated. The strategy for the pulsing operations was intended to maximize removal of the remaining contaminants from the treatment area by maximizing extraction from the wells and by varying the pressure levels within the subsurface. To maximize the extraction from individual wells, a pattern was initiated that consisted of operating half of the wells while the remaining one-half were shut down. To vary subsurface pressures, the extraction rates were reduced or increased concurrently with varying the power levels to the electrodes. VOC readings were taken from the wells with maximum extraction continuing at well locations with the highest VOC concentrations. The process was repeated for two cycles. Pulsed operations ended in October 2010 and power to the electrodes was turned-off. Vapor extraction continued for approximately five weeks to facilitate subsurface cooling.

4.1.2.4 Temperature, heating, and vapor recovery and groundwater extraction performance

A critical factor in the success of an *in situ* ERH project is the attainment of target temperatures that are at or above the boiling point of the target VOC(s). The target temperature requirements for the C-400 ERH project were developed to be depth specific for reasons described below. TCE, the target VOC at C-400, has a boiling point of approximately 189°F (87°C) at normal atmospheric pressure conditions. A TCE/water mixture will boil at a lower temperature than that of either TCE or water. The boiling point of a TCE/water mixture is approximately 163°F (73°C). The boiling temperature of TCE and that of a TCE/water mixture increases with depth below the water level (potentiometric surface) due to increasing hydrostatic pressures. These factors were considered in defining the C-400 IRA target temperatures. Figure 4.9 shows the relationship between boiling temperature and depth below the potentiometric surface for a TCE/water mixture, for free-phase TCE, and for groundwater (DOE 2011b; Kueper et al. 2014).

Figure 4.8. Treatment Equipment (Tent Area)

Photograph Date - Direction: 4/5/2010 - Looking West

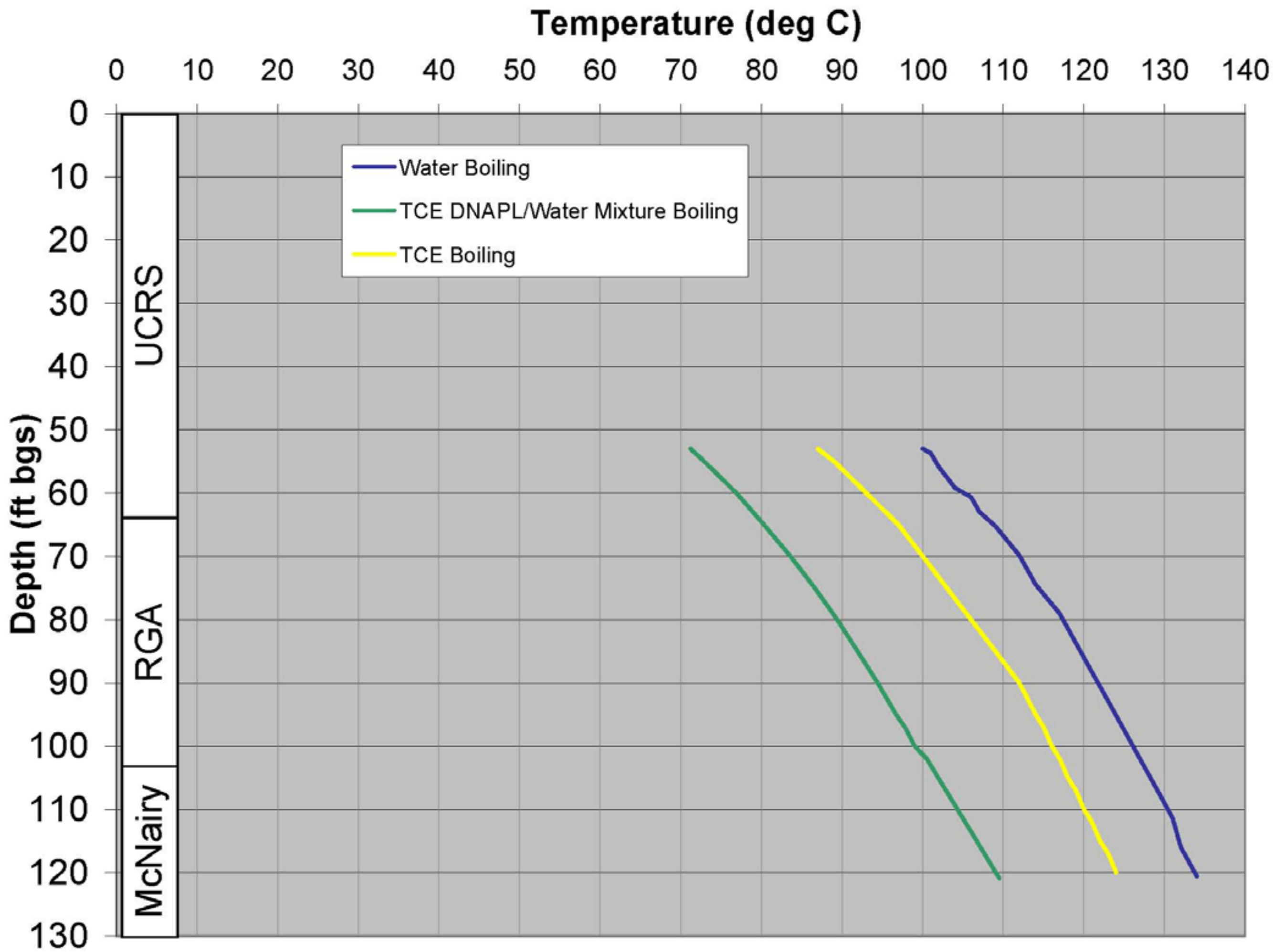

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Figure 4.9. Boiling Temperature versus Depth (Kueper, et. al. 2014)

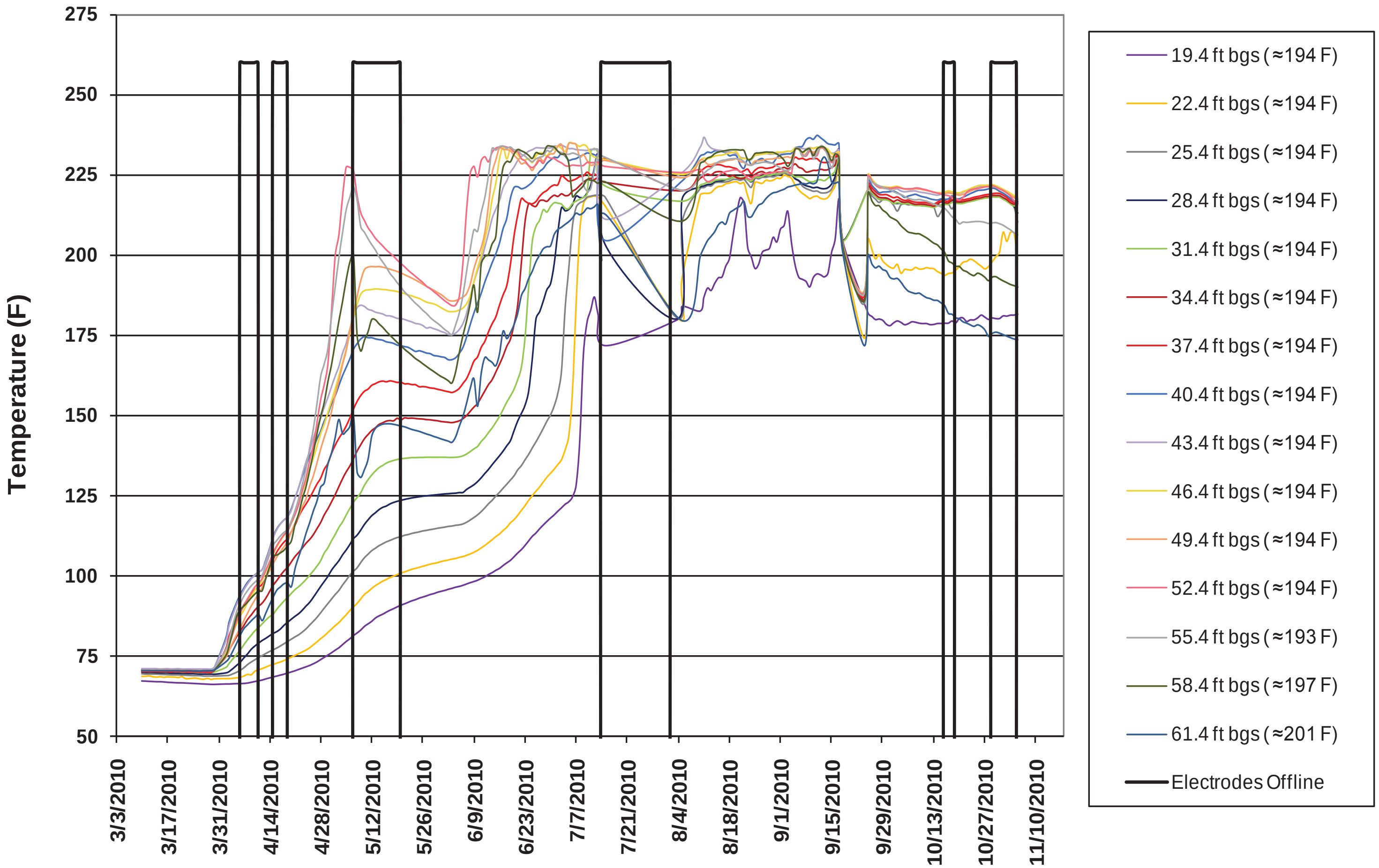
For the C-400 IRA Phase I, a target temperature was established for subsurface soils above the potentiometric surface and for soils below the potentiometric surface. The target temperature established for soils above the potentiometric surface of the RGA (approximately 53 ft bgs) is 194ºF (90°C) or higher. The target temperature for soils below the potentiometric surface of the RGA was established as the boiling point (or above) of free-phase TCE at the respective depth of treatment [e.g., approximately 189ºF (87°C) at the potentiometric surface and approximately 239ºF (115°C) at 98 ft bgs]. The free-phase boiling point of TCE (adjusted for depth below the water level) is a conservative goal since, as described above, a phase change for a TCE/water mixture is achieved at boiling temperature that is lower than that of the solvent itself.

Temperatures in the treatment zones were monitored by strings of digital temperature acquisition modules (digiTAMs™) installed through the target heated depth. DigiTAM™ strings generally were installed in locations that were between electrode borings and away from vapor extraction wells, typically the coolest zones of the treatment volume. DigiTAMs™ are digital temperature sensing devices composed of temperature and chemically resistant cable with imbedded sensors placed at 3-ft intervals. There were approximately 25 sensors per string on each digiTAM™ string monitoring temperatures through the bottom of RGA. The sensors have an accuracy of ± 0.5°C/0.9°F and can operate in temperatures ranging from -67°F (-55°C) to 257°F (125°C). Each sensor on the string is individually addressed so the data can be captured and stored on a data server.

In the East Treatment Area, eight digiTAM™ strings were installed to monitor subsurface temperatures throughout the target treatment volume, which ranged from 20 to 60 ft bgs. East Treatment Area digiTAM™ locations are shown on Figure 4.5. DigiTAM™ and vacuum monitoring/digiTAM™ wells are designated on the figure by the letter "D" followed by a number (e.g., D42) or by the letters, "DV" followed by a number (e.g., DV07). Thirteen digiTAM™ strings were installed in the Southwest Treatment Area to monitor subsurface temperatures throughout the target treatment volume at depths ranging from 20 ft bgs to approximately 93 ft bgs. Southwest Treatment Area digiTAM™ locations are shown on Figure 4.4. All digiTAM™ data for all locations in the East and Southwest Treatment Areas are in an electronic format (Appendix B) or they are available for viewing at the Environmental Information Center, 115 Memorial Drive, Paducah, KY, and are included in the Technical Performance Evaluation for Phase (DOE 2011b) (https://paducaheic.com/Search.aspx?accession=env 1.A-00027).

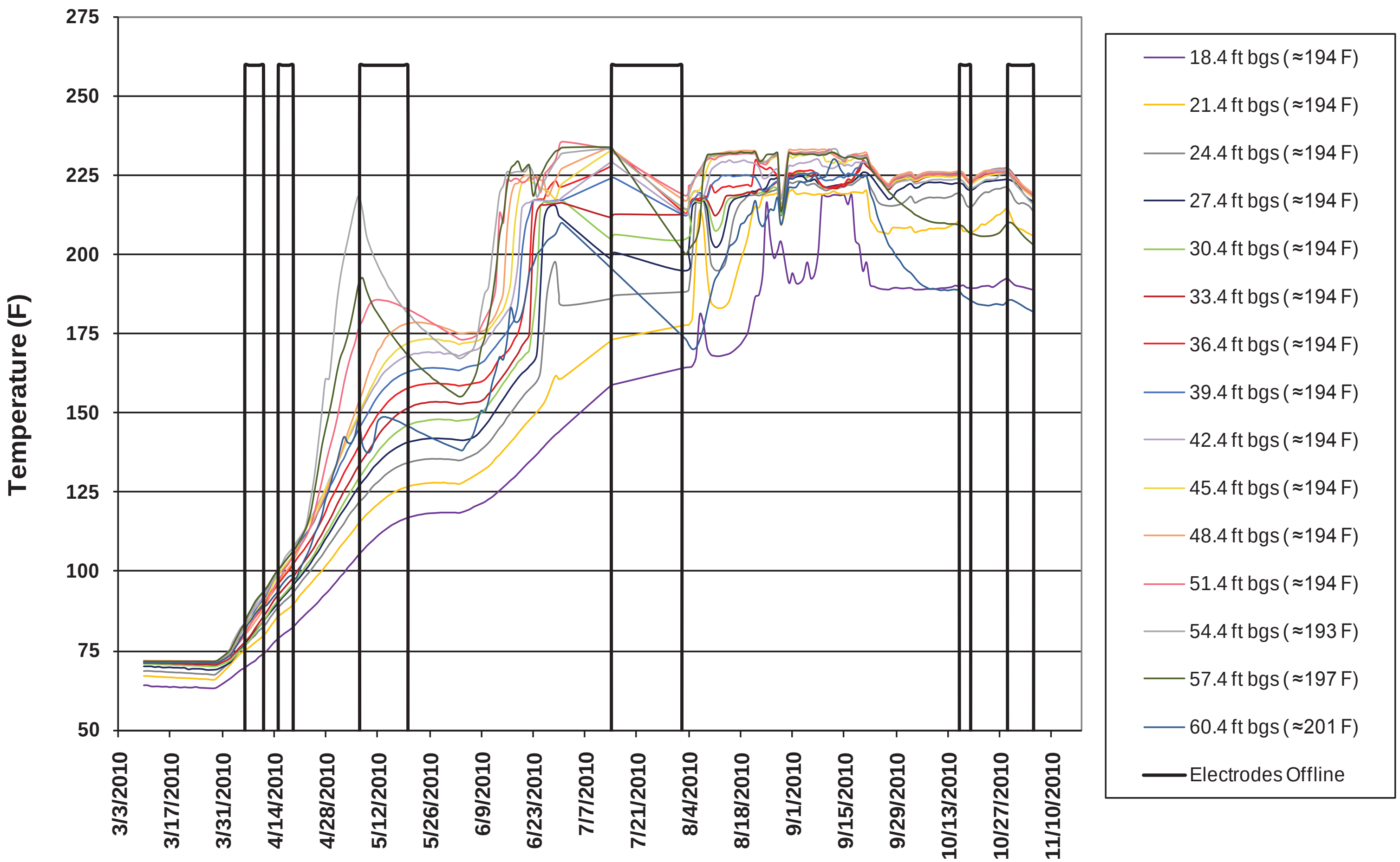
4.1.2.4.1 East Treatment Area heating performance

Figures 4.10, 4.11, and 4.12 present temperature monitoring results from the East Treatment Area at digiTAM™ locations D44, D43, and D46, respectively (DOE 2011b). D44 was centrally located in the east area where the target heated depth interval was 40 to 60 ft bgs (Figure 4.5). DigiTAMs™ D43 and D46 were located on the west side of the East Treatment Area where the target heated depth interval was 20–60 ft bgs. Figure 4.13 presents temperature monitoring results at digiTAM™ D44 from approximately 62–71 ft bgs. Geologic setting and electrode placement are important for understanding the heating performance. In the East Treatment Area, the UCRS extends to an average depth of 51 ft bgs. The Upper RGA (HU 4 unit) extends from 51 ft to 57 ft bgs. The Lower RGA extends from 57 ft bgs to the top of the McNairy Formation at 91 ft bgs. Heating performance discussed below also tied into the aquifer being addressed. Due to the lower hydraulic conductivity (resulting in lower groundwater inflow) and lower electrical resistivity, the UCRS is more conducive to heating than the RGA. The East Treatment Area treated soils are unsaturated soils or low saturation soils with little to no groundwater flow to provide input to digiPAMs™. Because subsurface conditions were unsaturated, digiPAM™ sensors were not utilized in the East Area. The heating electrodes in the East Treatment Area consisted of typical two interval electrodes placed from 36–46 ft and 53–63 ft bgs. The western borings contained a third electrode placed from 18–26 ft bgs. The discussion that follows compares heating performance based on geologic formation, water table, and electrode depth.



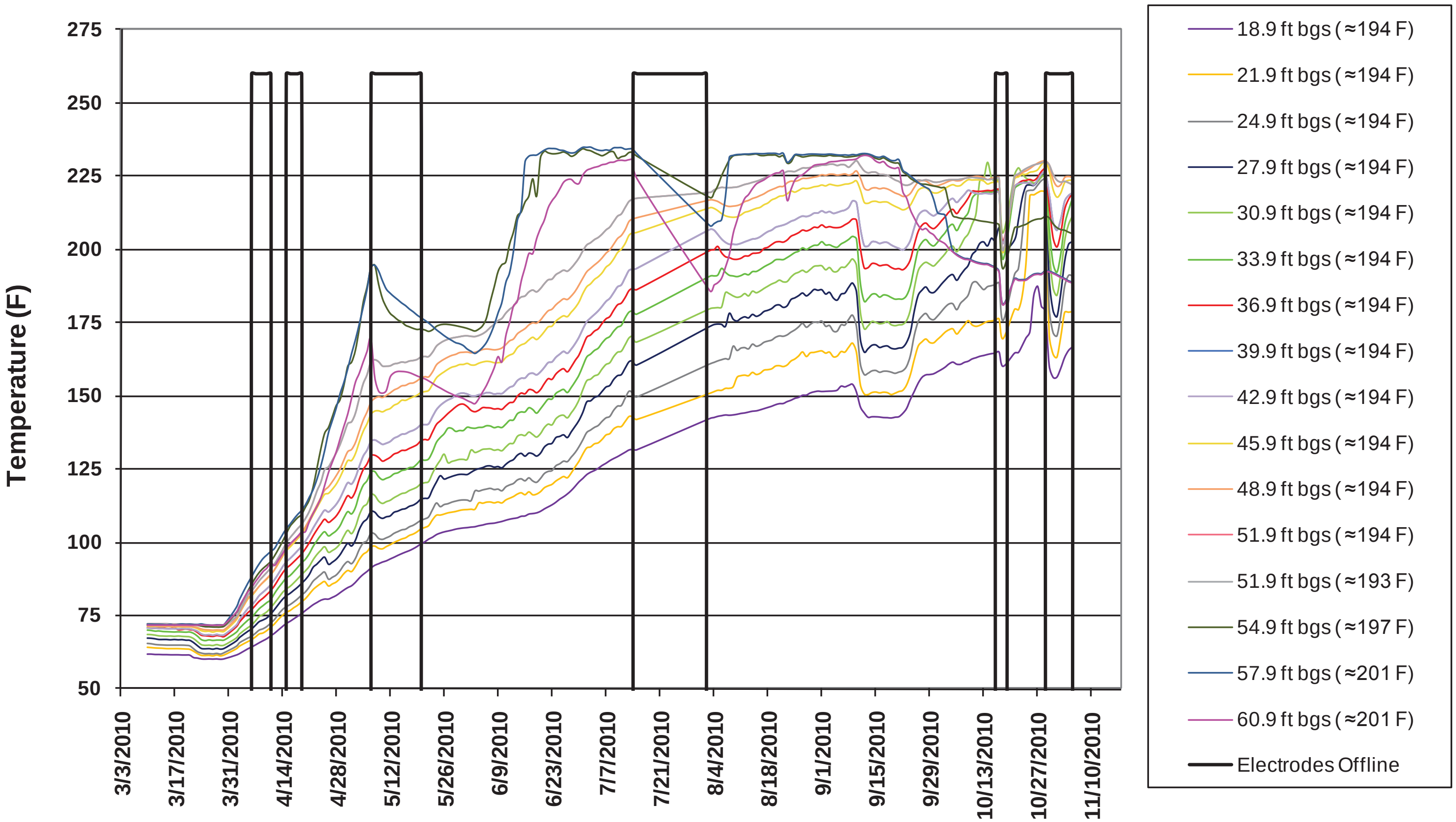
*Data spikes which exceed 20% of the adjacent values have been removed from the data set for presentation.
Numbers in parenthesis indicate target temperatures.

Figure 4.10. East Treatment Area Average Daily digiTAM™ D44 Readings, 18-62 ft bgs



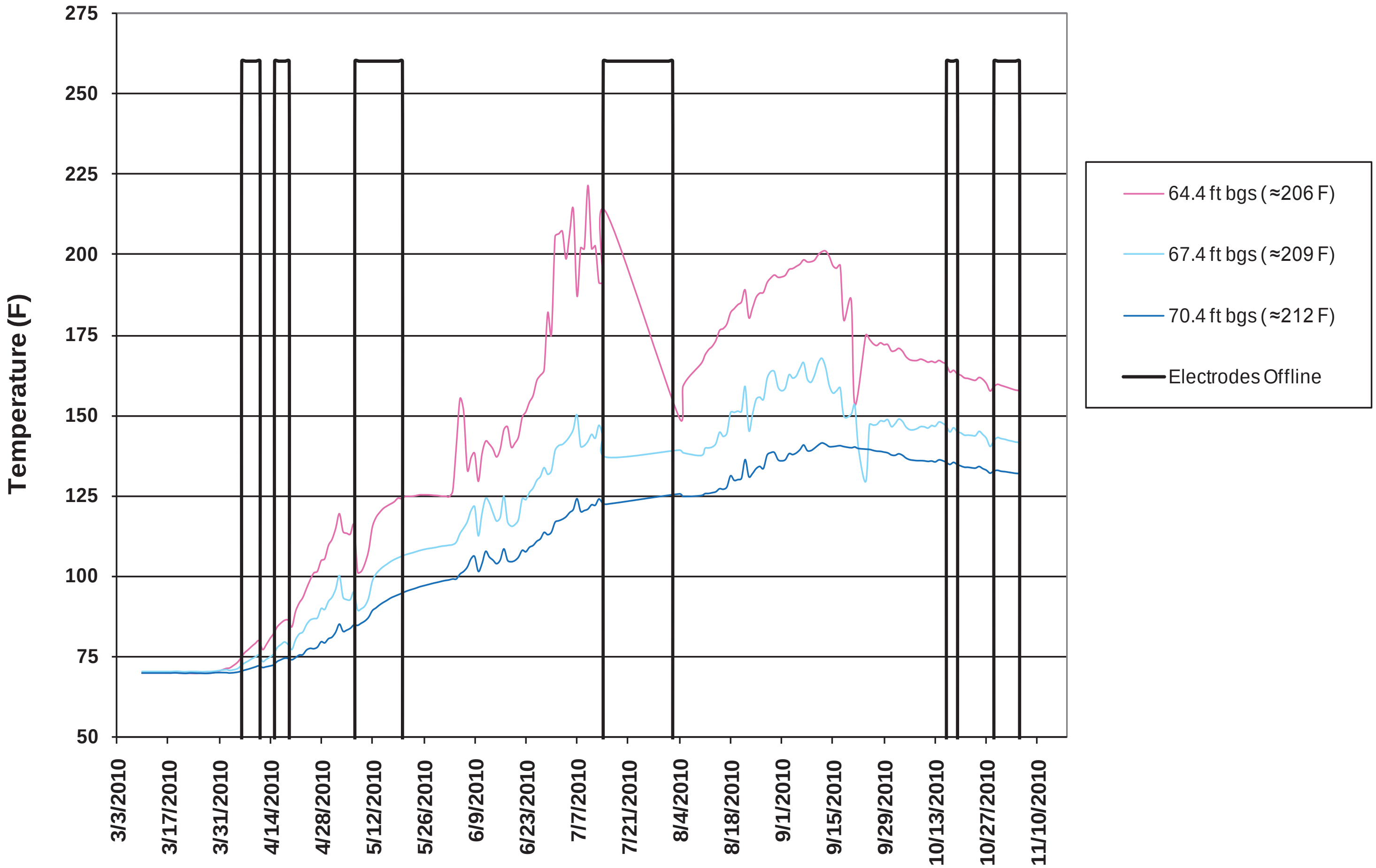
*Data spikes which exceed 20% of the adjacent values have been removed from the data set for presentation.
Numbers in parenthesis indicate target temperatures.

Figure 4.11. East Treatment Area Average Daily digiTAM™ D43 Readings, 18-62 ft bgs



*Data spikes which exceed 20% of the adjacent values have been removed from the data set for presentation.
Numbers in parenthesis indicate target temperatures.

Figure 4.12. East Treatment Area Average Daily digiTAM™ D46 Readings, 18-62 ft bgs



*Data spikes which exceed 20% of the adjacent values have been removed from the data set for presentation.
Numbers in parenthesis indicate target temperatures.

Figure 4.13. East Treatment Area Average Daily digiTAM™ D44 Readings, RGA 62-71 ft bgs

- All digiTAM™ sensors indicated attainment of target temperatures 194°F (90°C) in the targeted heated volumes above the potentiometric surface (≈ 53 ft bgs) by August 6, 2010, except for the 20 ft to 35 ft bgs depths at D46.

- By August 31, 2010, target temperatures were achieved for all depths below 30 ft bgs.

- The 194°F (90°C) target temperature eventually was achieved in all target heated intervals above 53 ft bgs by October 23, 2010.

- This 53-ft depth is below the UCRS and within the Upper RGA.

- Target temperatures in heated volumes below the potentiometric surface were achieved at all digiTAMs™ by July 5, 2010.

- Target temperatures were attained later in uppermost locations where heat loss was greatest due to the lack of electrodes above these settings; however, upper zone locations also experienced continued rises in temperature during periods of power outage, when vapor extraction was not active, and heat was not being extracted from the subsurface.

- D44 reached target temperature estimated at ≈ 62 ft (i.e., reached target temperature at 60.4 ft, but did not at 64.4 ft). To put this in context, the target temperature was reached to a depth within a ft of the bottom electrode (63 ft) and extended through the Upper RGA and 5 ft into the Middle RGA.

- D44 also displayed differences in the rate of heating prior and subsequent to a period of power outage in mid and late July due to the removal of condensate buildup in extraction hoses and conveyance piping during the outage, resulting in a higher rate of heat removal from the subsurface after the outage.

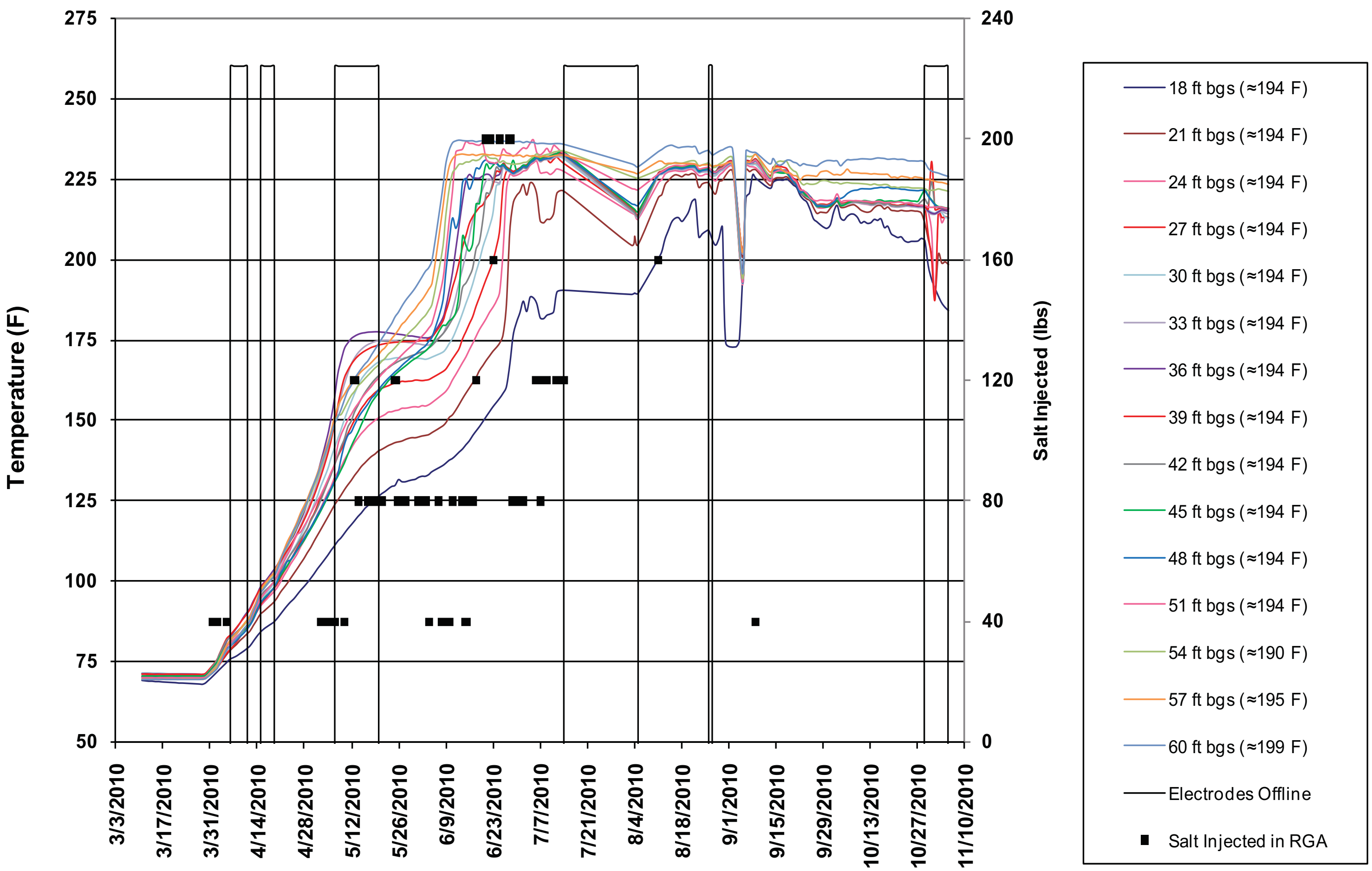
Electrode downtime is illustrated on the temperature plots by the black outlined bars. It is clear from the temperature plots that the two most significant downtime events in May 2010 and July 2010 had an impact on heating and extended the time needed to reach target temperatures.

