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PPPO-02-5207306-19C

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

TRANSMITTAL OF THE 30% REMEDIAL DESIGN REPORT FOR SWMU 211-A AND SWMU 211-B FOR VOLATILE ORGANIC COMPOUND SOURCES TO THE SOUTHWEST GROUNDWATER PLUME AT THE PADUCAH GASEOUS DIFFUSION PLANT, PADUCAH, KENTUCKY (DOE/LX/07-2435&D1)

Please find enclosed for review the *30% Remedial Design Report for SWMU 211-A and SWMU 211-B for Volatile Organic Compound Sources to the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-2435&Dl (RDR). This 30% RDR presents the conceptual design for source treatment using enhanced *in situ* bioremediation with interim land use controls (LUCs) for Solid Waste Management Unit (SWMU) 211-A and long-term monitoring with interim LUCs at SWMU 211-B. This RDR was prepared in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act and is consistent with the response action selected in the *Record of Decision for Solid Waste Management Units 1, 211-A, 211-B, and Part of 102 Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-0365&D2/R1.

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

Enclosure:
30% RDR for SWMUs 211-A and 211-B for VOC Sources to the SW Groundwater Plume, DOE/LX/07-2435&D1

Post Decision File—SWP-PD

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DOE/LX/07-2435&D1
Secondary Document

30% Remedial Design Report for SWMU 211-A and SWMU 211-B for Volatile Organic Compound Sources to the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

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Secondary Document

30% Remedial Design Report for SWMU 211-A and SWMU 211-B for Volatile Organic Compound Sources to the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

Date Issued—January 2019

U.S. DEPARTMENT OF ENERGY
Office of Environmental Management

Prepared by
FOUR RIVERS NUCLEAR PARTNERSHIP, LLC,
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Paducah Gaseous Diffusion Plant
under contract DE-EM0004895

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ACRONYMS

DNAPL	dense nonaqueous-phase liquid
DO	dissolved oxygen
DOE	U.S. Department of Energy
DPT	direct push technology
EISB	enhanced *in situ* bioremediation
EPA	U.S. Environmental Protection Agency
E/PP	excavation/penetration permit
EVO	emulsified vegetable oil
EVS-ES	Environmental Visualization Systems Expert System
FFA	Federal Facility Agreement
HU	hydrogeologic unit
KB-1®	bacterial consortium containing *Dehalococcoides ethenogenes* (DHE) microbial consortia capable of complete dechlorination of TCE to ethene
KB-1 Primer®	additive to control the pH and ORP of a water-based injectant solution
LCD	Lower Continental Deposits
LUC	land use control
MW	monitoring well
OREIS	Oak Ridge Environmental Information System
ORP	oxygen reduction potential
PGDP	Paducah Gaseous Diffusion Plant
PID	photoionization detector
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
SI	site investigation
SWMU	solid waste management unit
UCD	Upper Continental Deposits
UCRS	Upper Continental Recharge System
VOC	volatile organic compound
ZVI	zero-valent iron

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EXECUTIVE SUMMARY

This *30% Remedial Design Report for SWMU 211-A and SWMU 211-B for Volatile Organic Compound Sources to the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-2435&D1, (RDR) has been prepared for source treatment using enhanced *in situ* bioremediation with interim land use controls (LUCs) and groundwater sampling (referred to as long-term monitoring in Appendix A) for the remedial action for Solid Waste Management Unit (SWMU) 211-A and long-term monitoring with interim LUCs remedial action at SWMU 211-B. This 30% RDR was prepared in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act and is the response action selected in the *Record of Decision for Solid Waste Management Units 1, 211-A, 211-B, and Part of 102 Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-0365&D2/R1 (ROD) (DOE 2012a).

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

The ROD for SWMUs 211-A and 211-B specified that the remedy in the Upper Continental Recharge Systems (UCRS) soils to be implemented would be either enhanced *in situ* bioremediation with interim LUCs or long-term monitoring with interim LUCs. Final selection was determined by the Federal Facility Agreement (FFA) parties following performance of the final characterization that was part of the Remedial Design Support Investigation in 2012–2013; performance of additional groundwater characterization (July 2015); issuance of an Addendum to the Final Characterization Report (DOE 2016); and Letter Notification in December 2015 (DOE 2015a). The following are the final remedial actions discussed in the May 23, 2018, presentation to the FFA parties (DOE 2018).

- SWMU 211-A—Enhanced *In Situ* Bioremediation with Interim Land Use Controls and groundwater sampling (referred to long-term monitoring in Appendix A)

- SWMU 211-B—Long-Term Monitoring with Interim Land Use Controls

Interim LUCs currently are active at both SWMUs through use of the Paducah Site Excavation/Penetration Permit Program and posting of warning signs.

This 30% RDR contains conceptual information regarding design of the enhanced *in situ* bioremediation system and groundwater sampling system to be installed at SWMU 211-A and the long-term monitoring system to be installed at SWMU 211-B. Following the 30% design, additional information will be developed and included in a 60% design report that will be followed with a complete 90% remedial design for implementation. The following is information to be included in this 30% RDR.

<u>SWMU 211-A</u>

- Select bioamendment(s) and bioaugmentation materials for use.

- Design and prepare bioamendment(s) mixtures and injection protocols for use in *in situ* treatment of the saturated UCRS target soils in the selected treatment area to an average depth of approximately 61 ft.

- Design and create injection protocols for injection fracturing of the UCRS soils to allow for more uniform coverage of injected materials.

- Design and develop injection protocols of the bioaugmentation materials and the appropriate sequencing of the injection activities to allow for the best success in stimulating the SWMU 211-A subsurface (UCRS soils).

- Design and dimension an injection layout for UCRS soils that provides the best horizontal and vertical coverage of the area to be treated while minimizing the potential for surface breakouts of amendments.

- Select injection equipment and design the injection sequencing protocols.

- Design the monitoring system to be used in assessing the remediation process key parameters.

- Design the groundwater sampling (also referred to as long-term monitoring in Appendix A) network to monitor the progress of the UCRS remedial action through reduced VOC contaminant levels in the Regional Gravel Aquifer (RGA).

<u>SWMU 211-B</u>

- Design the long-term monitoring network to monitor the impact of SWMU 211-B UCRS VOC sources on RGA groundwater.

1. INTRODUCTION

This *30% Remedial Design Report for SWMU 211-A and SWMU 211-B for Volatile Organic Compound Sources to the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-2435&D1, (RDR) has been prepared for source treatment using enhanced *in situ* bioremediation with interim land use controls (LUCs) and groundwater sampling (referred to as long-term monitoring in Appendix A) remedial action for Solid Waste Management Unit (SWMU) 211-A and the long-term monitoring with interim LUCs remedial action at SWMU 211-B. The remedies planned for the SWMUs are documented in the *Record of Decision for Solid Waste Management Units 1, 211-A, 211-B, and Part of 102 Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-0365&D2 (DOE 2012a) (ROD). The ROD specified that the remedy to be implemented for SWMUs 211-A and 211-B Upper Continental Recharge System (UCRS) soils would be either enhanced *in situ* bioremediation with interim LUCs and groundwater sampling or long-term monitoring with interim LUCs. Final selection was determined by the Federal Facility Agreement (FFA) parties following performance of the final characterization that was part of the Remedial Design Support Investigation in 2012–2013; performance of additional groundwater characterization (July 2015); issuance of an Addendum to the Final Characterization Report (DOE 2016); and Letter Notification in December 2015 (DOE 2015a). An associated Remedial Action Work Plan (RAWP) also will be developed and will be used along with this 30% RDR to implement the selected remedial actions. The following are the final remedial actions discussed in a May 23, 2018, presentation to the FFA parties (DOE 2018).

- SWMU 211-A—Enhanced *In Situ* Bioremediation with Interim Land Use Controls and groundwater sampling (also referred to as long-term monitoring)

- SWMU 211-B—Long-Term Monitoring with Interim Land Use Controls

Interim LUCs currently are active at both of these SWMUs through use of the Paducah Site Excavation/Penetration Permit Program and posted warning signs.

The overall design process is described in the *Remedial Design Work Plan for Solid Waste Management Units 1, 211-A, and 211-B Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-1268&D2/R1 (DOE 2012b), and the *Addendum to the Remedial Design Work Plan for Solid Waste Management Units 1, 211-A, and 211-B Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, Sampling an Analysis Plant*, DOE/LX/07-1268&D2/R2/A1 (DOE 2015b).

The 30% remedial design information provided in this report includes the following:

- Site description
- Technology description
- Remedial action objectives (RAOs)
- Design requirements
- Process Description
- Construction requirements

PGDP is located approximately 10 miles west of Paducah, Kentucky, and 3.5 miles south of the Ohio River in the western part of McCracken County. PGDP is an inactive uranium enrichment facility owned by the U.S. Department of Energy (DOE) (Figure 1) that currently is undergoing deactivation and remediation (D&R). Bordering PGDP to the northeast, between the plant and the Ohio River, is the Tennessee Valley Authority Shawnee Fossil Plant. The remaining Paducah Site border is shared with the West Kentucky Wildlife Management Area.

Before PGDP was constructed, a munitions production facility, the Kentucky Ordnance Works, was operated at the current PGDP location and at an adjoining area southwest of the site. Munitions, including trinitrotoluene, were manufactured and stored at Kentucky Ordnance Works between 1942 and 1945. Construction of PGDP was initiated in 1951, and the plant began operation in 1952. PGDP construction was completed in 1955, and PGDP became fully operational in that year, supplying enriched uranium for commercial reactors and military defense reactors. PGDP enrichment operations ceased in 2013.

The Southwest Groundwater Plume refers to an area of groundwater contamination at the Paducah Site in the Regional Gravel Aquifer (RGA), which is south of the Northwest Groundwater Plume and west of the C-400 Cleaning Building (also known as the C-400 Building). The plume was identified during the WAG 27 Remedial Investigation in 1998 (DOE 1999). Additional work to characterize the plume was performed as part of the WAG 3 Remedial Investigation (DOE 2000a) and Data Gaps Investigation (DOE 2000b). As discussed in these reports, the primary groundwater contaminant of concern for the Southwest Groundwater Plume (hereinafter referred to as the Southwest Plume) is trichloroethene (TCE). Other contaminants found in the plume include additional VOCs, metals, and the radionuclide, technetium-99 (Tc-99).

DOE conducted a site investigation (SI) in 2004 to address the uncertainties associated with potential source areas to the Southwest Plume that remained after previous investigations. The SI further profiled the current level and distribution of VOCs in the dissolved-phase plume along the west plant boundary. Results of the SI were reported in the *Site Investigation Report for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-2180&D2/R1 (DOE 2007). The *Revised Focused Feasibility Study for Solid Waste Management Units 1, 211A, and 211B Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-0362&D2, (DOE 2011) is based on the SI (DOE 2007), and on previous investigations. An RDSI was performed in 2012 consistent with the RDWP (DOE 2012b). Additional characterization of SWMUs 211-A and 211-B was performed in 2015 before the FFA parties decided to proceed with implementing the remedial actions listed earlier in this section.

1.1 GEOLOGY AND HYDROGEOLOGY

Regional Geology. The Paducah Site is located in the Jackson Purchase Region of Western Kentucky, which represents the northern tip of the Mississippi Embayment portion of the Coastal Plain. The Jackson Purchase Region is an area of land that includes all of Kentucky west of the Tennessee River. The stratigraphic sequence in the region consists of Cretaceous, Tertiary, and Quaternary sediments unconformably overlying Paleozoic bedrock.

Mississippian carbonates form the nearest outcrop of bedrock and are exposed approximately 9 miles northwest of PGDP in southern Illinois (MMES 1992). Coastal Plain deposits unconformably overlie Mississippian carbonate bedrock and consist of the following: the Tuscaloosa Formation; sand 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.

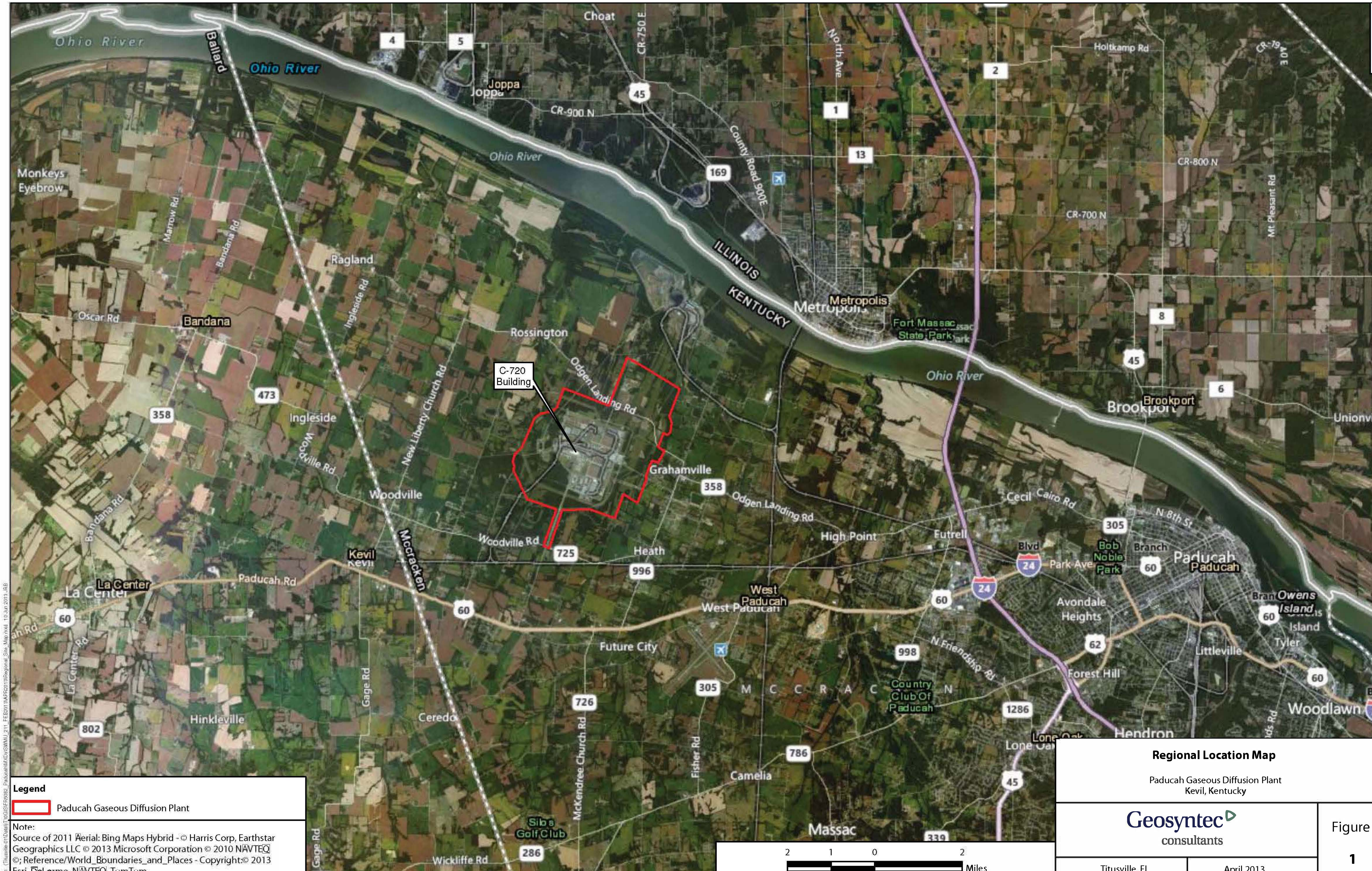

Figure 1. PGDP Site Location

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Relative to the shallow groundwater flow system in the vicinity of the Paducah Site, the Continental Deposits and the overlying loess and alluvium are of key importance. The Continental Deposits resemble a large low-gradient alluvial fan that covered much of the region and eventually buried the erosional topography. A principal geologic feature in the Paducah Site area is the Porters Creek Clay Terrace slope, a subsurface terrace that trends approximately east to west across the southern portion of the plant. The Porters Creek Clay Terrace slope represents the southern limit of erosion or scouring of the ancestral Tennessee River. Thicker sequences of Continental Deposits, as found underlying the Paducah Site, represent valley fill deposits and can be informally divided into a lower unit (gravel facies) and an upper unit (clay facies). The Lower Continental Deposits (LCD) are the gravel facies consisting of chert gravel in a matrix of poorly sorted sand and silt that rests on an erosional surface representing the beginning of the valley fill sequence. In total, the gravel units average approximately 30-ft thick, but some thicker deposits (as much as 50 ft) exist in deeper scour channels. The Upper Continental Deposits (UCD) primarily is a sequence of fine grained, clastic facies varying in thickness from 15 ft to 60 ft that consist of clayey silts with lenses of sand and occasional gravel.

The area of the Southwest Plume lies within the buried valley of the ancestral Tennessee River in which Pleistocene Continental Deposits (the fill deposits of the ancestral Tennessee River Basin) rest unconformably on Cretaceous marine sediments. Pliocene through Paleocene formations in the area of the Southwest Plume have been removed by erosion of the ancestral Tennessee River Basin. In the area of the Southwest Plume and its sources, the upper McNairy Formation consists of 60 to 70 ft of interbedded units of silt and fine sand and underlies the Continental Deposits. Total thickness of the McNairy Formation is approximately 225 ft.

The surface deposits found in the vicinity of the Paducah Site consist of loess and alluvium. Both units are composed of clayey silt or silty clay and range in color from yellowish-brown to brownish-gray or tan, making field differentiation difficult.

Regional Hydrogeology. The local groundwater flow system at the Paducah Site occurs within the sands of the Cretaceous McNairy Formation, Pliocene terrace gravels, Plio-Pleistocene lower continental gravel deposits and upper continental deposits, and Holocene alluvium (Jacobs EM Team 1997; MMES 1992). Four specific components have been identified for the groundwater flow system and are defined as follows from lowest to uppermost.

- McNairy Flow System. Formerly called the deep groundwater system, this component consists of interbedded sand, silt, and clay of the Cretaceous McNairy Formation. Sand facies account for 40% to 50% of the total formation's thickness of approximately 225 ft. Groundwater flow is predominantly horizontal and to the north.

- Terrace Gravel. This component consists of gravel deposits and later reworked sand and gravel deposits found at elevations higher than 320 ft above mean sea level (amsl) in the southern portion of the plant site; they overlie the Paleocene Porters Creek Clay and Eocene sands and are thought to be Pliocene in age. These deposits usually lack sufficient thickness and saturation to constitute an aquifer. Terrace Gravel is not present in the area of the Southwest Plume sources.

- RGA. This component consists of the Quaternary sand and gravel facies of the LCD and Holocene alluvium found adjacent to the Ohio River and is of sufficient thickness and saturation to constitute an aquifer. These deposits are commonly thicker than the Pliocene (?-age uncertain) gravel deposits, having an average thickness of 30 ft, and range up to 50 ft in thickness along an axis that trends east-west through the plant site. Prior to 1994, the RGA was the primary aquifer used as a drinking water source by nearby residents. The RGA has not been formally classified, but likely would be considered a Class II groundwater under U.S. Environmental Protection Agency (EPA) Groundwater

Classification guidance (EPA 1988). Groundwater flow is predominantly horizontal and north toward the Ohio River.

- UCRS. The UCRS consists of the surficial alluvium and UCD. Sand and gravel lithofacies appear relatively discontinuous in cross-section, but portions may be interconnected. The most prevalent sand and gravel deposits occur at an elevation of approximately 345 to 351 ft amsl; less prevalent deposits occur at elevations of 337 to 341 ft amsl. Groundwater flow predominantly is vertically downward into the RGA from the UCRS, which has a limited horizontal component in the vicinity of the Paducah Site.

The groundwater flow systems associated with the Southwest Plume and its sources are the UCRS and the RGA. In the area of the Southwest Plume, groundwater flow and contaminant migration through the upper 45 ft to 55 ft of subsurface soil (UCD) is predominantly vertically downward with little lateral spreading. This flow system is termed the UCRS. Locally, the UCRS consists of three hydrogeologic units (HUs), an upper silt interval (HU1), an intermediate horizon of sand and gravel lenses (HU2), and a lower silt and clayey silt interval (HU3). The silts and clays of the UCRS readily adsorb some contaminants, such as many metals and radionuclides, retarding the migration of these contaminants in groundwater from the source areas. Moreover, laterally extensive silt and clay horizons in the UCRS may halt the downward migration of dense nonaqueous-phase liquids (DNAPLs), but halting the movement results in potentially fostering the development of DNAPL pools in the subsurface.

Groundwater occurrence in the UCRS is primarily the result of infiltration from natural and anthropogenic recharge. Flow is predominantly downward. Groundwater in the UCRS provides recharge to the underlying RGA. The water table in the UCRS varies both spatially and seasonally due to lithologic heterogeneity and recharge factors (e.g., infiltration of focused run-off from engineered surfaces, seepage due to variations in water line integrity, rainfall and evapotranspiration), and averages approximately 17 ft in depth with a range of 2 to 50 ft.

Downward vertical hydraulic gradients generally range from 0.5 to 1 ft per ft where measured by monitoring wells (MWs) completed at different depths in the UCRS. MWs in the south-central area of PGDP (south of the C-400 Building and east of the C-720 Building) have lower water level elevations than MWs in other areas of the plant (DOE 1997). Horizontal hydraulic conductivity of the UCRS sand units has been determined from numerous slug tests in a previous investigation (CH2M HILL 1992). The measured hydraulic conductivity of the UCRS sands was 3.4E-05 cm/s at the C-720 Building (1.3E-05 inches/second). Measurements of the vertical hydraulic conductivity of the UCRS silt and clay units are not available for the C-720 Building; measurements of the vertical hydraulic conductivity of UCRS silt and clay units on-site range between 1.7E-08 and 2.1E-05 cm/s (6.7E-09 and 8.2E-06 in/s) (DOE 1997; DOE 1999). [The depth-averaged vertical hydraulic conductivity of the total UCRS interval is approximately 1E-06 cm/s (3.9E-07 in/s).]

A thick interval of late Pleistocene sand and gravel from a depth interval of 60 to 90 ft (LCD) represents the shallow, uppermost aquifer underlying most of the Paducah Site, referred to as the RGA. The RGA consists of a discontinuous upper horizon of fine to medium sand (HU4) and a lower horizon of medium to coarse sand, and gravel (HU5). The RGA is the main pathway for horizontal/lateral flow and dissolved contaminant migration off-site. Variations in hydraulic conductivity and the location of discrete sources of recharge govern the local direction and rate of groundwater flow; however, overall flow within the RGA trends north-northeast toward the Ohio River, which represents the regional hydraulic base level. The RGA typically has a high hydraulic conductivity with a range from 1.9E-02 to 2.0E+00 cm/s (7.5E-03 to 7.9E-01 in/s) as determined from aquifer testing. RGA horizontal hydraulic gradients range between 1.84E-04 and 2.98E-03 ft/ft and have average and median values of 7.81E-04 and 4.4E-04 ft/ft, respectively. Groundwater flow rates within higher hydraulic conductivity paths within the RGA average approximately 1 to 3 ft/day. Contaminant migration tends to be less retarded in the coarse sediments of the RGA due to its high groundwater flow rate and also due to the low fraction of organic carbon (0.02%).

Study Area Geology. Soil textures found in the upper 60 ft underlying the C-720 Building Area range from clays to silts to sands. Silt and clay are the predominant subsurface soil texture to a depth of 15 to 20 ft. Interbedded sand and clay units are commonly found below those depths. Clay and sandy clay/clayey sand are present near the bottom of most of the soil borings northeast of the C-720 Building (DOE 2007).

Immediately southeast of the C-720 Building, silt and clay are present to a depth of 15 ft with interbedded sand and clay layers found at deeper horizons. Medium-to-coarse-grained sand, suggestive of the contact between the UCD and LCD, was encountered near the bottom of borings in the southeast corner.

Study Area Hydrogeology. The Southwest Plume SI included soil sampling within the upper 60 ft of SWMU 211-A and 211-B. Soil samples verified the presence of the HU1, HU2, and HU3 members of the UCRS. The UCRS is comprised of alluvial deposits, which vary considerably in grain size and porosity. Based on geologic logs, the lithology reflects facies changes that range from silt to sand to clay. Some logs indicate clay is present from land surface to the top of the RGA, which confines the aquifer. Other logs indicate there are areas where only silt and sand are present from land surface to the top of the RGA, so the RGA is unconfined in these areas. The RGA receives recharge most readily in the unconfined areas. These areas may serve as pathways for contaminant migration from the UCRS to the RGA. HU3 sediments tended to be coarser grained than typical. The RGA was not encountered in all of the soil borings because many were terminated at a depth of 60 ft as planned. Although the final interval sampled 55 to 60 ft often revealed a noticeable increase in grain size and a significant increase in moisture content, consistent with trends near the top of the RGA.

1.2 TREATMENT SITE LOCATIONS

The treatment locations for implementing these remedial actions are SWMU 211-A and SWMU 211-B located in the southwestern portion of the Paducah Site. Specifically, SWMU 211-A is located near the northeast corner of the C-720 Building, while SWMU 211-B is located near the southeast corner of the C-720 Building. The two SWMU locations are shown in Figure 2 and are the focus of this 30% RDR.

A number of active and inactive utilities are located in and around both SWMUs. See Figures 3 and 4 for locations of nearby utilities associated with SWMU 211-A and SWMU 211-B, respectively. An inactive railroad is adjacent to the north side of SWMU 211-A. Because SWMU 211-A will utilize multiple closely-spaced injection borings for placement of bioamendments and bioaugmentation, it is expected that injection points will require adjustment due to utility infrastructure. The southern edge of the C-720 Building defines the northern edge of SWMU 211-B. Because the remedial action for SWMU 211-B is long-term monitoring with interim LUCs, it is expected that the remedial action will be implemented with little to no issues with infrastructure.

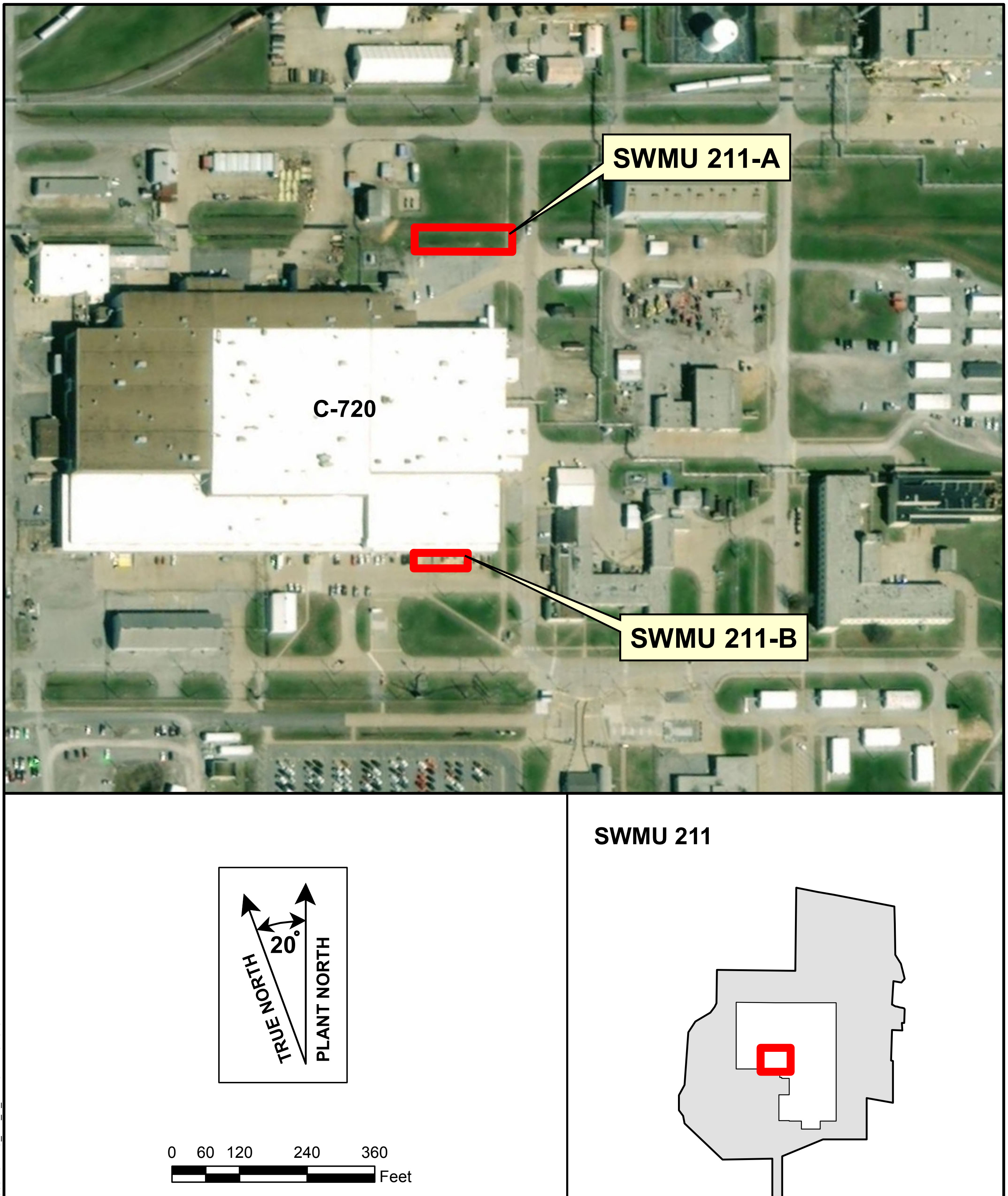

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Figure 2. SWMU 211-A and 211-B Location

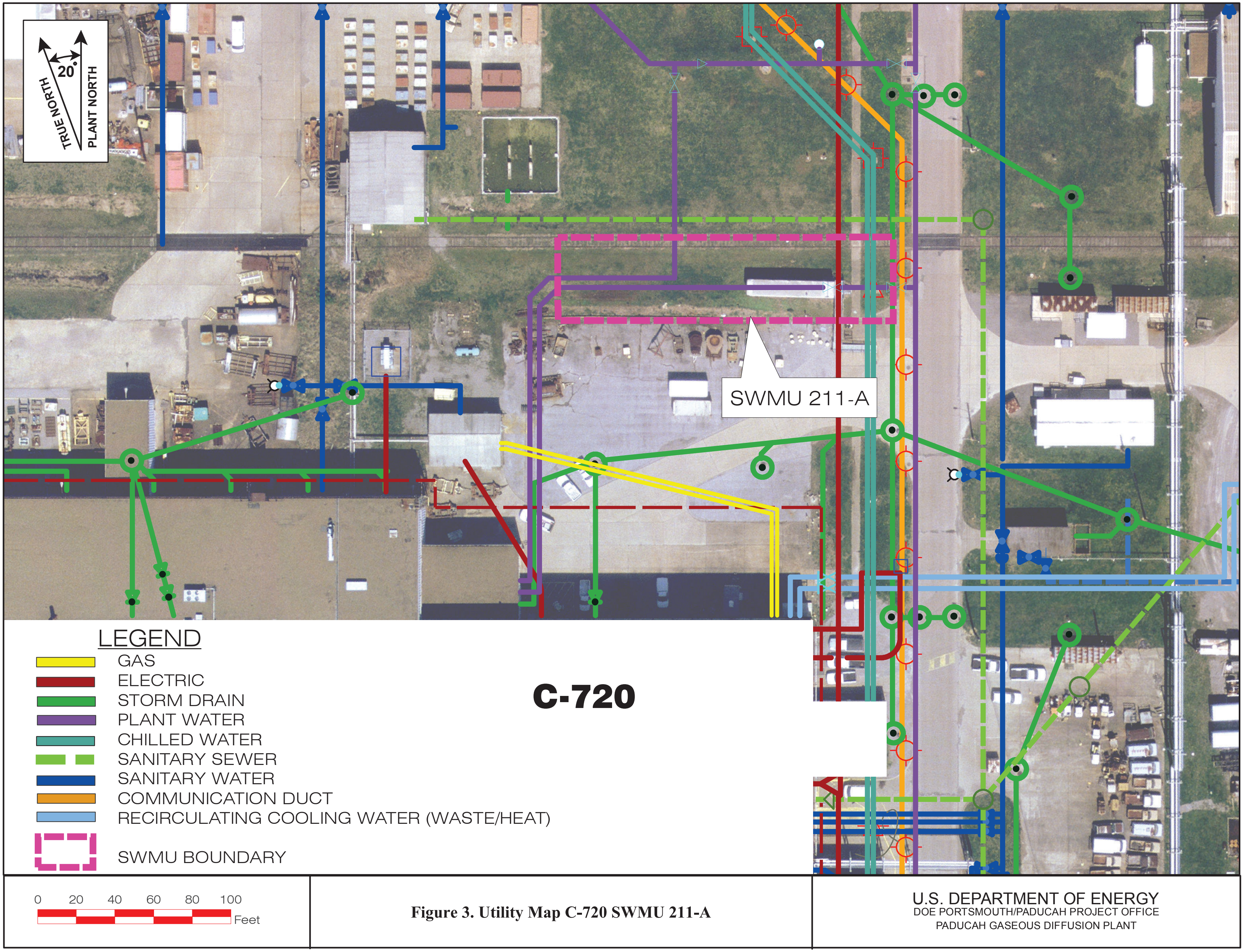

Figure 3. Utility Map C-720 SWMU 211-A

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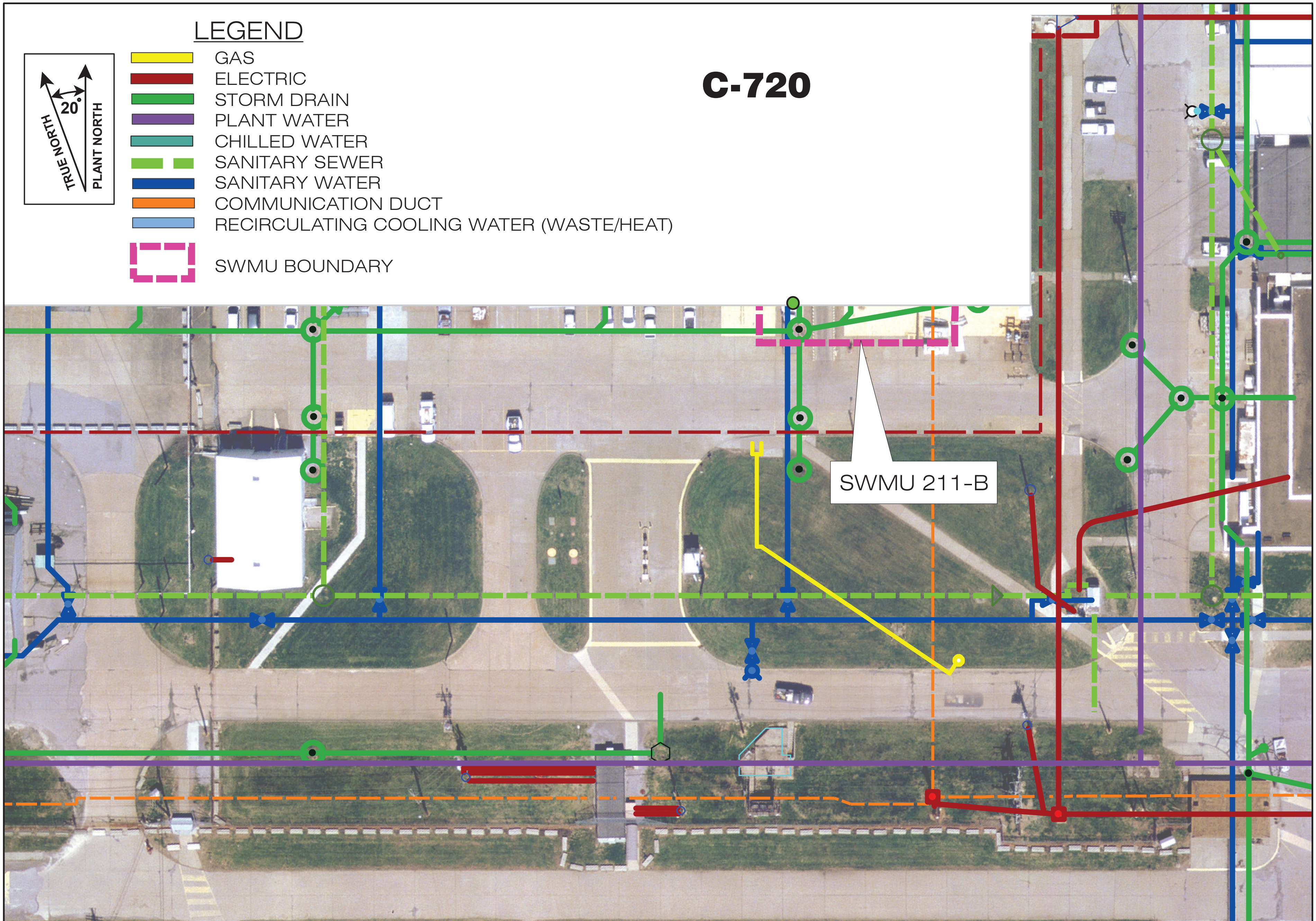

0 20 40 60 80 100 Feet

Figure 4. Utility Map C-720 SWMU 211-B

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1.3 REMEDIAL DESIGN SUPPORT INVESTIGATION (FINAL CHARACTERIZATION) AND MASS ESTIMATES

The SWMU 1 ROD included performance of an RDSI to support design and implementation of selected remedies for the UCRS soils (DOE 2012a). The RDSI for SWMU 211-A and SWMU 211-B was to provide additional data to allow the FFA parties to refine the remedy to be implemented, as discussed in the Section 1.