4.1.2.4.2 Southwest Treatment Area heating performance

Figures 4.14 and 4.15 present temperature monitoring results for the Southwest Treatment Area at digiTAM™ location D07 (DOE 2011b). D07 was centrally located in the treatment area and monitored temperatures in the depth interval from 20 to 93 ft bgs. The geologic setting and electrode placement are slightly different in the Southwest Treatment Area than in the East Treatment Area. The setting is important to understanding the heating performance. In the Southwest Treatment Area:

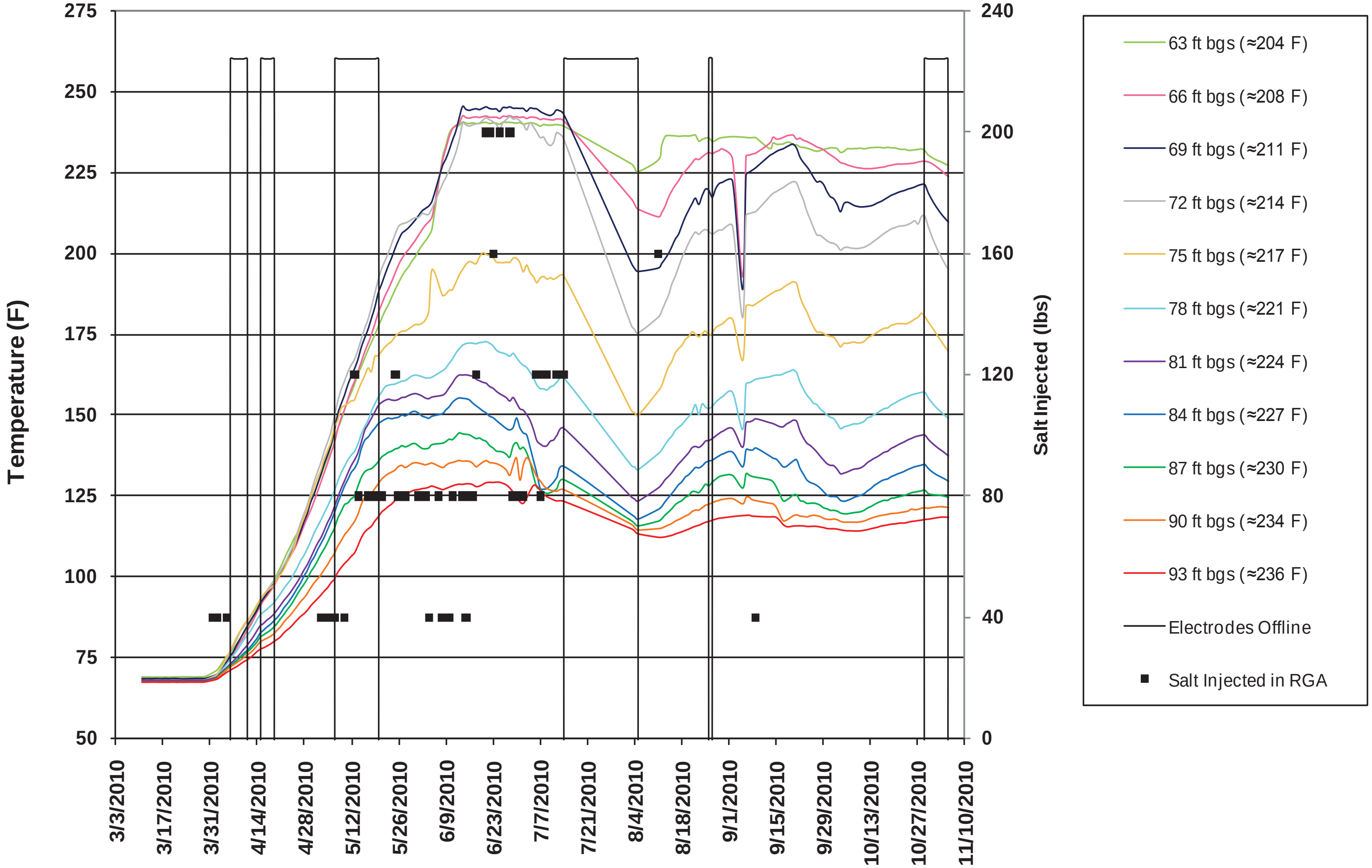
- The UCRS extends deeper to an average depth of 57 ft bgs;
- The Upper RGA (HU4 unit) extends from 57 ft to 67 ft bgs; and
- The Middle and Lower RGA extend from 67 ft bgs to the top of the McNairy at 95 ft bgs.

Heating performance discussed below also tied into the aquifer being addressed. Recall that the lower hydraulic conductivity (resulting in lower groundwater inflow) and lower electrical resistivity makes the UCRS more conducive to heating than the RGA. The heating electrodes in the Southwest Treatment Area typically consist of 3 interval electrodes, with electrodes placed from 18–28 ft, 36–46 ft, and 53–63 ft. For those borings surrounding D07, two additional electrodes were placed in the boreholes from 71–81 ft and 88–98 ft bgs.



*Data spikes which exceed 20% of the adjacent values have been removed from the data set for presentation.
Numbers in parenthesis indicate target temperatures.

Figure 4.14. Southwest Treatment Area Average Daily digiTAM™ D07 Readings, UCRS 18-62 ft bgs



*Data spikes which exceed 20% of the adjacent values have been removed from the data set for presentation.
Numbers in parenthesis indicate target temperatures.

Figure 4.15. Southwest Treatment Area Average Daily digiTAM™ D07 Readings, 62-100 ft bgs

The discussion that follows compares heating performance based on geologic formation, water table, and electrode settings.

- All digiTAM™ sensors in the Southwest Treatment Area indicated attainment of target temperature 194°F (90°C) in the targeted heated volume above the potentiometric surface (≈ 53 ft bgs) by July 13, 2010, except for the 20 to 26 ft bgs depths at D01 and D04. Target temperatures were attained later in uppermost locations where heat loss was greatest due to the lack of electrodes above these settings. Upper zone locations also experienced continued rises in temperature during periods of power outage when vapor extraction was not active and heat was not being extracted from the subsurface.

- By September 8, 2010, all sensors indicated that target temperature had been achieved above the potentiometric surface (see Figure 4.14).

- The target treatment volume in the Southwest Treatment Area included ERH infrastructure for heating in the RGA as a test of the Phase I design. DigiTAM™ D07 was installed to 93 ft bgs to measure heating throughout the RGA.

- Target temperatures were not attained in the Lower RGA, below approximately 72 ft bgs (as shown on Figure 4.15).

- The attainment of target temperature in the interval between 60 and 70 ft bgs in the Southwest Treatment Area is a result of additional layers of electrodes stacked below this depth.

- This hypothesis is supported by Figure 4.15, which presents temperature response in the East Treatment Area from 64.4 ft bgs to 70.4 ft bgs where electrodes extended only to about 63.5 ft bgs. Target temperature was reached at 64.4 ft bgs, about 1 ft below the electrode, but fell off significantly at lower depths.

- Based on this observed response in the East Treatment Area, it is clear that, without benefit of additional deeper electrodes, the 60 to 70 ft bgs interval would not have been heated adequately in the Southwest Treatment Area.

It is unclear from the data whether additional time or energy input to the electrodes would have enabled the East Treatment Area to reach target temperatures at 70 ft bgs [≈ 212°F (100°C)] without benefit of deeper electrodes. If one assumes the slope of the heating curve for the 70.4-ft bgs depth was constant and continuous, target temperature may have been reached around January 2011. This analysis did not account, however, for the fact that the rate of energy input may not overcome the cooling effects of RGA groundwater flow and temperature. Electrode downtime, due to system problems, is shown on the temperature plots by the black outlined bars. It is clear from the temperature plots that the two most significant downtime events in May 2010 and July 2010 had an impact on heating and extended the time needed to reach target temperatures. Operational contingency actions, as identified in the Phase I RAWP, were implemented to the extent practicable in an attempt to attain target temperatures in the Lower RGA of the Southwest Treatment Area:

- Operated the electrodes at maximum voltage (277 volts) in an attempt to overcome the high formation resistivity, to replace energy removed in extracted water and vapor, and to heat cool water entering from the perimeter of the heated formation volume; and

- Injected saltwater into RGA electrodes in batches (as much as 200 lb of salt added on some days) in an attempt to increase conductivity (see Figure 4.15 for injection dates and amounts).

4.1.2.4.3 Vapor and groundwater extraction performance

Soil vapor extraction (SVE) as a component of ERH is a technology that is used to extract volatile compounds from unsaturated soil. During SVE, a vacuum is applied to an extraction well to lower the vapor pressure in the vicinity of the well. Lowering the pressure at the extraction well induces an advective flow of soil vapors and flow of groundwater containing VOCs (primarily TCE and its breakdown products) from regions of higher pressure to the extraction point. This process enhances the volatilization of contaminants from within grains of soil and promotes the diffusion of sorbed contaminants into soil pores where they can be swept and extracted along with soil vapors. Vapor extraction performance is assessed by monitoring mass removal and ensuring that all areas within the treatment area had sufficient induced vacuum to recover the vapors generated by ERH. The radius of influence (ROI) generated by a vapor extraction well was assessed by measuring the vacuum induced at adjacent monitoring points. Vapor extraction well locations are shown on Figures 4.4 and 4.5 for the East and Southwest Treatment Areas. Vapor extraction wells were designated on the figure by the letter "X" followed by a number (e.g., X27). A picture of a vapor extraction well is shown in Figure 4.16. Wellfield vacuum pressure was monitored at vacuum piezometers installed near the perimeter of the treatment areas. These are designated on the Figures 4.4 and 4.5 by the letter "V" followed by a number (e.g., V06) or by the letters "DV" follow by a number (e.g., DV07).

Figure 4.16. Vapor Extraction Well

Photograph Date - Direction: 2/10/12 - Looking West

4.1.2.4.3.1 East Treatment Area

There were three vapor extraction wells and one contingency vapor extraction well (CX08) in the East Treatment Area. All vapor extraction points were connected to a common header, which transferred the TCE contaminated vapor to the treatment system for recovery and treatment and then release.

Table 4.3 provides a summary of flow rates achieved for vapor extraction points in the East Treatment Area. Vapor extraction flow rates from the primary vapor extraction points, "X##" and "CX##" wells, ranged from 7.0 scfm to just over 26 scfm with average rates ranging from 14 scfm to 17 scfm. Table 4.4 presents a summary of East Treatment Area vacuum pressure measurements achieved. Although maximum vacuum pressures of 5.5 and 4.2 inches of mercury were observed at monitoring locations V06 and DV07, respectively, many zero pressure readings were recorded. Pressure gauges installed on the vacuum monitoring locations were determined to not be sensitive enough to reliably measure/report operating pressures at levels that were as low as 1 or 2 inches of water (1 inch of mercury ≈ 13.6 inches of water). As a result, it was not possible to know for certain whether a zero pressure reading was indicative of no vacuum influence at the monitoring location or if it was just too low for the gauge to register.

Table 4.3. East Treatment Area Weekly Wellfield Flow Measurement Summary

Well ID	Minimum Flow (scfm)	Maximum Flow (scfm)	Average Flow (scfm)	Count of Measurements
X26	8.7	24.4	14.0	15
X27	7.5	23.6	15.2	14
X28	7.3	26.4	17.0	15
CX08	7.1	22.2	14.1	6

Scfm = standard ft^3 per minute

Table 4.4. East Treatment Area Vacuum Measurement Summary

Monitoring Location	Minimum Vacuum (inches Hg)	Maximum Vacuum (inches Hg)	Average Vacuum (inches Hg)	Count of Measurements
V06	0	5.5	1.8	91
DV07	0	4.2	0.3	91

inches Hg = inches of mercury

To address the issue of the standard gauges not being sensitive during routine operations, testing was conducted to determine the ROI using gauges rated in inches of water. Both the East and Southwest Treatment Areas were tested. The testing results are included in Table 4.5. The simple tests include a single vapor extraction well and a single observation point. Any result of measureable vacuum above 0.25 inches of water column is considered as an indicator that the vacuum extended to that point. Although the distances may vary, this process provides a check to confirm that the system generated sufficient vacuum to recover the vapors generated by ERH. The data in Table 4.5 indicate that the single well vacuum ROI was variable, with vacuum observed at greater than 16 ft in most cases, however there were several locations where vacuum influence was not observed at 9 ft or less. The setup for Phase I used a vapor point spacing of 26 ft or less. Using an expected ROI of 20 ft provides capture with this 26-ft spacing; however, response was not consistent across all data points. Some of the points did not have a response. This may be attributable to heterogeneous nature of the UCRS.

Throughout the treatment system start-up, testing, and routine operations, vapor samples were collected and analyzed to assess the progress of the IRA, to monitor the aboveground treatment system effectiveness, and to verify compliance with discharge criteria.

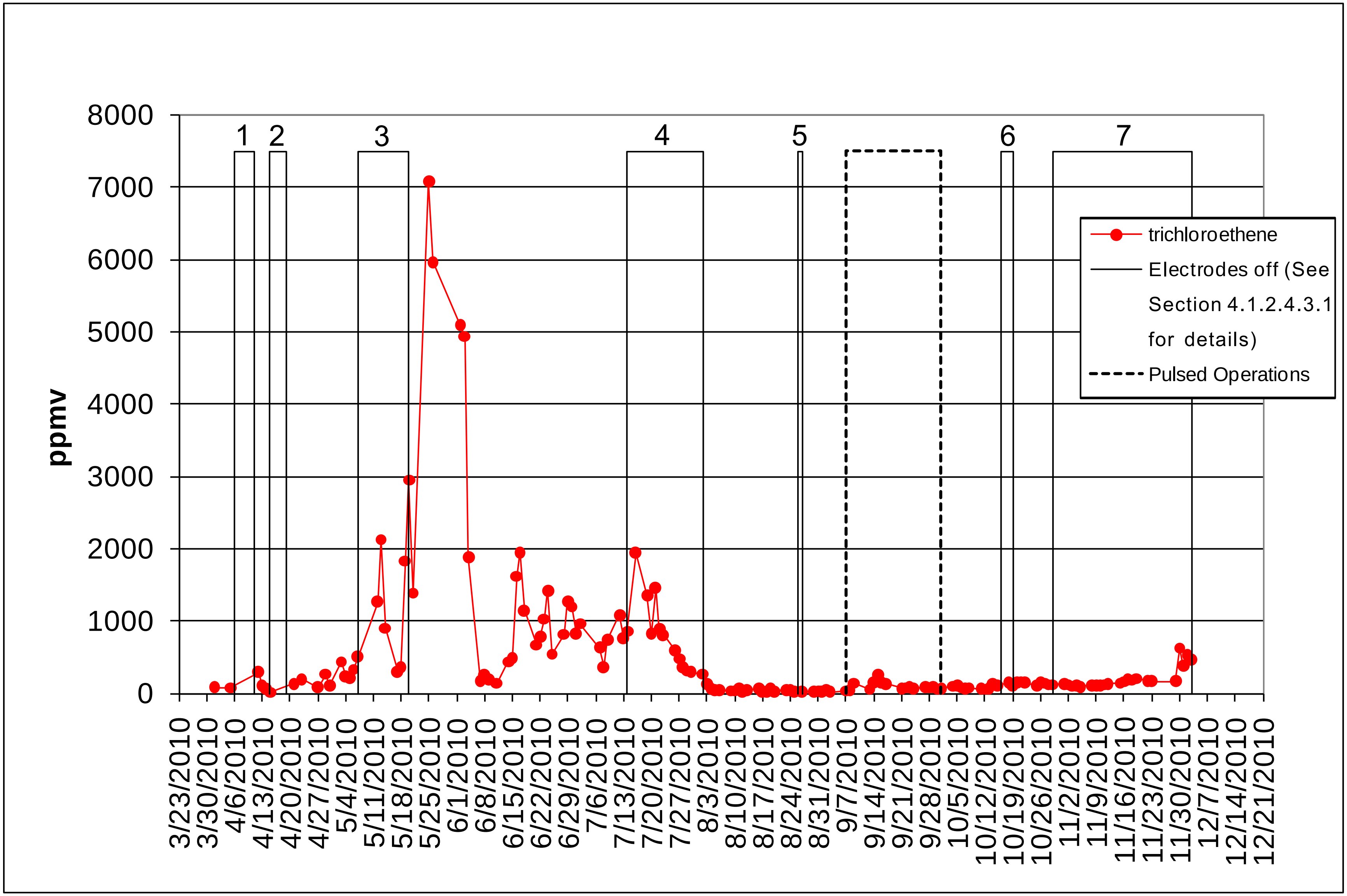
To assess the progress of the C-400 IRA, vapor samples were collected from vapor extraction wells and vapor extraction headers coming from the treatment areas. Vapor samples were collected periodically from various points in the vapor treatment stream to monitor the effectiveness of the treatment units.

Table 4.5. Vacuum Radius of Influence Testing during Pulsed Operation (September 2010)

Area	Vapor Point Operating	Observation Point	Vacuum Attained (Inches of Water Column)	Approximate Distance between Observation Point and Closest Extraction Wells	Comments
East	X217	XE099	1	15 ft	Confirmed influence
East	CX08	XE104	5	8 ft	Confirmed influence
Southwest	XE006 X01	DV01	1	11 ft	Confirmed influence
Southwest	X05, XE022, and XE016	V02	1.5	16 ft	Confirmed influence
Southwest	X02, CX02, X04, CX01, and X03	XE24 XE18 XE007 V01 DV02 XE013 XE012 XE006 XE010 XE011 X01 X05 XE022 XE017 XE023 XE019 X06	1 1.5 1.5 1 0 0 0 0 0 0 0 0 0 0 0 0 0	6 ft 9 ft 6 ft 26 ft 22 ft 11 ft 10 ft 25 ft 10 ft 11 ft 25 ft 30 ft 16 ft 9 ft 12 ft 14 ft 22 ft	Confirmed combined ROI of up to 26 ft in 4 wells and did not observe influence of 1-inch water column at 12 wells. The average confirmed influence was 12 ft and the average not confirmed was 17 ft. Note the instrument was not sensitive enough to read down to 0.25 inches of water column (typical range to confirm ROI).
Southwest	XE006	DV01	1	13 ft	Confirmed influence
Southwest	X05	V02	0.5	16 ft	Confirmed influence

Samples were collected from the lead vapor phase carbon vessel discharge to determine if and when a carbon change-out should be performed. Compliance with discharge criteria was monitored at the vapor treatment system stack. Vapor analyses were performed using photoacoustic analyzers and periodically by a DOE Consolidated Audit Program laboratory.

TCE concentrations in the vapor extraction header were monitored throughout operations using photoacoustic analyses. Figure 4.17 shows the East Treatment Area header photoacoustic readings (DOE 2011b). These data indicate that asymptotic levels were achieved in the wellfield during August 2010. Pulsed operations commenced in early September 2010 and were stopped at the end of



ppmv – parts per million by volume

Figure 4.17. East Treatment Area Header Average TCE Photoacoustic Readings

September 2010. Minimal contaminant response was received during pulsed operations. The electrodes were turned off at the end of October 2010, while vapor extraction continued for approximately another month to continue mass removal during cool down. These various operational periods are shown graphically on Figure 4.17. Figure 4.17 also includes the major periods during which electrodes were off and the reasons for the downtimes, if available:

1. Electrodes off due to nonoperational cryogenic unit vapor treatment system
2. Electrodes off due to nonoperational cryogenic unit vapor treatment system
3. UCRS electrodes off due to condensate buildup concerns
4. Electrodes off due to electrical feeder failure
5. Electrodes off due to electrical issue on Main Control Panel 1
6. Electrodes off due to vapor treatment system, and
7. Electrode operations end while vapor extraction continued.

TCE vapor concentrations also were measured at vapor extraction wells using the photoacoustic analyzer. Figure 4.18 displays the East Treatment Area average extraction well photoacoustic readings from the startup and testing through the end of Phase I operations (DOE 2011b). Figure 4.19 shows a more detailed presentation of the results from only August to December 2010 (DOE 2011b). Table 4.6 provides a summary of East Treatment Area photoacoustic measurements. Note that beginning approximately mid-October 2010, vacuum monitoring locations V06 and DV07 were added to the vapor extraction train to maximize mass recovery during cool down.

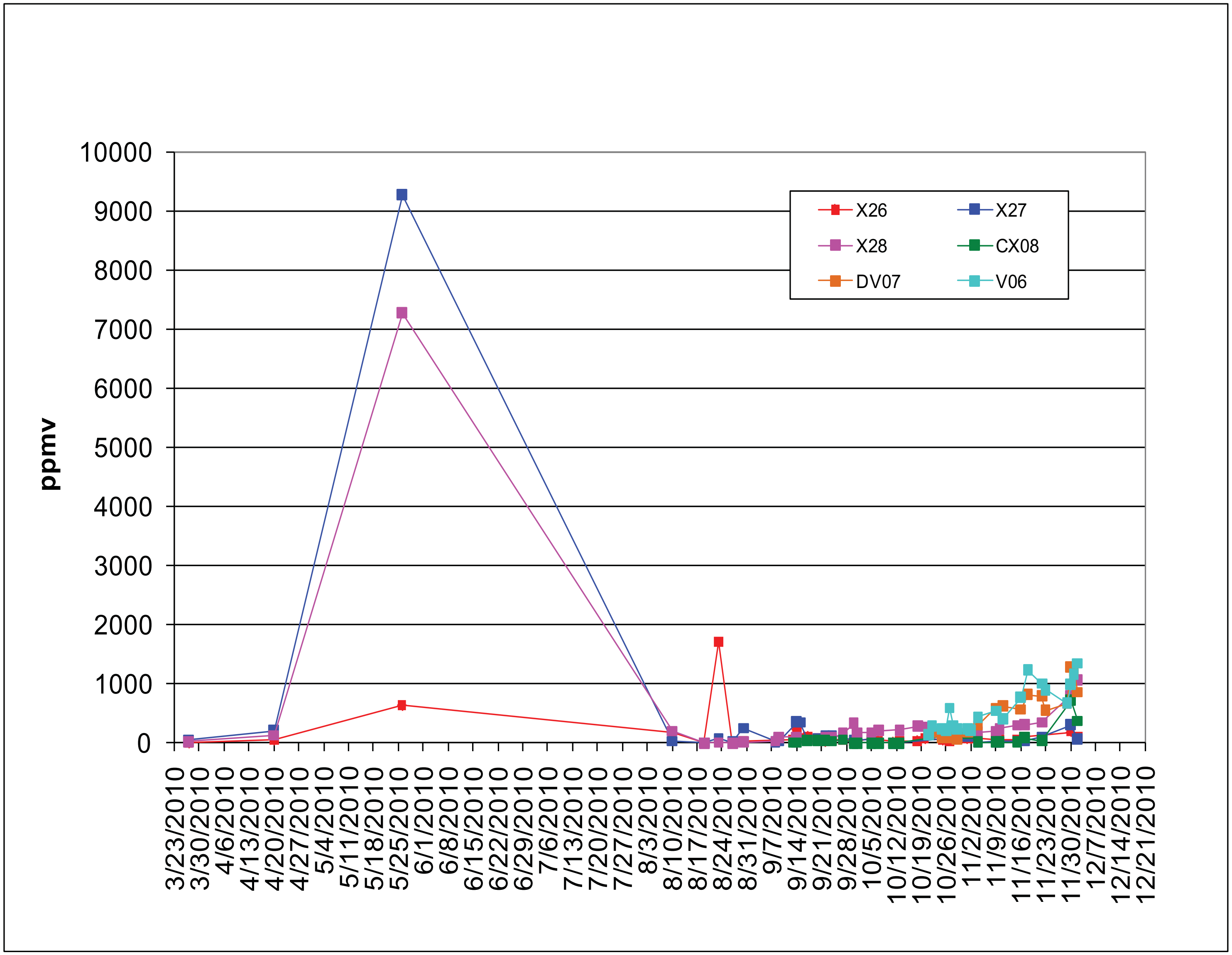
4.1.2.4.3.2 Southwest Treatment Area

There were six vapor extraction wells and two contingency vapor extraction wells (CX01 and CX02) in the Southwest Treatment Area. All Southwest Treatment Area vapor extraction points were connected to a common header, which transferred the TCE contaminated vapor to the treatment system for recovery.

Table 4.7 provides a summary of flow rates for vapor extraction points in the Southwest Treatment Area. Vapor extraction flow rates ranged from 0 scfm to nearly 46 scfm with average rates ranging from 13.4 scfm to 28.4 scfm. Table 4.8 presents a summary of Southwest Treatment Area vacuum pressure measurements. Although vacuum pressures of three or more inches of mercury were observed at all of the monitoring points, there were many zero pressure readings recorded by operators during rounds. As was the case in the East Treatment Area, the pressure gauges installed in the southwest were not sensitive enough to reliably measure/report operating pressures at levels that may have been as low as 1 or 2 inches of water.

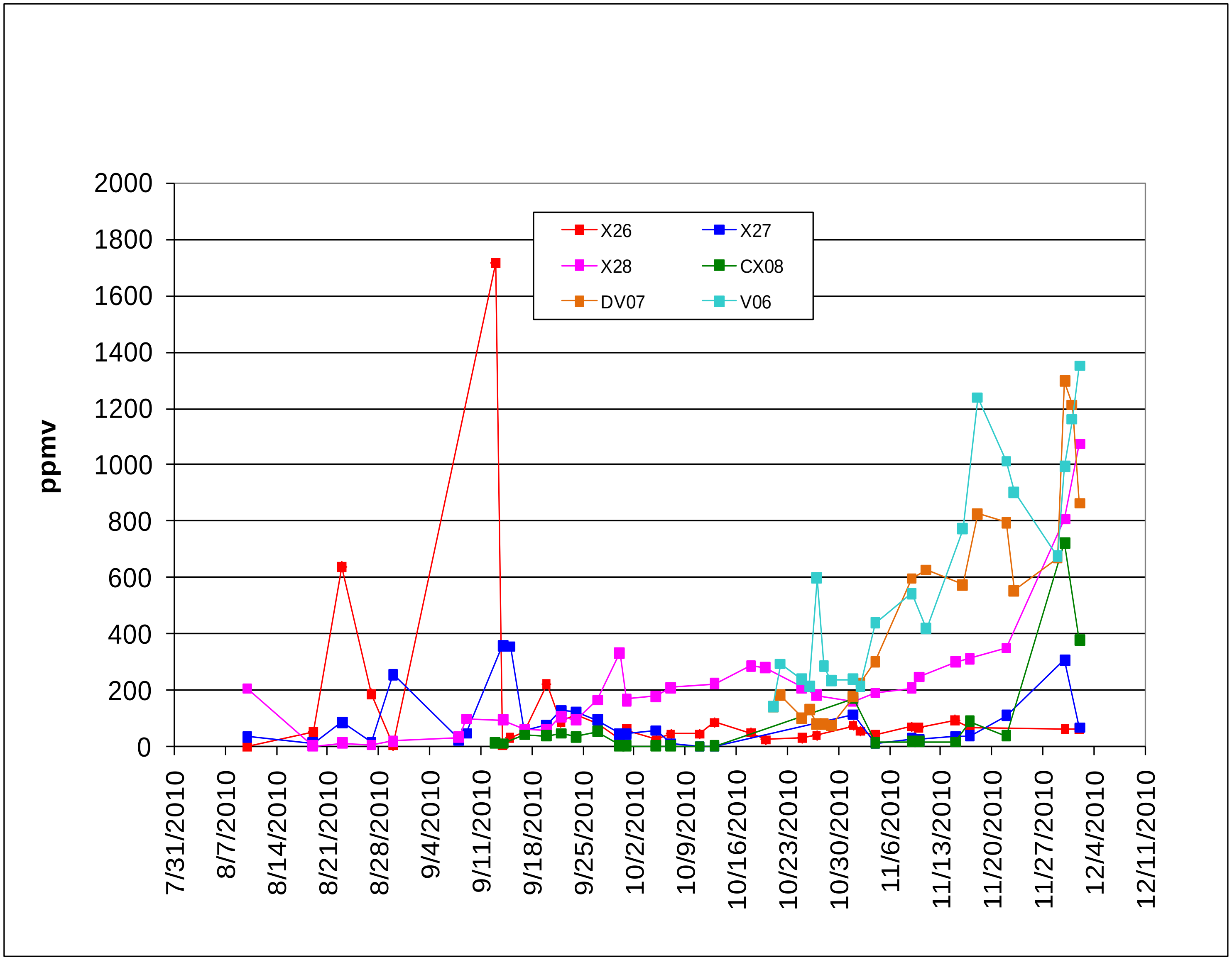
TCE concentrations in the southwest vapor extraction header were monitored throughout operations using photoacoustic analyses. Figure 4.20 shows the Southwest Treatment Area header photoacoustic readings (DOE 2011b). Figure 4.20 also includes the major periods during which electrodes were off and the reasons for the downtimes, if available:

1. Electrodes off due to nonoperational cryogenic unit vapor treatment system
2. Electrodes off due to nonoperational cryogenic unit vapor treatment system
3. UCRS electrodes off due to condensate buildup concerns
4. Electrodes off due to electrical feeder failure
5. Electrodes off due to electrical issue on Main Control Panel 1
6. Electrode operations end while vapor extraction continued.



ppmv – parts per million by volume

Figure 4.18. East Treatment Area Average Extraction Well TCE Photoacoustic Readings



ppmv – parts per million by volume

Figure 4.19. East Treatment Area Average Extraction Well TCE Photoacoustic Readings August to December 2010