The RDSI for both SWMUs UCRS soils was performed during the last half of 2013. Results of that field effort are documented in the *Final Characterization Report for Solid Waste Management Units 211-A and 211-B Volatile Organic Compound Source for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-1288&D2 (DOE 2013).

As a result of discussions among the FFA parties, it was determined that additional fieldwork would be implemented beyond the RDSI. The additional fieldwork scope was associated with RGA groundwater sampling only and was documented in *Addendum to the Remedial Design Work Plan for Solid Waste Management Units 1, 211-A, and 211-B Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, Sampling and Analysis Plan*, DOE/LX/07-1268&D2/R2/A1 (DOE 2015). The results of the fieldwork were compiled and documented in the report *Addendum to the Final Characterization Report for Solid Waste Management Units 211-A and 211-B Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-1288&D2/A1/R1 (DOE 2016). Further discussion by the FFA parties resulted in DOE proposing the following remedial actions for UCRS soils for this 30% RDR.

- SWMU 211-A—Enhanced *In Situ* Bioremediation with Interim Land Use Controls (including groundwater sampling and referred to here as long-term monitoring)
- SWMU 211-B—Long-Term Monitoring with Interim Land Use Controls

This plan was documented in a presentation to the FFA parties in May 2018. A copy of the presentation is included in Appendix A (DOE 2018).

SWMU 211-A

Forty-two direct-push technology (DPT) soil boring locations (30 original, 12 contingency), shown in Figure 5, were performed on and extending north of the parking lot off the northeastern portion of the C-720 Building. Collected soil cores were screened approximately every 0.5 ft using a photoionization detector (PID) to identify intervals of maximum organic vapor response, if present. Soil samples were collected from the 0.5 ft interval of maximum PID reading for each 5-ft soil core for VOC analysis. A total of 541 soil samples were collected from the 42 soil boring locations. Figure 5 further provides the soil TCE analyses for the SWMU 211-A investigation area, overlaid on a map. For reference, soil TCE analyses greater than 75 µg/kg (the borehole average project remediation goal) are noted by yellow highlight. As shown in Figure 5, there are two distinct areas with higher contamination levels. Both areas in SWMU 211-A will be addressed in this 30% RDR and by the implemented remedial action.

As part of the final characterization of SWMU 211-A, three-dimensional contamination models for SWMU 211-A were developed using results of the soil samples from the RDSI and historical data from Oak Ridge Environmental Information System (OREIS) as inputs to the Environmental Visualization Systems Expert System (EVS-ES) software. These models estimate the extent of TCE soil impacts and the total TCE mass in soil at SWMU 211-A (DOE 2013). Model results of the extent of TCE soil

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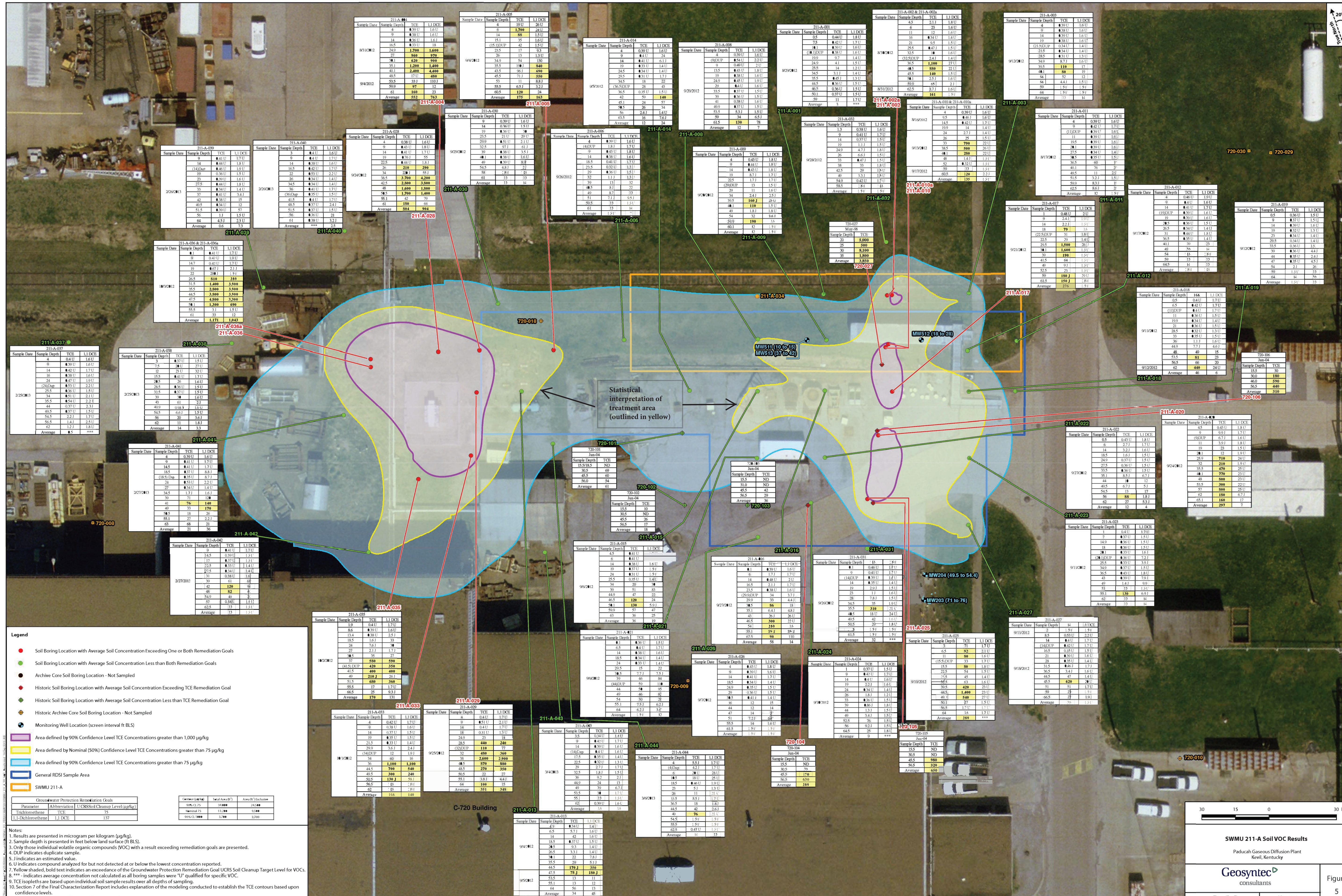

Figure 5. SWMU 211-A Soil VOC Results

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impacts for SWMU 211-A are illustrated in Figure 5 as the 50% and 90% confidence limits of 75 µg/kg soil TCE and the 90% confidence limit of 1,000 µg/kg soil TCE. The volume/mass estimates range from 0.2 gal/1 kg to 2.2 gal/12 kg for the 10% to 90% confidence level range with a volume/mass of 0.7 gal/4 kg for the 50% confidence level. A CD containing viewable three-dimensional model EVS-ES files and supporting calculations and technical details are included in *Final Characterization Report for Solid Waste Management Units 211-A and 211-B Volatile Organic Compound Source for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-1288&D2 (DOE 2013).

SWMU 211-B

Nineteen DPT soil boring locations (17 original and 2 contingency) (Figure 6) were performed on the parking lot south of the southeastern portion of the C-720 Building. Collected soil samples were screened approximately every 0.5 ft using a PID to identify intervals of maximum organic vapor response, if present. Soil samples were collected from the 0.5 ft interval of maximum PID reading for each 5-ft soil core for VOC analysis. A total of 256 soil samples was collected from the 19 soil boring locations. Figure 6 further provides the soil TCE analyses for the SWMU 211-B investigation area, overlaid on a map. For reference, soil TCE analyses greater than 75 µg/kg (the borehole average project remediation goal) are noted by yellow highlight. Figure 6 provides the lateral extent of 75 µg/kg soil TCE (90% confidence limit) and the smaller areas of 75 µg/kg soil TCE (50% confidence limit) and 1,000 µg/kg soil TCE (90% confidence limit) for comparison.

As with SWMU 211-A, three-dimensional contamination models for SWMU 211-B were developed using the results of the soil samples from the RDSI and historical data from OREIS as inputs to the EVS-ES software. These models estimate the extent of TCE soil impacts and the total TCE mass in soil at SWMU 211-B (DOE 2013). Model results of the extent of TCE soil impacts for SWMU 211-B are illustrated in Figure 6 as the 50% and 90% confidence limits of 75 µg/kg soil TCE and the 90% confidence limit of 1,000 µg/kg soil TCE. A CD containing viewable three-dimensional model EVS-ES files and supporting calculations and technical details are included in Appendices B and C of the *Final Characterization Report for Solid Waste Management Units 211-A and 211-B Volatile Organic Compound Source for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-1288&D2 (DOE 2013). The volume/mass estimates at SWMU 211-B range from 0.1 gal/0.6 kg to 0.8 gal/4 kg for the 10% to 90% confidence level range with a volume/mass of 0.3 gal/2 kg for the 50% confidence level.

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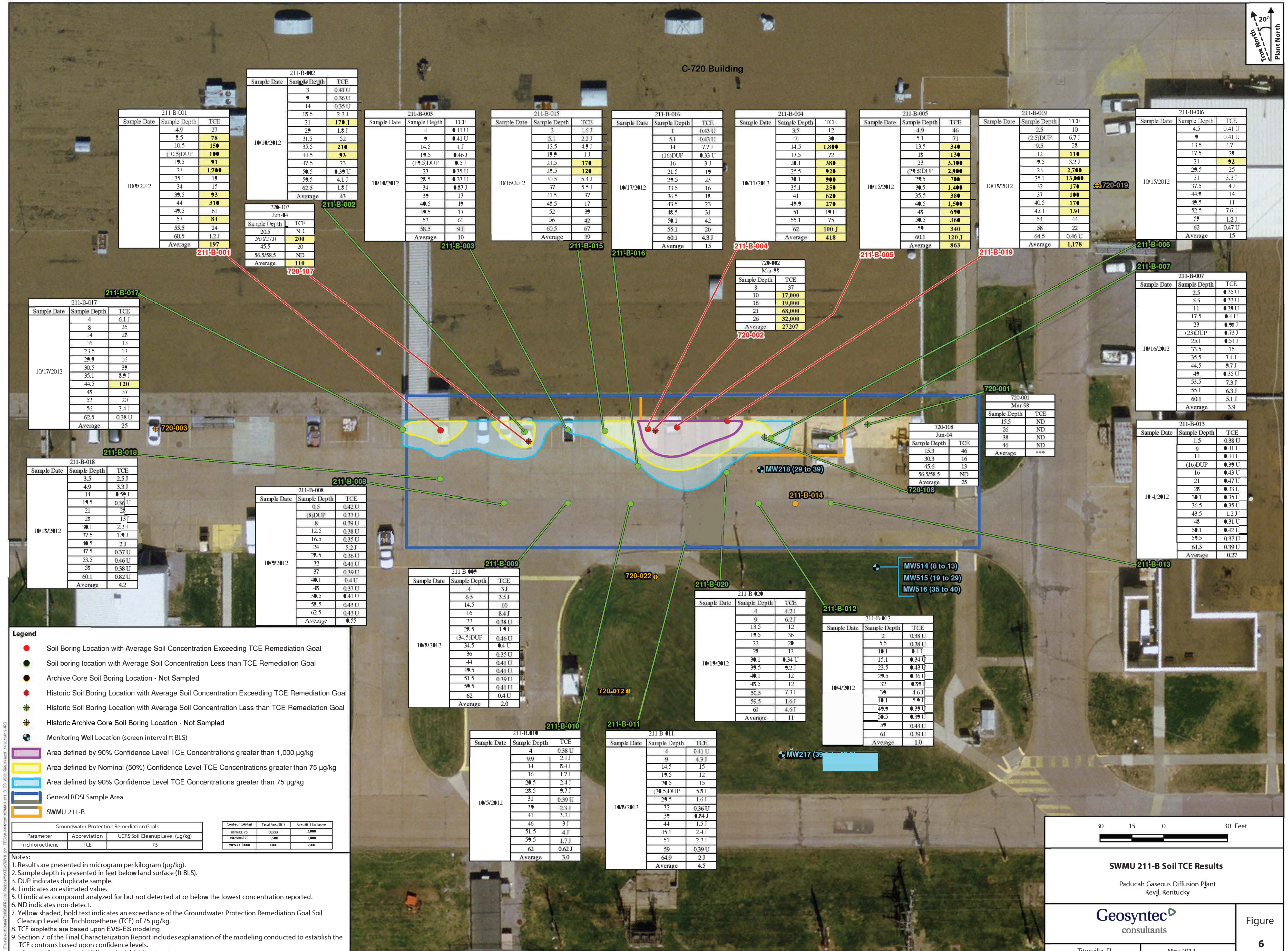

Figure 6. SWMU 211-B Soil TCE Results

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2. TREATMENT TECHNOLOGY

SWMU 211-A—Enhanced *In Situ* Bioremediation with Long-term Monitoring

The remedial action for saturated soils in the UCRS at SWMU 211-A is focused on providing *in situ* treatment for chlorinated VOC sources through application of enhanced *in situ* bioremediation (EISB) and groundwater sampling (also referred to as long-term monitoring). This section provides technical information on the bioremediation component of the selected remedy. A technical review of LUCs is unnecessary because LUCs already are implemented. Implementation of long-term monitoring for the SWMU-211-A bioremediation remedy and in the long-term is discussed in subsequent sections of this report.

Bioremediation can be defined as any process that uses either naturally-occurring (indigenous) or introduced (exogenous) microorganisms to degrade target contaminants. Many microorganisms thrive in subsurface environments; of these, bacteria are the primary microorganisms responsible for the biological transformation and/or destruction of chemicals in soil and groundwater. The goal of EISB is to provide an engineered subsurface environment that facilitates bacterial degradation of target chemicals, which are VOCs in the case of SWMU 211-A.

There are a wide variety of EISB applications that stimulate one or more degradation mechanisms. Reductive dechlorination is the degradation mechanism most frequently used for VOCs and will be used in the UCRS at SWMU 211-A. For this technology, the bacteria facilitate an aqueous reduction reaction. This reaction, called reductive dechlorination, is a process whereby electrons are transferred which results in the removal of chlorine molecules from the VOC and replacement with hydrogen molecules. The bacteria, specifically anaerobic dehalogenating bacteria, derive energy from the electron transfer by using the VOC as an electron acceptor which supports their growth and the sustainability of the reactions *in situ*.

This technology relies on the stimulation of bacteria, and often the addition of bacteria, in the subsurface so that these bacteria degrade the target chemicals in soil and groundwater. For SWMU 211-A, bacteria that derives energy from facilitating the reduction of TCE and TCE degradation products will be stimulated to degrade these compounds in the UCRS.

Reductive dechlorination of VOCs removes one chlorine molecule from the VOC, which results in sequential degradation of the parent VOC through breakdown products and eventually to an end product. The approach is common for TCE and results in dechlorination of TCE through degradation products consisting of dichloroethene (DCE)[1] and vinyl chloride, and then to ethene (i.e., ethene is fully reduced TCE with no chlorine molecules). Ethene is the primary end product of this process and is considered harmless. Figure 7 shows the pathway for reductive dechlorination of TCE; 1,1-DCE reduction, which follows a similar reductive pathway as TCE, also is shown in Figure 7.

EISB involves addition of biostimulants, such as electron donors [e.g., emulsified vegetable oil (EVO), sodium lactate, zero-valent iron (ZVI), etc.]; nutrients; pH buffers; and/or microorganisms to enhance the biodegradation processes. When these amendments are delivered into the subsurface, they support more robust biodegradation by indigenous bacteria (i.e., biostimulation) or robust biodegradation by bacteria added to the aquifer (i.e., bioaugmentation).

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[1] TCE preferentially reduces through *cis*-1,2-DCE. A small percentage of the reduction reactions, however, can follow alternative pathways such as through *trans*-1,2-DCE and 1,1-DCE. These reductive dechlorination pathways still result in ethene as the end product.

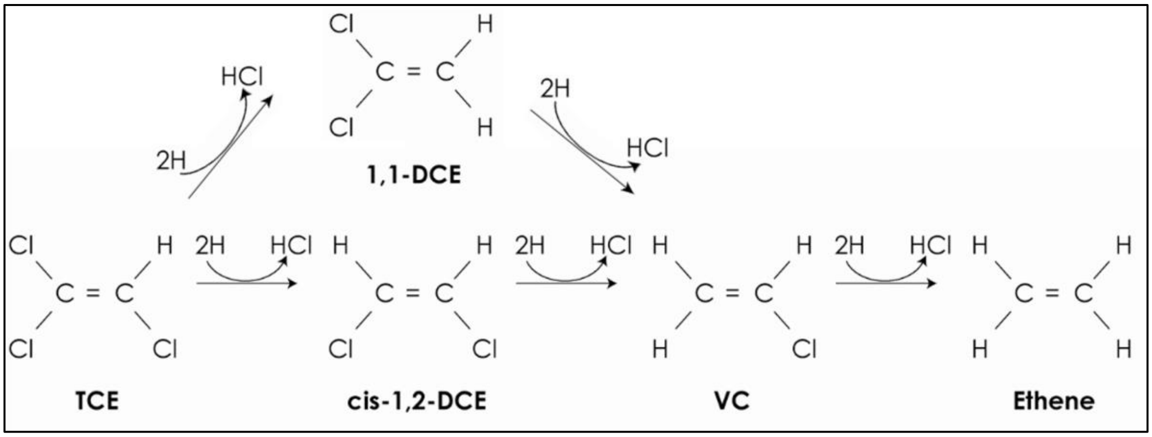


Figure 7. Pathway for Reductive Dechlorination of TCE and 1,1-DCE

The remedial action at SWMU 211-A will be focused on the UCRS; treatment of VOCs in the UCRS is anticipated to result in decreasing concentrations of TCE within the RGA underlying the UCRS. The selected remedial action technology involves injecting anaerobic water that will be amended with electron donor(s) and a consortium of dechlorinating bacteria into the UCRS at various intervals throughout the impacted zone. These materials are designed to create a suitable groundwater environment for the bacteria (i.e., anaerobic and circumneutral pH conditions) and a source of food for the bacterial consortium so that they can flourish and reductively dechlorinate TCE to ethene. The remedial action will include addition of a bacterial consortium to provide the microbes necessary for complete reduction of TCE and TCE breakdown products at SWMU 211-A because these bacteria do not exist naturally at sufficient concentrations to make the technology effective. The injections will be completed primarily using temporary wells; however, a portion of these wells may be converted to permanent wells to provide a means for adding additional amendments in the future, if necessary. Given the geology of the UCRS at SWMU 211-A, the design includes creating horizontal fractures in the UCRS within the treatment zone to facilitate delivery and distribution of amendments and bacteria into impacted areas. A more detailed description of the treatment approach and process is included in Section 4.

A second component of the SWMU 211-A remedial action is installation of a monitoring well network to monitor the progress of the EISB and provide for long-term monitoring of the VOC sources impacts to RGA groundwater. The network will consist of a series of monitoring wells that will be screened in the upper RGA. The network will provide both upgradient and downgradient groundwater samples of SWMU 211-A. Further details of the network are included in Section 4.

SWMU 211-B—Long-term Monitoring

The Final Characterization for SWMU 211-B identified that the VOC source area lies directly adjacent to the southern edge of the C-720 Building (Figure 6). RGA groundwater flow in the SWMU 211-B area is to the north, with water passing beneath the C-720 Building and toward SWMU 211-A. To provide downgradient monitoring, the MW network for SWMU 211-B will have MWs located north of the C-720 Building (immediately south/upgradient of SWMU 211-A). These wells will perform double duty by providing information as a downgradient point to SWMU 211-B and an upgradient point to SWMU 211-A. Figure 8 shows the RGA potentiometric surface in the area of the SWMUs 211-A and 211-B. Based on the potentiometric surface, the general location of the MW network that includes wells for both SWMUs 211-A and 211-B is shown in Figure 9. Refinement of MW locations will be performed further in the 60% RDR.

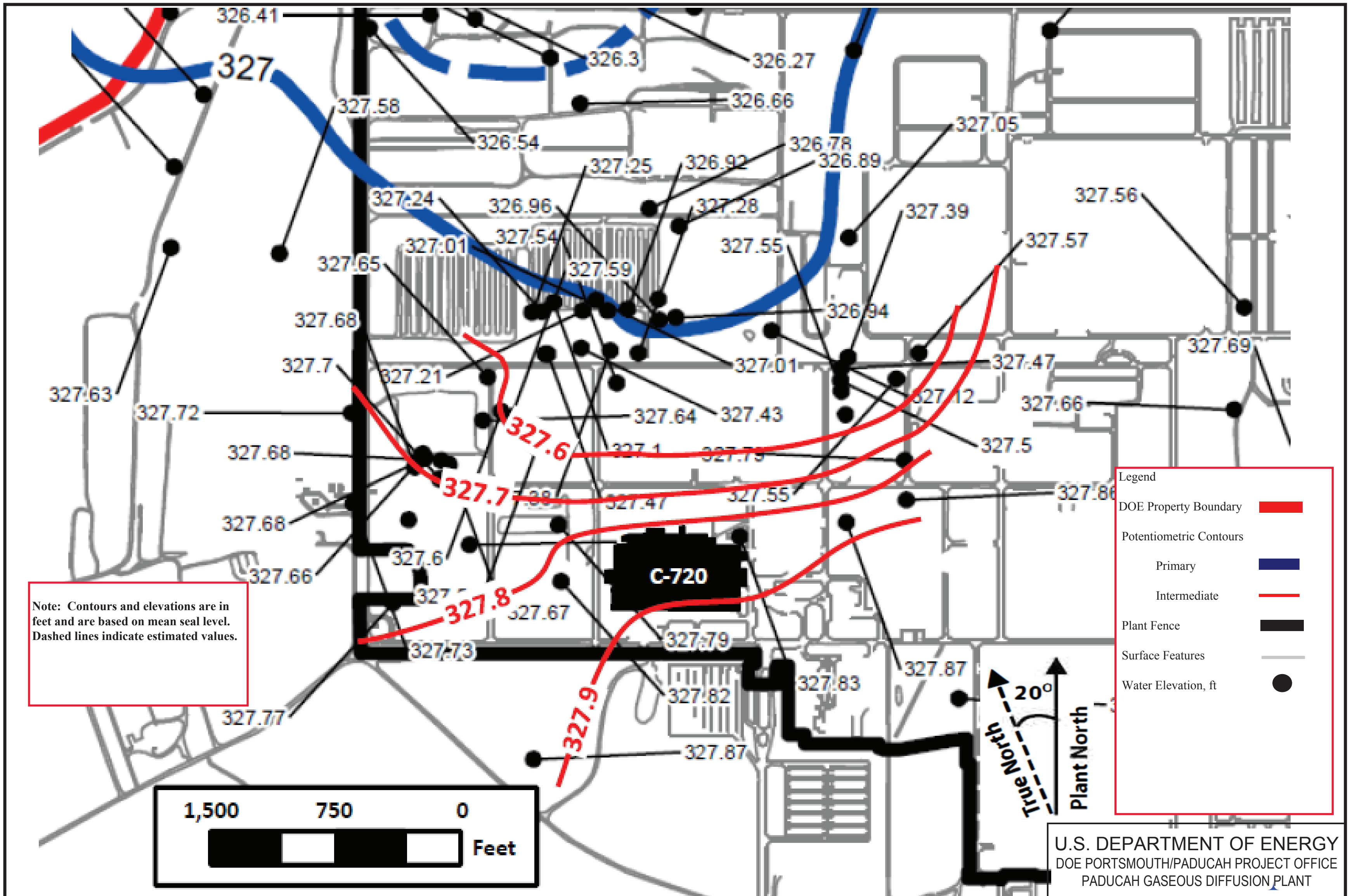


Figure 8. Regional Gravel Aquifer Potentiometric Map in C-720 Building Area (August 2016) – Adapted from Figure 10 of DOE 2017

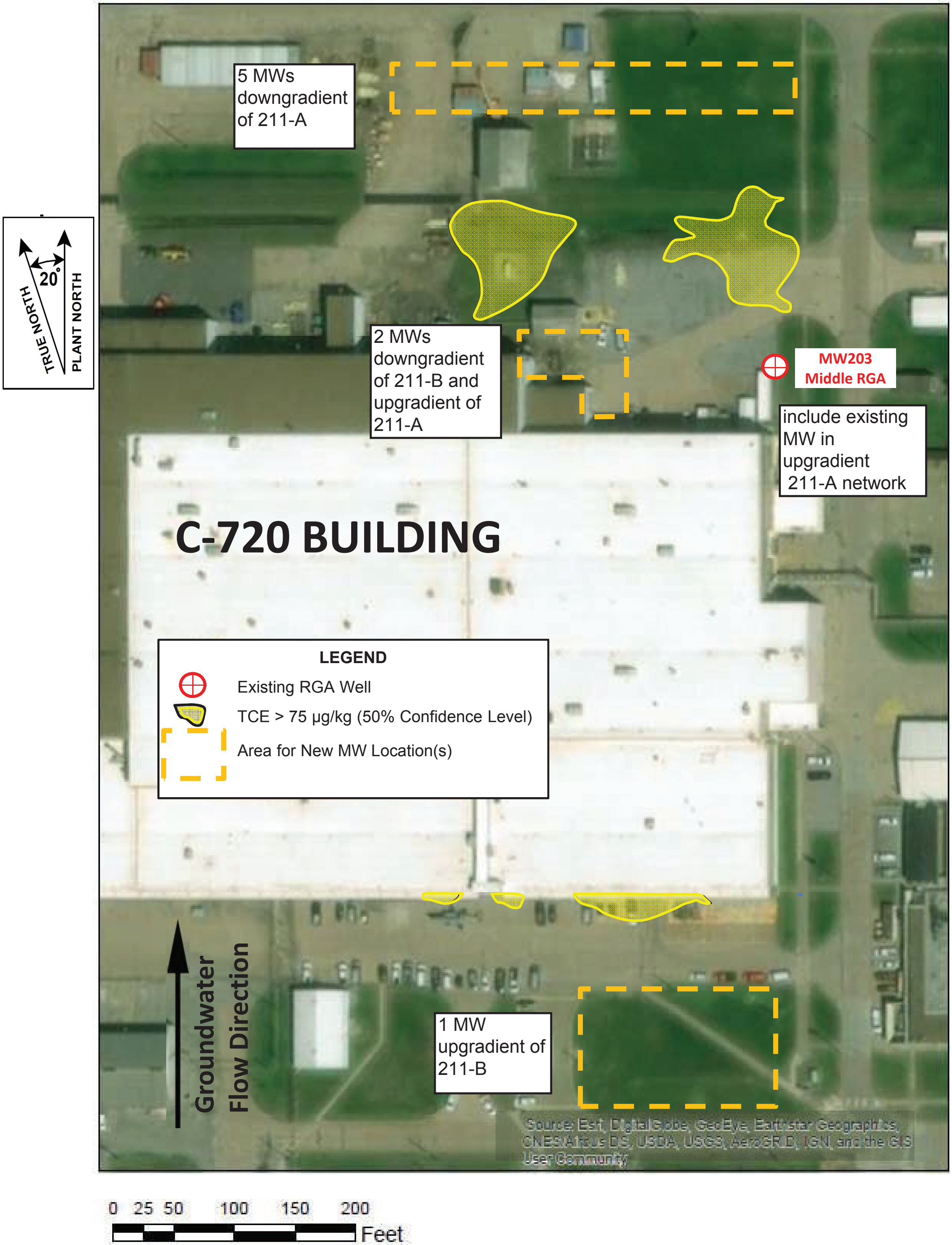


Figure 9. Conceptual Long-term Monitoring Well Locations for SWMUs 211-A and 211-B

3. TREATMENT SYSTEM OBJECTIVES

As discussed in Section 2, design information, including contaminant levels, areas of soil VOC impacts, and mass present in the treatment zone, was obtained during the RDSI and follow-on investigations. The RDSI information regarding distribution of VOCs in the treatment zone is used in this design to optimize the bioremediation treatment area layout. The following subsection provides the RAOs.

3.1 REMEDIAL ACTION OBJECTIVES

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

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

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

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

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

3.2 CONTAMINANT-SPECIFIC UCRS SOIL CLEANUP LEVEL OBJECTIVES

Consistent with the *Revised Focused Feasibility Study for Solid Waste Management Units 1, 211A, and 211B Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-0362&D2 (DOE 2011), and the *Record of Decision for Solid Waste Management Units 1, 211-A, 211-B, and Part of 102 Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-0365&D2/R1 (DOE 2012), the treatment zone for SWMU 211-A is the UCRS soils beneath the areal extent of 75 µg/kg TCE (as defined by the 50% confidence level). Figure 5 indicates the treatment area for enhanced *in situ* bioremediation of SWMU 211-A. No active treatment of SWMU 211-B currently is planned. Table 1 provides the soil protection cleanup levels for both SWMU 211-A and SWMU 211-B. Soil protection cleanup levels are VOC concentrations in subsurface soils in the treatment zone that would not result in exceedance of the maximum contaminant levels in the RGA, which would meet RAO 3 with no other controls necessary.

Table 1. UCRS Soil Cleanup Levels for SWMUs 211-A and 211-B Source Areas

Contaminant of Concern	Cleanup Levels, mg/kg
TCE	7.50E-02
1,1-DCE	1.37E-01
cis-1,2-DCE	6.19E-01
trans-1,2-DCE	5.29E+00
Vinyl chloride	6.70E-02

Note: See ROD Table 17 for the UCRS Soil Cleanup Levels for VOCs for protection of groundwater (DOE 2012a).

4. TECHNICAL DESIGN

4.1 TECHNICAL JUSTIFICATION FOR SELECTION OF REMEDIAL TECHNOLOGY

The selected remedial action technologies for SWMUs 211-A and 211-B are different. As documented in the 2012 ROD and, as determined by the FFA parties, the following are the remedial actions to be implemented.

- SWMU 211-A—Enhanced *In Situ* Bioremediation with Interim Land Use Controls and groundwater sampling (referred to as long-term monitoring in this report)

- SWMU 211-B—Long-Term Monitoring with Interim Land Use Controls

SWMU 211-A

Below are several technical factors that form the basis for selecting bioremediation for SWMU 211-A UCRS soils. A more complete description of the selection process for bioremediation, LUCs, and long-term monitoring at SWMU 211-A is provided in other documents such as DOE 2011, DOE 2012a, DOE 2013, DOE 2015, DOE 2016, and DOE 2018.

- Bioremediation is an effective treatment technology for TCE and the breakdown products of TCE reduction that are present at SWMU 211-A.

- Investigations at SWMU 211-A have shown that TCE concentrations are acceptable for bioremediation.

- Groundwater at SWMU 211-A is reducing, and some reduction of TCE already is ongoing; bioaugmentation and bioamendment delivery enhances these processes.

- Bioremediation is a destructive technology, converting TCE (and TCE breakdown products) to ethene.

SWMU 211-B

The basis for choosing long-term monitoring with interim LUCs for the UCRS soil contamination at SWMU 211-B was a consequence of soil sample results in the UCRS soils. It is estimated the mass of VOCs present to be approximately 1 gal. Additionally, water samples in the upper RGA indicate a potential presence of DNAPL in the RGA that was directly adjacent to and potentially underneath the C-720 Building. The FFA parties decided the most efficient approach for the contamination was to await the planned demolition of the C-720 Building and then to investigate the area fully and remediate as needed, including the SWMU 211-B contamination. As with SWMU 211-A, additional information concerning selection of long-term monitoring with interim LUCs is provided in other documents such as DOE 2011, DOE 2012a, DOE 2013, DOE 2015, DOE 2016, and DOE 2018.

4.2 CRITICAL PARAMETERS

Critical parameters for the remedial actions being implemented at SWMUs 211-A and 211-B are those operational parameters of the remedial system and the physical and chemical parameters of the media being treated that have the greatest impact on the ability of the technology to meet the performance goals. The following sections describe parameters that are critical to the success of the selected remedial action and the desired outcome of the technology application. Section 4.2.1 discusses critical parameters for SWMU 211-A, and Section 4.2.2 describes critical parameters for SWMU 211-B.

4.2.1 SWMU 211-A—Enhanced *In Situ* Bioremediation

Critical parameters for EISB include the physical properties of the geologic formation and the chemical properties of the groundwater system. These critical parameters relative to conditions in the UCRS at SWMU 211-A are discussed in the following sections.

Hydraulic Conductivity: The UCRS is reported to have a very low horizontal hydraulic conductivity, which hampers the efficient and even distribution of injected amendments and can decrease the radius of influence (ROI) for injection wells. The creation of higher permeability zones within the UCRS would improve the horizontal distribution of EISB amendments. Hydraulic fracturing techniques will be used to create these permeable zones. These techniques are described in more detail in Section 4.4.

Groundwater Geochemistry: TCE is treated by EISB because the bacteria facilitate an aqueous reduction reaction as described in Section 2. Because of this, EISB is effective only in saturated conditions; EISB can occur in the unsaturated zone, but only in water-filled pore spaces. The geochemistry of the groundwater environment also is critical and must be an environment that supports the survival of the bacteria and the reduction reaction. The bacteria that facilitate reductive dechlorination are strict anaerobes, so they require low dissolved oxygen (DO) concentrations in groundwater. The transformation of TCE to ethene is a reduction reaction, so a reducing environment [i.e., negative oxidation-reduction potential (ORP)] is necessary for EISB to be effective. Finally, bacterial activity is critical to the success of the technology, and this can be compromised if the pH of the aquifer is too far from neutral pH of 7 standard units. The ideal pH for EISB is between approximately 6 and 8 standard units.

The design described below accounts for geochemical factors that can affect EISB. Specifically, water from a hydrant (or other available source) will be used as a carrier fluid for amendments and bacteria. This water will be treated with a priming agent (e.g., KB-1 Primer®) that removes DO, thereby making the water more hospitable for the anaerobic bacteria. Batches of this anaerobic water will be prepared prior to blending with amendments/bacteria and injection into the injection wells. Water will be obtained from an on-site source; an evaluation of potential water sources will be completed in the 60% RDR. Sometimes a pH buffer such as sodium bicarbonate is also added to the anaerobic water prior to injection to raise pH and counteract pH decrease that can occur during EISB; however, the addition of a pH buffer is not proposed for SWMU 211-A because the hydraulic fracturing component of the design uses a sand-ZVI mixture as the proppant (see below) and the ZVI will counteract pH decreases that can occur during EISB.[2]

Injection Wells ROI and Overlap: The injection wells will be placed such that the ROI of each well overlaps, thereby attaining distribution of amendments to the impacted areas. A conceptual depiction of injection well spacing in the treatment area based on an assumed average overlap of 35% (which will be refined further in the 60% RDR) is presented in Figure 10. The spacing between injection locations may be closer in areas with higher TCE contamination to provide increased overlap of injection ROIs.

Underground utilities are present within the footprint of the treatment area; therefore, geophysical surveys will be conducted in the treatment area prior to injection activities. The geophysical surveys will assist in identifying subsurface utilities and or metal debris that may be present. Injection well locations will be adjusted as needed to avoid identified subsurface obstructions and to provide sufficient offset of utilities. Site features such as buildings and railroad tracks may also require adjustment to injection well locations. The final placement of injection wells will be selected to accommodate subsurface obstructions, aboveground site features, and other identified logistical constraints, while still retaining sufficient coverage of the treatment area with required injectants.

ZVI Dosing Concentration: A slurry mixture consisting of microscale ZVI (mZVI), water,[3] and sand will be delivered during the hydraulic fracturing process. The sand-mZVI will serve as a proppant to keep the fractures open after injection and provide a permeable zone for the injected amendments to infiltrate into the aquifer. The mZVI also will act as additional electron donor for the reductive dechlorination process and as a pH buffer as described above in "Groundwater Geochemistry." The mZVI will be injected at a similar concentration by weight at each injection point and injection interval. The sand-mZVI must be injected prior to delivery of the EISB amendments.