Table 4.6. East Treatment Area Photoacoustic TCE Readings Summary

Location	Average (ppmv)	Minimum (ppmv)	Maximum (ppmv)	Count of Measurements
CX08	79.65	2	752	110
DV07	470.16	1.01	1,350	98
E102	569.60	440	755	10
East header	516.47	1.58	7,710	731
V06	599.15	3.73	1,500	100
X26	127.89	0	2,940	161
X27	151.43	1.14	9,280	144
X28	261.85	2.01	7,280	156

ppmv = parts per million by volume

Table 4.7. Southwest Treatment Area Weekly Wellfield Flow Measurement Summary

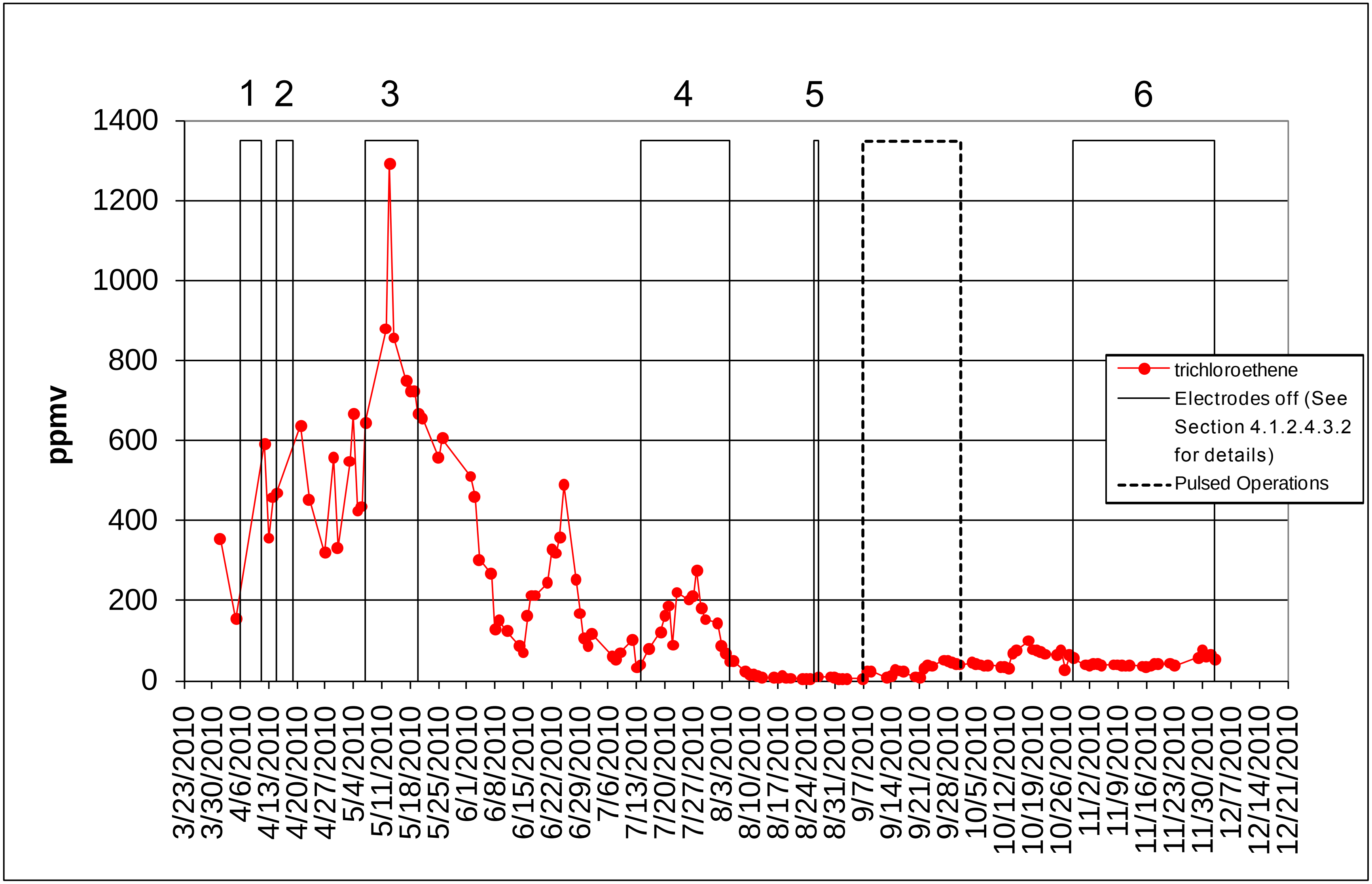
Well #	Minimum Flow (scfm)	Maximum Flow (scfm)	Average Flow (scfm)	Count of Measurements
X01	5.4	33.1	24.9	12
X02	11.1	45.9	28.4	11
X03	7.6	24.9	17.8	13
X04	12.2	27.6	22.5	13
X05	8.6	27.6	17.6	12
X06	13.5	32.4	24.1	12
CX01	5.5	27.9	13.4	10
CX02	0	37.6	17.6	10

scfm = standard ft^3 per minute

Table 4.8. Southwest Treatment Area Vacuum Measurement Summary

Monitoring Location	Minimum Vacuum (inches Hg)	Maximum Vacuum (inches Hg)	Average Vacuum (inches Hg)	Count of Measurements
V01	0	13.5	1.043	93
V02	0	3	0.048	93
DV01	0	5	0.679	93
DV02	0	4	0.579	93

inches Hg = inches of mercury



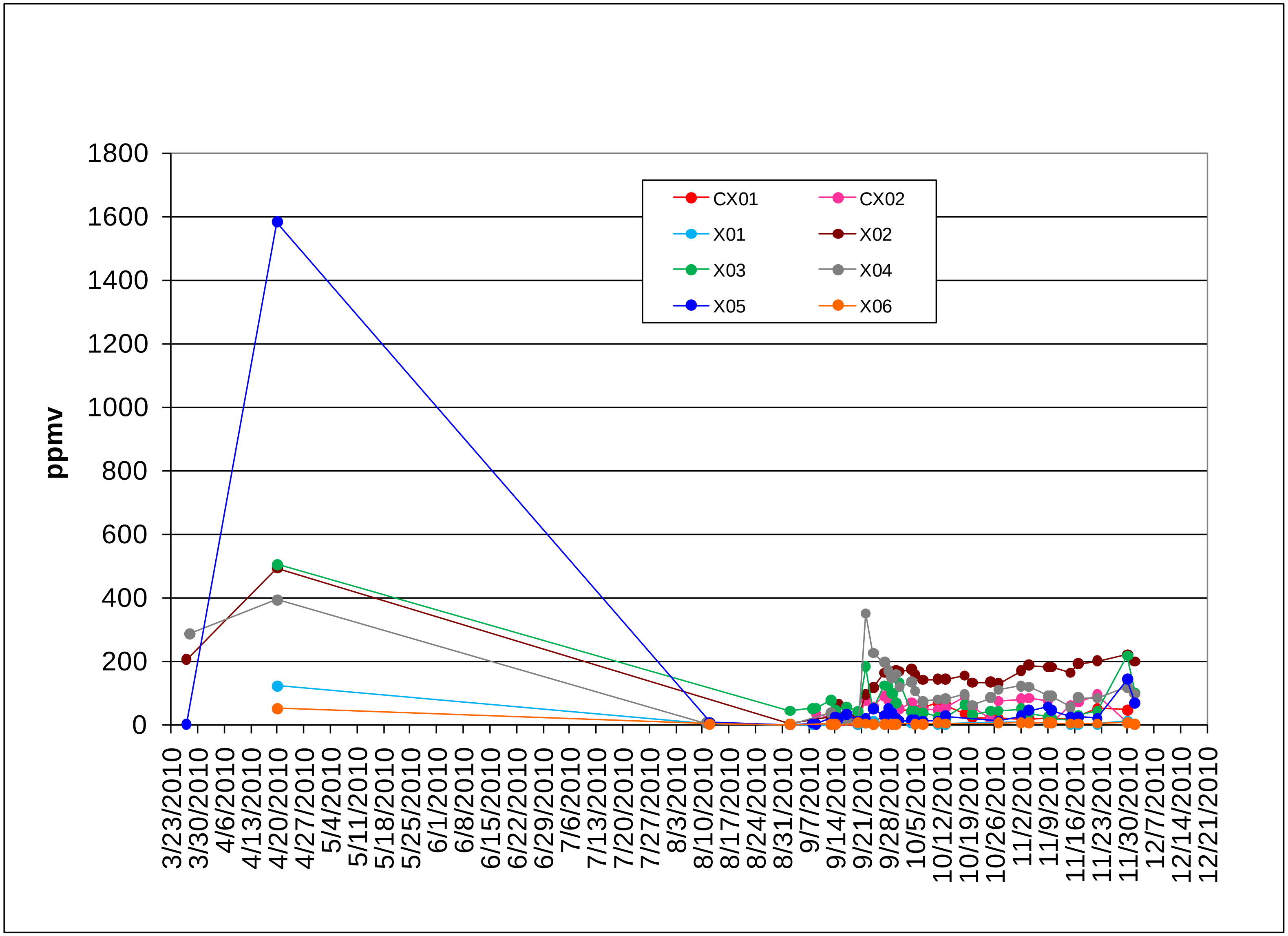
ppmv – parts per million by volume

Figure 4.20. Southwest Treatment Area Header Average TCE Photoacoustic Readings

TCE vapor concentrations also were measured at southwest vapor extraction wells using the photoacoustic analyzer. Figure 4.21 displays the Southwest Treatment Area average extraction well photoacoustic readings from the startup and testing through the end of Phase I operations (DOE 2011b). Figure 4.22 shows the Southwest Treatment Area average extraction well photoacoustic readings from August to December 2010. Table 4.9 provides a summary of Southwest Treatment Area photoacoustic measurements.

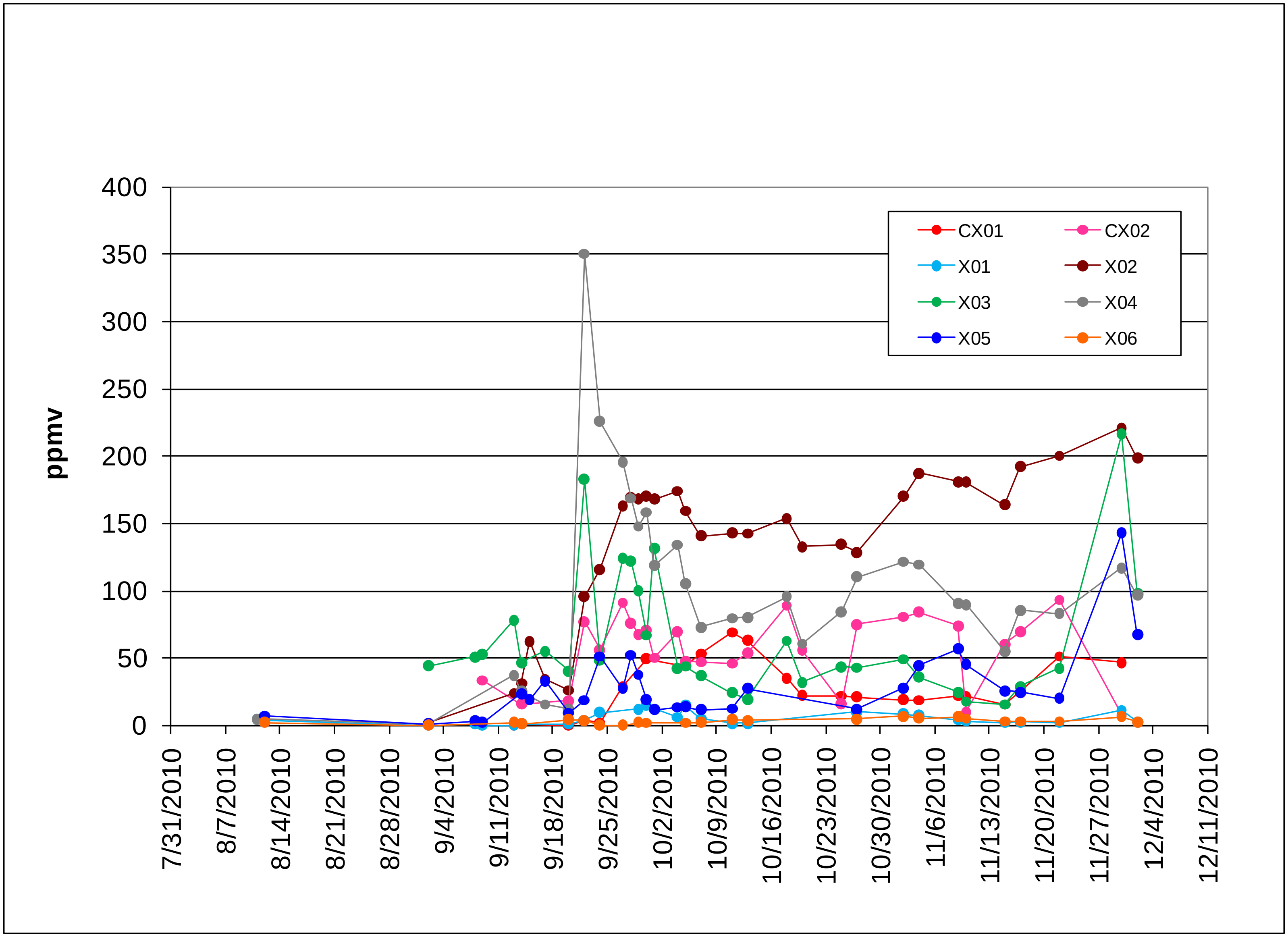
Pressure gauges installed for the vacuum wells were scaled in inches of mercury. These gauges were appropriate for the extraction wells operating at a range of 10–12 inches of mercury.

Perimeter vacuum levels were variable and tended to decrease with increasing temperature. Pressure gauges installed at vacuum piezometers displayed pressure in units of inches of mercury. This generally was not an appropriate unit of measure for vacuum pressures that could be less than one inch of water (1 inch of mercury = 13.6 inches of water) at perimeter monitoring locations. As a result, a significant number of zero pressure readings (< 1 inches mercury) were recorded during operations; however, there may have been a vacuum established that was not detectable with the pressure gauges used or was not detected due to potential short-circuiting with the ground surface.



ppmv – parts per million by volume

Figure 4.21. Southwest Treatment Area Average Extraction Well TCE Photoacoustic Readings



ppmv – parts per million by volume

Figure 4.22. Southwest Treatment Area Average Extraction Well TCE Photoacoustic Readings August to December 2010

Table 4.9. Southwest Treatment Area Photoacoustic Trichloroethene Readings Summary

Location	Average (ppmv)	Minimum (ppmv)	Maximum (ppmv)	Count of Measurements
CX01	27.52	0	80.40	115
CX02	56.33	3.33	102	140
Southwest header	169.58	2.77	1,640	734
X01	4.95	0	60.80	135
X02	134.25	0	225	160
X03	62.99	0	454	159
X04	98.35	0	437	160
X05	28.01	0	152	155
X06	3.15	0	9.42	125

ppmv = parts per million by volume

4.1.2.4.4 Groundwater extraction

Six multiphase extraction wells were installed and equipped with pumps (X01, X02, X03, X04, X05, and X06) in the Southwest Treatment Area, and three multiphase extraction wells were installed and equipped with pumps (X26, X27, and X28) in the East Treatment Area (see Figures 4.4 and 4.5 for well locations). Groundwater was extracted via these submersible pneumatic pumps during system operations to maintain hydraulic control, dewater the treatment area, and aid in the transport of VOCs to the multiphase extraction wells. Lower RGA groundwater extraction wells in the Southwest Treatment Area were installed with the bottom of the well screen set at the RGA/McNairy interface and included a 2-ft sump extending into the McNairy Formation to maximize potential direct DNAPL recovery. Table 4.10 provides a summary of groundwater extraction data from Phase I operations. For the southwest wellfield, 1.7 times more water was extracted from the southwest wellfield as was injected. In the east, the ratio was 1.6. The average extraction rate for individual Southwest Treatment Area wells was 2.0 gpm, for a total of 11.8 gpm. The average extraction rate for individual wells in the East Treatment Area was 2.6 gpm, for a total of 7.9 gpm.

Table 4.10. Extracted and Injected Groundwater during Phase I

	Southwest Treatment Area	East Treatment Area
Average Flow Rate by Area (gpm) Average Flow Rate per Well (gpm)	≈ 11.8 ≈ 2.0	≈ 7.9 ≈ 2.6
Groundwater Extracted (gal)	≈ 2,790,675	≈ 1,610,860
Groundwater Injected (gal)	≈ 1,610,860	≈ 992,260
Ratio of Extracted Groundwater to Injected Groundwater	1.7	1.6

Sample ports installed at each groundwater extraction wellhead allowed groundwater samples to be obtained.

Digital pressure acquisition modules (digiPAMs™) were installed to provide information relative to water levels inside and outside of the treatment areas but did not provide reliable data. This instrumentation did not have the capability to accurately measure the very small drawdown levels in interior monitoring locations. Steam is generated *in situ* during heating. The presence of steam at the water/vadose zone interface also resulted in steam in the digiPAM™ drop tubes. Because the digiPAM™ works by referring to a liquid phase density, it did not provide reliable data if steam was present in the drop tube.

During Phase I operations, sand and sediment infiltrated the six groundwater extraction wells located in the Southwest Treatment Area. Those extraction wells extended through the RGA to the McNairy interface. The infiltration is believed to have been caused by a combination of the wells being underdeveloped and the well screen slot size being too large. On a few occasions, the buildup of sand and sediment was significant enough to incapacitate the pumps. The pumps had to be removed to be serviced and the wells flushed to remove the sediment build up. The solids also negatively impacted operations at the SVGTS by plugging and filling the filter bags. This resulted in additional system downtime for replacement of the filter bags. The East Treatment Area extraction wells were not affected by the infiltration of solids as they did not penetrate the RGA. The design of future groundwater extraction wells should specify a smaller well screen slot size and require a more rigorous well development technique. Figure 4.23 shows a picture of sediment accumulation in the vapor extraction header pipe during Phase I operations.

Figure 4.23. Sediment in the Vapor Extraction Header

Photograph Date - Direction: 12/10/12 – N/A

4.1.3 Monitoring and Sampling

Three distinct phases of sampling and analysis occurred as a part of the C-400 Phase IIa IRA: baseline, operational, and postoperational. Baseline sampling and postoperational sampling were conducted as a means to determine the percent reduction in VOC contamination in the treatment area. The sampling for this project was completed in accordance with the SAP and Quality Assurance Program Plan (QAPP) contained in the Phase I RAWP (DOE 2011a), and no deviations from the plans occurred.

4.1.3.1 Baseline and postoperational sampling

The baseline sampling operations were performed in collocated locations to provide before and after treatment results. Baseline and postoperational soil samples were collected from 12 locations in the East Treatment Area and 15 locations in the Southwest Treatment Area. There were a total of 25 baseline soil samples collected for the East Treatment Area and 63 baseline soil samples collected for the Southwest Treatment Area. The baseline soil sampling was completed in May 2009, and postoperational soil sampling was completed in April 2011.

The selection of the sample interval was biased to characterize zones of highest VOC level, as determined by field monitoring instruments (e.g., photoionization detector). Soil core from a rotary sonic drill rig was sampled to characterize baseline VOC levels. The rotary sonic drill rig collected soil core in a flexible clear plastic liner. Collection of postoperational soil samples was performed using an auger drill rig with borings offset within 2 ft of the baseline locations. Postoperational soil samples were collected in stainless steel liners. High residual heat of soil samples collected after ERH operation presented an additional challenge to the samplers. Postoperational soil sampling involved capping the ends of the stainless steel liners and submerging them in an ice bath to lower the soil temperature and minimize the off-gassing of VOCs before collecting the sample. To ensure the sample collected was representative of the same area that was characterized in the baseline sampling effort, postoperational soil samples targeted the actual sample depth of the corresponding baseline sample.

To further understand the conceptual site model (CSM), groundwater samples were collected from extraction wells installed as a part of the ERH system evaluation in accordance with the SAP and QAPP contained in the Phase I RAWP. The sample results were used to characterize TCE concentrations in groundwater before, during, and after operation of the ERH system as an indicator of reduced TCE impacts to the RGA. Extraction wells that were independent of the electrodes provided groundwater and vapor extraction during the ERH heating phase and allowed for collection of groundwater samples for characterization of dissolved TCE concentrations, prior to, during, and subsequent to heating the subsurface. Each of the RGA wells was sampled three times over a four-week period before and after heating the subsurface to establish representative dissolved TCE (and TCE breakdown products) concentrations for each well for the period. Section 8 of the Phase I RAWP contains details of the groundwater sampling plan. Existing monitoring wells MW155 and MW156, located within the East Treatment Area, offered an opportunity for additional groundwater characterization. Both of these wells were sampled during the baseline and postoperational sampling events. Baseline groundwater sampling was completed in September 2009, approximately five months before heating operations commenced and postoperational sampling was completed in May 2011, approximately six months after heating ceased.

The results for those soil and groundwater baseline and postoperational sampling are discussed in Section 4.2.

4.1.3.2 Operation and maintenance sampling

Throughout the treatment system start-up, testing, and routine operation, vapor and water samples, gage readings, etc. were collected and analyzed to assess the progress of the IRA to monitor effectiveness of the aboveground treatment system. The data points collected included the following:

- Temperature readings,
- Pressure readings,
- Photo-acoustic readings of the vapor phase content in the treatment system,
- Tank level readings,
- Flowrate readings,

- Flow totals, and
- Analyzer group readings.

Sampling information is summarized and discussed in Section 4.1.2. The raw data collected from these operations is included in Appendix B.

4.2 TABULAR SUMMARIES

4.2.1 Volatile Organic Contaminants Removed

Baseline and postoperational soil and groundwater sample results indicated that, for areas where target temperatures were attained, contaminant recovery was effective in the Southwest and East Treatment Areas. Soil contaminant concentrations were reduced by an average of 99% in the Southwest Treatment Area and by 95% in the East Treatment Area. Groundwater concentrations in the southwest went from an average of 38,000 µg/L to an average of 315 µg/L, and in the east they went from 123,000 to 29,000, reductions of 99% and 76%, respectively (see Section 4.2.2). The estimated total quantity of TCE removed from the subsurface during the Phase I operations is 535 gal.

4.2.2 Cleanup Levels Achieved

The RAOs for this IRA, as documented in the ROD and presented in this RACR in Section 1.2.2, did not provide for a numerical cleanup value in soil or groundwater for TCE or any of the breakdown products. The RAOs specific to VOC contamination and VOC source indicated the following:

- Reduce VOC contamination (primarily TCE and its breakdown products) in UCRS soil at the C-400 Cleaning Building area to minimize the migration of these contaminants to RGA groundwater and to off-site POEs, and

- Reduce the extent and mass of the VOC source (primarily TCE and its breakdown products) in the RGA in the C-400 Cleaning Building area to reduce the migration of the VOC contamination to off-site POEs.

The following subsections provide a summary of the reduction in contaminant levels in the Phase I treatment areas.

4.2.2.1 East Treatment Area (soil)

Baseline and postoperational soil samples were collected from 12 locations in the East Treatment Area. Table 4.11 lists the soil sampling results, and Figure 4.24 shows the East Treatment Area sampling locations and presents the East Treatment Area soil data (DOE 2011b). For the East Treatment Area, there are 25 paired sampling sets for comparison. Comparing the average baseline to the average postoperational concentrations show a 95% reduction.

Note that in the eastern area, there were 18 samples that began and ended with a low concentration (< 100 µg/kg). The sample at E106 (20 ft depth) had a baseline concentration of 20 µg/kg and a postoperational concentration of 315 µg/kg. This apparent increase is not considered significant and could reflect redistribution of TCE during ERH operation. Alternatively, the apparent increase may simply reflect the variation of sample results (considering that the baseline and postoperational paired samples are not from identical locations but were collected no more than 2 ft apart).

Table 4.11. East Treatment Area Baseline and Postoperational Soil TCE Results[1]

Location	Depth (ft bgs)	Baseline Result (µg/kg)[2]	Postoperational Result (µg/kg)[2]	Reduction (Baseline −Postoperational) (µg/kg)	Reduction (%)
E095	20	10.9	5.5	5.4	49.5
E095	35	6.91	9.28	-2.37	-34.3
E095	52	1,880	< 5	1875	99.7
E095	60	5.46	75	-69.54	-1,273.6
E095	80	8.08	20.2	-12.12	-150.0
E097	35	< 4.98	36	-31.02	-622.9
E098	20	< 5.03	< 4.99	0.04	0.8
E098	35	< 5.02	< 5.01	0.01	0.2
E099	35	6.37	< 5.02	1.35	21.2
E100	20	7,820	< 5	7,815	99.9
E100	35	1,860	< 5.02	1,854.98	99.7
E102	20	27.9	< 4.99	22.91	82.1
E102	35	30.5	7.73	22.77	74.7
E103	20	< 4.99	< 5	-0.01	-0.2
E103	35	< 5.01	< 5.02	-0.01	-0.2
E103	52	< 5.02	< 5.01	0.01	0.2
E104	20	< 4.97	< 5.01	-0.04	-0.8
E104	35	196	9.4	186.6	95.2
E105	35	< 5	< 5	0	0
E106	20	20	315	-295	-1,475
E106	35	< 5	9.15	-4.15	-83
E107	35	60.2	118	-57.8	-96
E110	20	8.46	< 5.03	3.43	40.5
E110	35	10.6	46.1	-35.5	-334.9
E110	52	2,610	5.23	2,604.77	99.8
Count[1]		25	25		
Average[1] (µg/kg)		584	29	Average Reduction, %[3] = 95	
Minimum[1] (µg/kg)		4.97	4.99		
Maximum[1] (µg/kg)		7,820	315		
Count[1] < 70 µg/kg		20	22		
Count nondetectable[1]		9	16		
SB061	31		19.9		
SB061	43		< 5.01		
SB061	54		< 5.01		
SB061	59		125		
SB061	78		< 4.99		
SB062	31		15.2		
SB062	43		19		
SB062	54		13		
SB062	59		2,900		
SB062	78		6.15		

[1] Only the locations that have both a baseline and postoperational sample are included.
[2] Nondetectable included at stated detection level.
[3] Reduction percentage = (baseline average result−postoperational average result)/baseline average result × 100.
Table adapted from DOE 2011b.

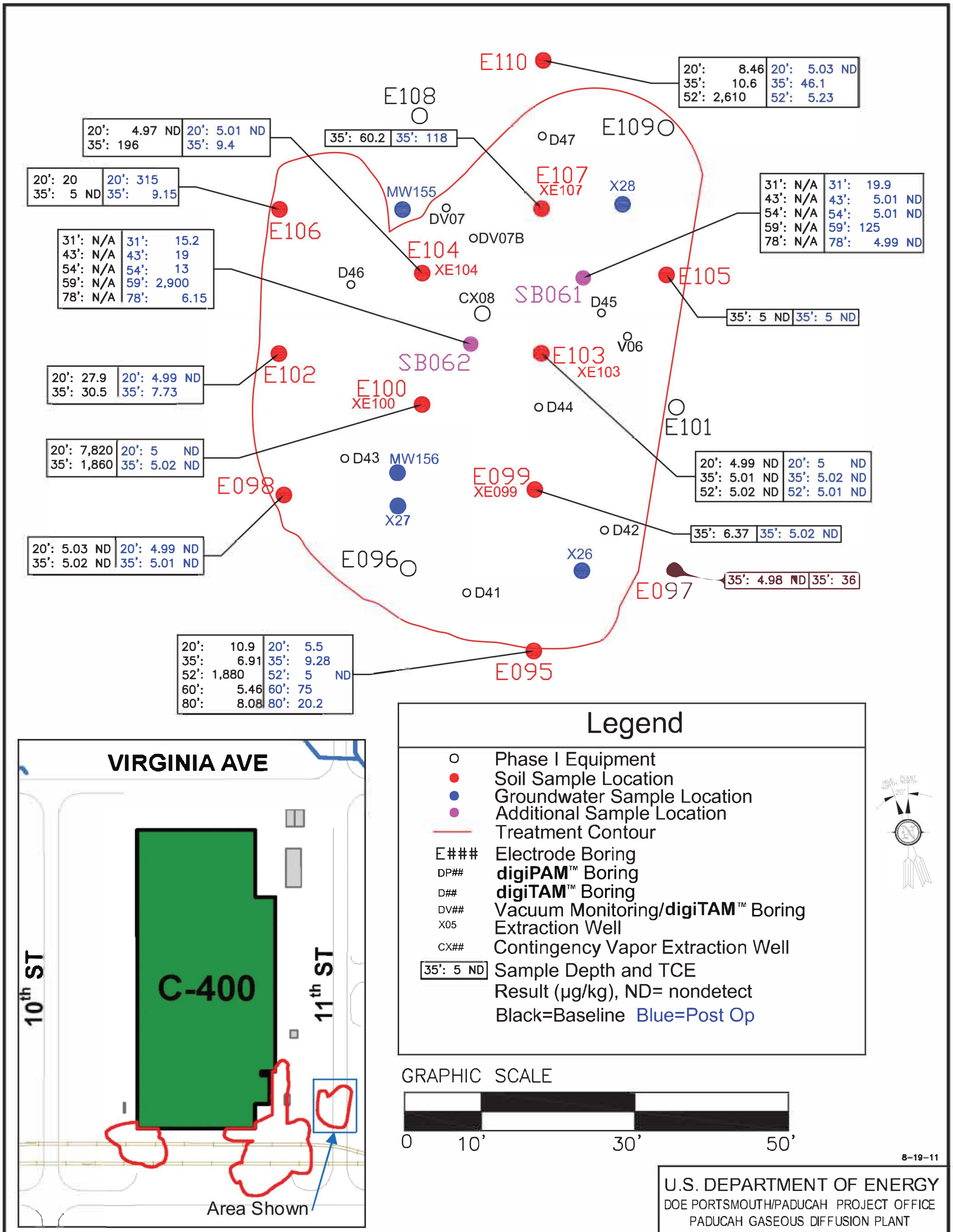


Figure 4.24. East Treatment Area Soil Sample Locations and Results

Additional postoperational data were collected from borings located between the electrodes where there is a potential for cooler areas and greater residual mass. Samples SB061 and SB062 were collected to help assess Phase I removal performance between the electrodes. The samples at depths of 31 ft, 43 ft, and 54 ft bgs all contained low concentrations (i.e., < 100 µg/kg) of TCE. Because there is not a baseline sample, the data from these locations do not provide information on treatment efficiency, but provide information that appreciable mass does not remain between the electrodes. The TCE concentration in deeper samples at 59 ft in SB061 still are considered low at 125 µg/kg. The result of 2,900 µg/kg for TCE at 59 ft bgs in SB062 is the highest postoperational value for the East Treatment Area and is well outside the range established for paired baseline and postoperational sample analyses. There are several potential explanations for this data point near the lower elevation of heating (heating was targeted to 60 ft). One explanation is that there was not as effective heating at this lower depth, as it is near the lower limit of the heating. Another explanation is that the 2,900 µg/kg soil data represents contamination from adjacent RGA groundwater 3 months after the remedy was completed. The 59-ft sample is within the sandy Upper RGA (HU4) above the Lower RGA gravel (HU5). For example, a concentration of 18,000 µg/L of TCE in groundwater resaturating a clean sand section at 59 ft could yield a soil concentration of 2,900 µg/kg (using a soil porosity of 0.30 and soil density of 1.84 g/cc). This hypothetical concentration is within the range of observed groundwater concentrations in the C-400 Cleaning Building area.

For the paired sampling data set, the average baseline concentrations were 584 µg/kg TCE and the postoperational was 29 µg/kg, yielding an average reduction of 95%. These data demonstrate significant mass reduction within the UCRS in the East Treatment Area. Postoperational soil sampling results indicate that the RAOs were achieved in the treatment areas (UCRS) in the East Treatment Area.

4.2.2.2 Southwest Treatment Area (soil)

Baseline and postoperational soil samples were collected from 15 locations in the Southwest Treatment Area. Table 4.12 lists the soil sampling results from the Southwest Treatment Area and Figure 4.25 shows the Southwest Treatment Area sampling locations and presents the Southwest Treatment Area soil data (DOE 2011b). While 9 of the 63 pairs with detectable results showed an increase from baseline results, both the baseline and postoperations results for these data pairs were relatively low (all < 100 µg/kg).

For the Southwest Treatment Area, there are 63 paired sampling sets for comparison. Comparing the baseline to the postoperational concentrations shows a 99% reduction in concentration. Note that in the Southwestern Treatment Area, there were 41 samples that began and ended with a low concentration (< 100 µg/kg). For those 41 samples, variations in concentrations are not considered significant. These data demonstrate significant mass reduction in the Southwest Treatment Area. Postoperational soil sampling results indicate that the RAOs were achieved in the treatment areas (UCRS) in the Southwest locations. The data from 60 to 80 ft intervals demonstrate a reduction in concentrations in the Upper RGA in accordance with the third RAO presented in Section 1.2.2.

4.2.2.2.1 Groundwater sample results

If the TCE is a leaking source from the UCRS and ERH was successful, groundwater concentrations in the RGA should decrease following application of ERH in the UCRS. If groundwater concentrations do not decrease in the RGA following ERH in the UCRS, it could be because the source removal was unsuccessful or due to ambient concentrations of TCE within the RGA in the vicinity.

To further understand the CSM, groundwater samples were collected from extraction wells installed as a part of the ERH system evaluation in accordance with the SAP and QAPP contained in the Phase I RAWP. The sample results were used to characterize TCE concentrations in groundwater before, during, and after operation of the ERH system as an indicator of reduced TCE impacts to the RGA. Extraction wells that were independent of the electrodes provided groundwater and vapor extraction during the ERH heating phase and allowed for collection of groundwater samples for characterization of dissolved TCE concentrations, prior to, during, and subsequent to heating the subsurface.

Table 4.12. Southwest Treatment Area Baseline and Postoperational Soil TCE Results[1]

Location	Depth (ft bgs)	Baseline Result (µg/kg)[2]	Postoperational Result (µg/kg)[2]	Reduction (Baseline −Postoperational) (µg/kg)	Reduction (%)
E003	20	< 5.01	< 5.01	0	0
E003	35	< 4.97	< 4.97	0	0
E006	20	6.31	< 5.02	1.29	20.4
E006	35	176	< 5.01	170.99	97.2
E006	52	373	< 4.98	368.02	98.7
E006	60	< 5.03	< 5	0.03	0.6
E006	80	< 5.01	13.2	-8.19	-163.5
E006	103	< 4.99	< 5.02	-0.03	-0.6
E007	20	< 5.02	< 5.04	-0.02	-0.4
E007	35	< 4.97	< 5.02	-0.05	-1
E007	52	124	< 5.03	118.97	95.9
E007	60	21.2	< 5.01	16.19	76.4
E007	80	< 5	< 4.98	0.02	0.4
E007	103	8.94	< 5	3.94	44.1
E009	20	12.3	< 4.98	7.32	59.5
E009	35	8,670	< 5.03	8,664.97	99.9
E010	20	1,010	< 5.03	1,004.97	99.5
E010	35	3,590	< 5.03	3,584.97	99.9
E010	52	873	< 5.01	867.99	99.4
E010	60	15	5.31	9.69	64.6
E010	80	< 5.01	< 5.03	-0.02	-0.4
E010	103	< 4.98	14.5	-9.52	-191.2
E011	20	5,720	< 5.02	5,714.98	99.9
E011	35	1,230	< 5.04	1,224.96	99.6
E011	52	5,240	5.01	5,234.99	99.9
E011	60	7,860	11	7,849	99.9
E011	80	14	8.14	5.86	41.9
E011	103	17.3	< 5.04	12.26	70.9
E012	20	99.5	< 5.03	94.47	94.9
E012	35	6,590	< 5.01	6,584.99	99.9
E012	52	14,500	< 5	14,495	100
E012	60	469	< 5.02	463.98	98.9
E012	80	195	38.1	156.9	80.5
E012	103	< 5.03	< 5.01	0.02	0.4
E013	20	7.09	< 5.02	2.07	29.2
E013	35	50.1	34	16.1	32.1

Table 4.12. Southwest Treatment Area Baseline and Postoperational Soil TCE Results[1] (Continued)

Location	Depth (ft bgs)	Baseline Result (µg/kg)[2]	Postoperational Result (µg/kg)[2]	Reduction (Baseline −Postoperational) (µg/kg)	Reduction (%)
E016	20	< 5.03	18.8	-13.77	-273.8
E016	35	28.9	< 5.03	23.87	82.6
E017	20	607	< 5.02	601.98	99.2
E017	35	3,770	< 5.02	3,764.98	99.9
E017	52	55.7	< 5.03	50.67	91
E017	60	< 46.3	< 4.99	41.31	89.2
E017	80	< 49.3	< 5.04	44.26	89.8
E017	103	< 4.97	< 5.01	-0.04	-0.8
E018	20	676	92.6	583.40	86.3
E018	35	522	14.3	507.70	97.3
E018	52	323	< 5.02	317.98	98.4
E018	60	706	228	478	67.7
E018	80	< 5.01	< 5.01	0	0
E018	103	6.57	< 5	1.57	23.9
E019	20	11.9	68.9	-57	-479
E019	35	69.7	< 4.98	64.72	92.9
E019	52	1,900	13.8	1,886.2	99.3
E020	20	120	< 5.04	114.96	95.8
E020	35	< 5.04	9.93	-4.89	-97
E026	20	26.7	< 4.99	21.71	81.3
E026	35	< 5	27.2	-22.2	-444
X06	20	< 5.02	< 5.03	-0.01	-0.2
X06	35	< 5.03	< 4.99	0.04	0.8
X06	52	< 5.03	88	-82.97	-1,649.5
X06	60	14.5	7.88	6.62	45.7
X06	80	< 5.03	24.6	-19.57	-389.1
X06	103	< 4.99	12.7	-7.71	-154.5
Count		63	63		
Average (µg/kg)		1,046	15	Average Reduction, %[3] = 99	
Minimum (µg/kg)		4.97	4.97		
Maximum (µg/kg)		14,500	228		
Count < 70 µg/kg		39	60		
Count nondetectable		23	43		

[1] Only the locations that have both a baseline and postoperational sample are included.
[2] Nondetectable included at stated detection level.
[3] Reduction percentage = (baseline average result −postoperational average result)/baseline average result × 100.
Table adapted from DOE 2011b.

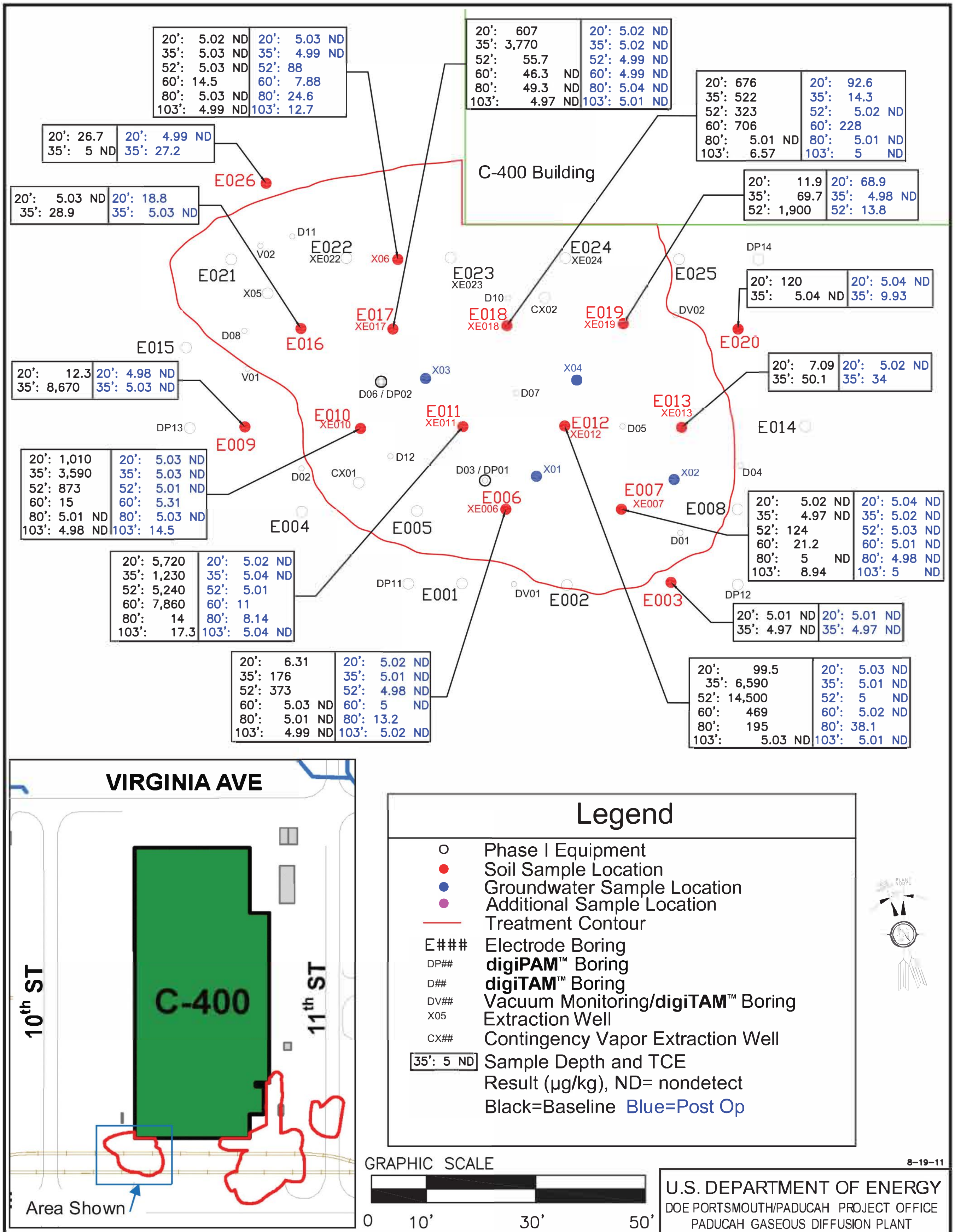


Figure 4.25. Southwest Treatment Area Soil Sample Locations and Results

Each of the RGA wells was sampled three times over a four week period before and after heating the subsurface to establish representative dissolved TCE (and TCE breakdown products) concentrations for each well for the period. Section 8 of the Phase I RAWP (DOE 2011a) contains details of the groundwater sampling plan.

Existing monitoring wells MW155 and MW156, located within the East Treatment Area, offered an opportunity for additional groundwater characterization. Both of these wells were sampled during the baseline and postoperational sampling events.

Results from groundwater samples collected at extraction wells throughout the treatment areas provided data for use in assessing the progress of the IRA. Water samples also were collected routinely from various sample ports throughout the groundwater treatment system in accordance with the Phase I O&M Plan to monitor the operational effectiveness of the treatment system (DOE 2009). Samples were collected routinely from the water treatment system effluent to ensure compliance with discharge criteria.

Baseline groundwater sampling was completed in September 2009, approximately five months before heating operations commenced, and postoperational sampling was completed in May 2011, approximately six months after heating had ceased.

4.2.2.2.2 East Treatment Area

Table 4.13 lists the baseline and postoperational results for the East Treatment Area groundwater samples. Figure 4.26 shows the East Treatment Area sampling locations and presents the East Treatment Area groundwater data (DOE 2011b).

Based on review of baseline data and postoperational data, there were significant decreases in TCE concentrations in the East Treatment Area in every location but one. The one anomalous location was MW156, which is screened from 63–70 ft bgs (Upper RGA). Extraction well X27 is located upgradient of MW156 and the screened interval intercepts groundwater from 55–65 ft bgs. The groundwater concentrations in X27 dropped by > 80%, while concentrations in MW156 increased. The apparent performance disparity for these two samples may be attributed to the fact that the heating target for the East Treatment Area was effective to 60 ft, but not effective down to 66.5 ft bgs (the mid screen depth of MW156). A second explanation of the data is that the groundwater in the vicinity of the western margin of the East Treatment Area may be downgradient or crossgradient of the yet to be addressed southeast area. Although the groundwater gradient in the vicinity of C-400 Cleaning Building is nominally north, the gradient is relatively flat (3.3×10^{-4} ft/ft) and local flow directions are to the northeast in the vicinity of the East Treatment Area indicating the potential for TCE values in groundwater beneath the East Treatment Area to be influenced by groundwater from the Southeast Treatment Area. Additionally due to the hydraulic gradients in the vicinity of C-400 Cleaning Building, chemical concentration gradients (from the Southeast Treatment Area to the East Treatment Area) also could play a factor in the increase.

In general, postoperational decreases in groundwater concentrations in the RGA are a positive indicator of successful remedial performance in the UCRS to a depth of 60 ft and support that the RAO of removing VOC source mass was met successfully. The East Treatment Area average baseline concentration was 123,000 µg/L, and the average postoperational sample was 29,000 µg/L, which is an average reduction of 76%.

Table 4.13. East Treatment Area Baseline and Postoperational Groundwater TCE Results

Location	Target Depth (ft bgs)	Event	Actual Screen Depth (ft bgs)	Baseline Result (µg/L)	Postoperational Result (µg/L)	Reduction (Baseline −Postoperational) (µg/L)	Reduction (%)
MW155	100	1	87–92	14,000	3,100	10,900	77.9
MW155	100	2	87–92	14,000	6,000	8,000	57.1
MW155	100	3	87–92	13,000	3,500	9,500	73.1
MW156	65	1	63–70	34,000	52,000	-18,000	-52.9
MW156	65	2	63–70	36,000	52,000	-16,000	-44.4
MW156	65	3	63–70	39,000	58,000	-19,000	-48.7
X26	65	1	55–65	110,000	73,000	37,000	33.6
X26	65	2	55–65	120,000	41,000	79,000	65.8
X26	65	3	55–65	120,000	49,000	71,000	59.2
X27	65	1	55–65	180,000	28,000	152,000	84.4
X27	65	2	55–65	190,000	20,000	170,000	89.5
X27	65	3	55–65	200,000	34,000	166,000	83
X28	65	1	55–65	250,000	4,300	245,700	98.3
X28	65	2	55–65	260,000	6,600	253,400	97.5
X28	65	3	55–65	260,000	8,300	251,700	96.8
Count				15	15		
Average (µg/L)				123,000	29,000	Average Reduction, %[1] = 76	
Minimum (µg/L)				13,000	3,100		
Maximum (µg/L)				260,000	73,000		

[1] Reduction percentage = (baseline average result −postoperational average result)/baseline average result × 100.
Table adapted from DOE 2011b.

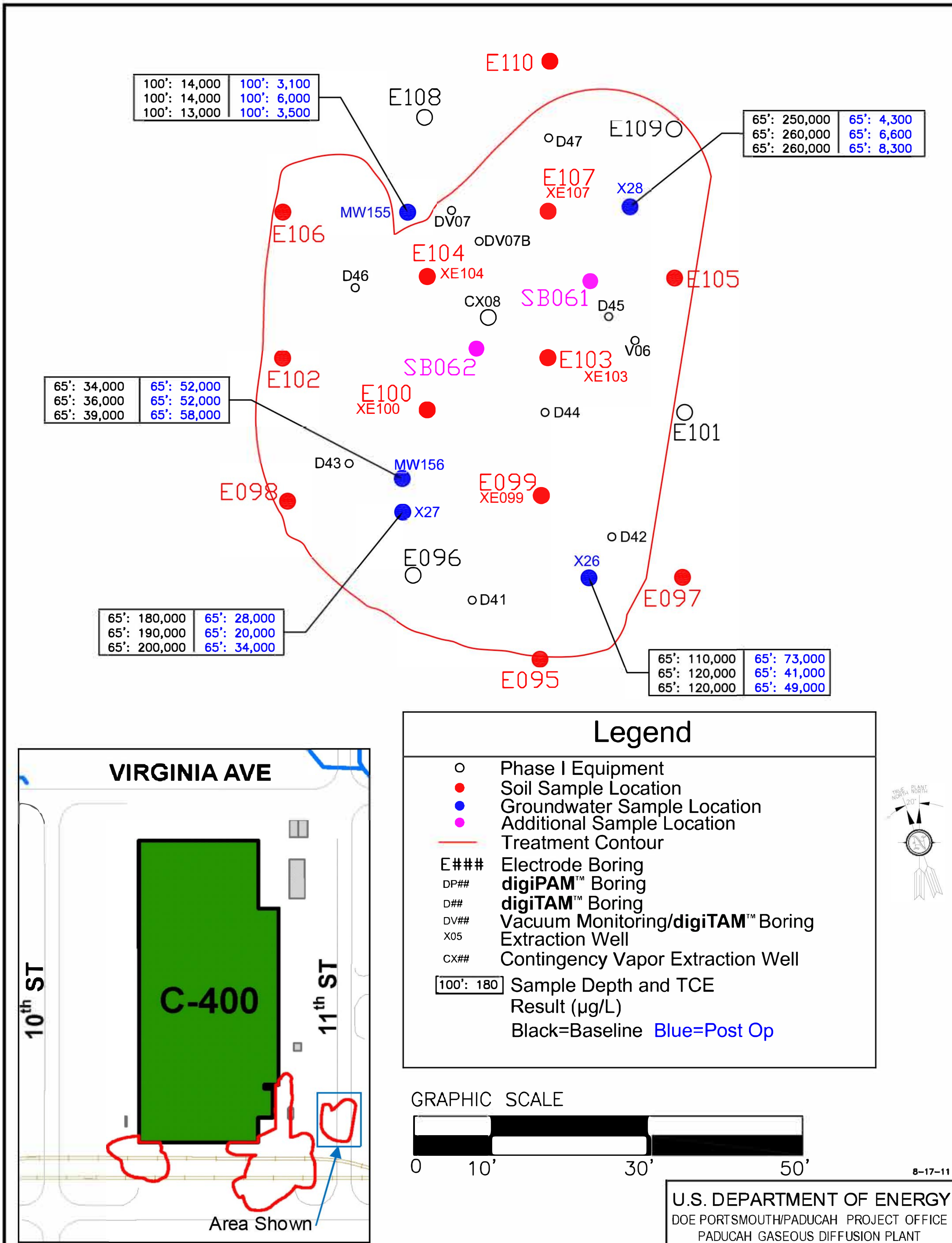


Figure 4.26. East Treatment Area Groundwater Sample Locations and Results

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4.2.2.2.3 Southwest Treatment Area

Table 4.14 lists the baseline and postoperational results for the Southwest Treatment Area groundwater samples, and Figure 4.27 shows the Southwest Treatment Area sampling locations and presents the Southwest Treatment Area groundwater data (DOE 2011b). Based on review of baseline data and postoperational data, there were significant decreases in TCE concentrations in the Southwest Treatment Area in all locations.

The Southwest Treatment Area average baseline concentration was 38,000 µg/L, and the average postoperational sample was 315 µg/L, which is an average reduction of 99%. Groundwater sample results in the Southwest Treatment Area indicate a significant reduction in TCE concentrations in the RGA. This would seem to confirm that TCE in the UCRS soils was the major contributor to the dissolved concentrations in the RGA in the Southwest Treatment Area. These reductions support that the RAO of removing VOC source mass was met successfully. DOE issued a letter October 29, 2010, to the other FFA parties indicating that the remedial goals had been met in the East and Southwest Treatment Areas for Phase I of the C-400 IRA (DOE 2010). KDEP and EPA provided documentation of concurrence with DOE's letter (KDEP 2010; EPA 2011).

4.2.3 Material and Equipment Used

Phase I IRA utilized ERH as the method for achieving the VOC contaminant source and mass removal consistent with the ROD. The specific trademarked ERH system utilized was ET-DSP™ developed by McMillan McGee Corporation. ERH via ET-DSP™ involves heating soil in the saturated and unsaturated zones by passing electric current between electrodes buried in the soil, with simultaneous injection of water through the electrodes in order to maintain conductivity and to transfer heat by convection. The coupling of ERH with heat transfer by convection greatly enhances the efficiency and uniformity of heating by ERH technology. Volatilization of contaminants is achieved as the temperature in the UCRS approaches the boiling point of TCE [189°F (87°C)] or the boiling point of the TCE/water mixture at depth below the potentiometric surface of the RGA. Simultaneous vapor extraction from vapor recovery wells in the heated volume removed the contaminants from the subsurface.

The injected makeup water supplied to electrodes is vaporized creating a guided steam front that strips contaminants away and carries them to extraction wells. In a typical application of ET-DSP™, electrodes are placed strategically in and around the contaminated zone. The pattern of electrodes is designed so conventional three-phase power can be used to heat the soil. The distance between electrodes and their alignment is determined from the heat transfer mechanisms associated with vapor extraction, electrical heating, and fluid movement in the contaminated zone. Soil vapor extraction wells and vacuum monitoring piezometers are located within the contaminated soil. The position of the extraction wells and piezometers relative to the electrodes is determined so that heat transfer by convection within the porous soil is maximized, thus minimizing heat loss and increasing the uniformity of the temperature distribution.

The subsurface portion or the ERH system consisted of electrodes, digiTAMs™, digiPAMs™, vapor extraction wells, vacuum monitoring well, and extraction wells. The quantities of specific subsurface equipment systems used in Phase I and their location was discussed in Section 4.1.2. The subsurface equipment was supported by an aboveground system that provided power conditioning and other utilities as well as a water and vapor phase treatment system to remove the VOC contamination. A detailed design for the aboveground systems is included in the Phase I RDR (DOE 2008a). Figure 4.6 provides a layout of the aboveground support system. The following is a summary level description of the major components included in the aboveground systems.

Table 4.14. Southwest Treatment Area and Postoperational Groundwater TCE Results

Location	Depth (ft bgs)	Event	Baseline Result (µg/L)	Postoperational Result (µg/L)	Reduction (Baseline −Postoperational) (µg/L)	Reduction (%)
X01	65	1	40,000	48	39,952	99.9
X01	65	2	38,000	19	37,981	100
X01	65	3	39,000	33	38,967	99.9
X01	75	1	33,000	43	32,957	99.9
X01	75	2	31,000	28	30,972	99.9
X01	75	3	30,000	41	29,959	99.9
X01	100	1	41,000	180	40,820	99.6
X01	100	2	41,000	42	40,958	99.9
X01	100	3	44,000	19	43,981	100
X02	65	1	13,000	140	12,860	98.9
X02	65	2	12,000	150	11,850	98.8
X02	65	3	13,000	270	12,730	97.9
X02	75	1	9,600	150	9,450	98.4
X02	75	2	8,300	150	8,150	98.2
X02	75	3	8,700	170	8,530	98
X02	100	1	15,000	940	14,060	93.7
X02	100	2	12,000	350	11,650	97.1
X02	100	3	13,000	1,800	11,200	86.2
X03	65	1	46,000	340	45,660	99.3
X03	65	2	51,000	170	50,830	99.7
X03	65	3	50,000	100	49,900	99.8
X04	65	1	66,000	140	65,860	99.8
X04	65	2	63,000	290	62,710	99.5
X04	65	3	62,000	350	61,650	99.4
X04	75	1	61,000	360	60,640	99.4
X04	75	2	55,000	280	54,720	99.5
X04	75	3	55,000	440	54,560	99.2
X04	100	1	64,000	1,500	62,500	97.7
X04	100	2	62,000	280	61,720	99.5
X04	100	3	63,000	630	62,370	99
Count			30	30		
Average (µg/L)			38,000	315	Average Reduction, %[1] = 99	
Minimum (µg/L)			8,300	19		
Maximum (µg/L)			66,000	1,800		

[1] Reduction percentage = (baseline average result −postoperational average result)/baseline average result × 100.
Table adapted from DOE 2011b.

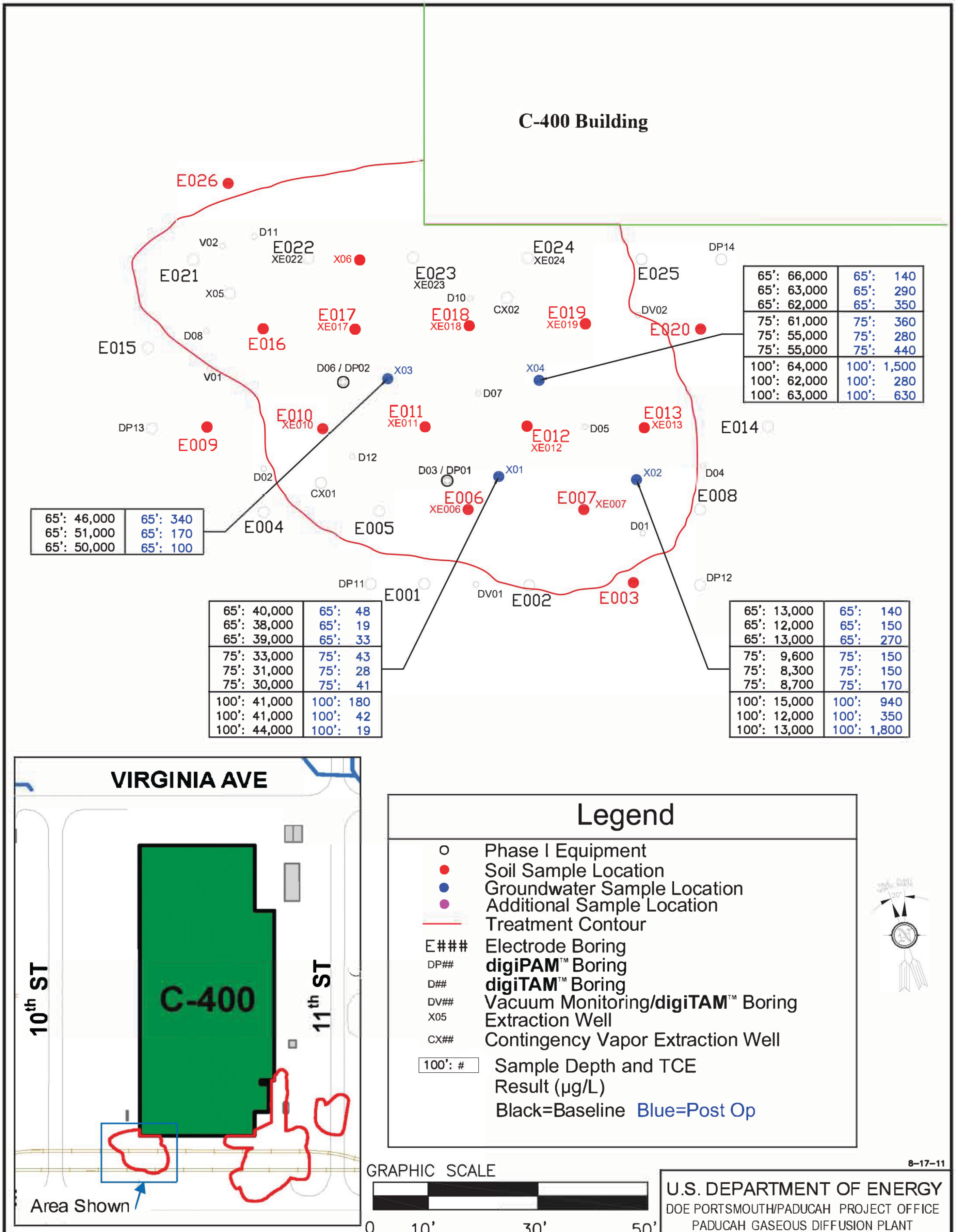

Figure 4.27. Southwest Treatment Area Groundwater Sample Locations and Results

- Power Delivery System
- Liquid Treatment System
  - DNAPL Separator
  - Air Stripper
  - Groundwater Filter
  - Ion Exchange System
  - Liquid Phase Carbon Polishing
- Vapor Treatment System
  - Vapor Liquid Separators
  - Heat Exchangers
  - Chiller System
  - Vacuum Blowers
  - Cryogenic Adsorption System
  - Air Compressor
  - Vapor Phase Polishing Systems
  - Photoacoustic Analyzer
- System Controller

4.2.4 Waste Materials Generated

The waste materials generated during the complete implementation of both Phase I and Phase IIa included both solid materials and liquid materials, TCE liquid recovered, and process water produced during the heating operations. Table 4.15 contains the summary of the wastes generated during the performance of the IRA. All of the wastes generated during implementation of the IRA were disposed of consistent with applicable or relevant and appropriate requirements identified in the 2005 ROD.

Table 4.15. Waste Materials Generated from ERH Interim Remedial Action

Interim Remedial Action Phase	Waste Material Type[1]			
			Liquid/Water	
	TCE Recovered (gal)	Solid Materials[2] (ft^3)	Water[3] (ft^3)	ERH Operations Water Production, (gal)
Phase I	535	88,009	20,364	4,401,535
Phase IIa	1,137			7,570,127

[1] Wastewater (non-ERH Operations) and solid materials were combined and not segregated by C-400 project phase (Phase I, Phase IIa, and steam TS). The Steam TS generated *de minimis* quanities of solid materials and water that are included in the numbers above.
[2] Solid materials include soil, plastic, personal protective equipment, miscellaneous refuse, etc.
[3] Wastewater includes decontamination water, wastewater from construction activities, purge water, drilling wastewater, etc.

4.3 NAMES AND ROLES OF REMEDIAL ACTION CONTRACTORS

LATA Environmental Services of Kentucky, LLC, (LATA Kentucky)/Paducah Remediation Services, LLC (PRS). Primary contractor to DOE at PGDP during the Phase I implementation period. Provided project management and miscellaneous heavy equipment to support Phase I fieldwork; executed infrastructure removal, aboveground equipment construction, and operations. LATA Kentucky and PRS served as the primary point of contact with DOE for on-site environmental remediation and environmental management activities, including completing the Phase I activity. LATA Kentucky/PRS 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 the 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 for the Phase I IRA; and coordinated day-to-day activities of all subcontractors.

Chase Environmental Group. Drilling subcontractor used for all drilling associated with Phase I subsurface equipment installation and postoperational sampling.

McMillan-McGee, Inc. Primary subcontractor used for the ERH system components and system operations. McMillan-McGee manufactured the electrodes, digiPAMs™, digiTAMs™, and the three phase electrical conversion and conditioning system. They also provided day-to-day guidance on the system technical operations and settings.

Shaw Federal Services, Inc. Primary subcontractor used for the groundwater and vapor treatment system fabrication, installation and day-to-day operational support.

4.4 PARTICIPATION BY OTHER AGENCIES

EPA, KDEP, and DOE entered into an FFA in 1998 for the investigation and remediation of PGDP, a federal facility Superfund site (EPA 1998). DOE is the lead agency for implementation of the C-400 IRA, and EPA and KDEP provide regulatory oversight. EPA signed the 2005 ROD and Kentucky concurred on selecting the remedial action for C-400 IRA (DOE 2005).

4.5 LESSONS LEARNED

4.5.1 How Effective Was the ERH System in Removing Contaminants?

Baseline and postoperational soil and groundwater sample results indicate that, for areas where target temperatures were attained, contaminant recovery was effective in the Southwest and East Treatment Areas. Soil contaminant concentrations were reduced by an average of 99% in the Southwest and by 95% in the East Treatment Area. Groundwater concentrations in the Southwest went from an average of 38,000 µg/L to an average of 315 µg/L, and in the East they went from 123,000 to 29,000—reductions of 99% and 76%, respectively. Phase I removed 535 gal of TCE during ERH operations.

4.5.2 Were Target Temperatures Achieved in Contaminant Treatment Zones in the East and Southwest Treatment Areas?

Target temperatures were achieved in the UCRS soils of Phase I treatment areas. Target temperatures also were achieved in the targeted Upper RGA (≈ 60 to 70 ft bgs) in the Southwest Treatment Area. Target temperatures, which are the threshold metric for effective ERH operation, were not attained in the Lower RGA below 70 ft bgs in Phase I. Contingency actions, including application of additional electrical power and injection of electrolytic fluids to enhance conductance, were implemented in accordance with the Phase I RAWP. Observed maximum operating temperatures in the Lower RGA below 70 ft bgs fell short of target temperature objectives. Although target temperatures were not achieved in the lower RGA, data collected and presented in earlier sections shows a decrease in the TCE concentration in the RGA.

4.5.3 What Was the Heating Performance of the ERH Design through the RGA to the McNairy Interface in the Southwest Treatment Area?

Target temperatures were not attained in the Lower RGA. Key factors that affected attainment of target temperatures in the Lower RGA include groundwater flow velocity and formation resistivity. Both of these parameters have the potential to impact thermal performance significantly. Observed formation temperatures during Phase I operations in the Lower RGA fell short of target temperatures. Contingency thermal engineering techniques identified in the Phase I RAWP to boost formation heating were implemented during Phase I in attempts to attain target temperatures. These techniques included injection of saline solutions and maximizing the delivery of electrical power to the electrodes in the Lower RGA.

4.5.4. Baseline/Postoperations Sampling Plan Modification Required to Evaluate TCE Levels in Areas between Electrodes and Extraction Well Locations

Lesson Learned Statement: As a result of comments by the state and federal regulators concerning the lack of data to evaluate TCE levels in areas between electrodes and extraction well locations, additional samples were collected to investigate centroid regions between electrode and extraction well locations, to evaluate TCE levels, and to confirm these zones had been treated successfully by the thermal remediation technology. Analytical data collected from these additional locations confirmed that areas between electrode extraction wells had similar percent reductions in VOCs.

5. PHASE IIa ACTIVITIES

5.1 NARRATIVE DESCRIPTION

The C-400 IRA Phase IIa RAWP (DOE 2013a) required implementation of subsurface ERH technology and an aboveground SVGTS near the southeast corner of the C-400 Cleaning Building and included removal of contaminants (i.e., VOCs, primarily TCE) from the Southeast Treatment Area in both the UCRS and Upper RGA. The target treatment zone for Phase IIa was approximately 20–60 ft bgs, which encompasses a portion of the UCRS and includes approximately 5 ft of the Upper RGA. Figure 5.1 delineates the Phase II treatment areas.

The construction phase of the Phase IIa ERH system included site preparation and installation of subsurface electrodes, extraction wells, subsurface temperature monitoring equipment, vacuum monitoring piezometer, and an aboveground vapor and liquid treatment system.

Site preparation included removal of interfering C-400 Cleaning Building infrastructure. In the Southeast Treatment Area, a concrete loading dock wall was removed to allow for drilling and installation of ERH components. A vapor cap constructed of high-density polyethylene was installed in grassy and gravelly areas in the Southeast Treatment Area.

Many components of the ERH system were installed in subsurface borings. These borings were completed under the direction of a Kentucky certified well driller. Sonic drilling was the preferred method of installation for the ERH electrodes; however, in some locations, sonic drilling equipment was unable to fit within the congested work area and an alternate drilling method was incorporated (i.e., a hollow stem auger rig).

The extraction piping and wellheads were installed with the completion of the subsurface equipment. After the power delivery system and water circulation systems were in place, the leads and hoses were run from the wellheads to their preassigned location at each piece of equipment.

Preliminary construction activities associated with dismantling of Phase I piping systems commenced on July 31, 2012. Phase IIa construction activities were initiated on September 26, 2012, with the completion of the Internal Field Review and approval of management to initiate work. The following subsections describe the work performed to implement Phase IIa of the C-400 IRA.

5.1.1 Site Preparation

Site preparation involved modifications to the existing Phase I SVGTS configuration and several surface features. The major changes are summarized below.