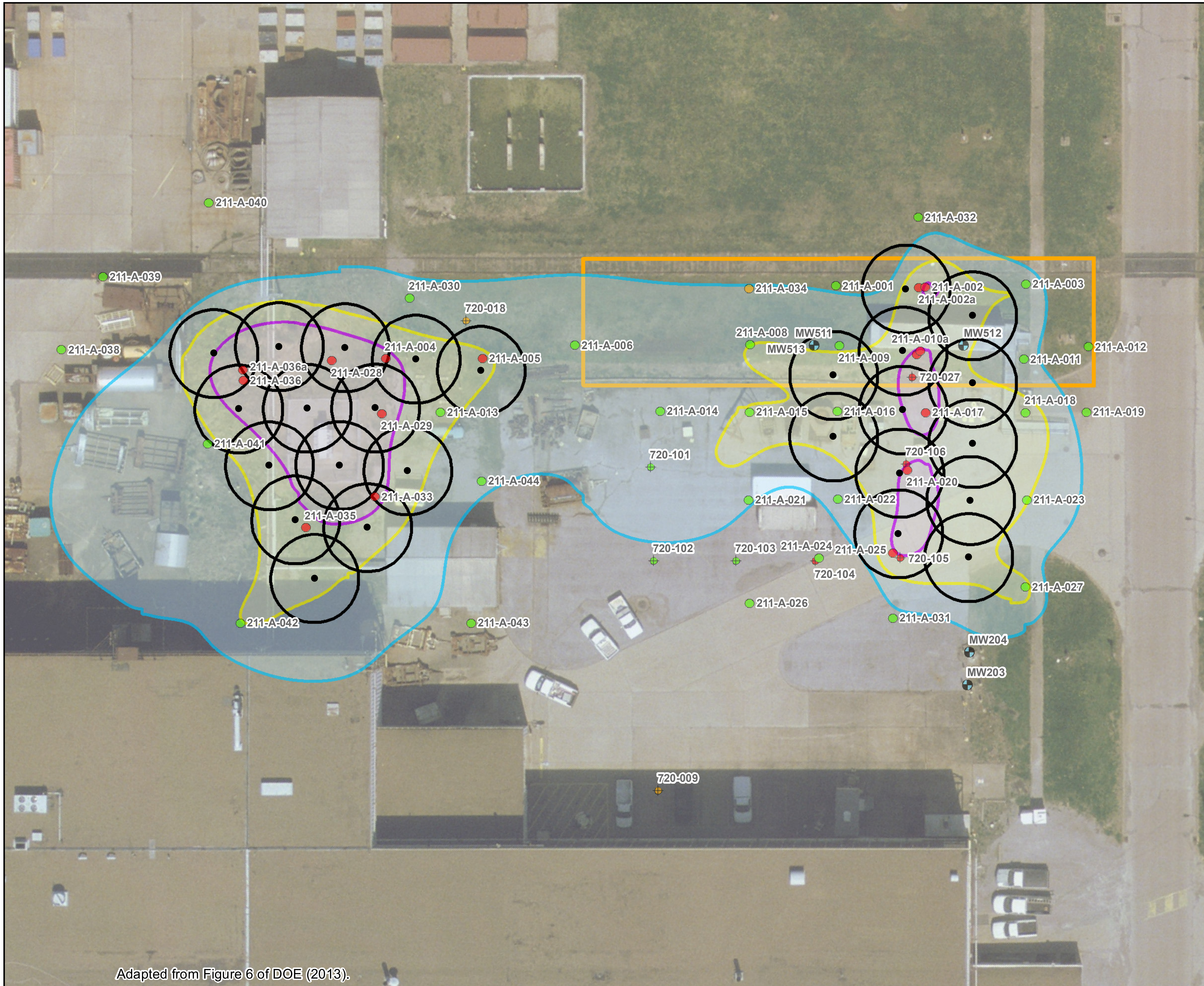
Bioremediation Amendment Dosing Concentrations: EISB amendments will consist of a commercial EVO product mixed with water (EVO solution) and KB-1® reductive dechlorination bacterial consortium. These amendments will be delivered into each injection well and will serve the following purposes:

- EVO will serve as a relatively-long term electron donor to support bacteria that facilitate reductive dechlorination of TCE to ethene. The EVO will ferment *in situ* to produce hydrogen and the hydrogen will provide the electron donor for the bacteria during the reduction of TCE and breakdown products. Commercial EVO products are an aqueous emulsion of vegetable oil that provide a complex mixture of long-chain organic carbon compounds which take longer to ferment compared to other electron donors such as sodium lactate. The slower fermentation of EVO allows it to support EISB for a longer period (e.g., 1 to 3 years). Once in the subsurface, EVO droplets forming the emulsion "break" and the hydrophobic vegetable oil coats the surfaces of the geologic matrix. This allows the oil to remain and ferment where emplaced and aids in its effectiveness.

- Water that has been conditioned to remove most of the DO will be used as a carrier fluid to deliver the EVO product and bacteria into the aquifer away from injection wells. The mixture of EVO product and anaerobic water is referred to as the EVO solution.

[2] Fermentation of electron donor added for EISB produces hydrogen that can result in decreasing groundwater pH. ZVI in groundwater releases hydrogen, which is quickly consumed, and hydroxide, which results in a pH increase. Using ZVI with EISB is an effective means for pH control. In addition to supporting EISB, ZVI abiotically reduces TCE to ethene.

[3] Deoxygenated water is not required for fracturing because the water will become anaerobic very quickly and reducing when mixed with mZVI.



20°
True North
Plant North

Legend

- Injection Point
- 15' Injection Point Radius
- Soil Boring Location with Average Soil Concentration Exceeding One or Both Remediation Goals
- Soil Boring Location with Average Soil Concentration Less than Both Remediation Goals
- Archive Core Soil Boring Location - Not Sampled
- Historic Soil Boring Location with Average Soil Concentration Exceeding TCE Remediation Goal
- Historic Soil Boring Location with Average Soil Concentration Less than TCE Remediation Goal
- Historic Archive Core Soil Boring Location - Not Sampled
- Monitoring Well Location (screen interval ft BLS)
- Area defined by 90% Confidence Level TCE Concentrations greater than 1,000 µg/kg
- Area defined by Nominal (50%) Confidence Level TCE Concentrations greater than 75 µg/kg
- Area defined by 90% Confidence Level TCE Concentrations greater than 75 µg/kg
- SWMU 211-A

Notes:
1. TCE isopleths are based upon individual soil sample results over all depths of sampling.
2. Section 7 of the Final Characterization Report includes explanation of the modeling conducted to establish the TCE contours based upon confidence levels.
3. Source of 2009 Aerial: Williams Aerial & Mapping, Inc.

30 15 0 30 Feet

SWMU 211-A Injection Layout

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September 2018

Figure 10

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Figure 10. SWMU 211-A Injection Layout

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- KB-1® or approved equivalent is a bacterial consortium consisting of the species of *Dehalococcoides ethenogenes* (DHE), necessary for the full dechlorination of TCE, plus supporting bacteria such as fermenting bacteria, methanogens, sulfate reducers, etc. DHE are a family of anaerobic bacteria that derives energy by facilitating reductive dechlorination of chlorinated ethenes (like TCE). While there are a number of dehalogenating bacteria that can dechlorinate TCE, only DHE bacteria can complete the degradation process to ethene. The KB-1® or approved equivalent consortium is a mixture of bacteria that includes all necessary species to support complete reduction of TCE to ethene.

The volume of EVO solution delivered into each well will be selected to provide a design percentage of EVO relative to the pore volume of the aquifer; each injection well is expected to receive approximately the same volume of EVO solution. The KB-1® or approved equivalent will be delivered into each of the injection intervals during the EVO solution delivery. Following injection of the microbial consortium, a final injection of EVO solution followed by anaerobic water will be completed to surround the microbial consortium with an anaerobic groundwater environment that contains EVO. Field-based decisions informed by data (to be specified in the 60% design phase) collected during the injection activities may be used to adjust the EVO solution and KB-1® or approved equivalent dosing concentrations. In the event an injection interval does not accept the target amendment volume, this material may be injected at an alternate location or depth interval, to be determined based on field conditions.

Impact to Surrounding Structures, Utilities, and Operations: It must be possible to implement the technology within the treatment area with limited interference to site personnel and facility operations. Based on current site conditions, use, and infrastructure, most of the target injection area appears free of obstructions and accessible for injection activities. Existing features that prevent injection (e.g., equipment within buildings) will be accommodated by adjusting injection well locations around these areas to the extent feasible. All planned injection locations are exterior to buildings.

Contaminants of Concern: The technology is designed specifically for the treatment of TCE, TCE breakdown products, and 1,1-DCE. Other contaminants, if present, in the soil and groundwater may not be treated by the technology described herein.

4.2.2 SWMU 211-B—Long-Term Monitoring

Monitoring Well Placement—The RDSI and follow-up sampling determined that the contamination present in the UCRS soils at SWMU 211-B is located directly adjacent to the southern wall of the C-720 Building and that TCE source contaminant levels are present in the upper RGA. As indicated in Section 2 and Figure 8, the groundwater flow in the area of SWMU 211-B is generally horizontal and toward plant north, which would transport dissolved contamination reaching the RGA beneath the building. The area beneath the C-720 Building is not planned to be investigated until the Soils and Slabs Operable Unit, which will assist in determining further the locations and levels of contamination adjacent to the northern edge of SWMU 211-B. As discussed in Section 2, the downgradient MWs for 211-B will be located north of the C-720 Building. Locating the downgradient wells here provides key information:

- Changes in contaminant levels occurring at SWMU 211-B,
- Changes in contaminant levels occurring in potential sources located beneath the building, and
- Upgradient contaminant levels for SWMU 211-A.

The specific location of both the upgradient and downgradient SWMU 211-B MWs will be developed in the 60% RDR.

4.3 DESIGN REQUIREMENTS

The general input requirements for the implementation of the planned remedial actions are discussed in the following sections.

4.3.1 SWMU 211-A—Enhanced *In Situ* Bioremediation

Steps to implement EISB are described in subsequent sections of this design. The items below are factors considered when developing the EISB design for SWMU 211-A.

Parameters Affecting Design

The factors below have been considered when developing the design approach described in this document.

- Site location and general site logistics that may restrict locations for invasive work or equipment access:
  - Buildings, railroad tracks, and other aboveground structures;
  - Subsurface utilities and other subsurface obstructions;
  - Access for drilling and injection equipment; and
  - Site activity.

- Availability of water
  - Up to 300,000 gal of site water is anticipated to be needed.

- Shape and depth of the treatment area
  - The treatment footprint is assumed to be approximately 13,200 ft^2 and consists of two distinct areas interpreted to contain greater than 75 µg/kg TCE from soil borings.

  - The treatment depth interval is assumed to be approximately 40 ft in thickness, generally extending from 25 ft to 65 ft bgs, which corresponds to an elevation of 350 ft to 310 ft amsl.

- Site geology and hydrogeology
  - Depth to groundwater, hydraulic conductivity of the UCRS (known to be relatively low), groundwater flow velocity and direction, and achievable injection rate for existing wells at the site.

  - Concentrations of TCE and TCE breakdown products in wells that are screened within the UCRS and RGA.

- Contaminant-specific remediation goals defined in the FFS (DOE 2011) and ROD (DOE 2012a) are listed in Table 1.

- Compliance with applicable or relevant and appropriate requirements (DOE 2012a).

Implementation Approach Assumed for Design

The site-specific conditions listed above direct how EISB would be implemented at SWMU 211-A. The resulting design assumes the implementation approach described below.

- Hydraulic fracturing injections
  - — Hydraulic fracturing using DPT jet injection to deliver sand-mZVI as proppants will be utilized to create more permeable zones within the UCRS.
  - — Injection of mZVI during the hydraulic fracturing process also will serve as an electron donor source and will be injected at the quantity needed to reach between 0.5 and 1% percent by volume concentration.
- Injection of the EISB amendments
  - — Anaerobic water will be prepared by adding KB-1 Primer® or approved equivalent to water obtained from an on-site source.
  - — EVO will be injected as the primary electron donor for the bioremediation process.
  - — EVO will be mixed with anaerobic water (EVO solution) and injected at the quantity needed to reach up to 2% dosage of EVO in the aquifer.
  - — EVO solution will be injected into each injection well.
  - — KB-1® or approved equivalent microbial consortium will be injected into each injection well. Between 2 and 10 liters of KB-1® or approved equivalent is anticipated to be needed per injection well.
  - — Injection pressures and rates will be kept to the lowest effective levels required to distribute the EISB amendments through the UCRS.
  - — Injection pressures within these zones are anticipated preliminarily to range between 15 lb per square inch (psi) and 40 psi.
  - — Injection rates should exceed 1 gal per minute (gpm) per injection point to make the implementation effective.

SWMU 211-A will have a long-term monitoring well system to monitor the long-term effects of implementing enhanced *in situ* bioremediation on RGA groundwater contamination to support RAO 3 and to support development of five-year review reports. The MWs that make up the network that support SWMU 211-A will be composed of eight MWs (Figure 9). Seven new wells are planned, and the project will utilize one existing network well, MW203. The two new upgradient RGA wells also will provide downgradient contaminant data in support of the MW network for SWMU 211-B, which is discussed in the next section. The specific details for the well locations, completion depths, construction details, and planned sampling frequency will be developed further in the 60% RDR.

4.3.2 SWMU 211-B—Long-Term Monitoring

The SWMU 211-B UCRS soils remedial action is long-term monitoring. The purpose of the system will be to provide data to identify if contaminant conditions are changing and to support development of the Paducah Site Five-Year Review reports. The MWs that make up the network supporting SWMU 211-B will be composed of three MWs (Figure 9). The two downgradient RGA wells also will provide upgradient contaminant data to support the MW network for SWMU 211-A, which is discussed in the previous section. The specific details for the well locations, completion depths, construction details, and planned sampling frequency will be developed further in the 60% RDR.

4.4 PROCESS DESCRIPTION FOR ENHANCED *IN SITU* BIOREMEDIATION

The effectiveness of EISB can be limited by poor distribution of amendments, which can occur in low-permeability formations when using conventional technologies. Due to this site-specific challenge, DPT jet injection was selected to enhance the permeability of the UCRS and facilitate the effective delivery of EISB amendments to the subsurface at SWMU 211-A. DPT jet injection is an amendment delivery process that combines high pressure jetting (10,000 psi) and controlled hydraulic fracturing for delivery of amendments into low-permeability geologic matrices. The addition of sand-mZVI in the injection slurry creates zones of enhanced permeability to facilitate subsequent injection of amendments. As mentioned above, the inclusion of sand-mZVI also will support EISB. The EISB remedy for SWMU 211-A will be performed using the following outlined process.

1. Create horizontal fractures filled with sand-mZVI using DPT jet injection methods.
2. Install injection wells at each DPT jet injection location using methods that hydraulically connect the well screens with the fractures.
3. Inject EISB amendments through injection wells and/or borings.
4. Monitor to measure the performance of EISB.

4.4.1 Equipment Summary

The general process for performing the *in situ* bioremediation injections in the UCRS includes installation of sand-mZVI filled fractures using DPT jet injection, installation of injection wells that have screens in contact with the fractures, and injection of EVO solution and KB-1® or approved equivalent into the subsurface through the injection wells. A general description of the equipment used for these stages is provided in these subsections and will be refined further in the 60% RDR.

4.4.1.1 DPT jet injection equipment

The DPT jet injection process relies upon three categories of equipment: (1) the DPT drilling platform with custom injection tooling; (2) the high-pressure water system; and (3) the slurry mixing and injection system. An appropriately sized Geoprobe® or approved equivalent will be used to advance the injection tooling to the target depth for a given fracture. The high-pressure water system is used to pressurize water up to 10,000 psi (690 bar). A water purge pump may be operated in parallel with the high-pressure water system. The purge pump delivers continuous water flow to the injection nozzles to prevent clogging of the injection tooling during DPT advancement. The slurry mixing and injection system will include equipment needed to stage and meter granular solids and liquids, a mixer to prepare the slurry for injection, and a slurry injection pump capable of injecting a highly viscous slurry at the design pressures (e.g., a progressing cavity positive displacement pump).

DPT jet injection method or approved equivalent technique and associated tooling to fracture low-permeability formations and deliver proppants such as sand-mZVI. FRx, Inc., (FRx) developed a proprietary method of jet injection along with custom tooling to fracture low-permeability soils. This injection method has been used successfully to implement EISB in low-permeability formations at other sites and is considered suitable for EISB at this site because it will promote successful delivery of amendments at SWMU 211-A and provide mZVI *in situ*, which is beneficial for EISB.

Injection wells will be installed using DPT drilling methods after completing DPT jet injection at each location as described in Section 4.4.2.

4.4.1.2 EISB injection equipment

EISB injection amendments will be gravity-fed and/or pumped from a stock tank, where the EVO solution is prepared and then introduced into injection wells. Injections will begin by plumbing the stock tank to the well heads through an injection manifold equipped with flow meters and pressure gauges for each well head connection. Initially, the injection fluid will be allowed to flow directly into the injection wells under gravity. If flowrates are below one gpm, then a transfer pump may be connected inline between the stock tank and the injection wells to create sufficient pressure for delivery, between 15 and 40 psi. Pressures and flowrates will be monitored throughout the injection period, and pressures will not be allowed to exceed 60 psi at the well heads.

Bioaugmentation with KB-1® or approved equivalent typically is performed via a port on the injection manifold. The KB-1® or approved equivalent consortium is supplied by the vendor in sealed vessels. Compressed argon (or nitrogen) gas is used to push the culture from the vessel and into the manifold. A scale is used to measure the amount of KB-1® or approved equivalent delivered (i.e., the volume added is determined by the change in weight of the vessel divided by the density of KB-1®). A photograph of a vendor's injection manifold and KB-1® vessel is provided in Figure 11. In this photograph, the blue hoses lead to individual injection wells. Pressure and flow gauges are located directly upstream of the blue hoses on the manifold. The KB-1® vessel is the stainless-steel cylinder that is on a scale. The white tubing from the KB-1® vessel to one of the channels of the manifold is used to transfer KB-1® into that line where it is carried to the injection well.

4.4.2 Implementation Sequence

The general steps for creating fractures with DPT jet injection include (1) drilling a borehole to the desired fracture depth; (2) inscribing a kerf into the wall of the borehole to focus injection stresses; (3) nucleating a fracture with hydraulic pressure and further propagating the fracture with remediation materials (i.e., sand-mZVI) suspended in a viscous slurry; and (4) monitoring the injection pressure. Fractures created using controlled jet injection methods are relatively thin, sheet-like structures with a horizontal attitude. Fractures typically have a design radius of 15 ft from the injection boring and an average aperture of approximately one centimeter.

Jet injection of sand-ZVI in the subsurface at SWMU 211-A will be accomplished by preparing a slurry with a carrier fluid (i.e., hydrant water plus guar gum) to promote delivery and limit aggregation of the sand-mZVI within the aquifer matrix. The sand-mZVI mixture will be delivered in the target treatment zone using DPT drilling techniques and high-pressure jet injection. It is assumed that hydrant water is available near SWMU 211-A and can be used for injections.