5.1.1.1 Installation of vapor cap barrier

Lower than anticipated vacuum levels were observed during Phase I in the wellfield without a surface seal, suggesting possible short circuiting to the atmosphere. Based on this observation, a vapor cap was installed to prevent short-circuiting of vacuum to atmosphere in areas without concrete/asphalt surfaces and consisted of 20-ft wide panels of 30-mil black plastic sheeting overlapped a minimum of 1 ft and covered with 4 inches of stone. Figure 5.2 shows the vapor cap locations in relationship to the Phase IIa well locations.

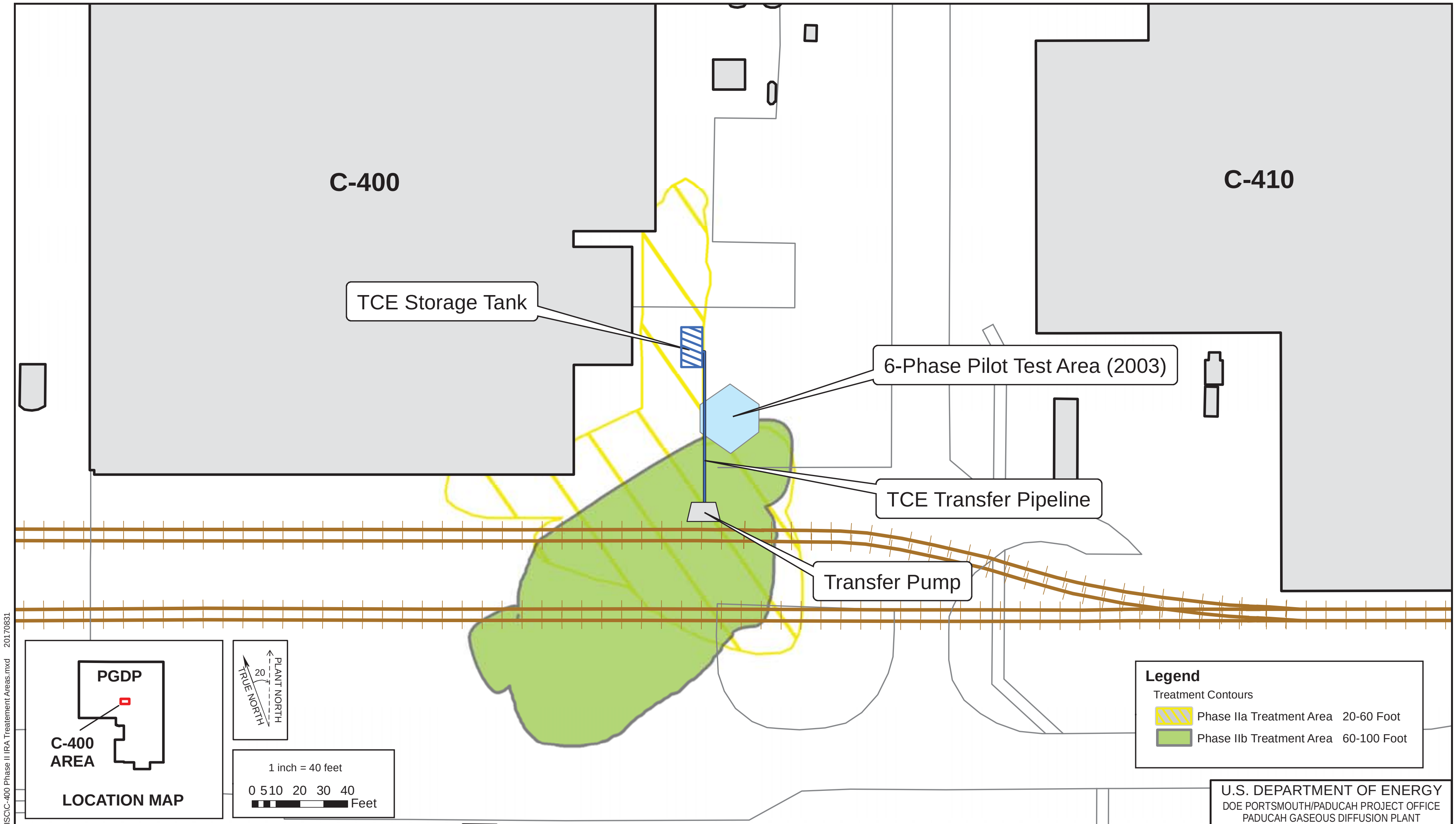

Figure 5.1. C-400 Phase II IRA Treatment Areas

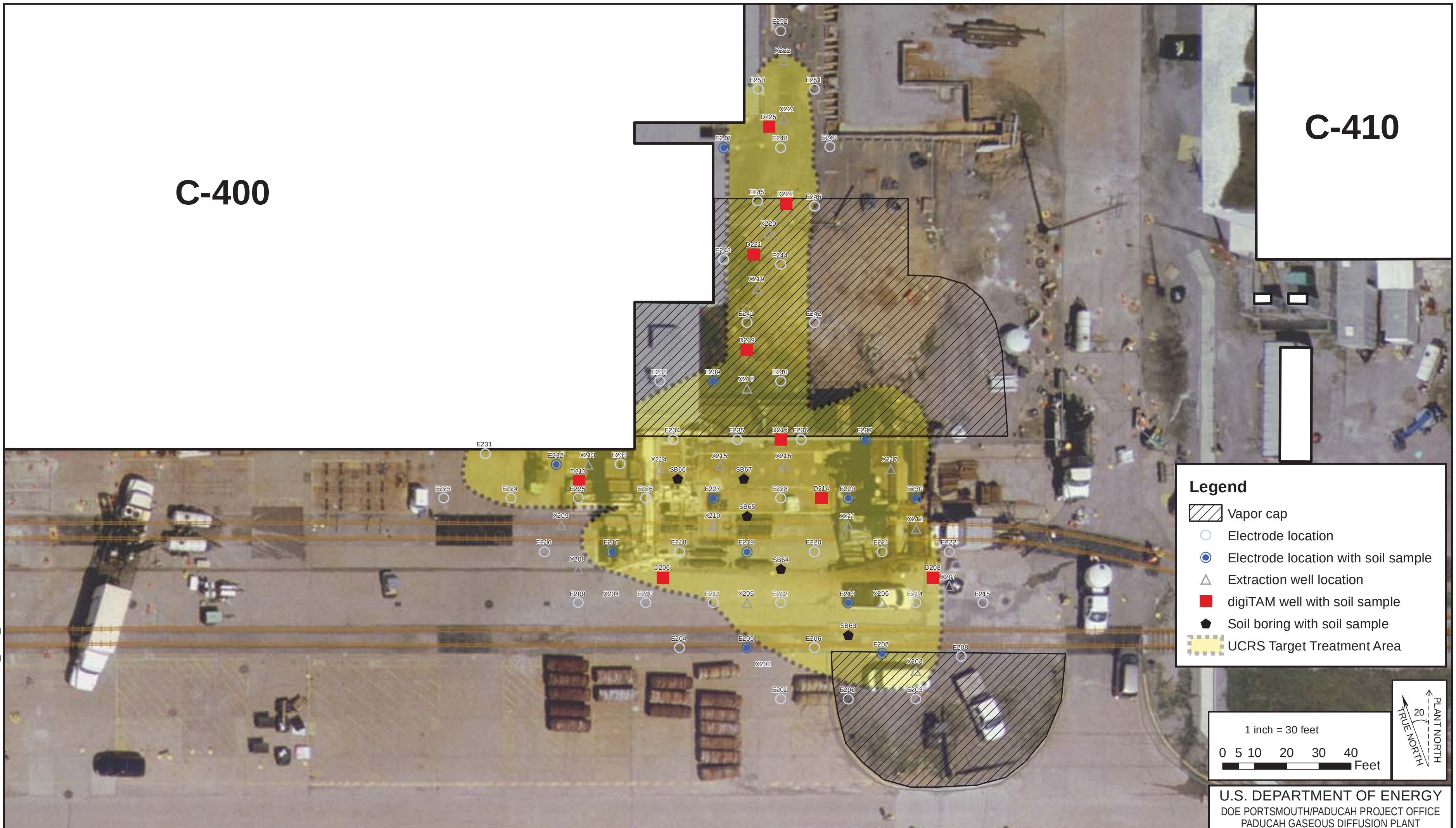

Figure 5.2. C-400 Phase IIa Vapor Cap Layout for SE Wellfield

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5.1.1.2 Removal of gantry crane loading dock support wall

In order to allow drill rig access to several ERH well locations, parts of the gantry crane loading dock support wall were demolished.

5.1.1.3 Demolition of Phase I Treatment System lateral lines and modification to Phase IIa Treatment System manifold

The SVGTS piping manifold and lateral lines from the East and Southwest Treatment Areas, discussed in Section 4, were disassembled and/or were modified to allow the Southeast Treatment Area system to be plumbed into the existing SVGTS. Figure 5.3 delineates the new Phase IIa ERH lateral line layout.

5.1.1.4 Installation of Phase IIa Southeast Treatment Area ERH wells

Installation of ERH wells was performed between September 26, 2012, and March 8, 2013. A total of 129 ERH wells were installed during Phase IIa. See Table 5.1 for a breakdown of the various well types installed during this phase of work. Refer to the Southeast Treatment Area depicted in Figure 5.4, for ERH borehole well locations. Prior to initiating drilling activities, all proposed ERH boring locations were surveyed and flagged, and all nearby utilities were located and potential subsurface anomalies were identified and documented in an excavation/penetration permit. Project team members performed a final walkdown of the Southeast Treatment Area, prior to commencing drilling activities to identify any other potential issues that might affect drilling operations.

When adding sand to an electrode well, sand was added to the inside of the sonic drill stem maintaining 2 ft of fill material inside the drill stem at all times. Sonic casing was vibrated as it was being removed, which allowed the sand to be packed around the electrode and into the annulus. Where required, a well screen was installed and sanded in place. The boring then was completed with well backfill materials (bentonite, grout, etc.) per the design.

Extraction well borings were approximately 8-inch borings; digiTAM™ sensor borings and vacuum monitoring or combination vacuum monitoring/digiTAM™ sensor borings were approximately 7-inch borings; and digiTAM™ sensor well borings were 6-inch borings. Where required, a well screen was installed and sanded in place. The boring then was completed with well backfill materials (bentonite, grout, etc.) per the design.

During Phase I, multiphase extraction wells experienced excessive silting, theorized to be due to sizing of well screen (0.02-inch slot) and filter pack sand (#20/30 sieve sand), because both were too coarse to prevent silt located at the UCRS depths from entering the wells. To address this issue, the Phase IIa RDR specified multiphase extraction wells to be completed with 0.006-inch well screen slot and #30/70 sieve size sand pack, and the wells were developed until turbidity levels were less than 50 nephlometric turbidity units.

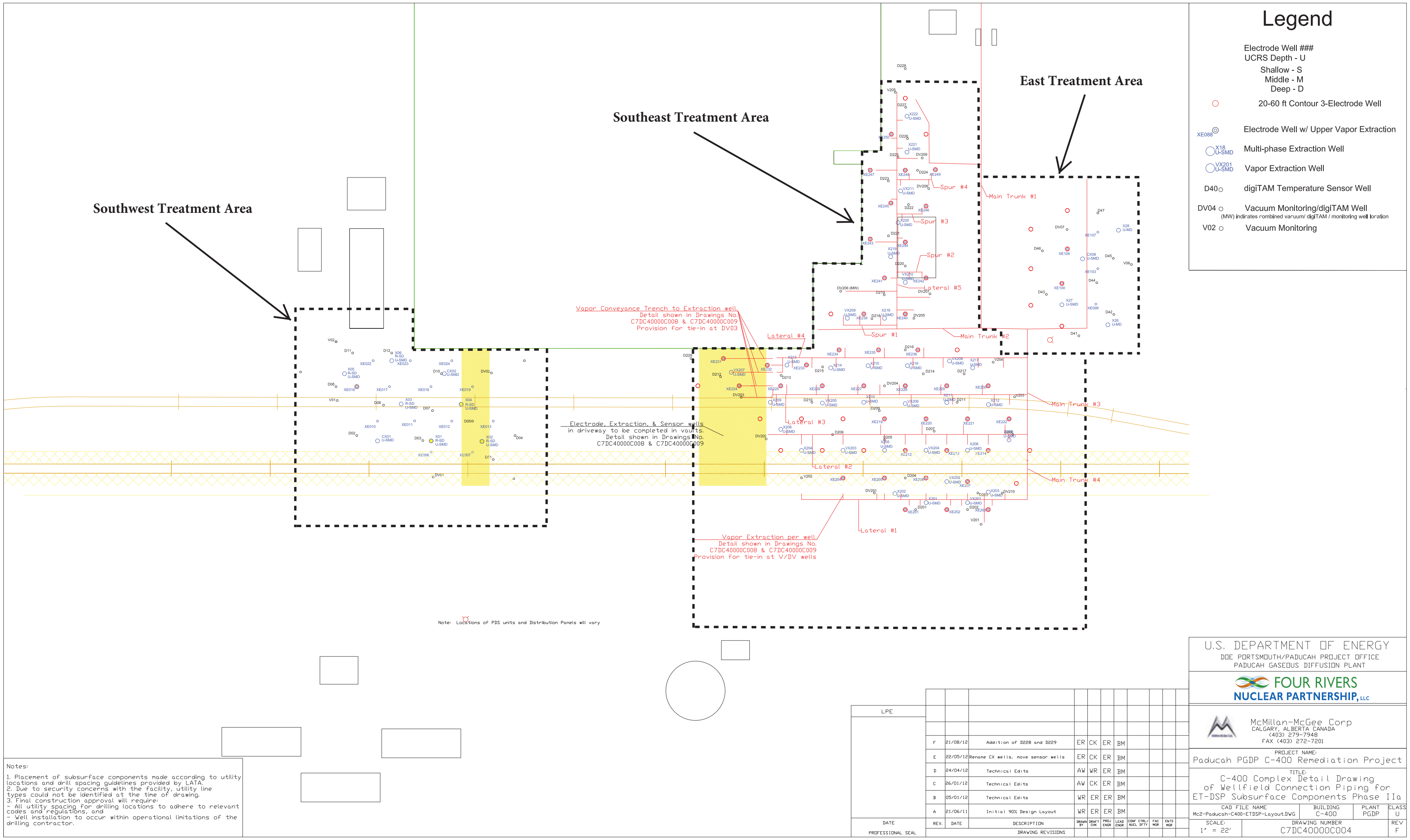

Figure 5.3. C-400 IRA Treatment Areas with Phase IIa ERH Lateral Line Layout

Table 5.1. Summary List of Phase IIa Well Types Installed

ERH Well Type	Southeast Treatment Area	Notes
Electrode Wells (E-XXX)	13	Configured with 3 Electrodes
Upper Vapor Extraction/Electrode Wells (XE-XXX)	39	Configured with 3 Electrodes
Multiphase Extraction Wells (X-XXX)	22	Vapor and Groundwater Extraction Well
digiTAM™ Wells (D-XXX)	29	Temperature Sensor Well
digiTAM™/Vacuum Monitoring Well (DV-XXX)	10	Temperature Sensor and Vacuum Monitoring Well
Vacuum Monitoring Well (V-XXX)	5	
Vapor Extraction Well (VX-XXX)	11	
Total Wells	129	

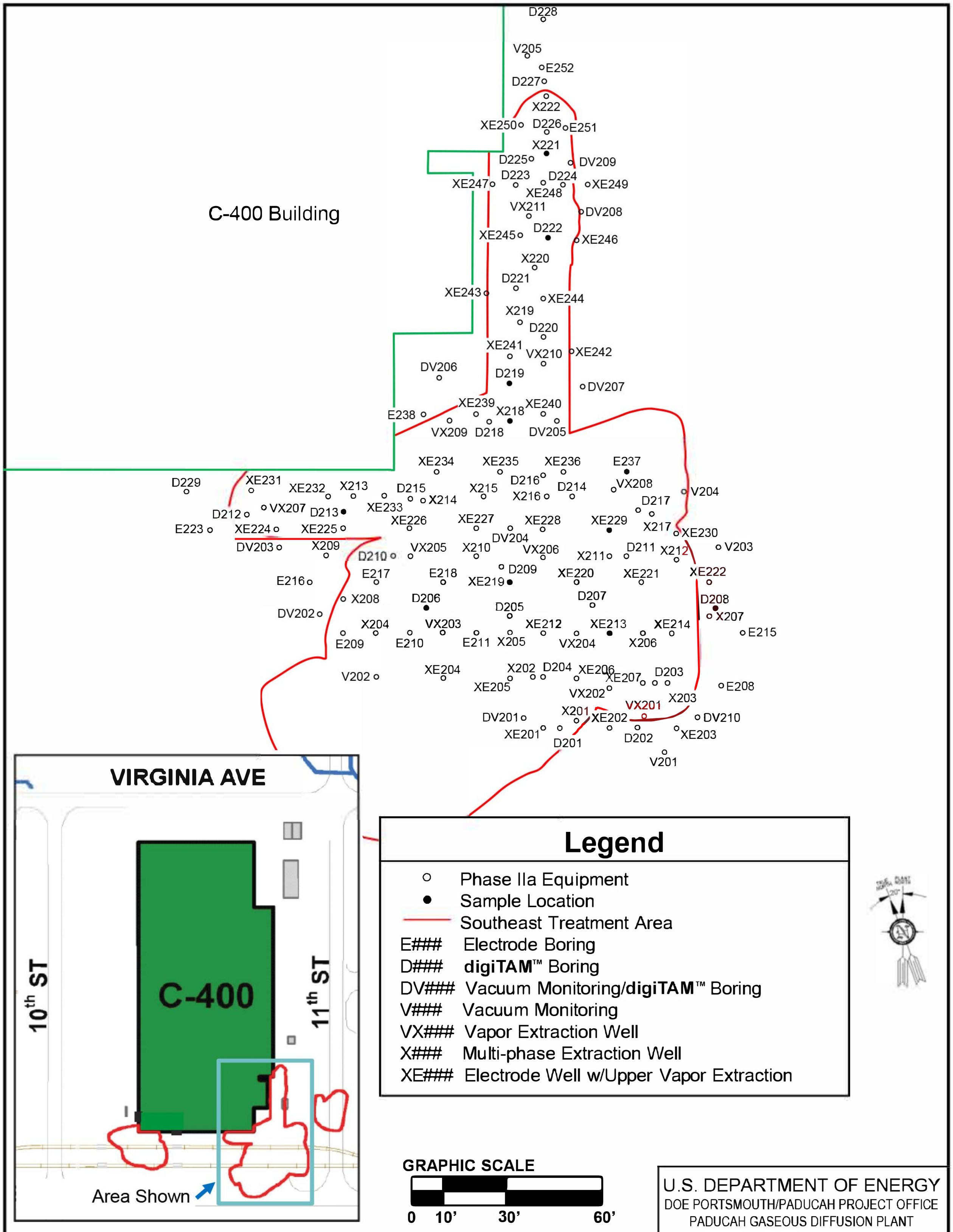

Figure 5.4. Southeast Treatment Area ERH Well Location Map

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5.1.1.5 Description of Soil Vapor and Groundwater Treatment System

Phase IIa construction activities, including drilling and modification to the SVGTS, commenced on September 26, 2012, and concluded on May 30, 2013. Refer to Figure 4.7 for an aerial photograph of the SVGTS system. A generalized Phase IIa SVGTS process flow diagram is illustrated on Figure 5.5. The C-400 Cleaning Building IRA at PGDP included the design, installation, operation, and subsequent decommissioning of an ERH system to selectively heat discrete (vertical and horizontal) subsurface intervals, which resulted in the volatilization, removal, and recovery of VOCs, primarily TCE and its breakdown products, from the C-400 Cleaning Building Southeast Treatment Area. The ERH system was comprised of a network of electrodes placed in the subsurface treatment area located to the southeast area of the C-400 Cleaning Building. Power delivery systems supplied power to the electrodes (refer to Figure 5.6), which, in turn, generated resistive heat in the subsurface soils. As a result of the resistive heating, VOCs volatilized and steam was produced *in situ*; the VOCs and steam subsequently were captured via a series of SVE wells. The captured vapors were treated through an SVGTS. The vapor stream was treated such that the VOCs and steam were condensed and the VOCs were captured. A nominal amount of groundwater was extracted to establish and maintain hydraulic control in the Upper RGA. Extracted groundwater was treated by the SVGTS. A portion of the treated water was injected back into the electrodes to maintain electrical conductivity and facilitate heat transfer by convection. The balance of the treated groundwater was discharged through Kentucky Pollutant Discharge Elimination System Outfall 001.

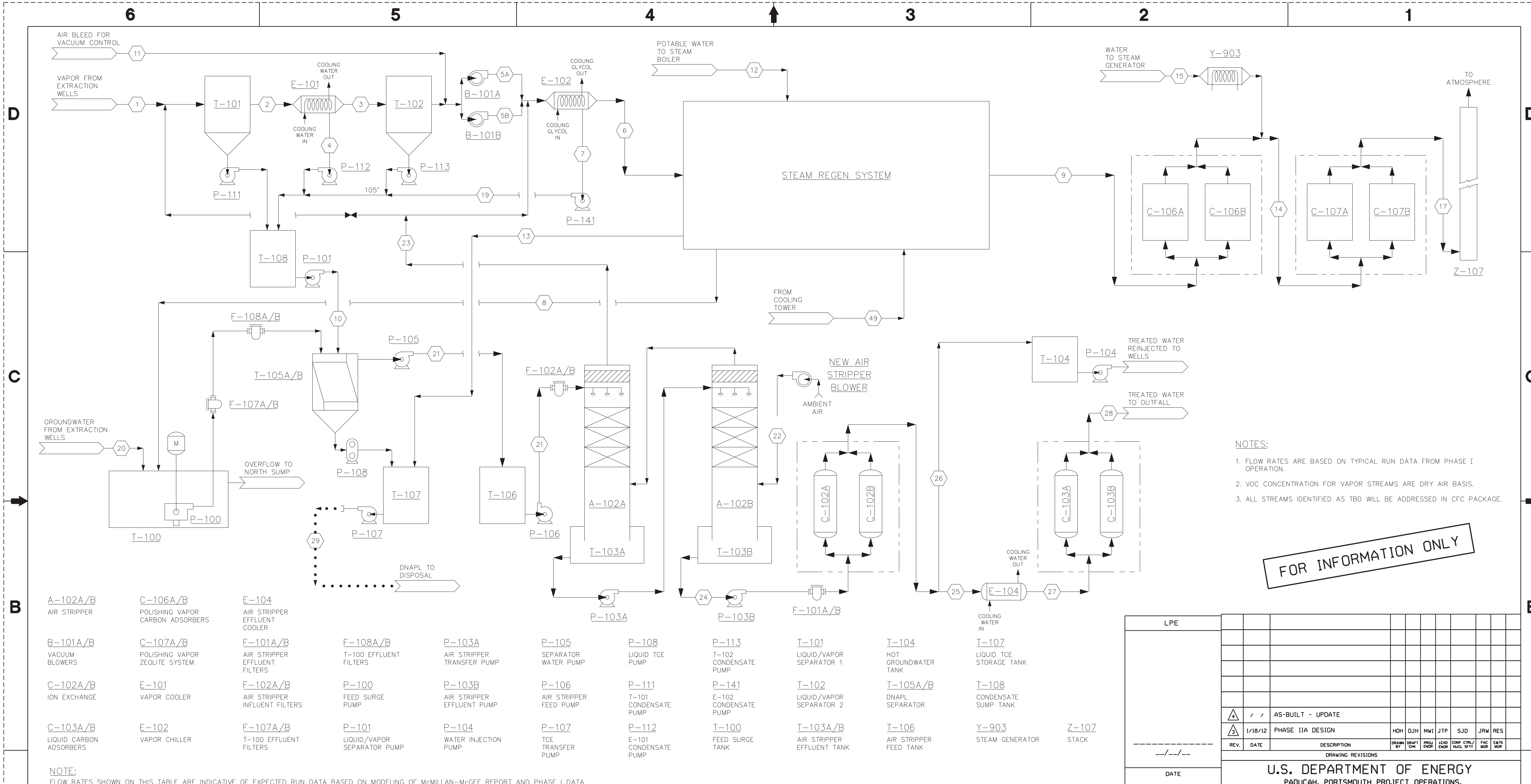
5.1.1.6 Phase IIa major upgrades/modifications to the SVGTS

The original Phase I configuration of the SVGTS was modified during Phase IIa to improve system operations based on lessons learned from Phase I operations. The groundwater portion of the SVGTS had a minor modification to the configuration of the air strippers: an air blower was installed to reroute air stripper discharge to the downgradient side of the displacement blowers. This modification was required due to the higher vacuum requirements in the wellfield. The main modifications to the SVGTS were to the soil vapor portion of the SVGTS. Some of these modifications included replacing the cryogenic VOC recovery system with a new steam regenerated carbon absorption system and associated steam boiler, and upgrading the rotary positive displacement blowers with more efficient liquid ring vacuum blowers to meet the relatively high vacuum design parameters for Phase IIa (15 inches of mercury at wellhead). These and other modifications are discussed in detail in Section 4 and Section 5 of the Phase IIa RDR (DOE/LX/07-1272&D2/R1) (DOE 2012). Several photos of SVGTS system components are included in Section 5.2.3.

5.1.2 Operations

Following construction, commissioning and testing began with testing ambient air and potable water in a logical sequence to ensure that the subsystems worked correctly. Batch treatment operations then were performed to ensure VOC removal by the SVGTS met design criteria.

Prior to commencement of normal operations, extensive step and touch potential testing was implemented in and around the energized wellfield to identify and eliminate induced stray voltages greater than 15 volts, per National Electrical Code requirements (based on the National Electric Code on conductive surfaces). Hundreds of measurements were taken, and no induced stray voltages greater than 15 volts were observed. A few minor stray voltages (below 15 volts) were observed during this testing period, and



NOTE:
FLOW RATES SHOWN ON THIS TABLE ARE INDICATIVE OF EXPECTED RUN DATA BASED ON MODELING OF McMILLAN-McGEE REPORT AND PHASE I DATA

STREAM NO. / COMPONENT	1 VAPOR FROM SVE HEADER	2 VAPOR COOLER INLET	3 VAPOR COOLER OUTLET	4 CONDENSATE FROM VAPOR COOLER	5A VAPOR FROM VACUUM BLOWER	5B VAPOR FROM VACUUM BLOWER	6 VAPOR FROM CHILLER	7 CONDENSATE FROM VAPOR CHILLER	8 AQUEOUS FROM DECANTER	9 CARBON OUTLET VAPOR	10 CONDENSATE FROM COOLER/CHILLER	11 AIR BLEED FOR VACUUM CONTROL	12 POTABLE WATER TO STEAM BOILER	13 TCE FROM DECANTER
DRY AIR lb/hr	3,099	3,099	3,099		1550	1550	4,055			3,647.292		TBD		
STEAM/WATER VAPOR lb/hr	972	880	165		82.5	82.5	30.5			26.94		TBD		3
TOTAL VOCs (PRIMARY TCE) lb/hr	29	29	29	0.03	14.5	14.5	29	0.01		0.288	0.045	TBD		28.6
GROUNDWATER /CONDENSATE lb/hr				867				135			1,094	TBD		
TOTAL STREAM FLOW lb/hr	4,100	4,008	3,293	867	1,785	1,785	4,146	135		3,674.52	1,094	TBD		
GAS FLOW acfm												TBD		
LIQUID FLOW gpm				1.8				0.3	2.61		2.2	TBD	2.4	0.45
TOTAL VOCs ppmv (mg/L)	7,000	5,668.491	5,668.491	(34)				(74)			(40)	TBD		
TEMPERATURE °F	203	199	105	105	138	138	70	70	50	50	101	TBD	80	50
PRESSURE psia	6.81	6.58	6.38	14.9	14.9	14.9	14.7	14.95	14.9	14.9	14.7	TBD	70	14.9

STREAM NO. / COMPONENT	14 CARBON ADSORBER OUTLET	15 STEAM FOR HUMIDITY	17 VAPOR TO STACK	19 CONDENSATE	20 GROUNDWATER FROM MPE WELLS	21 AIR STRIPPER FEED	22 AIR TO STRIPPER	23 AIR FROM STRIPPER	24 AIR STRIPPED GROUNDWATER	25 GROUNDWATER TO E-104	26 HOT GROUNDWATER TO REINJECTION	27 GROUNDWATER TO C-103A/B	28 GROUNDWATER TO DISCHARGE	29 DNAPL TO DISPOSAL	49 COOLING WATER TO CONDENSER
DRY AIR lb/hr	3,640		3,640	TBD			1,454	955.1						TBD	
STEAM/WATER VAPOR lb/hr	20	107	127	TBD				152.9						TBD	
TOTAL VOCs (PRIMARY TCE) lb/hr	0.05		0.02	TBD	44.1	44.4		0.246	0.21	0.05	0.16	0.05		TBD	
GROUNDWATER /CONDENSATE lb/hr				TBD	40,032	44,083			42,553	10,708	31,825	10,708	10,708	TBD	
TOTAL STREAM FLOW lb/hr	3,660.05	107	3,767.02	TBD	40,076	44,128	1,454	1,108.246	42,553	10,708	31,826	10,708	10,708	TBD	
GAS FLOW acfm		30		TBD										TBD	
LIQUID FLOW gpm				TBD	80	88			85	21.4	63.6	21.4	21.4	TBD	100
TOTAL VOCs ppmv (mg/L)	14		5	TBD	(1,100)	(1,006)		217	(5)	(5)	(5)	(5)		TBD	
TEMPERATURE °F	50	220	50	TBD	203	194	70	139.6	157	157	157	100	100	TBD	100
PRESSURE psia	14.9	14.9	14.9	TBD	14.7	14.7	15.6	14.9	14.7	14.7	14.7	14.7	14.7	TBD	50

Figure 5.5. C-400 Phase IIa Generalized SVGTS Process Flow Diagram

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Figure 5.6. C-400 Phase IIa Power Delivery Systems

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Photograph Date - Direction: 1/16/14 - Looking Northwest the conductive surfaces where the stray voltages were observed subsequently were covered by insulating material to reduce any potential hazard. In addition to the step and touch potential testing performed by the project team, PGDP personnel performed independent step and touch potential testing inside the C-400 Cleaning Building. The threshold criterion used by PGDP was a much more conservative 1 volt limit. No problematic areas were identified during PGDP testing. Throughout normal operations, step and touch potential testing also was performed daily and whenever transformer tap changes were initiated or when significant operational changes occurred.

System testing was concluded in July 2013 and normal remedial operations were initiated. The system ran intermittently during commissioning activities through late November 2013 at which time the system was shutdown to address operational issues (primarily related to cold weather and troubleshooting problems with the new carbon regeneration unit). Operations resumed January 14, 2014, after cold weather issues had been addressed. Operations continued through July 2014 when TCE concentrations in recovered vapor had dropped to asymptotic levels. Pulsed operations were initiated. The strategy for the pulsing operations was intended to maximize removal of the remaining contaminants from the treatment area by maximizing extraction from the wells and by varying the pressure levels within the subsurface. To maximize the extraction from individual wells, a pattern was initiated that consisted of operating half of the wells while the remaining one-half were shut down. To vary subsurface pressures, the extraction rates were reduced or increased concurrently with varying the power levels to the electrodes. VOC readings were taken from the wells with maximum extraction continuing at well locations with the highest VOC concentrations. The process was repeated for two cycles. Pulsed operations ended in September 2014, at which time the FFA parties reached consensus that asymptotic conditions had been achieved in the treatment zone. DOE requested approval from EPA and Kentucky Department for Environmental Protection (KDEP) regulators to shut off the ERH electrode array in a letter dated October 3, 2014, PPPO-02-2572921-14 (DOE 2014). Following approval by the regulators (EPA 2014; KDEP 2014), ERH electrodes were turned off on October 9, 2014, to allow the subsurface to cool down. The SVGTS remained operational to continue mass removal during the cool down period. The SVGTS continued to operate through November 5, 2014, at which time operations ceased, and the remedial action portion of Phase IIa project was considered complete.