DPT jet injection of sand-mZVI will consist of the following steps for a single depth-discrete injection:

- A DPT rig of appropriate size is used to advance specialized injection tooling with a 3.5-inch outside diameter into the subsurface to the first target injection depth; injections are performed using a top-down approach.

- After injection tooling is advanced to depth, high pressure water jetting is used to erode a horizontal disc shape (kerf) in the formation surrounding the injection tooling.

- A viscous slurry composed of water, guar gum, sand, and mZVI is mixed just prior to the start of injection at each depth interval.

Figure 11. Photograph of an Injection Manifold Attached to a KB-1® Vessel and Scale

- After the water jetting step is complete, the viscous guar slurry is injected under sufficient pressures (anticipated to be between 75 and 150 psi) to create sand/ZVI-filled horizontal fractures with a target ROI of 15 ft.

- The slurry injection rate is typically 10 to 20 gpm, and each injection point is anticipated to require between 30 and 90 minutes to complete.

- After the target volume of slurry has been injected, the tooling is advanced to the next injection interval or retracted after the deepest injection is completed.

After DPT jet injection is completed at each location, the injection tooling will be removed from the borehole, and an injection well will be installed in the existing borehole using methods designed to place the sand filter pack surrounding the well screen in contact with the permeability enhanced fractures. The use of drilling methods that increase the likelihood of compromising the effectiveness of permeability enhanced fractures by smearing these zones with clay must be avoided.

A maximum well screen length of 15 ft will be used to minimize the likelihood of creating vertical preferential pathways through the UCRS, where downward hydraulic gradients have been observed (DOE 2013). In areas where the target treatment interval thickness is greater than 15 ft, the well screen will be installed in the lower portion of the target treatment interval, and a second injection well will be installed in the upper portion of the treatment interval with a lateral offset less than 5 ft from the injection location. Well screen intervals will be refined in the 60% RDR.

4.4.2.1 Injection layout

As described above, DPT jet injection will create horizontal fractures with enhanced permeability in the UCRS. These fractures will extend radially from the injection locations and fracture ROIs will be overlapped to cover the treatment area. The fractures will serve as pathways to deliver EISB amendments as described below. As described above, the shape of the fractures is generally circular, but will depend on micro-features of the geology. The locations of injection points are selected to get lateral coverage of the treatment footprint with some overlap between fractures as a factor of safety. For SWMU 211-A, the target treatment area is comprised of two distinct areas with higher TCE contamination in UCRS soils with a total area of approximately 13,200 ft^2. Treatment areas were defined based on the results of soil samples collected during the RDSI in 2012 and 2013 (DOE 2013) and include soil boring locations where the vertically averaged concentration of TCE exceeds the cleanup level. The proposed injection area is shown in Figure 10. The target treatment depth interval is generally between 25 and 65 ft bgs. A cross section of the treatment area is shown in Figure 12. Discrete injection depths for DPT jet injection at each location will be defined in the 60% RDR, based on RDSI soil sample results and interpolated TCE concentrations.

The ROI is the determining factor when selecting the layout of injection locations. A design ROI of 15 ft is anticipated to be used for this site. Figure 10 provides the anticipated layout of injection locations with a 15-ft ROI and an overlap of approximately 35%.

4.4.2.2 Amendment preparation and injection process

Following injection of sand-mZVI and installation of the injection wells, EISB amendments will be injected into the target treatment interval in the UCRS. Most commercial EVO products contain about 50% vegetable oil, 50% water and minor amounts of sodium lactate, stabilizers/emulsifying agents, and nutrient additives. A commercially available EVO product will be mixed with water to create an EVO solution, and the EVO solution will be injected in each injection well as an electron donor to support bioremediation. The volume of EVO solution added at each injection well will be assessed during the 60% remedial design, but in general the target concentration of EVO in the aquifer is up to 2%. Water for mixing with the EVO product will be taken from a specified on-site water source and pre-treated to remove oxygen (e.g., with KB-1 Primer® or approved equivalent). The EVO solution will be gravity fed or pumped into the wells with equipment identified in Figure 11 utilizing a temporary aboveground piping network. Each injection well header will be fitted with a pressure gauge and a flow meter to document that the required volume of EVO solution is added at each injection well. If necessary, the EVO solution may be pumped into fractures under pressure but not at a pressure high enough to fracture the UCRS. During injection activities, routine water level measurements, and field geochemical testing (DO and ORP) may be conducted at MWs and/or injection wells near the treatment area.

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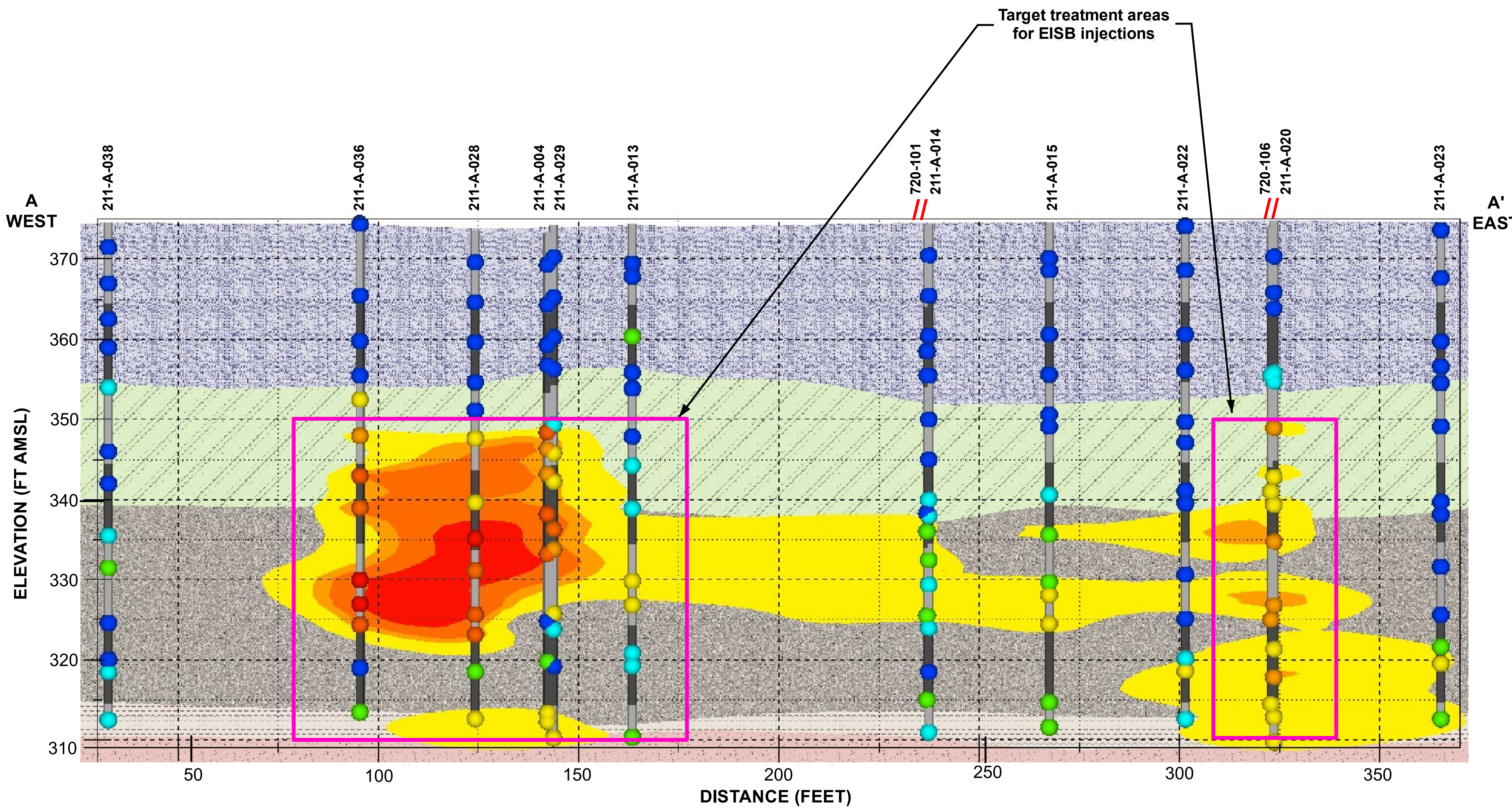

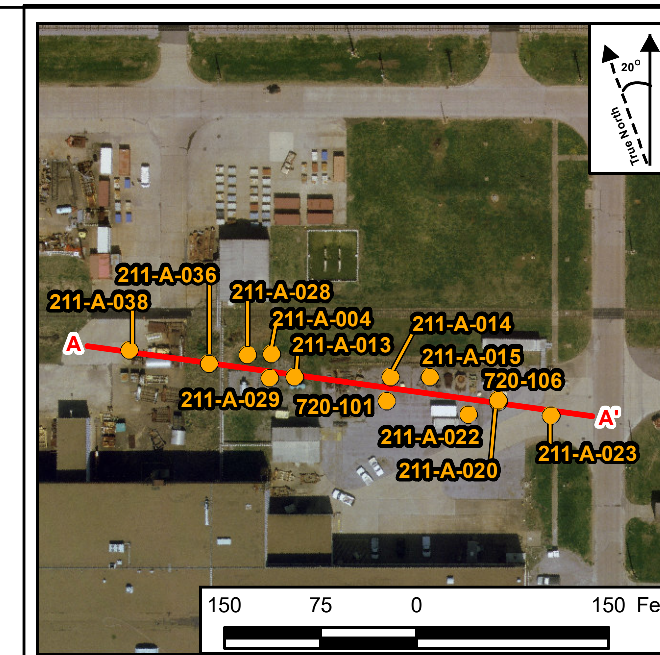

Notes:
1. // indicates location of overlapping soil borings. TCE concentrations for both locations appear graphically superimposed on the soil borings above.
2. Soil samples collected from 4 October 2012 to 6 March 2013.
3. Results are presented in microgram per kilogram (µg/kg).
4. FT AMSL indicates feet above mean sea level.
5. Trichloroethene (TCE) isopleths are based upon depth discrete individual results, not average borehole soil concentrations.
6. C Tech's Environmental Visualization Systems Expert System used to develop TCE isopleths.
7. Select soil borings were used to determine the hydrologic units.
8. Soil borings within 15 feet of transect are projected onto it.
9. TCE concentrations projected onto the cross section were derived from the EVS-ES nominal (50%) confidence level.
10. Enhanced *in situ* bioremediation (EISB) treatment depths will be defined for each injection location based on soil sample results and interpolated TCE concentrations.

Adapted from Figure 9 of DOE (2013).

SWMU 211-A Cross-Section with TCE Isopleths and Hydrogeologic Units

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

FOUR RIVERS NUCLEAR PARTNERSHIP, LLC

September 2018

Figure 12

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Figure 12. SWMU 211-A Cross Section with TCE Isopleths and Hydrogeologic Units

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Bioaugmentation will be performed at each injection well after approximately half of the design volume of EVO solution has been injected. Between 2 and 10 liters of KB-1® or approved equivalent will be added to each injection well, using methods designed to prevent exposure of KB-1® or approved equivalent to oxygen. KB-1® or approved equivalent addition will be followed by flushing with EVO solution and anaerobic water to push the bacterial consortium into the formation. Prior to bioaugmentation, groundwater conditions will be assessed to confirm that the geochemistry is appropriate for the bacteria (e.g., DO < 1 mg/L, and ORP < -100 millivolts [mV] and circumneutral pH).

If KB-1® or approved equivalent is supplied by the vendor in vessels, then the KB-1® vessel integrity will be verified by injection personnel upon receipt (in the field). The KB-1® injection vessel will be connected to aboveground injection piping, and the system will be purged with argon (or nitrogen) gas for approximately 5 minutes at pressures of approximately 10 to 20 psi to displace oxygen from the well column and maintain inert gas in the well above the water table. The required volume of KB-1® or approved equivalent consortium will be metered into the injection well using compressed gas to transfer it from the vessel into the well. Alternatively, KB-1® or approved equivalent can be injected directly into the manifold used for the EVO solution if the vendor performing the work has appropriate plumbing connections. Further, KB-1® recently has become available in FIT tubes, which are small, sealed containers used to deliver a premeasured dose of KB-1® without the need for line purging. Whether KB-1® or approved equivalent will be provided in vessels or FIT tubes will be determined prior to field implementation based on cost, vendor capability, and the EISB contractor’s equipment; the delivery of KB-1® or approved equivalent will follow manufacturer’s standard procedures.

After bioaugmentation with KB-1® or approved equivalent is complete, the remaining volume of EVO solution will be injected into the injection well followed by anaerobic water to clear the EVO solution out of the well screen and sand pack. This step helps to prevent fouling of the wells.

4.4.2.3 Real time process monitoring

Field observations and measurements will be recorded during DPT jet injection and EISB implementation to ensure injections are conducted in accordance with the plans described above.

The following parameters will be recorded at each location during field activities.

- During DPT jet injection to create fractures:
  - Quantities of materials injected, and actual injection pressures and flow rates at each injection interval.

- During EISB amendment delivery
  - Quantities of materials injected, volume of KB-1® or approved equivalent added, and actual injection pressures and flow rates for EISB amendments at each injection well.

Monitoring activities during injections shall also include the following.

- Observe the ground surface during jet injections and EISB injections for surficial breakthrough of injection materials;

- Check equipment and tooling to ensure proper functioning during injections;

- Check water levels in nearby monitoring and/or injection wells periodically; and

- Measure geochemical parameters (e.g., ORP) of stock tanks used for EISB injections periodically.

Injection monitoring will be recorded in daily inspection logs. Injection pressures, flowrates, and depths will be recorded as appropriate to determine relative differences between injection locations and changes over time.

5. CONSTRUCTION REQUIREMENTS

5.1 MONITORING WELL DRILLING EQUIPMENT

MW construction will be performed at both SWMU 211-A and 211-B as part of implementing their respective remedial actions. As planned, eight new MWs (total) will be installed for both SWMUs. Section 2 provides additional information on the planned placement of MWs. The MWs will be constructed and completed consistent with engineering drawings in Appendix B:

- C7DCWELLSA002—Groundwater Monitoring Wells Typical Well Details, and
- C7DCWELLSA003—Groundwater Monitoring Wells Typical Well Details.

Monitoring wells will be constructed utilizing sonic drilling technology for efficiency and reduced waste generation. If a sonic drilling unit is not available or there are positive technical and/or cost impacts from utilizing a different construction method, the wells also may be installed with a hollow-stem auger system, dual-wall reverse circulation rotary system, or other acceptable system.

Installation of MWs also will include using general construction equipment in support functions. The following are some of this equipment and its applications.

- Forklift—Handle drillpipe, waste containers, construction supplies and equipment, etc.

- Box/Flatbed Truck(s)—Haul and stage drilling and well pipe, supplies, water, etc.

- Skidsteer—Handle waste concrete and soil, drill/construct bollards, excavate well and drill pads, break up concrete pavement, etc.

5.2 DPT JET INJECTION AND ENHANCED *IN SITU* BIOREMEDIATION EQUIPMENT

Equipment typically used for DPT jet injection and EISB amendments injection is presented in Section 4.4.1. In addition to the equipment described in Section 4.4.1, the following equipment likely will be required during implementation of injection activities:

- A Geoprobe® DPT or approved equivalent drilling rig for injection and well installation activities. An appropriately sized (series 8000 or greater) rig with the largest available hammer is recommended to advance drill rods to the desired depths in the UCRS;

- An all-terrain forklift for unloading, moving, and loading of sand-mZVI during DPT jet injection activities and EVO solution during EISB injections;

- A fractionation tank used to store water temporarily and create batches of anaerobic water that will be mixed with EVO;

- Multiple 200 to 2,500-gal storage tanks to store water temporarily, mix slurry in batches, and prepare EVO solution in batches;
- Pumps for transferring water, slurry, and EVO solution between tanks;
- Pumps for moving EVO solution through a manifold and into injection wells;
- A multi-channel injection manifold with gauges, meters and valves that allows the delivery of EVO solution to multiple injection wells simultaneously; and
- Hoses, pipes, and other equipment to complete the plumbing network.

5.3 WATER REQUIREMENTS

Site water, which is available from a hydrant near SWMU 211-A, will be used during remedy implementation. The total volume of water required is expected to be less than 300,000 gal. Specific stages of work requiring water include high-pressure water jetting during DPT jet injection, preparation of the mZVI slurry, and preparation of the EVO solution for EISB injections. Pretreatment is not anticipated to be needed for water used for DPT jet injection or sand-mZVI slurry preparation. The water utilized to prepare batches of EVO solution will be treated with KB-1 Primer® to reduce DO in the water and promote anaerobic conditions. Pretreatment requirements will be further evaluated in the 60% RDR.

5.4 SITE PREPARATION

SWMU 211-A—Enhanced *In Situ* Bioremediation

Site preparation associated with the *in situ* bioremediation will require extra effort compared to SWMU 211-B remedial action. It is expected that bioremediation amendments and bioaugmentation material will be introduced to the UCRS soils through injection. These placement points are expected to be spaced closely and will be numerous. The total number and locations will be defined further in later versions of the remedial design process. The SWMU 211-A eastern treatment area is mostly covered with concrete or asphalt pavement. The western treatment area is generally soil covered with a limited area of gravel covering. Both the east and west treatment areas of SWMU 211-A contain utilities with the eastern treatment area having a higher utility density. As such, implementation of the remedial action will require development of excavation/penetration permits (E/PPs) to allow working around the utilities present. Areas with concrete or asphalt pavement will be core drilled to allow access to soil below it for deep drilling.

It is expected that seven MWs will be installed around the SWMU 211-A treatment area. Depending on the well locations, concrete or asphalt core drilling may be needed to provide drilling rig access to the subsurface.

The SWMU 211-A area also typically is covered by mobile equipment, some of which may require moving during the action. There also are some equipment sheds, fencing/guardrail, railroad line, and electrical transformers that will require allowances to be made during remedial action implementation. Storm-water drains are located in the SWMU 211-A. These may require placement of storm-water control measures if activities are planned in their drainage area.

SWMU 211-B—Long-Term Monitoring

An evaluation of the SWMU 211-B area identified that little site preparation is needed for the implementation of the Long-Term Monitoring remedial action. The SWMU lies adjacent to the south edge of the C-720 Building and within the C-720 South Parking/Equipment lot (Figure 4). When the specific location of the upgradient well is identified (Figure 9), further evaluation for obstructions will be performed. At the time of drilling, it may be necessary to relocate the mobile equipment in the immediate area. Confirmation of utility locations and an E/PP will be developed to allow surface concrete to be removed as needed and to allow drilling. The downgradient monitoring wells that are part of the SWMU 211-B long-term monitoring remedial action will be installed on the north side of the C-720 Building and will function as part of the SWMU 211-A remedial action monitoring network.

Similar to the SWMU 211-A area, storm-water drains are located in the vicinity of SWMU 211-B. These may require placement of storm-water control measures, if activities are planned for their drainage area.

5.5 PERMITTING

Site-specific permits will be required for the implementation of both remedial actions. The following are the applicable, site-specific permits.

- E/PPs
- Lockout/tagout permits
- Hot work permits

The use of best management practices related to storm-water management is required for the drilling and construction within the SWMU 211-A and 211-B areas. Accordingly, it is anticipated that silt fence or similar equipment will be installed in the site construction area as a component of a site-specific, storm-water best management practice, as discussed in Section 5.4.

6. SAMPLING AND MONITORING

SAMPLING AND MONITORING POSTREMEDIAL ACTION

SWMU 211-A—Enhanced *In Situ* Bioremediation

The selected remedy includes groundwater sampling (referred to as long-term monitoring in this report), and implementation of EISB requires sampling for parameters that provide an indication of the efficacy and continuity of the remedial action. The bioremediation activity, once active, is self-sustaining as long as geochemical and chemical parameters in the subsurface remain supportive. A second portion of the sampling and monitoring is the monitoring of the levels of contaminants of concern emanating from the UCRS following treatment implementation. This change is identified by sampling of groundwater in the RGA via the MW network. Section 2 provides the 30% RDR information developed for the MW network. Monitoring well locations, sampling parameters, and frequencies will be developed further in the 60% RDR.

SWMU 211-B—Long-Term Monitoring

The implementation of the Long-Term Monitoring remedial action by itself will not result in the reduction of contamination present in the subsurface. The Long-Term Monitoring remedial action was selected by the

FFA parties because the presence of DNAPL in the RGA at SWMU 211-B negates the benefit of a UCRS action. The ROD does not address treatment in the RGA. The only ongoing activity associated with the 211-B remedy is long-term monitoring utilizing the monitoring network. Section 2 provides the 30% RDR information for the monitoring well network. The 60% RDR will expand on the monitoring well locations and the sampling parameters and frequencies planned after well construction.

7. DATA MANAGEMENT

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

8. HEALTH AND SAFETY

A general health and safety plan overview will be included in the RAWP, and a project-specific health and safety plan will be developed for field implementation.

9. WASTE MANAGEMENT

All waste generated will be managed according to the most recent revision of the *Four Rivers Nuclear Partnership, LLC, Paducah Deactivation and Remediation Project Waste Management Plan*, CP2-WM-0001, along with other applicable site procedures and DOE requirements. Additionally, this Waste Management Plan will comply with all applicable regulatory requirements of Comprehensive Environmental Response, Compensation, and Liability Act, Resource Conservation and Recovery Act, Toxic Substances Control Act, and Paducah Site radiation control policies, as appropriate. Any deviations from this sitewide plan will be documented in the project-specific RAWP.

10. REFERENCES

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APPENDIX A

SWMU 211-A AND SWMU 211-B OPTIONS PRESENTATION (MAY 23, 2018)

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U.S. DEPARTMENT OF ENERGY | OFFICE OF ENVIRONMENTAL MANAGEMENT

SWMU 211-A and SWMU 211-B Options

May 23, 2018

Introduction

Purpose:

- Summarize site conditions at SWMU 211-A and at SWMU 211-B
  - SWMU 211-A and SWMU 211-B are UCRS sources addressed in Southwest Plume ROD
- Define recommended pathforward for SWMU 211-A and SWMU 211-B
- Explain how recommended pathforward meets current ROD

Introduction

Background:

- 2012 ROD selected two alternative UCRS remedies:
  - Enhanced in-situ bioremediation with long-term monitoring, OR
  - Long-term monitoring
  - Specific Remedy to be selected based on data collected during RDSI

- ROD excluded actions for the RGA:
  - 2008 Dispute Resolution Agreement for the SW Plume Site Investigation Report (DOE/OR/07-2180&D2/R1, June 2017) states "Address the Southwest Dissolved Phase Plume (in particular the Regional Gravel Aquifer from the source areas to the leading edge of the plumes) as part of the Groundwater OU (GWOU) Dissolved Phase Plumes Project." Item (3) of the signed Resolution Agreement, letter PPPO-02-392-08, March 24, 2008.
  - "this ROD focuses on reducing the high concentrations of TCE in soils of the UCRS at the C-747-C Oil Landfarm (SWMU 1) and C-720 Northeast (SWMU 211-A) and Southeast Sites (SWMU 211-B)". Section 2.4, Scope and Role of the Operable Unit, SW Plume ROD.

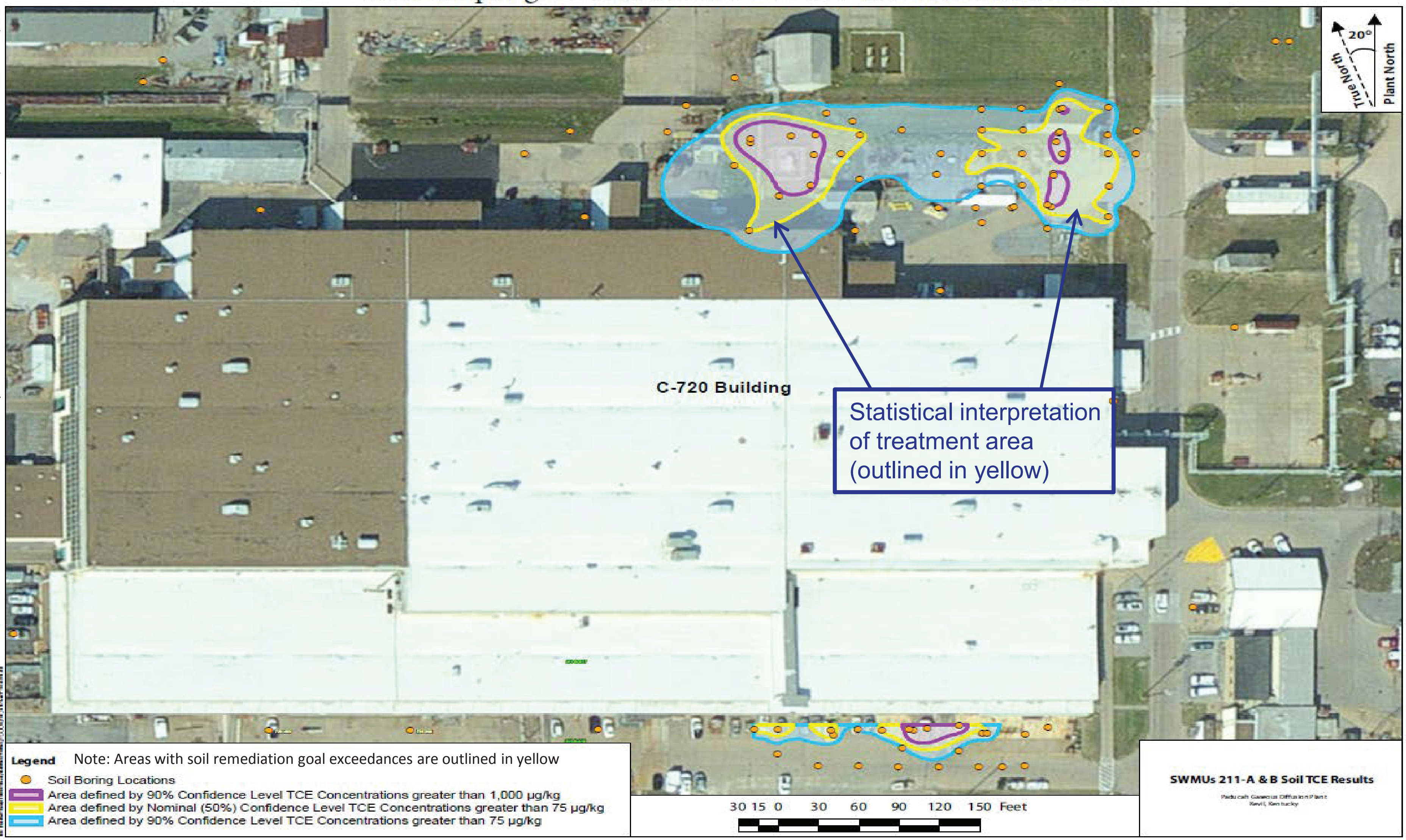
Post-ROD Investigations—RDSI

UCRS and HU4 (uppermost RGA) **RDSI investigation**:

- 2012 and 2013
- Direct Push Technology (DPT)
- VOC analysis for each 5-ft interval
  - Land surface down to refusal (60-to-67.5 ft depth)
  - 42 DPT borings in SWMU 211-A
  - 19 DPT borings in SWMU 211-B
- Results reported in the Final Characterization Report for SWMUs 211-A and 211-B indicated very low mass of VOCs present in soil in the area sampled
  - ~2 gallons at SWMU 211-A
  - ~1 gallon at SWMU 211-B
- DOE recommended LTM based on mass of TCE
- EPA requested collection of additional data
- Water samples were collected, only to support the remedial design (SW Plume RDWP)

Soil Sampling Locations

Soil Sampling Locations at SWMU 211-A and SWMU 211-B



Developed from Figures 6 and 8 of the Final Characterization Report for SWMUs 211-A and 211-B (DOE/LX/07-1288&D2)

A-7

Post-ROD Investigations—Additional Work

RGA groundwater investigation (EPA Additional Work Request):

- 2015
- Water sample collection via Hollow Stem Auger (HSA) borings
- VOC analysis at each 5 ft depth
  - 65 ft depth to base of RGA (90 to 100 ft depth)
- 5 HSA borings in SWMU 211-A
- 1 HSA boring in SWMU 211-B

Decision Rules from RDWP Addendum

Downgradient wells
Median TCE < 400 ppb and
Then
CSM validated

↓

Implement LTM

Downgradient wells
Median TCE > 400 ppb and
Median TCE < 11,000 ppb

Then
CSM validated

↓

Implement EISB/LTM

Upgradient wells
Median TCE > 11,000 ppb

Then is source of DNAPL to RGA other than 211-A and 211-B

↓

FFA Parties convene and discuss path forward for SW Plume

Downgradient wells
Median TCE ≥ 11,000 ppb

Then
CSM is invalid due to presence of DNAPL in RGA

↓

FFA Parties convene and discuss path forward for SW Plume

OFFICE OF ENVIRONMENTAL MANAGEMENT

Site Conditions –SWMU 211-A and SWMU 211-B

RGA Data collected based on EPA Additional Work Request

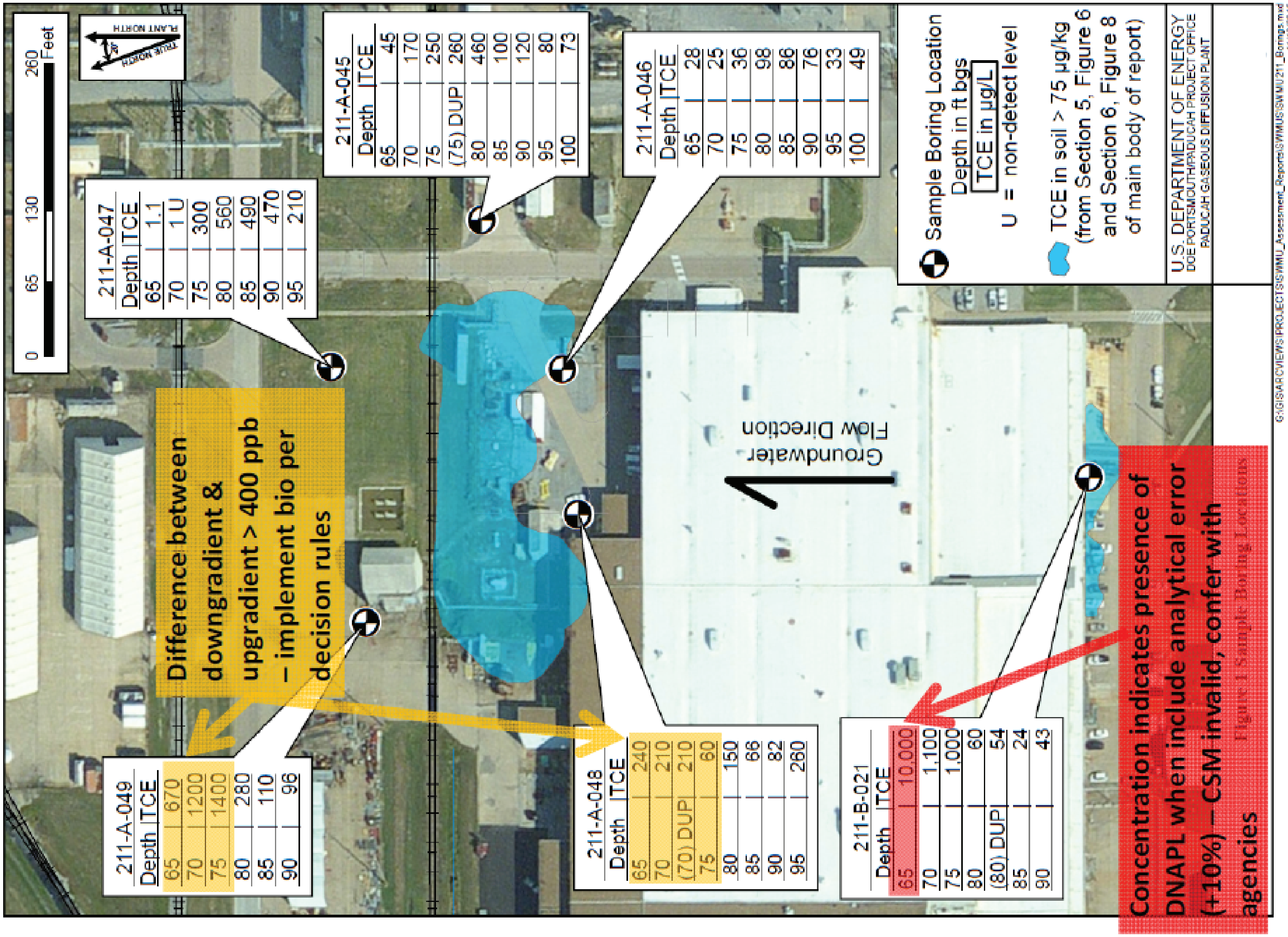


Figure from Addendum to Final Characterization Report for SWMUs 211-A and 211-B (DOE/LX/07-1288&D2/A1/R1)

A-10

Site Conditions Summary—SWMU 211-A

SWMU 211-A:

- Soil sampling defined areal extent of TCE
- Groundwater sample results indicate RGA is being impacted by VOC releases from soils at SWMU 211-A
- Consistent with Conceptual Site Model (CSM)
- Application of RDWP decision rules supports the choice of Enhanced In Situ Bioremediation with Long-term Monitoring (EISB/LTM) in the UCRS

SWMU 211-A: Statement of Problem & Regulatory Framework

Statement of Problem – SWMU 211-A:

- VOC Contamination in UCRS soils is contributing to the RGA at levels exceeding the established decision rules

Regulatory Framework per Decision Rules – SWMU 211-A:

A-12

- Implement Enhanced In Situ Bioremediation & Long-term Monitoring (EISB/LTM) at SWMU 211-A UCRS as defined under the Existing ROD and SMP
  - Develop and issue remedial design in accordance with SMP

Site Conditions Summary—SWMU 211-B

A-13

SWMU 211-B:

- Soil sample results in the UCRS estimate the mass of VOCs present to be ~1 gal
- Groundwater sample results indicate potential DNAPL at top of RGA
- Single groundwater sampling result in the RGA:
  - CSM invalid for SWMU 211-B
  - Does not define extent of DNAPL
- Groundwater flow direction is from South to North, so DNAPL at SWMU 211-B could influence RGA groundwater conditions under SWMU 211-A

SWMU 211-B : Statement of Problem, Regulatory Framework , & Recommended Solution

Statement of Problem – SWMU 211-B:

- Soil sample results in the UCRS do not support active remediation in the UCRS
- Data indicates potential for RGA DNAPL contamination under SWMU 211-B with unknown nature and extent, which is not addressed in current ROD

Regulatory Framework per Decision Rules – SWMU 211-B:

- CSM invalid
- FFA parties convene and discuss path forward

Recommended Solution – SWMU 211-B:

- Implement LTM in RGA for UCRS soil contamination at SWMU 211-B to close ROD
- Use LTM data to support future RGA investigation as part of C-720 Soils & Slabs

---

Other Regulatory Option to Close ROD for SWMU 211-B UCRS:

- Prepare a ROD modification

Advantages of this Strategy

- **SWMU 211-A:**
  - Implements a remedy in the UCRS
  - Closes SW Plume ROD

- **SWMU 211-B:**
  - Provides monitoring of area
  - Collects information supporting future action for C-720 Soils & Slabs including DNAPL at SWMU 211-B
  - Closes SW Plume ROD

- **C-720 Soils & Slabs:**
  - Complete evaluation of DNAPL and other contaminants potentially under C-720, including DNAPL at SWMU 211-B

SWMU 211-A Schedule

Activity Name	Primary -Secondary Document	SWMU 211-A[1] Enhanced In Situ Bioremediation (EISB) Remedy
30% Remedial Design Report	Secondary	2nd Q 2019
60% Remedial Design Report	Secondary	3rd Q 2019
D1 Remedial Design Report (90%)	Primary	11/8/2019[2] (1st Q 2020)
Remedial Action Work Plan Scoping		3rd Q 2019
D1 Remedial Action Work Plan	Primary	12/8/2019[1] (1st Q 2020)
Remedial Action Fieldwork		2nd Q 2020
D1 Remedial Action Completion Report	Primary	2nd Q 2021[1]

Notes:

[1] If implement activities at 211-B, intent is not to impact regulatory dates of this schedule.