5.1.2.1 Temperature, heating, and vapor recovery and groundwater extraction performance

A critical factor in the success of an *in situ* ERH project is the attainment of target temperatures that are at or above the boiling point of the target VOC(s). The target temperature requirements for the C-400 ERH project were developed to be depth specific for reasons described below. TCE, the target VOC at C-400, has a boiling point of approximately 189°F (87°C) at normal atmospheric pressure conditions. A TCE/water mixture will boil at a lower temperature than that of either TCE or water. The boiling point of a TCE/water mixture is approximately 163°F (73°C). The boiling temperature of TCE and that of a TCE/water mixture increases with depth below the water level (potentiometric surface) due to increasing hydrostatic pressures. These factors were considered in defining the C-400 IRA target temperatures. Previously presented, Figure 4.8 shows the relationship between boiling temperature and depth below the potentiometric surface for a TCE/water mixture, for free-phase TCE, and for groundwater.

For the C-400 IRA Phase IIa, a target temperature was established for subsurface soils above the potentiometric surface and for soils below the potentiometric surface. The target temperature established for soils above the potentiometric surface of the RGA (approximately 53 ft bgs) was 194ºF (90°C) or higher. The target temperature for soils below the potentiometric surface of the RGA was established as the boiling point (or above) of free-phase TCE at the respective depth of treatment [e.g., approximately 189ºF (87°C) at the potentiometric surface and approximately 199°F (93°C) at 60 ft bgs]. The free-phase boiling point of TCE (adjusted for depth below the water level) is a conservative goal because, as described above, a phase change for a TCE/water mixture is achieved at boiling temperature that is lower than that of the solvent itself.

Temperatures in the treatment zones were monitored by strings of digital temperature acquisition modules (digiTAMs™) installed through the target heated depth. DigiTAM™ strings generally were installed in locations that were between electrode borings and away from vapor extraction wells, typically the coolest zones of the treatment volume. DigiTAMs™ are digital temperature sensing devices composed of temperature and chemically resistant cable with imbedded sensors placed at 3-ft intervals. There were approximately 15 sensors on each digiTAM™ string monitoring temperatures through the Upper RGA. The sensors have an accuracy of ± 0.5°C (0.9°F) and can operate in temperatures ranging from -67°F (-55°C) to 257°F (125°C). Each sensor on the string is addressed individually so the data can be captured and stored on a data server.

In the Southeast Treatment Area, 39 digiTAM™ strings were installed to monitor subsurface temperatures throughout the target treatment volume, which ranged from 19.5 to 61.5 ft bgs. Southeast Treatment Area digiTAM™ locations are shown on Figure 5.4. They are designated on the figure by the letter "D" followed by a number (e.g., D213). All digiTAM™ data for all locations in the Southeast Treatment Area are included in Appendix B.

5.1.2.2 Southeast Treatment Area heating performance

Geologic setting and electrode placement are important for understanding the heating performance. In the Southeast Treatment Area, the UCRS extends to an average depth of 51 ft bgs. The Upper RGA (HU 4) extends from 51 ft to 57 ft bgs. Heating performance discussed below also tied into the aquifer being addressed. Due to the lower hydraulic conductivity (resulting in lower groundwater inflow) and lower electrical resistivity, the UCRS is more conducive to heating than the RGA. The heating electrodes in the Southeast Treatment Area consisted of typical three interval electrodes with electrodes placed from 18–28 ft, 36–46 ft, 53–63 ft bgs. The discussion that follows compares heating performance based on geologic formation, water table, and electrode depth.

Figures 5.7 and 5.8 present average digiTAM™ temperatures by depth and area results from the Southeast Treatment Area. Figure 5.7 depicts digiTAM™ sensor readings various depths bgs. The groundwater potentiometric surface typically was encountered at approximately 53 ft bgs.

DigiTAM™ temperature sensors above the potentiometric surface were these:

- Sensors staged between 18.5–24.5 ft bgs achieved and maintained target temperatures (194°F/90°C) from late-May through mid-October 2014.

- Sensors staged between 24.5–30.5 ft bgs achieved and maintained target temperatures (194°F/90°C) from late-April through mid-October 2014.

- Sensors staged between 30.5–36.5 ft bgs achieved and maintained target temperatures (194°F/90°C) from late-March through mid-October 2014.

- Sensors staged between 36.5–42.5 ft bgs achieved and maintained target temperatures (194°F/90°C) from mid-March through late-October 2014.

- Sensors staged between 42.5–48.5 ft bgs achieved and maintained target temperatures (194°F/90°C) from early-March through late-October 2014.

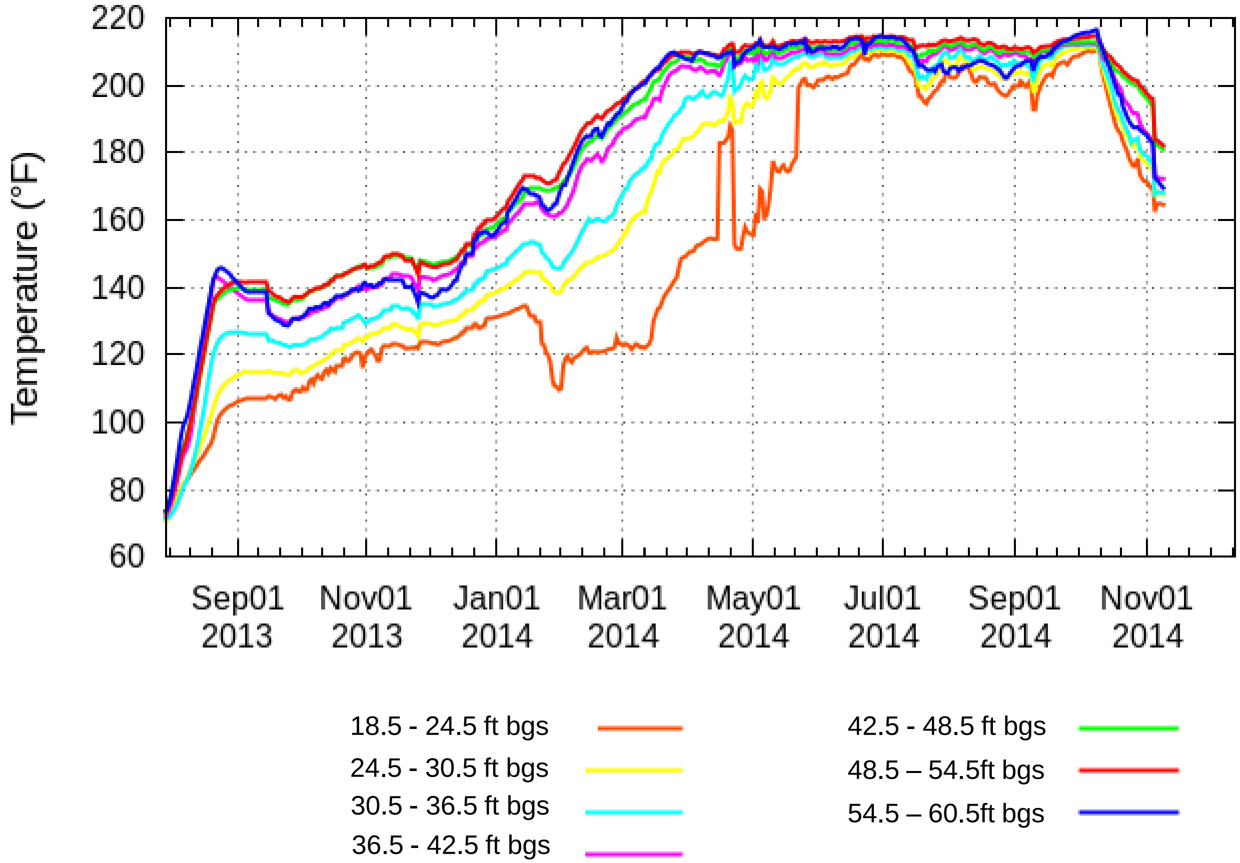

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Figure 5.7. C-400 Phase IIa – Average digiTAM™ Temperature by Depth

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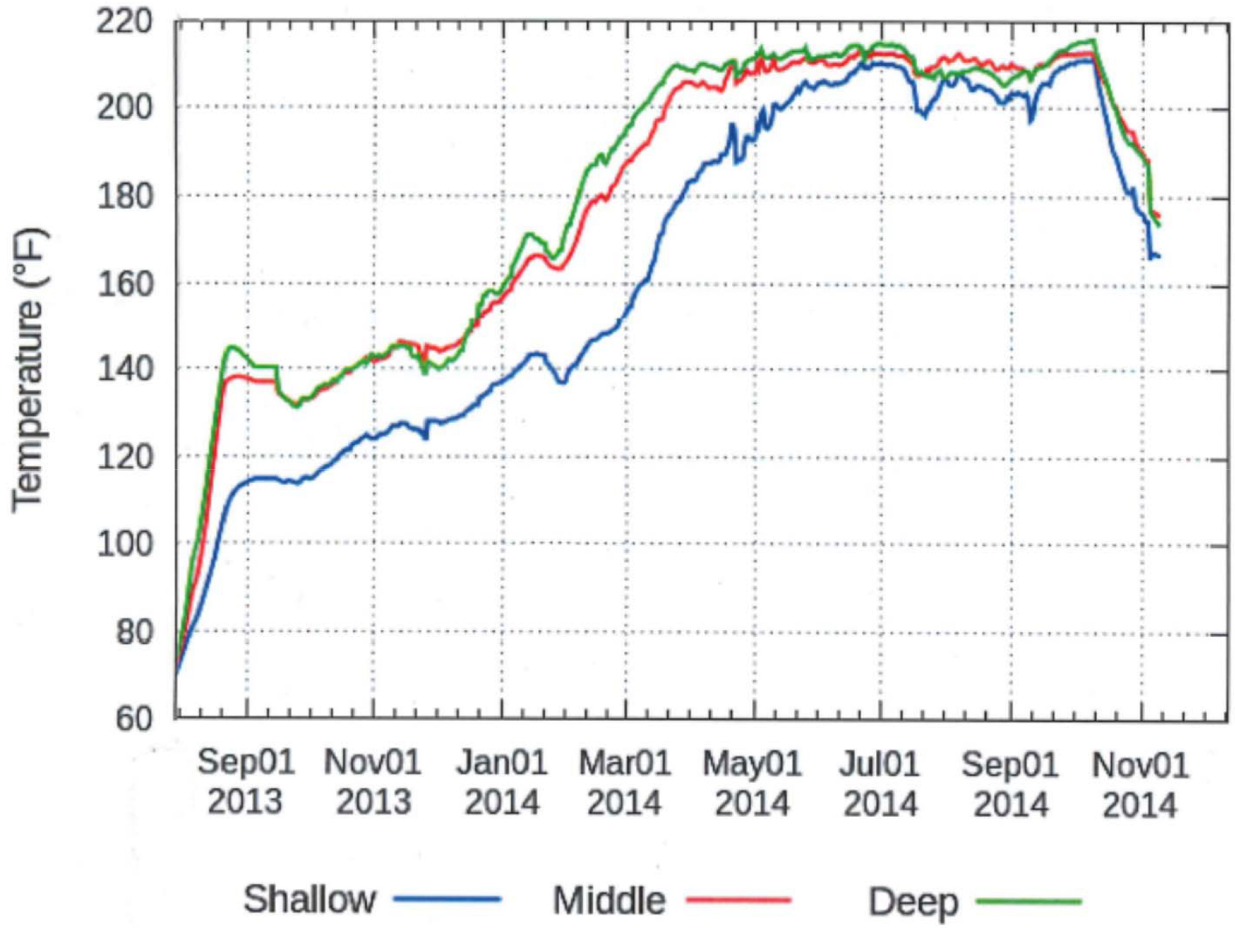

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Figure 5.8. C-400 Phase IIa – Average digiTAM™ Temperature by Electrode Area

- The 194°F (90°C) target temperatures, above the potentiometric surface (above 53 ft bgs), were achieved in all target heated intervals by late-May 2014.

Sensors staged at or below the potentiometric surface were these:

- Sensors staged between 48.5–54.5 ft bgs achieved and maintained target temperatures (199°F/93°C) from early-March through late-October 2014.

- Sensors staged between 54.5–60.5 ft bgs achieved and maintained target temperatures (199°F/93°C) from early-March through mid-October 2014.

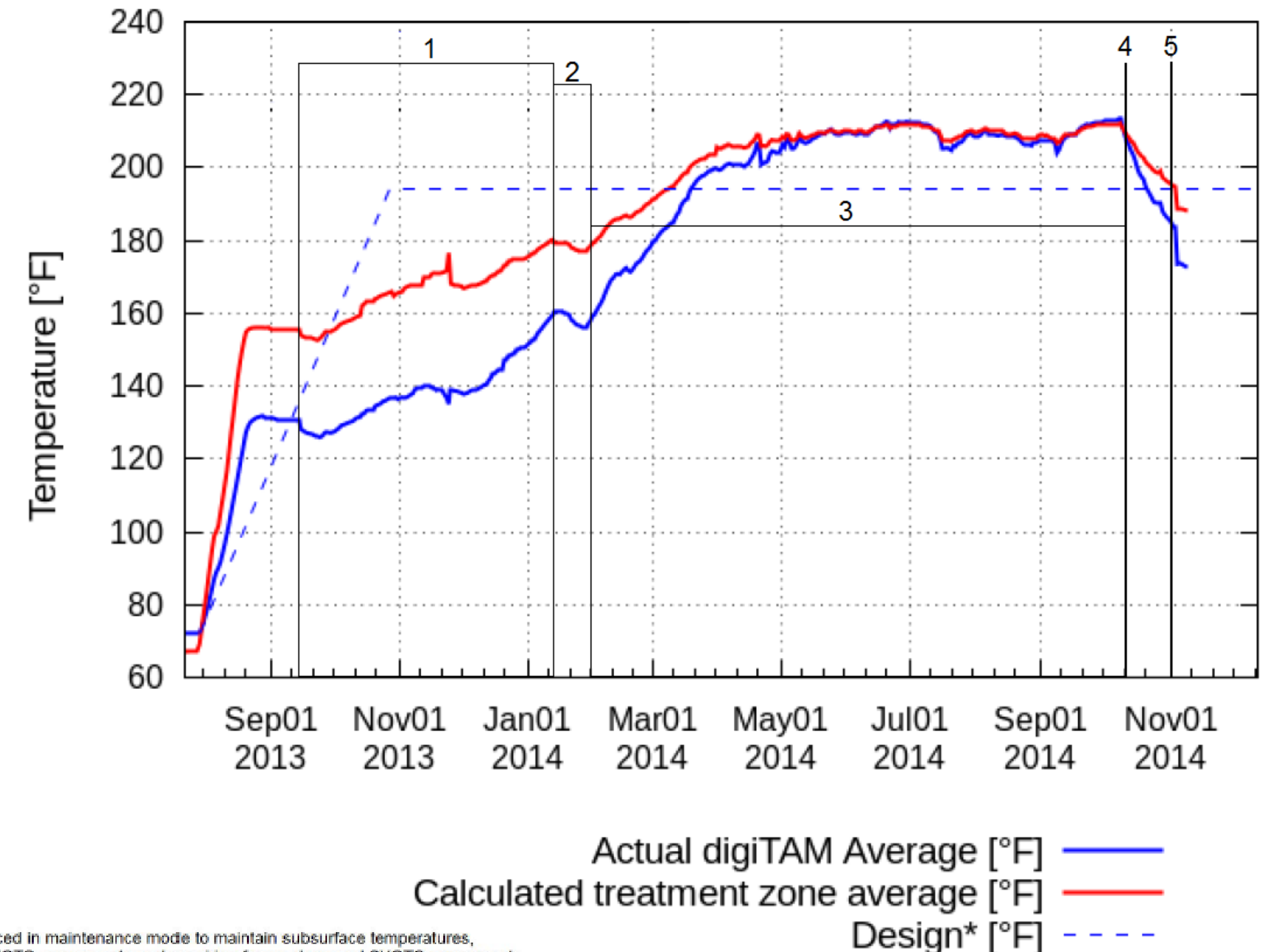
- The 199°F/93°C target temperatures, below the potentiometric surface, were achieved in all heated intervals by early-March 2014.

Figure 5.8 shows data based by area temperatures for shallow, middle, and deep interval electrodes.

Figure 5.9 graphically illustrates the rapid temperature increase in subsurface temperatures during August 2013 when electrodes were powered up and the subsequent leveling off of temperature. Figure 5.9 also denotes major events (timeline) that impacted the operation of the Phase IIa ERH Remediation. The SVGTS was shut down in late November through mid-January to troubleshoot weather-related system issues and problems with the carbon regeneration unit. The ERH electrode system was operated as necessary during the periods of treatment system downtime to minimize the loss of subsurface heat as reflected on the temperature curves. After the SVGTS issues were resolved, full power to the wellfield electrodes was resumed January 14, 2014. For the remainder of January 2014, the SVGTS system was subjected to levels of VOCs higher than anticipated, requiring additional fine-tuning of the SVGTS to address the VOC spikes. In turn, the power to the wellfield electrodes was lowered to reduce VOC concentrations at the SVGTS intake. Full power to the wellfield electrodes resumed in early February 2014 and the ERH and SVGTS systems ran without any significant incidents. The ERH system was shut down in early October 2014, as depicted by the sharp decline in energy on Figure 5.10. The SVGTS system was shut down November 5, 2014.

5.1.2.3 Vapor and groundwater extraction performance

SVE, as a component of ERH, is a technology that is used to extract volatile compounds from unsaturated soil. During SVE, a vacuum is applied to an extraction well to lower the vapor pressure in the vicinity of the well. Lowering the pressure at the extraction well induces an advective flow of soil vapors and flow of groundwater containing VOCs (primarily TCE and its breakdown products) from regions of higher pressure to the extraction point. This process enhances the volatilization of contaminants from within grains of soil and promotes the diffusion of sorbed contaminants into soil pores where they can be swept and extracted along with soil vapors. Vapor extraction performance is assessed by monitoring mass removal and ensuring that all areas with the treatment area had sufficient induced vacuum to recover the vapors generated by ERH. Vapor extraction well locations used are shown on Figure 5.4 for the Southeast Treatment Area. Vapor extraction wells were designated on the figure by the letter "VX" followed by a number (e.g., VX209). A picture depicting both a vapor and a multiphase extraction well is shown in Figure 5.11. Wellfield vacuum pressure was monitored at vacuum piezometers installed near the perimeter of the treatment areas. These are designated on Figure 5.4 by the letter "V" followed by a number (e.g., V201) or by the letters "DV" follow by a number (e.g., DV201).



1 Electrode power placed in maintenance mode to maintain subsurface temperatures, while intergrating SVGTS components and repairing freeze damaged SVGTS components.

2 Electrode power reduced to troubleshoot elevated VOC levels from wellfield.

3 ERH and SVGTS system operation as designed.

4 Power to electrodes turned off.

5 November 5, 2014 SVGTS system shutdown.

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Figure 5.9. C-400 Phase IIa Actual and Design Temperature Curves

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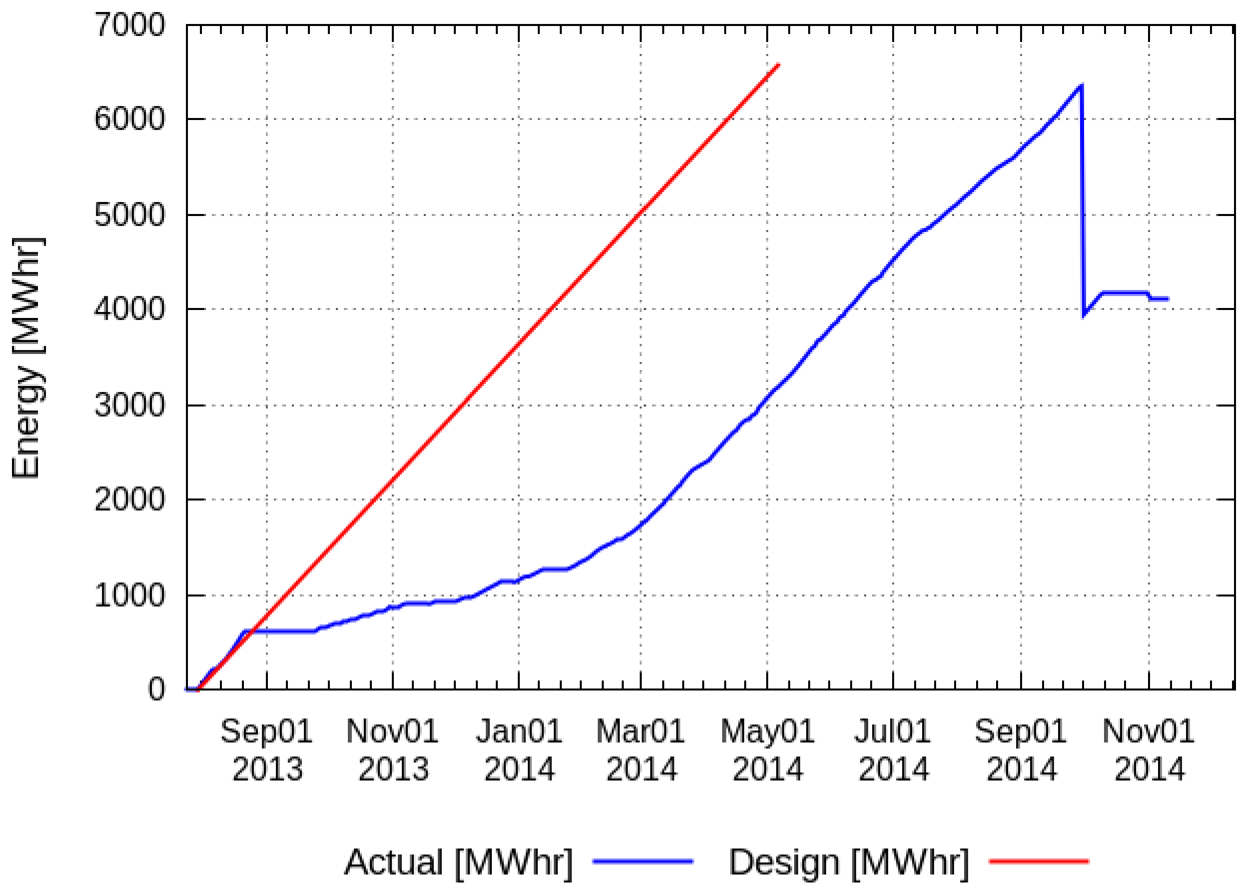

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Figure 5.10. C-400 Phase IIa Actual and Design Energy Curves

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Figure 5.11. C-400 Phase IIa ERH Wellfield

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Photograph Date - Direction: 1/16/14 - Looking West

5.1.2.4 Southeast Treatment Area

There were 33 vapor extraction and multiphase extraction wells in the Southeast Treatment Area that were connected to one of five headers, which were plumbed into the main header to the treatment system. All vapor extraction points were connected to a common header, which transferred the TCE-contaminated vapor to the treatment system for recovery and treatment and then release. As a result of lessons learned from Phase I, the Phase I blower component of the SVGTS system was upgraded to increase vacuum levels from -10 inHg to -15 inHg in order to achieve more consistent vacuum levels across the Phase IIa treatment area.

Table 5.2 provides a summary of flow rates achieved for vapor extraction points in the Southeast Treatment Area. Vapor extraction flow rates from the primary vapor extraction points, "X###" and "VX###" wells, ranged from 0.0 scfm to just over 73 scfm with average rates ranging from 2.9 scfm to 59.5 scfm. Table 5.3 presents a summary of Southeast Treatment Area vacuum pressure measurements achieved. Although maximum vacuum pressures of 12, 10, and 10.5 inches of mercury were observed at monitoring locations D204, DV208 and DV209, respectively, many zero pressure readings were recorded. Pressure gauges installed on the vacuum monitoring locations were determined to not be sensitive enough to measure/report operating pressures reliably at levels that were as low as 0.04 inches of mercury or 0.5 inches of water (1 inch of mercury ≈ 13.6 inches of water). As a result, it was not possible to know for certain whether a zero pressure reading was indicative of no vacuum influence at the monitoring location or if it was just too low for the gauge to register. As a result of lessons learned from Phase I, when a zero inches of Hg reading occurred, a capsuhelic gauge was employed to gather the vacuum reading in inches of water. Wells DV202, DV207, DV208, DV209, DV210, V203, and V204 periodically required the collection of vacuum readings utilizing a capsuhelic gauge to record vacuum readings in inches of water.

Throughout the treatment system start-up, testing, and routine operations, vapor samples were collected and analyzed to assess the progress of the IRA, to monitor the aboveground treatment system effectiveness, and to verify compliance with discharge criteria.

To assess the progress of the C-400 IRA, vapor samples were collected from vapor extraction wells and vapor extraction headers coming from the treatment areas. Vapor samples were collected periodically from various points in the vapor treatment stream to monitor the effectiveness of the treatment units. Samples were collected from the lead vapor phase carbon vessel discharge to determine if and when a carbon change-out should be performed. Compliance with discharge criteria was monitored at the vapor treatment system stack. Vapor analyses were performed using photoacoustic analyzers and periodically by a DOE Consolidated Audit Program laboratory.

Table 5.2. Phase IIa Wellfield Flow Measurement Summary

Well ID	Minimum Flow (scfm)	Maximum Flow (scfm)	Average Flow (scfm)	Count of Measurements
VX201	0.0	51.2	13.8	23
VX202	0.0	56.1	23.2	23
VX203	12.7	72.3	37.2	31
VX204	7.1	73.0	35.9	31
VX205	16.3	71.3	41.6	31
VX206	0.0	71.9	24.4	31
VX207	0.0	25.3	12.3	34

Table 5.2. Phase IIa Wellfield Flow Measurement Summary (Continued)

Well ID	Minimum Flow (scfm)	Maximum Flow (scfm)	Average Flow (scfm)	Count of Measurements
VX208	0.0	12.6	5.0	37
VX209	0.0	69.8	18.9	29
VX210	5.3	69.4	33.6	29
VX211	16.3	70.9	37.6	29
X201	0.0	19.2	8.0	23
X202	16.6	73.0	26.7	23
X203	16.6	33.0	19.5	23
X204	17.1	73.8	41.7	31
X205	16.3	72.7	40.3	31
X206	0.0	22.8	16.4	31
X207	0.0	14.4	6.0	31
X208	16.3	72.6	41.4	31
X209	17.0	71.3	41.7	31
X210	15.5	71.2	35.7	31
X211	0.0	27.6	11.7	31
X212	1.5	19.8	13.7	31
X213	5.1	66.0	28.3	67
X214	0.0	38.6	23.5	67
X215	8.7	71.4	47.7	67
X216	8.7	70.7	39.1	67
X217	0.0	19.0	2.9	67
X218	11.3	58.6	33.8	63
X219	16.4	72.7	59.5	59
X220	16.5	72.0	55.7	63
X221	16.4	72.0	55.5	63
X222	16.6	72.5	39.4	63

scfm = standard ft^3 per minute

Table 5.3. Phase IIa Area Vacuum Measurement Summary

Monitoring Location	Minimum Vacuum	Maximum Vacuum (inches Hg)	Average Vacuum (inches Hg)	Count of Measurements
DV201	0.00	7.00	2.74	89
DV202	0.00	9.00	3.40	89
DV204	0.50	12.00	5.70	89
DV205	0.00	9.50	2.88	89
DV206	0.00	9.00	3.71	89
DV207	0.00	8.00	2.99	89

Table 5.3. Phase IIa Area Vacuum Measurement Summary (Continued)

Monitoring Location	Minimum Vacuum	Maximum Vacuum (inches Hg)	Average Vacuum (inches Hg)	Count of Measurements
DV208	0.00	10.00	3.27	89
DV209	0.00	10.50	3.51	89
DV210	0.00	4.50	1.38	89
V201	0.00	6.00	3.18	90
V202	0.30	8.50	3.05	90
V203	0.00	6.00	1.93	90
V204	0.00	0.37	0.04	90
V205	0.00	5.00	2.09	90

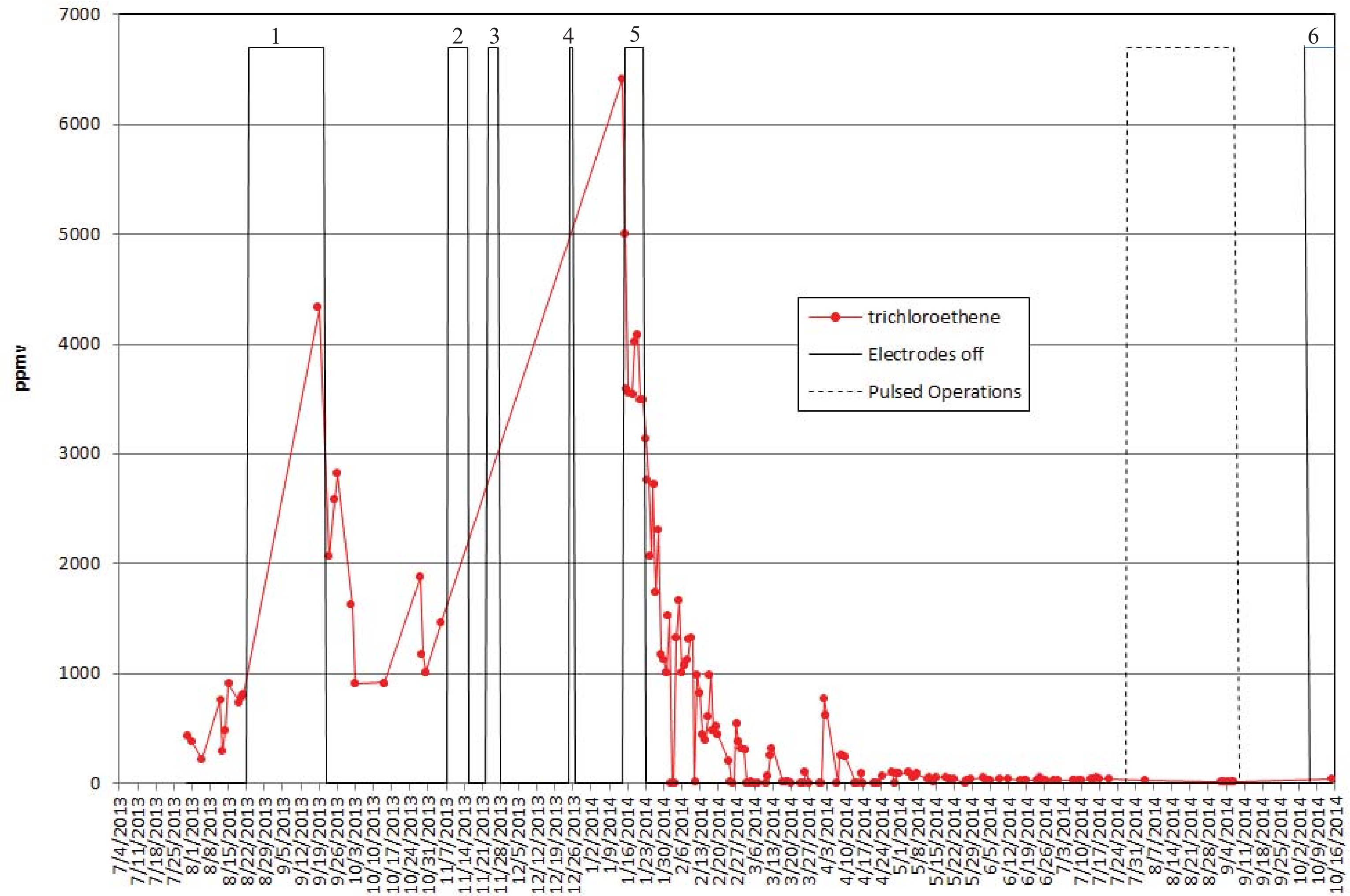
inches Hg = inches of mercury

TCE concentrations in the vapor extraction header were monitored throughout operations using photoacoustic analyses. Figure 5.12 shows the Southeast Treatment Area header photoacoustic readings, and electrode downtimes also are depicted on the figure. These data indicate that asymptotic levels were achieved in the wellfield during July 2014. Pulsed operations commenced in late-July 2014 and were stopped at the end of September 2014. Minimal contaminant response was received during pulsed operations. The electrodes were turned off on October 8, 2014, while vapor extraction continued for approximately another month to continue mass removal during cool down.