[2] 2018 SMP date

APPENDIX B

MONITORING WELL ENGINEERING DRAWINGS

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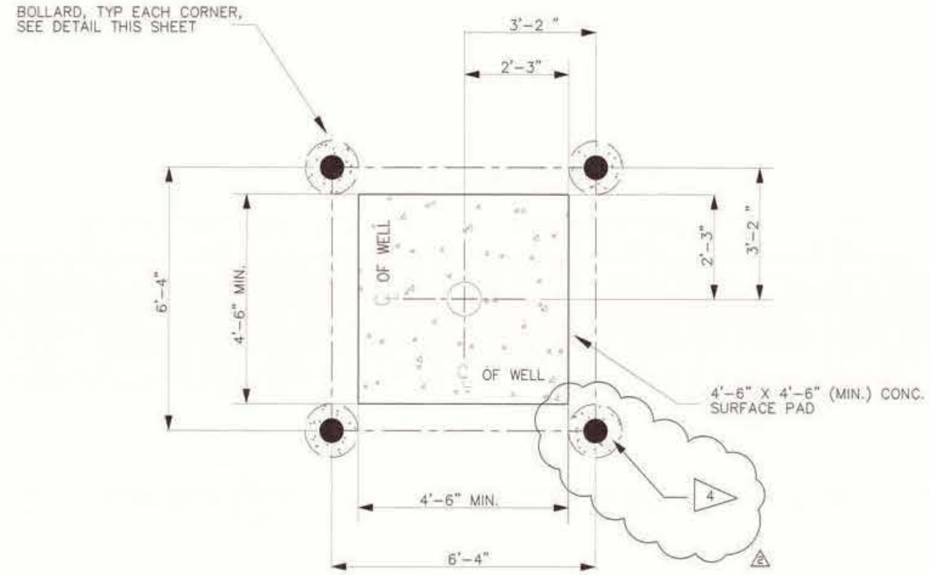
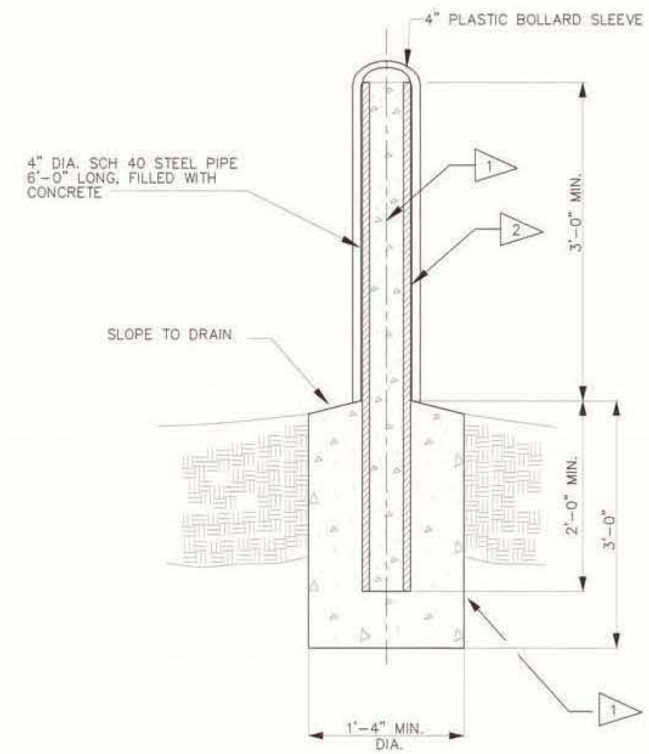
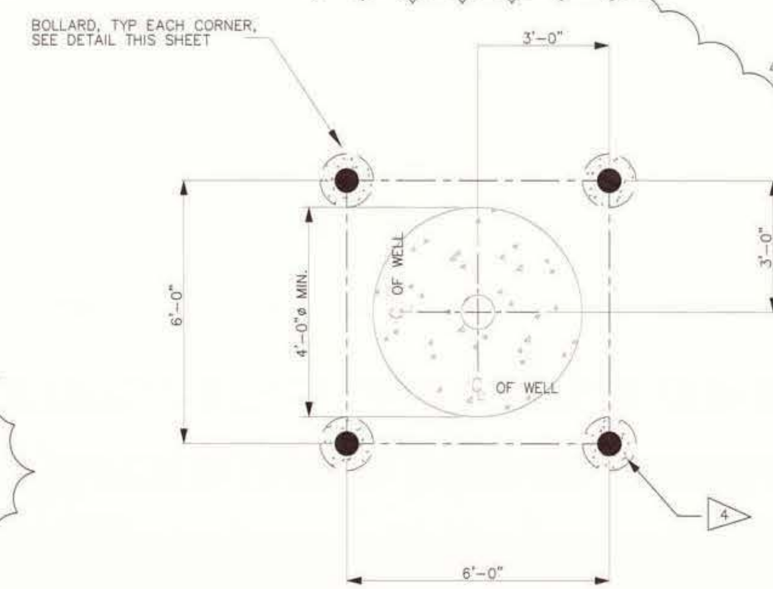


SQUARE CONCRETE PAD AND BOLLARD LOCATION PLAN



TYPICAL BOLLARD DETAIL



CIRCULAR CONCRETE PAD AND BOLLARD LOCATION PLAN

GENERAL NOTES:

1. CONCRETE FOR BOLLARDS SHALL BE CLASS "A" IN ACCORDANCE WITH KENTUCKY DEPARTMENT OF HIGHWAYS STANDARD SPECIFICATION SECTION 601. ADMIXTURES REQUESTED BY THE PROJECT SHALL BE REVIEWED AND APPROVED BY ENGINEERING ON A CASE BY CASE BASIS.
2. BOLLARD SHALL BE CLEANED ACCORDING TO SSPC-SP6 AND PRIMED WITH TNEMEC SERIES 37H @ 3-5 MILS OR COMPANY ACCEPTED EQUAL. AFTER PRIMING IS COMPLETE INSTALL PLASTIC BOLLARD POST SLEEVE ($\frac{1}{4}$" THICK MINIMUM) PER MANUFACTURER'S INSTRUCTIONS. TRIM EXCESS LENGTH AS REQUIRED TO MATCH HEIGHT OF CONCRETE BOLLARD. BOLLARD SLEEVES SHALL BE A HIGHLY VISIBLE COLOR.
3. SURFACE COMPLETIONS SHALL BE INSTALLED IN ACCORDANCE WITH 401 KAR 6:350, MONITORING WELL CONSTRUCTION PRACTICES AND STANDARDS.
4. FIELD ADJUST BOLLARD SPACING, AS NEEDED, WITH APPROVAL FROM THE COMPANY.

REFERENCE DRAWINGS	DRAWING NO.
GROUND WATER PIEZOMETER WELLS INSTALLATION DETAILS	C5E-FA1950-A12
GROUND WATER MONITORING WELLS INSTALLATION DETAILS	C7DCWELLSA003

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STATE OF KENTUCKY KAREN A. SIZEMORE 21059 LICENSED PROFESSIONAL ENGINEER
Karen A. Sizemore 8/30/18
DATE
PROFESSIONAL SEAL

SECTION AND DETAIL KEY: SECTION NUMBER OR DETAIL LETTER; DRAWING ON WHICH SECTION OR DETAIL IS TAKEN; DRAWING ON WHICH SECTION OR DETAIL IS SHOWN

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS ± $\frac{1}{16}$"
XX DECIMALS
XXX DECIMALS
ANGLES
BREAK SHARP EDGES MAX.
FINISH

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REV. NO.	ISSUE / REVISION DESCRIPTION	DATE	DRW	CHKR	RE	TR	APPD
2	CERTIFIED FOR CONSTRUCTION FOR FCT-CCA-FA5120-002	X	X	X	X	X	X
0	AS-BUILT ENTIRE DRAWING FOR ESO FA1950, INC ECN-2016-0059	X	X	X	X	X	X
FA2	CERTIFIED FOR CONSTRUCTION FOR ECN-2016-0059	X	X	X	X	X	X
FA1	CERTIFIED FOR CONSTRUCTION FOR ESO FA1950	3/2/16	DJH	GWD	GWD	N/A	KAS
1	GENERAL REVISIONS	6/28/13	KTW	PAC	KRO	N/A	PAC

REVISION OR ISSUE APPROVALS

DRAWING APPROVALS	DATE
DRW D. HATTON	9/8/16
CHKR T.A.WALKER	9/8/16
RE T.A.WALKER	9/8/16
TR N/A	
APPD K.SIZEMORE	9/8/16

DRAWING APPROVALS		DATE
REV.	2	
DRW.	[signature]	9/22/18
CHKR.	[signature]	8/29/18
R.E.	[signature]	9/22/18
T.R.	N/A	N/A
APPD.	[signature]	8-23-18

Aug 22, 2018

FOUR RIVERS NUCLEAR PARTNERSHIP, LLC
DOE PRIME CONTRACT # DE-EM0004895

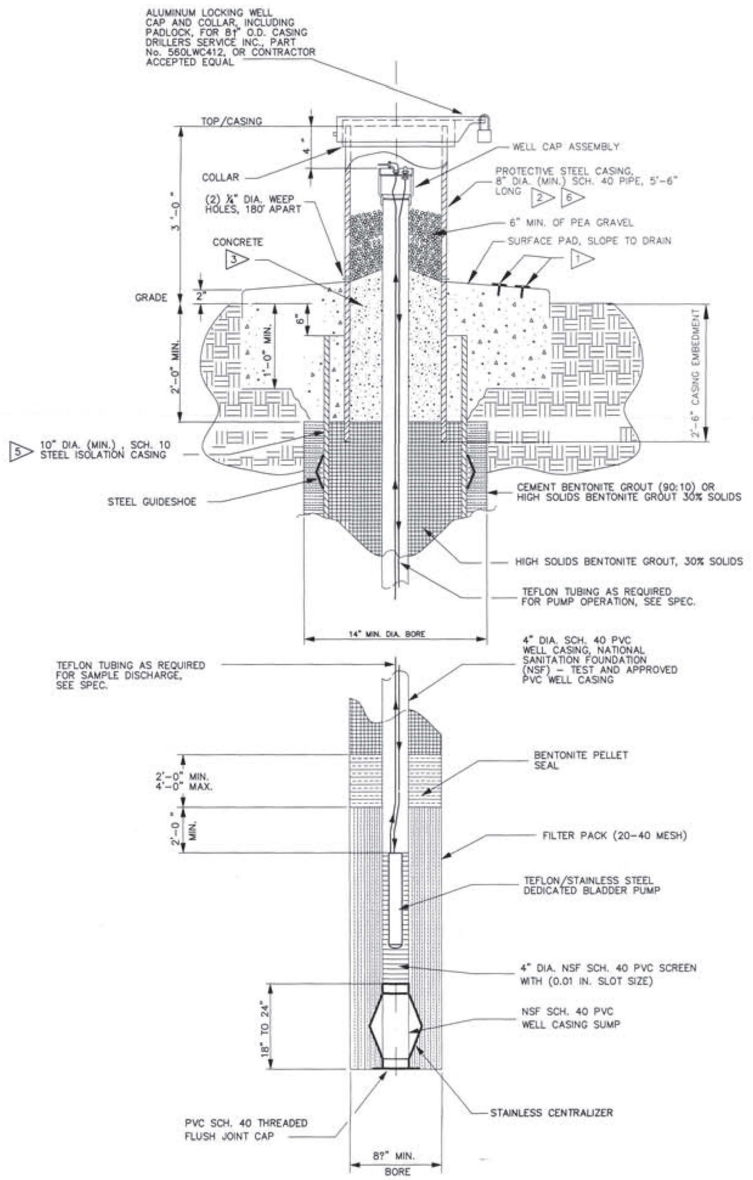
FLUOR. PADUCAH DEACTIVATION PROJECT
DOE Prime Contract #DE-DT0007774

GROUND WATER MONITORING WELLS TYPICAL WELL DETAILS

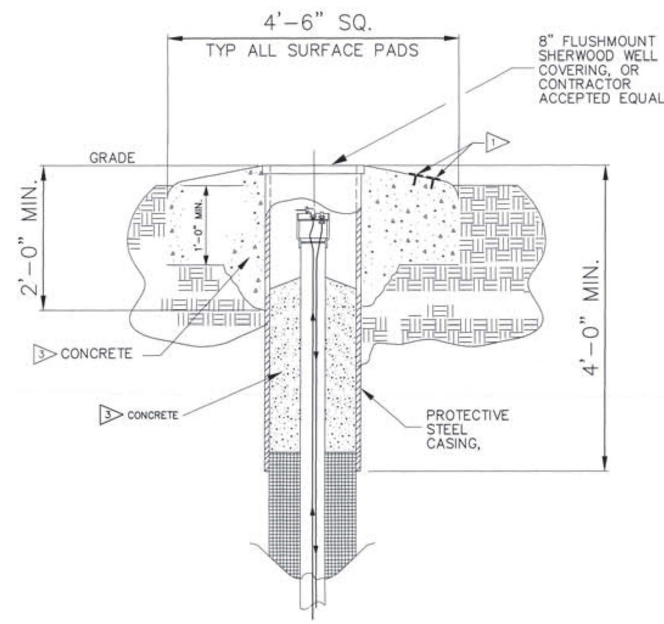
NON-ESSENTIAL

SCALE	PLANT	BLDG	FL	CLASS
NONE	PGDP	N/A	N/A	U

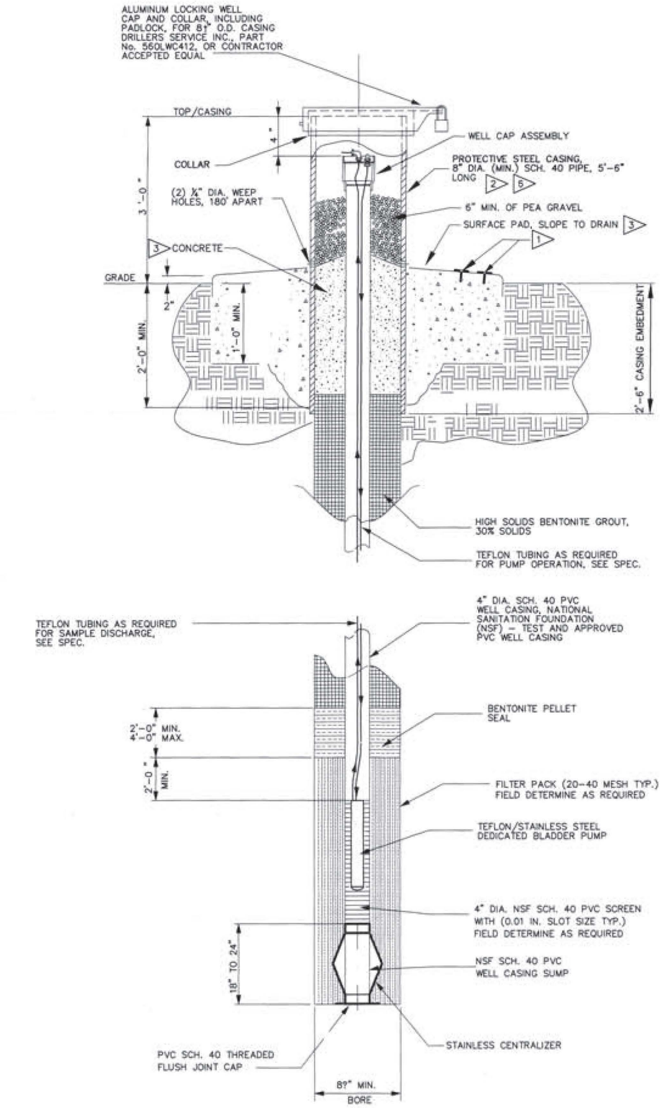
ID FA1950 | C7DCWELLSA002 | REV 2



MONITORING WELL WITH ISOLATION CASING



FLUSH MOUNT SURFACE PAD ARRANGEMENT



MONITORING WELL WITHOUT ISOLATION CASING

GENERAL NOTES:

1. INSTALL TWO BRASS PLATE MONUMENTS. SUB-CONTRACTOR SHALL STAMP WELL NUMBER, COORDINATES, ELEVATIONS, AND ASSEMBLED KENTUCKY GROUNDWATER DATABASE REGISTRATION NUMBER (MIN. OF ⅛" SIZE LETTERS) IN BRASS PLATE. BRASS PLATE SHALL BE DOMED SURVEY MARKER 3" DIA. LIETZNUMBER 8134-18 OR CONTRACTOR ACCEPTED EQUAL.
2. PROTECTIVE CASING SHALL BE CLEANED ACCORDING TO SSPC-SP6 AND PRIMED WITH TNEMEC SERIES 37-77W @ 3-5 MILS AND FINISHED WITH TNEMEC SERIES 82-BW56 @ 2-3 MILS, OR CONTRACTOR ACCEPTED EQUAL.
3. CONCRETE FOR PAD AND PROTECTIVE WELL CASING SHALL BE CLASS "A" IN ACCORDANCE WITH KDH STANDARD SPECIFICATION SECTION 601
4. OMIT
5. ISOLATION CASING TO BE INSTALLED IN CONFINING LAYER ABOVE RGA.
6. EACH PROTECTIVE CASING SHALL BE LABELED WITH BLACK LETTERS. LABEL SHALL INCLUDE THE PREFIX MW FOR MONITORING WELLS, THE PREFIX PZ FOR PIEZOMETERS AND THE NUMBER ASSIGNED BY THE CONTRACTOR. LETTERS SHALL BE A MINIMUM OF 2 INCHES HIGH.

REFERENCE DRAWINGS	DRAWING NO.
GROUND WATER MONITORING WELLS TYPICAL WELL DETAILS	C7DCWELLSA002

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STATE OF KENTUCKY — KAREN A. SIZEMORE — 21059 — LICENSED PROFESSIONAL ENGINEER

Karen A. Sizemore 9/25/17

DATE

PROFESSIONAL SEAL

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DRAWING ON WHICH SECTION OR DETAIL IS SHOWN
SECTION AND DETAIL KEY

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS ± $\frac{1}{16}$"
XX DECIMALS
XXX DECIMALS
ANGLES
BREAK SHARP EDGES MAX.
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0	AS-BUILT ENTIRE DRAWING FOR ESO FA1950	9/25/17	KTW	Jaw	Jaw	X	KAS
FA1	CERTIFIED FOR CONSTRUCION FOR ESO FA1950	X	X	X	X	X	X

REVISION OR ISSUE APPROVALS

DRAWING APPROVALS		DATE
DRW	D.HATTON	3/2/16
CHKR	G.DUNCAN	3/2/16
RE	G.DUNCAN	3/2/16
TR	N/A	
APPD	K.SIZEMORE	3/2/16

FOUR RIVERS NUCLEAR PARTNERSHIP, LLC

FLUOR. PADUCAH DEACTIVATION PROJECT
DOE Prime Contract #DE-DT0007774

GROUND WATER MONITORING WELLS INSTALLATION DETAILS

PRIORITY 3

SCALE	PLANT	BLDG	FL	CLASS
NONE	PGDP	N/A	N/A	U

ID FA1950 — C7DCWELLSA003 — REV 0

Sep 13, 2017