TCE vapor concentrations also were measured at vapor extraction wells using the photoacoustic analyzers. Table 5.4. provides a summary of the four extraction wells with the highest Southeast Treatment Area photoacoustic measurements and from the combined wellfield header.

5.1.2.5 Groundwater extraction

Twenty-two multiphase extraction wells were installed and equipped with pumps (X201 through X222), in the Southeast Treatment Area (see Figure 5.4 for well locations). Groundwater was extracted via these submersible pneumatic pumps during system operations to maintain hydraulic control and dewater the treatment area and to aid in the transport of VOCs to the multiphase extraction wells. Upper RGA groundwater extraction wells in the Southeast Treatment Area were installed with the bottom of the well screen including a 2-ft sump extending approximately 68 ft bgs. Table 5.5 provides a summary of groundwater extraction data from Phase IIa operations. For the southeast wellfield, three times more water was extracted from the southeast wellfield as was injected. The average extraction rate for individual Southeast Treatment Area wells was 2.0 gpm, for a total of 45.0 gpm. Sample ports installed at each groundwater extraction wellhead allowed groundwater samples to be obtained.



1 Startup testing
2 System maintenance
3 System maintenance

4 System maintenance
5 System maintenance
6 Electrodes shutdown

ppmv – parts per million by volume

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Figure 5.12. C-400 Phase IIa Header Average TCE Photoacoustic Readings

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Table 5.4. Phase IIa Area Weekly Average Photoacoustic TCE Readings Summary—Combined Wellfield Header and Vapor Extraction Wells with Highest Combined Volatile Organic Compound Concentrations

Location	Average (ppmv)	Minimum (ppmv)	Maximum (ppmv)	Count of Measurements
Combined Wellfield Header	789.28	0.25	6,412	145
VX208	3,388.55	0.53	15,136	34
X215	508.61	0.52	4,020	31
X216	2,889.94	0.56	14,600	32
X217	530.53	0.19	9,640	35

Table 5.5. Extracted and Injected Groundwater during Phase IIa

	Southeast Treatment Area
Average Flow Rate by Area (gpm) Average Flow Rate per Well (gpm)	≈ 45.0 ≈ 2.0
Groundwater Extracted (gal)	≈ 7,570,127
Groundwater Injected (gal)	≈ 2,503,061
Ratio of Extracted Groundwater to Injected Groundwater	3.0

Digital pressure acquisition modules (digiPAMs™) were not installed during Phase IIa because they did not provide reliable data during Phase I operations due to the presence of steam in the digiPAM™ drop tubes.

During Phase IIa operations, sand and sediment infiltration into select groundwater extraction wells located in the Southeast Treatment Area continued to cause minor problems. Those extraction wells extended through the Upper RGA. The infiltration is believed to have been caused by the wells being underdeveloped.

5.1.3 Monitoring and Sampling

5.1.3.1 Baseline sampling event

Baseline soil samples were collected in conjunction with Phase IIa ERH well installation activities. The baseline samples were collected between October 23, 2012, and November 28, 2012. A total of 146 baseline soil samples was collected from various depths from 26 soil boring locations and analyzed for VOCs to evaluate both location-specific and area-wide distribution of VOCs in the treatment area. Baseline groundwater samples were collected after Phase IIa ERH well installation activities were completed. A total of 22 baseline groundwater samples was collected from Phase IIa multiphase extraction wells; these samples then were analyzed for VOCs to evaluate both location-specific and area-wide distribution of VOCs in the treatment area. The samples were collected between August 6, 2013, and August 14, 2013. Refer to Figure 5.13 to identify specific sample locations.

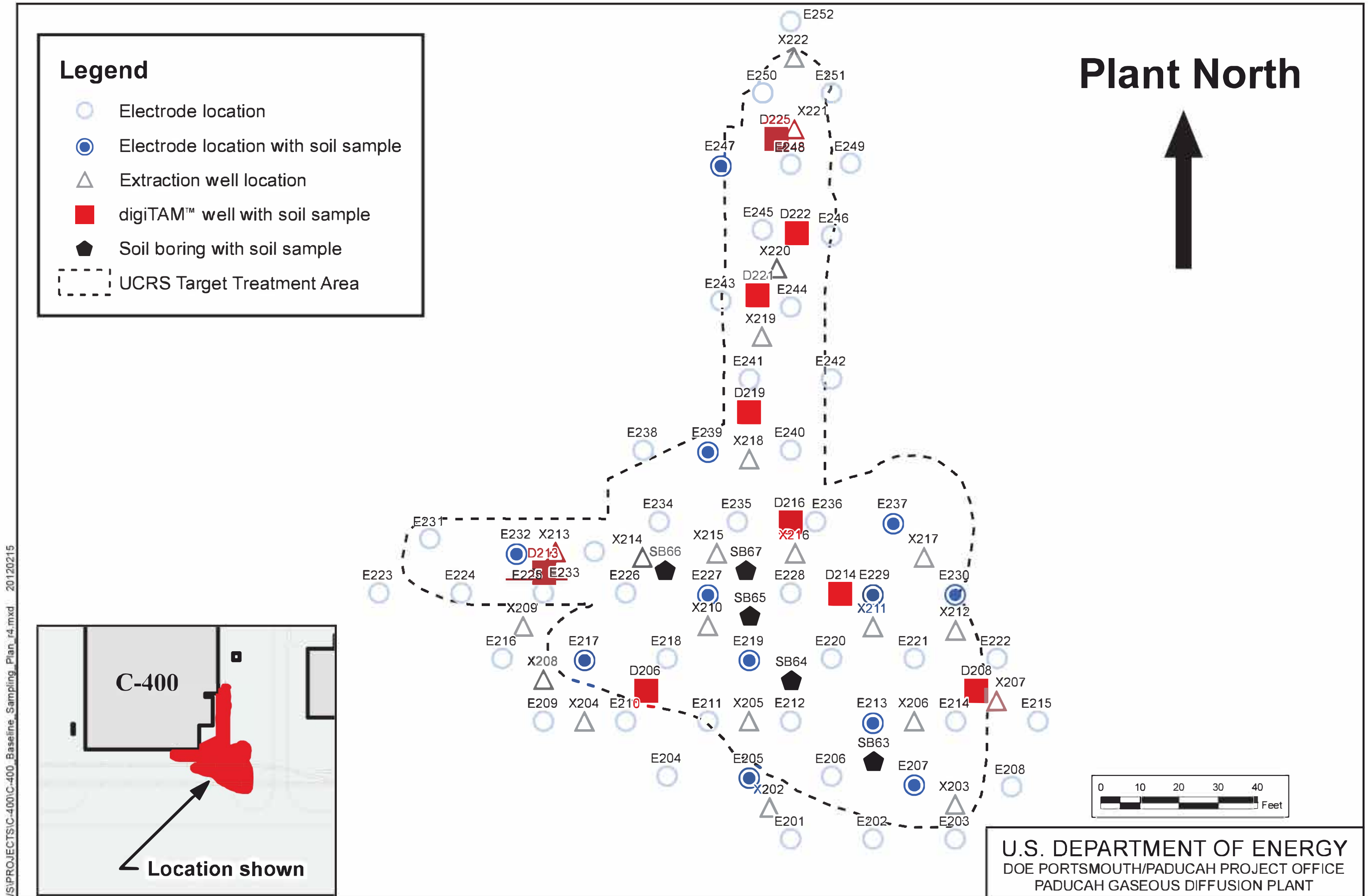

Figure 5.13. C-400 Phase IIa Baseline Soil Sample Location Map

From RAWP, DOE/LX/07-1271&D2/R3 (DOE 2013a)

5.1.3.2 Operation and maintenance sampling

Throughout the treatment system start-up, testing, and routine operation, vapor and water samples were collected and analyzed to assess the progress of the IRA, to monitor the aboveground treatment system effectiveness and to verify compliance with discharge criteria.

To assess the progress of the C-400 IRA, vapor samples were collected from vapor extraction wells and vapor extraction headers coming from the treatment areas. Vapor samples were collected periodically from various points in the vapor treatment stream to monitor the effectiveness of the treatment units. For example, samples were collected from the lead vapor phase carbon vessel discharge to determine if and when a carbon change-out should be performed. Compliance with discharge criteria was monitored at the vapor treatment system stack. Vapor analyses were performed using photoacoustic analyzers and periodically by a fixed-based laboratory.

Water samples were collected from various sample ports throughout the groundwater treatment system in order to monitor the operational effectiveness of the treatment system. For example, results from water samples collected upstream of aqueous-phase carbon vessels were compared to those from downstream of the carbon vessel to determine when a carbon change-out should take place. Samples were collected routinely from the water treatment system effluent to monitor it for compliance with discharge criteria.

5.1.3.3 Postoperations confirmation soil sampling

Postoperational confirmation sampling commenced on February 24, 2015, and concluded on March 12, 2015. A total of 104 postoperational soil samples (including 4 QA/QC duplicate samples) was collected from 18 collocated soil boring locations and analyzed to evaluate both location-specific and areawide trends in TCE removal efficiency. Postoperation soil sampling was performed in accordance with procedure PAD-ENM-2300, *Collection of Soil Samples*, and the following additional steps. The high temperature soil samples were collected in stainless steel sleeves and field crews removed the cores with thermal protective gloves, then the core liners were capped and sealed with silicone tape to minimize the off-gassing of VOCs. Initially, it was anticipated that the cores would require submersion in an ice bath, but sufficient time had elapsed to allow subsurface temperatures to drop, and this step was not required. Thereafter, the samplers removed the end seals, extruded the soil core, and collected the sample following contractor sampling procedures. Refer to Figure 5.14 for the specific location of postoperations soil sample borings. Baseline/postoperational soil sampling results are presented in Section 5.2.1.

5.1.3.4 Postoperational confirmation groundwater sampling

Details regarding sampling of groundwater from Phase IIa extraction wells during operation are discussed in the Phase IIa O&M Plan, DOE/LX/07-1285&D2 (DOE 2013b). Postoperational groundwater samples were collected from the Upper RGA within and downgradient of the Phase IIa treatment zones. Groundwater samples were collected for analysis of VOCs. Postoperation groundwater sampling was performed in accordance with procedure PAD-ENM-2101, *Groundwater Sampling*, with the following additional step in accordance with the Phase IIa RAWP (DOE 2013a). The field crew routed the sample discharge stream through a coil of tubing submerged in an ice bath to lower the groundwater temperature before collecting the sample.

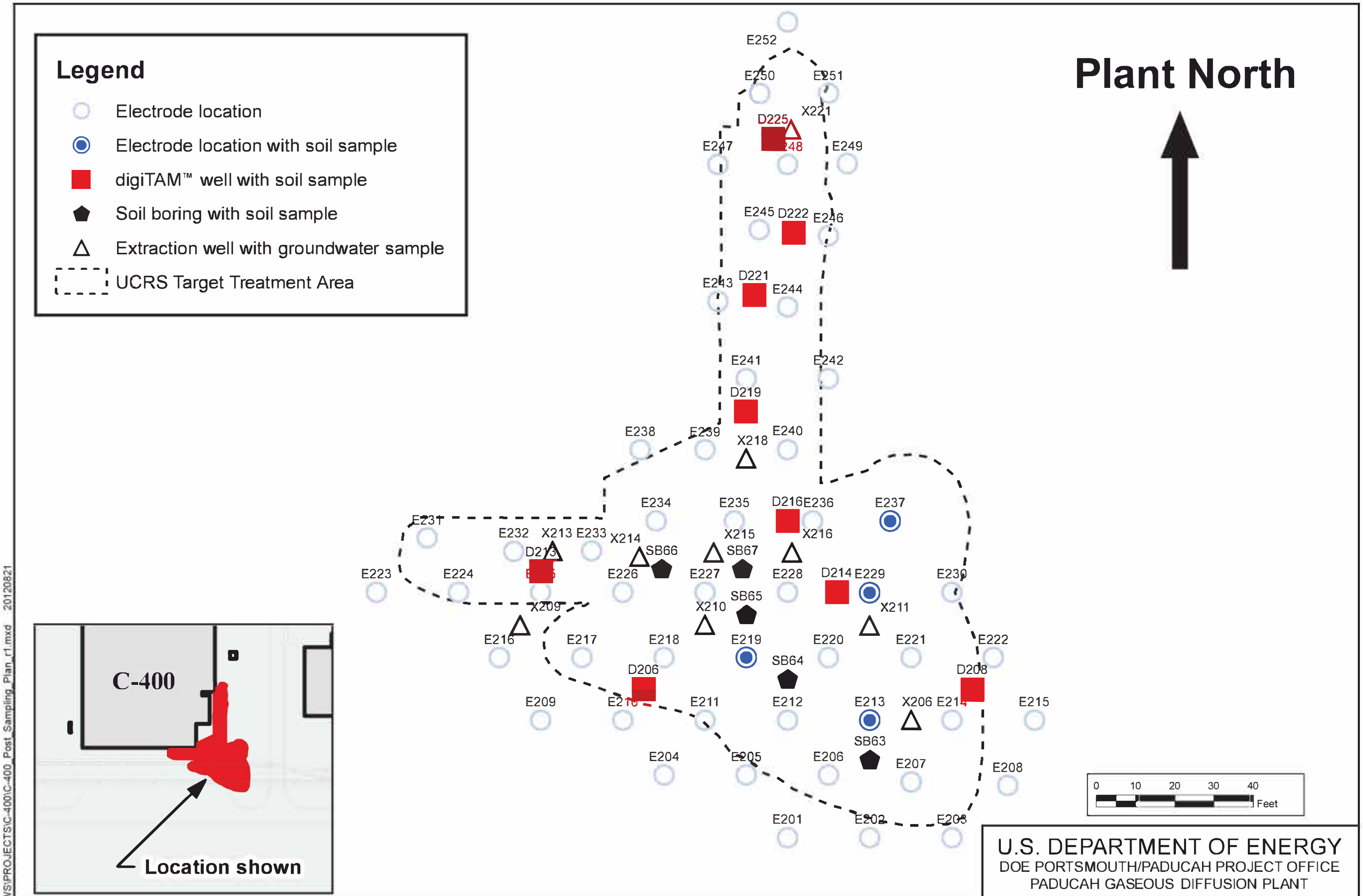

Figure 5.14. C-400 Phase IIa Postoperations Soil and Groundwater Sample Location Map

From RAWP, DOE/LX/07-1271&D2/R3 (DOE 2013a)

Ten multiphase extraction wells were selected for the collection of postoperational groundwater samples. These wells were a subset of a network of 22 multiphase extraction wells that provided for groundwater and vapor extraction during the ERH heating phase and allow collection of groundwater samples for characterization of dissolved TCE concentrations. Multiphase extraction wells X209, X213, X214, and X218 were selected as the best available locations to represent downgradient collection points. These wells are located adjacent to the downgradient limit of the targeted heating zone and were selected to best reflect groundwater in the treatment zone that was migrating downgradient. Due to the treatment zone configuration and the presence of the C-400 Cleaning Building, it was not possible to establish monitoring wells immediately downgradient of the treatment zone. Prior to the collection of postoperational groundwater samples, the pneumatic groundwater extraction pumps were raised from 68 ft bgs (base of pump) to 60 ft bgs to sample groundwater from the Upper RGA (estimated at 52–60 ft bgs).

Each of these wells was sampled three times over a four-week period, after ERH operations ceased, to establish the representative dissolved TCE and TCE breakdown products concentrations for each well for the period. Baseline/postoperational groundwater sampling results are presented in Section 5.2.1.

5.1.4 Plugging and Abandonment of Phase I and Phase IIa ERH Wells

C-400 IRA ERH Phase I and Phase IIa well plugging activities were performed concurrently with the C-400 Phase IIb Steam TS construction activities. In order to install Phase IIb TS components, previously installed ERH wells were plugged and abandoned following criteria defined in the RAWP for Phase IIa (DOE 2013a). Due to complications plugging 3/8-inch injection lines associated with electrode wells (manufacturer recommended grout mixture was too viscous to pump in 3/8-inch tubing), EPA approved a Class IV Underground Injection Control well plugging procedure modification variance to plug 12 electrode wells located within the footprint of the TS area. This variance allowed for the water injection and return lines to be cut off 2 ft bgs, plugging the ends of the lines with stainless steel plugs and filling the boring with grout to grade. The variance allowed the electrodes to be abandoned in a manner that differed from the method discussed in the RAWP (2013a). The ERH Phase I and Phase IIa well plugging activities included an additional 82 electrodes located outside of the footprint of the TS area that had similar complications plugging the injection lines. DOE demonstrated that the potential for residual shallow subsurface volatile contamination to migrate into the electrode borings 3/8 inch injection line tubing was minimal and requested a similar variance for the remaining 82 electrodes. EPA agreed to an interim path forward to abandon the remaining electrodes per DOE’s original variance request (copies of the EPA variance letters are included in Appendix C, per EPA’s request). The number of electrode borings plugged under this variance is 94: 16 in the East, 26 in the Southwest, and 52 in the Southeast treatment areas. The electrode borings plugged under this variance may leave treatment areas susceptible to vertical migration of contaminants through the subsurface. Abandonment activities were completed on June 17, 2015. A combined total of 214 ERH wells were plugged and abandoned during this project. Refer to Table 5.6 for a detailed breakdown of total number of individual well types to be plugged and abandoned. An itemized list of wells plugged and abandoned has been placed in Appendix D.

5.2 TABULAR SUMMARIES

5.2.1 Volatile Organic Contaminants Removed

Phase IIa operations were completed and consisted of the implementation of ERH in the UCRS and Upper RGA in the Southeast Treatment Area. Phase IIa operations removed approximately 1,137 gal of PVOCs (primarily TCE). The average of soil TCE concentration reductions in collocated preoperational

Table 5.6. Summary List of Phase I and IIa Well Types

ERH Well Type	Well Type Totals	East	Southwest	Southeast	Notes
Electrode Wells (E)	37	11	13	13	Configured with either 2, 3, 4, or 5 electrodes
Upper Vapor Extraction/Electrode Wells (XE)	57	5	13	39	Configured with 2, 3, 4, or 5 electrodes
Multiphase Extraction Wells (X)	31	3	6	22	Vapor and Groundwater Extraction Well
Contingency Well (CX-XXX)	3	1	2	0	Phase I only
digiTAM™ Wells (D)	47	7	11	29	Temperature Sensor Well
digiTAM™/Vacuum Monitoring Well (DV)	14	2	2	10	Temperature Sensor and Vacuum Monitoring Well
Vacuum Monitoring Well (V)	8	1	2	5	
Vapor Extraction Well (VX)	11	0	0	11	
digiPAM™ Well (DP)	6	0	6	0	Pressure Sensor Well
Totals	214	30	55	129	

versus postoperational samples collected in the Southeast Treatment Area was 99.8%. The average of groundwater TCE concentration reductions in preoperational versus postoperational samples collected in the Southeast Treatment Area was 99.3%. Refer to Table 5.7 for soil baseline/postoperation TCE results and percent reductions. Refer to Table 5.8 for groundwater baseline/postoperation TCE results and percent reductions.

Table 5.7. Southeast Treatment Area Baseline and Postoperational Soil TCE Results[1]

Location	Depth (ft bgs)	Baseline Result (μg/kg)[2]	Postoperational Result (μg/kg)[2]	Reduction (Baseline −Postoperational) (μg/kg)	Reduction[3] (%)
D206	0–10	29	1	28	96.6
D206	10–20	127	1	126	99.2
D206	20–30	1,140	1	1,139	99.9
D206	30–40	966	< 2	964	99.8
D206	40–52	8,190	4	8,186	100.0
D206	52–60	579	2	577	99.7
D208	0–10	< 6	< 1	5	83.3
D208	10–20	118	10	108	91.5
D208	20–30	674	79	595	88.3
D208	30–40	6,170	51	6,119	99.2
D208	40–52	1,080	385	695	64.4
D208	52–60	156	17	139	89.1
D213	0–10	3,950	4	3,946	99.9
D213	10–20	5,520	2	5,518	100.0
D213	20–30	13,300	1	13,299	100.0
D213	30–40	1,750	< 1	1,749	99.9
D213	40–52	9,660	23	9,637	99.8
D213	52–60	723	26	697	96.4
D214	0–10	2,790	233	2,557	91.6
D214	10–20	77,770	85	77,685	99.9
D214	20–30	31,700	9	31,691	100.0
D214	30–40	87,900	11	87,889	100.0

Table 5.7. Southeast Treatment Area Baseline and Postoperational Soil TCE Results[1] (Continued)

Location	Depth (ft bgs)	Baseline Result (µg/kg)[2]	Postoperational Result (µg/kg)[2]	Reduction (Baseline −Postoperational) (µg/kg)	Reduction[3] (%)
D214	40–52	47,000	3	46,997	100.0
D214	52–60	994,000	1	993,999	100.0
D216	0–10	73	164	-91	-124.7
D216	10–20	135	5	130	96.3
D216	20–30	1,410	1	1,409	99.9
D216	30–40	320	8	312	97.5
D216	40–50	6,220	84	6,136	98.6
D216	50–60	68,900	10,100	58,800	85.3
D219	0–10	2,450	5	2,445	99.8
D219	10–20	4,800	2	4,798	100.0
D219	20–30	874	< 95	779	89.1
D219	30–40	264	2	262	99.2
D219	40–52	15,000	4	14,996	100.0
D219	52–60	461	3	458	99.3
D221	0–10	2,110	21	2,089	99.0
D221	10–20	861	< 1	860	99.9
D221	20–30	256	1	255	99.6
D221	30–40	356	< 1	355	99.7
D221	40–52	5,420	11	5,409	99.8
D221	52–60	23,800	43	23,757	99.8
D222	0–10	1,850	15	1,835	99.2
D222	10–20	471	2	469	99.6
D222	20–30	1,510	1	1,509	99.9
D222	30–40	2,030	1	2,029	100.0
D225	0–10	13	2	11	84.6
D225	10–20	9	< 1	8	88.9
D225	20–30	3	1	2	66.7
D225	30–40	161	1	160	99.4
E213	0–10	1,100	3	1,097	99.7
E213	10–20	1,400	1	1,399	99.9
E213	20–30	790	1	789	99.9
E213	30–40	2,300	1	2,299	100.0
E213	40–52	300	1	299	99.7
E213	52–60	< 1	4	-3	-300.0
E219	0–10	1,400	85	1,315	93.9
E219	10–20	3,500	7	3,493	99.8
E219	20–30	6,400	38	6,362	99.4
E219	30–40	21,000	< 1	20,999	100.0
E219	40–52	88,000	8	87,992	100.0
E219	52–60	32,000	54	31,945	99.8
E229	0–10	140,000	7,850	132,150	94.4
E229	10–20	57,700	19	57,681	100.0
E229	20–30	45,500	1	45,499	100.0
E229	30–40	5,620,000	5	5,619,995	100.0
E229	40–52	156,000	1	155,999	100.0
E229	52–60	21,600	31	21,569	99.9
E237	0–10	21,400	< 1	21,399	100.0
E237	10–20	18,500	148	18,352	99.2
E237	20–30	11,900	2	11,898	100.0
E237	30–40	7,380	77	7,303	99.0

Table 5.7. Southeast Treatment Area Baseline and Postoperational Soil TCE Results[1] (Continued)

Location	Depth (ft bgs)	Baseline Result (μg/kg)[2]	Postoperational Result (μg/kg)[2]	Reduction (Baseline −Postoperational) (μg/kg)	Reduction[3] (%)
E237	40–52	975	5	970	99.5
E237	52–60	56,000	12	55,988	100.0
SB63	0–10	6	1	5	83.3
SB63	10–20	18	< 1	17	94.4
SB63	20–30	133	1	132	99.2
SB63	30–40	164	2	162	98.8
SB63	40–52	10	< 1	9	90.0
SB63	52–60	2,620	1	2,619	100.0
SB64	0–10	1,650	69	1,581	95.8
SB64	10–20	2,080	3	2,077	99.9
SB64	20–30	13,300	3	13,297	100.0
SB64	30–40	22,100	3	22,097	100.0
SB64	40–52	8,820	1	8,819	100.0
SB64	52–60	286,000	406	285,594	99.9
SB65	0–10	7,610	15	7,595	99.8
SB65	10–20	2,700	2	2,698	99.9
SB65	20–30	19,700	3	19,697	100.0
SB65	30–40	4,500	< 1	4,499	100.0
SB65	40–52	6,320	9	6,311	99.9
SB65	52–60	30,500	54	30,446	99.8
SB66	0–10	5,880	18	5,862	99.7
SB66	10–20	70,900	54	70,846	99.9
SB66	20–30	90,100	97	90,003	99.9
SB66	30–40	7,370	1	7,369	100.0
SB66	40–52	1,800	1	1,799	99.9
SB66	52–60	411,000	4	410,996	100.0
SB67	0–10	3,910	158	3,752	96.0
SB67	10–20	161	1	160	99.4
SB67	20–30	732	4	728	99.5
SB67	30–40	7,190	< 1	7,189	100.0
SB67	40–52	548,000	1	547,999	100.0
SB67	52–60	462,000	22	461,978	100.0
Count		104	104		
Average (μg/kg)		93,918	200	Average Reduction % = 99.8	
Minimum (μg/kg)		1	1		
Maximum (μg/kg)		5,620,000	10,100		
Count < 70 (μg/kg)		9	89		
Counts nondetectable		2	13		

[1] Only locations that have both a baseline and postoperational sample are included.
[2] Nondetectable included at stated detection level.
[3] Reduction percentage = (baseline result–postoperational result)/baseline result × 100.

Table 5.8. Phase IIa Southeast Treatment Area Baseline and Postoperations Groundwater Sampling Results

LOCATION ID	SAMPLE INTERVAL (Upper RGA)			
	Baseline TCE Results (μg/L)	Postoperations TCE Results (μg/L)[1]	Reduction (Baseline −Postoperational) (μg/L)	Reduction[2] %
X206	100,000	1,800[3]	98,200	98.2
X209	5,900	110	5,790	98.1
X210	6,500[3]	69	6,431	98.9
X211	350,000	440	349,560	99.9
X213	23,000	270	22,730	98.8
X214	75,000	37	74,963	99.9
X215	100,000	140	99,860	99.9
X216	260,000	2,500	257,500	99.0
X218	120,000	1,200	118,800	99.0
X221	37,000	520	36,480	98.6
Average (μg/L)	107,740	709	Average Reduction % = 99.3	
Minimum (μg/L)	5,900	37		
Maximum (μg/L)	350,000	2,500		
Count	0	10		

[1] Groundwater pump raised from 68 ft bgs to 60 ft bgs for collection of postoperations groundwater samples per Phase IIa RAWP.
[2] Reduction percentage = (baseline result–postoperational result)/baseline result × 100.
[3] The greater of the regular result and field duplicate result is presented.

5.2.2 Cleanup Levels Achieved

Numerical cleanup levels were not specified for this IRA; however, the criteria for ceasing operations were achieved. Both KDEP and EPA concurred on October 9, 2014 (EPA 2014; KDEP 2014), that both remedial goals, set forth in Section 2.9.3 of the ROD had been met sufficiently (DOE 2005). Project target temperatures in the subsurface were reached and maintained, and TCE recovery achieved asymptosis.

Project management routinely reviewed system performance relative to the project remedial goals and briefed the FFA parties with regular updates on system operations.

5.2.3 Material and Equipment Used

The general process flow diagram for the SVGTS system for the C-400 Phase IIa source area is provided in Figure 5.5. General unit processes shown include piping and manifold network, vapor extraction and conditioning; recovered-liquid storage, liquid treatment, and disposal; and vapor treatment. The liquid and vapor treatment systems are reviewed in detail in Section 4 of the C-400 Phase IIa RDR (DOE 2012). Figures 5.15 and 5.16 are photographs of various components associated with the SVGTS.

5.2.4 Waste Materials Generated

Waste materials generated during the complete implementation of Phase I and Phase IIa included both solid materials and liquid materials. Individual totals are provided for recovered TCE and ERH operations water. Totals for solid materials and construction related waters are recorded as cumulative volumes for both Phase I and Phase IIa on Table 4.15. All of the wastes generated during implementation of the IRA were disposed of, consistent with applicable or relevant and appropriate requirements identified in the 2005 ROD.

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Figure 5.15. C-400 Phase IIa Construction of ERH Laterals

Photograph Date - Direction: 1/16/14 - Looking West

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Figure 5.16. C-400 Phase IIa Carbon Regeneration Component

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Photograph Date - Direction: 6/26/13 - Looking West

5.3 NAMES AND ROLES OF REMEDIAL ACTION CONTRACTORS

LATA Kentucky—Primary contractor to DOE at PGDP from July 2010–July 2015. LATA Kentucky provided support for C-400 IRA Phase IIa fieldwork activities and served as the primary point of contact with DOE for on-site environmental remediation and environmental management activities, including completing the C-400 IRA Phase IIa scope of work. LATA Kentucky 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 the 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 C-400 IRA Phase IIa Project; and coordinated day-to-day activities with the subcontractors involved in the project.

McMillan-McGee Corporation—ERH subcontractor and SME on thermal technologies was responsible for oversight of drilling contractor installing ERH components and installation of power distribution systems.

Chase Environmental Group—Drilling subcontractor used for subsurface borings for ERH well installations. Chase Environmental was supported by Boart Longyear Drilling Company, Inc., for well installations requiring sonic drilling technology.

Cascade Drilling, LP—Drilling subcontractor used to plug and abandon Phase I and IIa ERH wells.

5.4 PARTICIPATION BY OTHER AGENCIES

EPA, KDEP, and DOE entered into an FFA in 1998 for the investigation and remediation of PGDP, a federal facility Superfund site (EPA 1998). DOE is the lead agency for implementation of the C-400 IRA, and EPA and KDEP provide regulatory oversight. EPA signed the 2005 ROD selecting the remedial action for C-400 IRA, and KDEP concurred (DOE 2005).

5.5 LESSONS LEARNED/PROBLEMS ENCOUNTERED

5.5.1 Freeze Protection Not Adequately Implemented and Operational Difficulties Lead to Failure of Process Piping Components

Lesson Learned Statement: Operational difficulties experienced with the newly installed steam regenerated carbon adsorption skid unit and unseasonably cold weather results in freeze damage to C-400 SVGTS. Installation of freeze protection equipment (heat trace, insulation, and jacketing) was not complete prior to freezing weather settling into the PGDP area, resulting in extensive damage to system process piping, instrument sensing lines, valves, fitting, and other items requiring replacement or repair.

Discussion: Following Phase IIa ERH initiation in late July 2013, operational difficulties were experienced with the integration of the new steam regenerated carbon adsorption skid and equipment remaining from Phase I operations. Process engineers experienced in troubleshooting and operating vapor and water treatment systems assisted in evaluation and recommended modifications to the C-400 SVGTS. During troubleshooting and modification of the C-400 SVGTS, unseasonably cold temperatures during November and December of 2013 resulted in extensive freeze damage to components of the SVGTS because the system was not operational. Modifications to the steam regenerated carbon adsorption skid and freeze damage repairs were completed, and the vapor system was restarted on January 14, 2014, with water extraction and reinjection being restarted on February 4, 2014.

Recommended Actions: Freeze protection should be installed concurrently with the installation of system components subject to freeze damage. In addition, a winterization plan should be in place and followed to protect sensitive water treatment components from freeze damage.

5.5.2 Power Loss to Heater Units Results in Freeze Damage to Groundwater Treatment System

Lesson Learned Statement: Heating capacity to the C-400 groundwater treatment system tent enclosure was lost when the main breaker for permanent power to the treatment system tripped, resulting in loss of power to the groundwater treatment system. The automatic transfer switch activated the backup diesel generator, which provides limited power to key system components of the SVGTS treatment system. Only one of the two heating units providing heat to the liquid treatment system components was supplied by the backup generator. With only one unit supplying heat to the liquid treatment system enclosure and ambient temperatures falling to single digit values, temperatures in the enclosure fell below freezing, resulting in freezing conditions and component damage.

Recommended Action: Maintain alternate backup heating options, such as, salamander heating units on-site during cold weather periods to supplement lost heating capacity.

5.5.3 Regulatory Variances Should be in Place Prior to Performing Work

Lesson Learned Statement: Future projects should ensure that any required regulatory variances are addressed during preparation of Comprehensive Environmental Response, Compensation, and Liability Act documents prior to performing work. Kentucky Division of Water (KDOW) regulation, 401 *KAR* 6:350 does not permit use of well lubricants unless a variance for the use of a specific product is granted. During field work, it was identified that no variance was on record for using a lubricant for well installation. Although the lubricant previously has been used on-site, variance requests are not to be used for the entire site; rather, they are used for each individual project, and a certified well driller is required to submit the variance request. A formal Work Pause was issued until KDOW approved the variance request. Additional upfront project planning, to identify any required variances, will reduce the chance of similar occurrences.

5.5.4 Challenges with Abandonment of ERH Electrodes Potentially Leaves Treatment Areas Susceptible to Vertical Migration of Contaminants through the Subsurface

Lessons Learned Statement: Grouting electrode housing voids through 3/8-inch diameter tubing did not prove feasible due to high viscosity of manufacturers' recommended bentonite grout weight (refer to Section 5.1.4 for more information). Future projects should consider other options to abandon electrode borings to reduce the potential for migratory pathways for contaminants.

6. FINAL INSPECTION

6.1 LIST OF INSPECTION ATTENDEES

The implemented IRA at C-400 Cleaning Building was not of a nature that can be inspected to determine the efficacy of the action. Most of the active remedial action took place in the subsurface during the heating and extraction processes. Because a visual inspection of the C-400 Cleaning Building remedial action does not provide information on the efficacy of the action in the subsurface, a final inspection was not necessary. The IRA operation was visited multiple times by the FFA parties.

6.2 DEFICIENCIES FOUND

The deficiency identified in the remedial action was the inability of ERH to achieve target temperatures in the lower portions of the RGA, reducing the contaminant quantity removed. A steam enhanced extraction treatability study demonstrated that the technology proved to be implementable technically in the hydrogeologic conditions tested (DOE 2016). The FFA parties in an August 2017 MOA integrated the Phase IIb source action to the C-400 Complex OU. As a result of the integration, the TCE principal threat source remains in the Middle and Lower RGA.

6.3 RESOLUTIONS OF DEFICIENCIES

The FFA parties signed the *Memorandum of Agreement on the C-400 Cleaning Building under the Federal Facility Agreement for the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, on August 8, 2017 (DOE 2017a). The memorandum accelerates the investigation and cleanup of the C-400 Cleaning Building area for all sources of contamination associated with and underlying the C-400 Cleaning Building and integrates the Phase IIb source area into a final action for the C-400 Complex OU.

The FFA parties also signed the *Memorandum of Agreement for Resolution of Formal Dispute Regarding the Non-concurrence by EPA and KDEP on the DOE Milestone Modification Request for Submittal of the Revised Proposed Plan for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-2407&D1 (DOE 2017b). The FFA parties agreed in the MOA that the remediation work under the 2005 C-400 Cleaning Building Interim Action ROD was complete.

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7. CERTIFICATION THE REMEDY WAS OPERATIONAL AND FUNCTIONAL[1]

7.1 STATEMENT OF WORK WAS PERFORMED WITHIN DESIRED SPECIFICATIONS

Implementation of the ERH IRA was performed consistent with remedial designs, RAWPs, and agreements made among the FFA parties. These guiding documents include the signed ROD from 2005, which included treating both the UCRS and RGA soils near the C-400 Cleaning Building for VOCs.

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

Phase I and Phase IIa of the IRA were completed successfully. As discussed in the previous section, Phase IIb will be integrated into the C-400 Complex OU, consistent with an MOA signed by the FFA parties. The following are the RAOs from the ROD for this IRA (DOE 2005):

1. Prevent exposure to contaminated groundwater by on-site industrial workers through institutional controls (e.g., excavation/penetration permit program).

2. Reduce VOC contamination (primarily TCE and its breakdown products) in UCRS soil at the C-400 Cleaning Building area to minimize the migration of these contaminants to RGA groundwater and to off-site POEs.

3. Reduce the extent and mass of the VOC source (primarily TCE and its breakdown products) in the RGA in the C-400 Cleaning Building area to reduce the migration of the VOC contamination to off-site POEs.

The RAOs, as noted, do not stipulate that numerical performance standards or cleanup targets be achieved by the implementation of the IRA. RAO 1 was met by the implementation of the LUCIP (DOE 2008c). The IRA met the second and third RAOs by reducing VOC contamination in the UCRS soils and by reducing the extent and mass of VOC in the RGA. The reductions of VOC mass achieved by Phase I and Phase IIa are detailed in Sections 4.2 and 5.2. Phase I TCE concentrations in the Southwest Treatment Area went from an average of 1,046 µg/kg to an average of 15 µg/kg; and in the east, TCE concentrations went from 584 µg/kg to 29 µg/kg—reductions of 99% and 95%, respectively. Groundwater TCE concentrations in the Southwest Treatment Area went from an average of 38,000 µg/L to an average of 315 µg/L; and in the East Treatment Area, TCE concentrations went from 123,000 µg/L to 29,000 µg/L, reductions of 99% and 76%, respectively. The estimated total quantity of TCE removed from the subsurface during the Phase I operations is 535 gal.

Phase IIa TCE soil concentrations in the Southeast Treatment Area went from an average of 93,918 µg/kg to an average of 200 µg/kg, a reduction of 99.8%. Groundwater TCE concentrations in the Southeast Treatment Area went from an average of 107,740 µg/L to an average of 709 µg/L, a reduction of 99%. The estimated total quantity of VOCs (primarily TCE) removed from the subsurface during the Phase IIa operations is 1,137 gal.

[1] The title, “Certification the Remedy is Operational and Functional,” is consistent with PGDP FFA Primary Document Outlines. The remedial action documented in the RACR is completed and no longer operational.

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8. OPERATIONS AND MAINTENANCE

8.1 HIGHLIGHTS OF OPERATIONS AND MAINTENANCE

This IRA does not have O&M requirements consistent with 40 *CFR* § 300.435(f)(1). ERH was active only during the period where the subsurface was heated to the target temperature and the vacuum system was activated and bringing volatile contaminants to the surface system for treatment. Once the vacuum system was disengaged, the contaminant removal was stopped, and the total quantity of VOC removed by the action was complete.

An activity that is required as part of O&M for this IRA is monitoring, inspecting, and reporting on land use controls (LUCs). As provided in the LUCIP (DOE 2008c), these activities should be consistent with Table 2, "Summary of LUC Monitoring Requirements for the C-400 Area at PGDP." The ROD required the incorporation of LUCs as a component of the IRA.

The LUCs were implemented under the LUCIP (DOE 2008c). The LUCIP is a portion of the Primary Document, *Remedial Design Report, Certified for Construction Design Drawings and Technical Specifications Package, for the Groundwater Operable Unit for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion Plant*, *Paducah, Kentucky*, DOE/LX/07-0005&D2/R1 (DOE 2008a).

8.2 POTENTIAL PROBLEMS OR CONCERNS

No problems or concerns have been identified with the monitoring of this IRA.

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9. SUMMARY OF PROJECT COSTS

9.1 FINAL COSTS

The cost for design and implementation of the IRA for the Groundwater OU for the VOC Contamination at the C-400 Cleaning Building was $66.8 million. This cost includes the efforts to accomplish the following work:

- Developed the RDWP,
- Performed RDSI,
- Developed the RDRs for Phase I and Phase IIa,
- Developed the RAWPs for Phase I and Phase IIa,
- Prepared the site including removal and disposal of interfering infrastructure,
- Implemented the ERH action in Phase I and Phase IIa areas,
- Procured materials, equipment, and electrical power,
- Performed pretreatment and posttreatment evaluations through soil borings and monitoring well installation,
- Managed and disposed of generated wastes,
- Performed project management, and
- Prepared this RACR.

9.2 COMPARISON OF FINAL COSTS TO ORIGINAL COST ESTIMATE

The signed ROD estimated the cost of implementing the IRA for the Groundwater OU for the VOC Contamination at the C-400 Cleaning Building was $40.7 million (DOE 2005). 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 upon implementation. The order-of-magnitude adjustments allow the actual project costs to be between $28.5 million and $61.1 million. The $66.8 M actual project costs, as shown in Section 9.1, are not within the range of the ROD estimate.

9.3 NEED FOR AND COST OF MODIFICATIONS

A modification to this IRA is not needed.

9.4 SUMMARY OF REGULATORY AGENCY OVERSIGHT COSTS

Regulatory agency oversight costs for this project are unavailable.

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Special Note: Supporting documentation associated with implementation of the IRA is included in the post-ROD administrative record (**Index**: (PD) (6PHASE-PD) Post-decision File for C-400 Cleaning Bldg) located in the DOE Paducah Environmental Information Center at the following address: **https://paducaheic.com/Search.aspx**

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APPENDIX A

AS-BUILT DRAWINGS

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APPENDIX A

AS-BUILT DRAWINGS (CD)

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APPENDIX B

PHASE I AND PHASE IIa OPERATIONAL DATA FILES

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APPENDIX B

PHASE I AND PHASE IIa OPERATIONAL DATA FILES (CDs)

(MC2 Data—CD 1 of 2)

(Operational Data—CD 2 of 2)

APPENDIX C

EPA PLUGGING VARIANCE FOR ELECTRODE WELLS

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 4
ATLANTA FEDERAL CENTER
61 FORSYTH STREET
ATLANTA, GEORGIA 30303-8960

March 19, 2015

4WD-FFB

Jennifer Woodard
United States Department of Energy
Portsmouth/Paducah Project Site Office
P.O. Box 1410
Paducah, Kentucky 42002

RE: **EPA Response to DOE's Variance Request for Well Abandonment as Specified in the** *Remedial Action Work Plan for Phase IIa of the Interim Remedial Action for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion, Plant, Paducah, Kentucky, DOE/LX/07-1271&D2/R2*

Dear Ms. Woodard,

The Environmental Protection Agency (EPA) has received the Department of Energy's (DOE) request, via the March 16, 2015 email (enclosed), for a variance to abandon 94 electrode wells as specified in the *Remedial Action Work Plan for Phase IIa of the Interim Remedial Action for the Volatile Organic Compound Contamination at the C-400 Cleaning Building at the Paducah Gaseous Diffusion, Plant, Paducah, Kentucky, DOE/LX/07-1271&D2/R2* (RAWP). Section 11.4.10 Underground Injection Control of the RAWP specifies methodology for abandoning the wells: "...The plugging and abandonment method that will be used to meet the substantive requirements for closure under 40 CFR 144.23(b)(1) is as follows. During installation, all of the electrode borings will have high temperature cement grout installed to a minimum depth of 5.0 ft bgs. This is intended to minimize the potential of infiltration of surface waters along the borehole. Electrode borings that contain screened intervals will have the 2-inch fiberglass pipe perforated down to the screened interval and then filled with grout to the surface. All electrode borings will have grout pumped through the water injection lines into the electrodes that are 53.15 ft bgs and above (53.15 ft bgs is the depth of the electrode nearest the UCRS/RGA interface, which is at approximately 55 ft bgs)....".

DOE was unable to abandon the wells as specified in the RAWP due to the high viscosity of the grout pumped into the 3/8 inch diameter water injection lines. Therefore, DOE has recommended that the 94 electrode wells be abandoned by cutting the water injection lines a minimum of 2 ft. bgs, plugging the end of each line with stainless steel screws, and filling the borings with grout to grade. EPA is concerned with abandoning the wells in this manner due to several factors, but the main issue being that the well is constructed in such a way that the annular space is not plugged/sealed from 5 feet below land surface to the upper zone of the RGA. The sand/graphite pack placed in the well has a vertical permeability that could be several orders of magnitude greater than UCRS soils. Therefore, groundwater in the UCRS has a direct conduit via the well annular space to the RGA. The preferential flow pathway creates potential issues regarding contaminated groundwater mixing between the UCRS and RGA, and also potential adverse impact to the success of Steam Enhanced Extraction (SEE) if selected as the remedy for RGA sources. These issues are discussed below.

EPA's concern regarding residual chlorinated solvent contamination present in the UCRS soils is that groundwater will continue to leach and/or migrate from the UCRS to the RGA along the annular space of the wells. Evaluation of UCRS soil sample data in the area of Electrical Resistance Heating (ERH) treatment is necessary to determine potential impact to the RGA. It is possible that treatment of the UCRS has resulted in concentrations in UCRS soils/groundwater to levels that will not impact RGA groundwater. However, if it is determined that soil/groundwater concentrations are a potential continuing source of contamination to RGA groundwater, then the wells should be abandoned in a manner that seals the annular space to protect the RGA.

Another concern is in regard to full scale implementation of SEE. Given the large number of electrode wells to be abandoned (94), the diameter of the borings (14 inches), the spacing of the borings (~20 feet), and well construction that does not include a seal in the annular space, abandoning the wells as DOE has proposed could result in the SEE steam bubble being short-circuited by the wells, preventing SEE implementation from being effective. If SEE is the selected remedy for RGA sources, SEE experts should be consulted to determine if the well construction is problematic for SEE implementation. If SEE experts recommend sealing the wells before implementation, then the work can be completed as part of SEE full scale implementation.

As discussed in the March 18, 2015 meeting, in the interest of keeping the SEE Treatability Study (TS) on schedule, EPA approves DOE's request for a variance to the electrode well abandonment process in the RAWP in order to abandon 12 electrode wells as specified in DOE's March 16, 2015 email. It is EPA's understanding from the March 18 meeting that the 12 wells are located in the C-400 area needed for equipment set-up for the SEE TS. However, until DOE/FFA parties can obtain more information from ERH vendors regarding well abandonment methodology that includes information regarding sealing the well annular space, the remaining 82 electrode wells should not be abandoned. The FFA parties discussed additional time of no longer than 2 to 3 weeks to complete research: during that time work to abandon the 12 electrode wells, and other types of ERH wells (vapor extraction, digitam, multiphase, etc) will continue. Once information is obtained from the vendors, the FFA parties will determine the best path forward for abandoning the remaining 82 electrode wells.

Until more information is provided regarding UCRS soil/groundwater concentrations and SEE project information, abandonment of the electrode wells in accordance with the proposal in the DOE March 16, 2015, variance request should be considered an interim measure to keep the SEE Treatability Study on schedule. Although EPA has granted a variance for abandoning the 12 electrode wells, the final electrode well abandonment for the 94 electrode wells must comply with 40 CFR § 144.23(b)(1) where "prior to abandoning any Class IV well, the owner or operator shall plug or otherwise close the well in a manner acceptable to the Regional Administrator."

A copy of this correspondence should be included in the Remedial Action Completion Report (as proposed in the March 16 variance request) and the C-400 Phase 2b SEE Treatability Study Report. If you have any questions or require additional information, please contact me at (404) 562-8547.

Sincerely,

Julie L. Corkran

Julie L. Corkran, Ph.D.
Senior Remedial Project Manager
Federal Facilities Branch
Superfund Division

Enclosure (as stated)

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Powers, Todd

From:	Corkran, Julie <Corkran.Julie@epa.gov>
Sent:	Tuesday, June 02, 2015 4:06 PM
To:	Dollins, Dave; brian.begley@ky.gov
Cc:	Powers Todd (TP1); Jones, Craig Steven (N8E); Jennifer Woodard; White, Jana L (FMT); April.Webb@ky.gov; Guffey, Mike (EEC); Brewer, Gaye (EEC); Jones, Craig Steven (N8E); Montgomery, Bradley J (NBM); Jay Dablow; Ronald Falta; Richards, Jon M.; Ahsanuzzaman, Noman; Davis, Eva
Subject:	RE: C-400 Treatability Study status meeting presentation - Well abandonment in Phase I and Phase IIa areas as of 06/02/2015 - interim path forward for 24 wells

Dave:

In my email correspondence of 4/30/2015, I provided the following feedback regarding an interim path forward on a subset of the Phase I and Phase IIa wells:

Interim Path forward:

- ***In Phase I and Phase IIa areas, the casings of the "XE" wells will be split and grout injected to 13 feet bgs as described in your summary memo Response to EPA for C-400 well abandonment dated 4/17/2015.***
- ***In the Phase IIa area, the electrode wells will be abandoned per DOE's original variance request dated March 16, 2015.***

As of 4/30/15, a decision has not been reached on electrode well abandonment path forward in the Phase I areas: no action should be taken by DOE to abandon those wells at this time.

The purpose of this note is to provide feedback on **the remaining 24 wells**, a universe of wells that I understand includes Electrode wells (not "XE" wells) in the Phase I areas only. To support analysis of the potential for residual shallow subsurface VOCs in the Phase I areas to migrate into the electrode wells if they are abandoned per the March 16, 2015, variance request from DOE:

- You provided follow-up information dated May 5, 2015, to help EPA and KY understand the potential for residual shallow subsurface volatile contamination to migrate into electrode shafts below 5 feet; and
- there was additional discussion and data analysis between KY (Brian) and the team while I was away from the office (May 6-12), including provision of an additional map depicting MIP locations in the Phase I East Treatment area.

Although there remains uncertainty regarding extent of VOC contamination that persists in the shallow subsurface of the Phase I areas, the information available to the Parties at this time suggests that the risk for any residual shallow subsurface VOC contamination to migrate into the vertical electrode shafts is likely to be low if these EWs are abandoned as described in the DOE March 26, 2015, variance request email. Accordingly, and in consultation with Kentucky, **the interim path forward for the remaining 24 wells is:**

- ***In the Phase I areas, the 24 remaining electrode wells will be abandoned per DOE's original variance request dated March 16, 2015.***

The path forward for this subset of wells (like the other subsets of wells we have worked through over the last 2.5 months), is characterized as interim. As noted in EPA's original well abandonment variance letter of March 19, 2015, a follow-on formal letter from EPA will include re-opener language regarding the potential need to re-visit the abandonment variance for any or all of these wells in the Phase I and Phase II a areas in the future in support of an effective cleanup.

In the near term, KY has expressed the expectation that the groundwater modeling team will be briefed on the scope of this well abandonment discussion and the groundwater team will explore whether/how the variance to electrode abandonment could impact localized hydraulic gradients in that area (as well as other subsurface infrastructure and local geology), particularly in the C-400 building source area. Please ensure that this item is added to the agenda for the GW Team Meeting scheduled for June 16-17 in Nashville.

I will be in the office tomorrow if you have any questions about this note.

Thanks,

Julie

Julie L. Corkran, Ph.D. | Senior Remedial Project Manager
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APPENDIX D

LIST OF C-400 PHASE I AND IIa ERH WELLS PLUGGED AND ABANDONED

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List of C-400 Phase I and IIa ERH Wells Plugged and Abandoned

Phase I—East Treatment Area			
Identification Number	**Wellfield**	**Designed Purpose**	**Depth (ft)**
X26*	East	Multiphase Extraction Well	68.42
X27	East	Multiphase Extraction Well	68.58
X28*	East	Multiphase Extraction Well	68.75
CX08*	East	Contingency Well	56.33

Phase I—East Treatment Area			
Identification Number	**Wellfield**	**Designed Purpose**	**Depth (ft)**
E095*	East	Electrode	63.83
E096*	East	Electrode	64.00
E097*	East	Electrode	64.67
E098	East	Electrode	64.00
E101*	East	Electrode	64.00
E102	East	Electrode	64.00
E105*	East	Electrode	65.00
E106	East	Electrode	64.00
E108	East	Electrode	65.67
E109*	East	Electrode	65.42
E110*	East	Electrode	63.33
XE099*	East	Electrode—Extraction Well	65.42
XE100	East	Electrode—Extraction Well	64.58
XE103*	East	Electrode—Extraction Well	65.08
XE104	East	Electrode—Extraction Well	65.00
XE107*	East	Electrode—Extraction Well	65.42

Phase I—East Treatment Area			
Identification Number	**Wellfield**	**Designed Purpose**	**Depth (ft)**
D41*	East	digiTAM™	70.00
D42*	East	digiTAM™	70.75
D43	East	digiTAM™	71.67
D44*	East	digiTAM™	74.33
D45*	East	digiTAM™	71.00
D46	East	digiTAM™	71.00
D47*	East	digiTAM™	70.17
V06*	East	Vacuum Monitoring	51.83
DV07A*	East	digiTAM™/Vacuum Monitoring	90.67
DV07B*	East	digiTAM™/Vacuum Monitoring	70.50

*Wells within the 11th Street footprint temporarily abandoned after Phase I.

Phase I—Southwest Treatment Area			
Identification Number	**Wellfield**	**Designed Purpose**	**Depth in Feet (as built)**
X01	Southwest	Multiphase Extraction Well	99.00
X02	Southwest	Multiphase Extraction Well	100.58
X03	Southwest	Multiphase Extraction Well	99.00
X04	Southwest	Multiphase Extraction Well	103.00
X05	Southwest	Multiphase Extraction Well	101.58
X06	Southwest	Multiphase Extraction Well	107.75
CX01	Southwest	Contingency Well	57.08
CX02	Southwest	Contingency Well	55.83

Phase I—Southwest Treatment Area			
Identification Number	**Wellfield**	**Designed Purpose**	**Depth in Feet (as built)**
E001	Southwest	Electrode	47.33
E002	Southwest	Electrode	46.50
E003	Southwest	Electrode	46.00
E004	Southwest	Electrode	45.25
E005	Southwest	Electrode	97.00
E008	Southwest	Electrode	47.25
E009	Southwest	Electrode	47.50
E014	Southwest	Electrode	47.00
E015	Southwest	Electrode	46.92
E020	Southwest	Electrode	47.67
E021	Southwest	Electrode	47.67
E025	Southwest	Electrode	47.67
E026	Southwest	Electrode	45.58
XE006	Southwest	Electrode—Extraction Well	98.00
XE007	Southwest	Electrode—Extraction Well	95.00
XE010	Southwest	Electrode—Extraction Well	96.67
XE011	Southwest	Electrode—Extraction Well	97.17
XE012	Southwest	Electrode—Extraction Well	99.67
XE013	Southwest	Electrode—Extraction Well	97.00
XE016	Southwest	Electrode—Extraction Well	92.50
XE017	Southwest	Electrode—Extraction Well	94.75
XE018	Southwest	Electrode—Extraction Well	97.00
XE019	Southwest	Electrode—Extraction Well	99.17
XE022	Southwest	Electrode—Extraction Well	47.42
XE023	Southwest	Electrode—Extraction Well	46.33
XE024	Southwest	Electrode—Extraction Well	46.75

Phase I—Southwest Treatment Area			
Identification Number	**Wellfield**	**Designed Purpose**	**Depth in Feet (as built)**
D01	Southwest	digiTAM™	101.00
D02	Southwest	digiTAM™	97.00
D03	Southwest	digiTAM™	99.50
D04	Southwest	digiTAM™	102.00
D05	Southwest	digiTAM™	100.08
D06	Southwest	digiTAM™	94.00
D07	Southwest	digiTAM™	102.00
D08	Southwest	digiTAM™	97.07
D10	Southwest	digiTAM™	95.92
D11	Southwest	digiTAM™	98.50
D12	Southwest	digiTAM™	100.17
DP01	Southwest	digiPAM™	99.50
DP02	Southwest	digiPAM™	94.00
DP11	Southwest	digiPAM™	71.00
DP12	Southwest	digiPAM™	71.50
DP13	Southwest	digiPAM™	71.17
DP14	Southwest	digiPAM™	70.25
V01	Southwest	Vacuum Monitoring	50.00
V02	Southwest	Vacuum Monitoring	50.50
DV01	Southwest	digiTAM™/Vacuum Monitoring	98.00
DV02	Southwest	digiTAM™/Vacuum Monitoring	96.00

Phase IIa—Southeast Treatment Area			
Identification Number	**Identification Number**	**Identification Number**	**Identification Number**
X201	Southeast	Multiphase Extraction Well	68.50
X202	Southeast	Multiphase Extraction Well	68.90
X203	Southeast	Multiphase Extraction Well	68.17
X204	Southeast	Multiphase Extraction Well	69.00
X205	Southeast	Multiphase Extraction Well	68.50
X206	Southeast	Multiphase Extraction Well	68.50
X207	Southeast	Multiphase Extraction Well	68.50
X208	Southeast	Multiphase Extraction Well	71.00
X209	Southeast	Multiphase Extraction Well	68.50
X210	Southeast	Multiphase Extraction Well	68.50
X211	Southeast	Multiphase Extraction Well	68.50
X212	Southeast	Multiphase Extraction Well	68.50
X213	Southeast	Multiphase Extraction Well	68.50
X214	Southeast	Multiphase Extraction Well	68.50
X215	Southeast	Multiphase Extraction Well	68.50
X216	Southeast	Multiphase Extraction Well	68.50
X217	Southeast	Multiphase Extraction Well	68.50
X218	Southeast	Multiphase Extraction Well	68.50
X219	Southeast	Multiphase Extraction Well	68.50
X220	Southeast	Multiphase Extraction Well	68.12
X221	Southeast	Multiphase Extraction Well	67.96
X222	Southeast	Multiphase Extraction Well	68.00
VX201	Southeast	Vapor Extraction Well	50.23
VX202	Southeast	Vapor Extraction Well	50.73
VX203	Southeast	Vapor Extraction Well	51.00
VX204	Southeast	Vapor Extraction Well	50.50
VX205	Southeast	Vapor Extraction Well	49.77
VX206	Southeast	Vapor Extraction Well	50.14
VX207	Southeast	Vapor Extraction Well	51.45
VX208	Southeast	Vapor Extraction Well	49.76
VX209	Southeast	Vapor Extraction Well	50.43
VX210	Southeast	Vapor Extraction Well	50.70
VX211	Southeast	Vapor Extraction Well	50.54
NOTE: Top of vapor extraction screen is 15 ft bgs.			

Phase IIa—Southeast Treatment Area			
Identification Number	Wellfield	Designed Purpose	Depth in Feet (as built)
E208	Southeast	Electrode	64.40
E209	Southeast	Electrode	65.00
E210	Southeast	Electrode	64.00
E211	Southeast	Electrode	65.00
E215	Southeast	Electrode	64.00
E216	Southeast	Electrode	64.00
E217	Southeast	Electrode	65.00
E218	Southeast	Electrode	63.75
E223	Southeast	Electrode	64.00
E237	Southeast	Electrode	63.90
E238	Southeast	Electrode	64.20
E251	Southeast	Electrode	64.25
E252	Southeast	Electrode	64.00
XE201	Southeast	Electrode—Extraction Well	63.50
XE202	Southeast	Electrode—Extraction Well	64.50
XE203	Southeast	Electrode—Extraction Well	65.00
XE204	Southeast	Electrode—Extraction Well	63.60
XE205	Southeast	Electrode—Extraction Well	63.91
XE206	Southeast	Electrode—Extraction Well	64.10
XE207	Southeast	Electrode—Extraction Well	64.50
XE212	Southeast	Electrode—Extraction Well	64.90
XE213	Southeast	Electrode—Extraction Well	65.00
XE214	Southeast	Electrode—Extraction Well	64.75
XE219	Southeast	Electrode—Extraction Well	64.00
XE220	Southeast	Electrode—Extraction Well	64.90
XE221	Southeast	Electrode—Extraction Well	64.75
XE222	Southeast	Electrode—Extraction Well	63.50
XE224	Southeast	Electrode—Extraction Well	63.95
XE225	Southeast	Electrode—Extraction Well	65.00
XE226	Southeast	Electrode—Extraction Well	65.00
XE227	Southeast	Electrode—Extraction Well	65.00
XE228	Southeast	Electrode—Extraction Well	65.00
XE229	Southeast	Electrode—Extraction Well	65.00
XE230	Southeast	Electrode—Extraction Well	64.50
XE231	Southeast	Electrode—Extraction Well	64.20
XE332	Southeast	Electrode—Extraction Well	65.00
XE233	Southeast	Electrode—Extraction Well	64.60
XE234	Southeast	Electrode—Extraction Well	64.00
XE235	Southeast	Electrode—Extraction Well	64.20
XE236	Southeast	Electrode—Extraction Well	64.25
XE239	Southeast	Electrode—Extraction Well	64.00
XE240	Southeast	Electrode—Extraction Well	64.00
XE241	Southeast	Electrode—Extraction Well	64.60
XE242	Southeast	Electrode—Extraction Well	64.55
XE243	Southeast	Electrode—Extraction Well	64.00
XE244	Southeast	Electrode—Extraction Well	64.80
XE245	Southeast	Electrode—Extraction Well	64.00
XE246	Southeast	Electrode—Extraction Well	64.00

Phase IIa—Southeast Treatment Area (Continued)			
XE247	Southeast	Electrode—Extraction Well	64.00
XE248	Southeast	Electrode—Extraction Well	64.20
XE249	Southeast	Electrode—Extraction Well	64.50
XE250	Southeast	Electrode—Extraction Well	64.25
NOTE: Top of vapor extraction screen is 6.5 ft bgs.			

Phase IIa—Southeast Treatment Area			
Identification Number	**Wellfield**	**Designed Purpose**	**Depth in Feet (as built)**
D201	Southeast	digiTAM™	70.00
D202	Southeast	digiTAM™	70.00
D203	Southeast	digiTAM™	69.50
D204	Southeast	digiTAM™	70.00
D205	Southeast	digiTAM™	70.00
D206	Southeast	digiTAM™	70.00
D207	Southeast	digiTAM™	70.00
D208	Southeast	digiTAM™	70.00
D209	Southeast	digiTAM™	70.00
D210	Southeast	digiTAM™	70.00
D211	Southeast	digiTAM™	70.00
D212	Southeast	digiTAM™	70.00
D213	Southeast	digiTAM™	70.00
D214	Southeast	digiTAM™	70.00
D215	Southeast	digiTAM™	70.00
D216	Southeast	digiTAM™	69.50
D217	Southeast	digiTAM™	70.00
D218	Southeast	digiTAM™	68.50
D219	Southeast	digiTAM™	70.00
D220	Southeast	digiTAM™	68.50
D221	Southeast	digiTAM™	70.00
D222	Southeast	digiTAM™	70.00
D223	Southeast	digiTAM™	70.00
D224	Southeast	digiTAM™	70.00
D225	Southeast	digiTAM™	70.00
D226	Southeast	digiTAM™	70.00
D227	Southeast	digiTAM™	70.00
D228	Southeast	digiTAM™	70.00
D229	Southeast	digiTAM™	70.00
DV201	Southeast	digiTAM™/Vacuum Monitoring	69.50
DV202	Southeast	digiTAM™/Vacuum Monitoring	70.00
DV203	Southeast	digiTAM™/Vacuum Monitoring	70.00
DV204	Southeast	digiTAM™/Vacuum Monitoring	70.00
DV205	Southeast	digiTAM™/Vacuum Monitoring	69.00
DV206	Southeast	digiTAM™/Vacuum Monitoring	70.00
DV207	Southeast	digiTAM™/Vacuum Monitoring	69.00
DV208	Southeast	digiTAM™/Vacuum Monitoring	70.00
DV209	Southeast	digiTAM™/Vacuum Monitoring	70.00
DV210	Southeast	digiTAM™/Vacuum Monitoring	69.50
V201	Southeast	Vacuum Monitoring	50.50
V202	Southeast	Vacuum Monitoring	50.34
V203	Southeast	Vacuum Monitoring	51.03
V204	Southeast	Vacuum Monitoring	50.58
V205	Southeast	Vacuum Monitoring	50.50

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