Department of Energy

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DEC 19 2019

PPPO-02-10002809-20

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

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

Dear Mr. Begley and Ms. Corkran:

TRANSMITTAL OF THE CERTIFIED FOR CONSTRUCTION REMEDIAL DESIGN REPORT FOR SWMU 211-A FOR VOLATILE ORGANIC COMPOUND SOURCES TO THE SOUTHWEST GROUNDWATER PLUME AT THE PADUCAH GASEOUS DIFFUSION PLANT, PADUCAH, KENTUCKY (DOE/LX/07-2435&D2)

References:

1. Letter from B. Begley to T. Duncan, "RE: Approval of the 90% Remedial Design Report for SWMU 211-A for Volatile Organic Compound Sources to the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant (DOE/LX/07-2435&D1), Paducah Site, Paducah, McCracken County, Kentucky, #KY8-890-008-982," dated December 6, 2019
2. Letter from V. Weeks to T. Duncan, "RE: U.S. Environmental Protection Agency Comments for the 90% Remedial Design Report for SWMU 211-A, to remediate Volatile Organic Compound Sources to the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, Primary Document (DOE/LX/07-2435&D1), transmittal date of November 7, 2019," dated December 5, 2019

Please find enclosed the *Certified for Construction Remedial Design Report for SWMU 211-A for Volatile Organic Compound Sources to the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-2435&D2, (RDR) for approval. This D2 version of the RDR incorporates U.S. Environmental Protection Agency (EPA) comments on the 90% RDR, received on December 5, 2019. A comment response summary addressing comments received from EPA on the 90% RDR is included to assist with the review of the RDR. The Kentucky Department for Environment Protection (KDEP) did not provide comments on the D1 90% RDR and approved the D1 90% RDR on December 6, 2019. In addition, the number of monitoring wells were corrected to reflect that nine new monitoring wells will be installed

(Sections 5.1 and 5.4). A redline comparison document also is provided that reflects the changes made between the 90% and D2 RDR.

In accordance with Section XX and Appendix F of the Paducah Federal Facility Agreement, EPA and KDEP have a 30-day review and comment period. The U.S. Department of Energy looks forward to EPA's and KDEP's approval of the D2 RDR.

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

Sincerely,

Tracey Duncan
Federal Facility Agreement Manager
Portsmouth/Paducah Project Office

Enclosures:

1. Certification Page
2. Professional Engineer's Certification
3. CFC RDR for SWMU 211-A, DOE/LX/07-2435&D2 – Clean
4. CFC RDR for SWMU 211-A, DOE/LX/07-2435&D2 – Redline
5. Comment Response Summary for 90% RDR—EPA

Administrative Record File—SWP-PD

cc w/enclosures:
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CERTIFICATION

Document Identification: ***Certified for Construction Remedial Design Report for SWMU 211-A for Volatile Organic Compound Sources to the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,*** **DOE/LX/07-2435&D2, dated December 2019**

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

Four Rivers Nuclear Partnership, LLC

12/19/19

Myrna E. Redfield, Program Manager
Four Rivers Nuclear Partnership, LLC

Date Signed

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

U.S. Department of Energy

Jennifer Woodard

12/19/19

Jennifer Woodard, Paducah Site Lead
Portsmouth/Paducah Project Office
U.S. Department of Energy

Date Signed

PROFESSIONAL ENGINEER'S CERTIFICATION

Document Identification: *Certified for Construction Remedial Design Report for SWMU 211-A for Volatile Organic Compound Sources to the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, **DOE/LX/07-2435&D2, dated December 2019**

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

Stefanie Fountain, PhD, PE (KY)
KY Professional Engineer #27930
Geosyntec Consultants, Inc.

12/18/2019
Date Signed

SEAL

STEFANIE
A. FOUNTAIN
27930

DOE/LX/07-2435&D2
Primary Document

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

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Primary Document

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

Date Issued—December 2019

U.S. DEPARTMENT OF ENERGY
Office of Environmental Management

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

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CONTENTS

FIGURES

TABLES

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ACRONYMS

amsl	above mean sea level
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CVOC	chlorinated volatile organic compound
DCE	dichloroethene
DHC	*Dehalococcoides ethenogenes*
DHG	dissolved hydrocarbon gases
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
EVO	emulsified vegetable oil
EVS-ES	Environmental Visualization Systems Expert System
FFA	Federal Facility Agreement
HU	hydrogeologic unit
KB-1® Plus	bacterial consortium containing *Dehalococcoides ethenogenes* microbial consortia capable of complete dechlorination of trichloroethene 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
mZVI	microscale zero-valent iron
OM&M	operations, maintenance, and environmental monitoring
OREIS	Oak Ridge Environmental Information System
ORP	oxidation-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
SMP	Site Management Plan
SWMU	solid waste management unit
TCE	trichoroethene
T/E/PP	trenching/excavation/penetration permit
TOC	total organic carbon
UCD	Upper Continental Deposits
UCRS	Upper Continental Recharge System
VOC	volatile organic compound

WAG	waste area grouping
ZVI	zero-valent iron

EXECUTIVE SUMMARY

This *Certified for Construction Remedial Design Report for SWMU 211-A for Volatile Organic Compound Sources to the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-2435&D2, (RDR) has been prepared for Upper Continental Recharge System (UCRS) source treatment using enhanced *in situ* bioremediation (EISB) with interim land use controls (LUCs) and UCRS and Regional Gravel Aquifer (RGA) groundwater sampling for the remedial action for Solid Waste Management Unit (SWMU) 211-A. This RDR was prepared in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) 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 UCRS and RGA 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 SWMU 211-A specified that the remedy in the UCRS soils to be implemented would be either EISB 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 RGA groundwater characterization (July 2015); issuance of an Addendum to the Final Characterization Report (DOE 2016); and Letter Notification in December 2015 (DOE 2015a). In August 2017, the FFA parties signed the *Memorandum of Agreement on the C-400 Complex under the Federal Facility Agreement for the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, that agreed that all projects (except Southwest Plume SWMU 211-A) would be resequenced in the fiscal year 2018 Site Management Plan (SMP) (DOE 2017). As a result of that agreement, the planned remedial activity for SWMU 211-B will not be included in this remedial design document. Future activities associated with SWMU 211-B, including developing additional CERCLA decision documents, if needed, will be reevaluated and resequenced as part of the PGDP SMP process(es).

The interim LUCs that were included in the signed ROD are in place and operating. The LUCs associated with SWMU 211-B will remain in place pending SWMU 211-B future activities determined during SMP development. The LUCs are being implemented through the use of the Paducah Site trenching/excavation/penetration permit program and posting of warning signs.

The remedial action to be implemented for SWMU 211-A was arrived at during the final remedial actions discussed in the May 23, 2018, presentation to the FFA parties. The presentation utilized in the May 23, 2018 meeting is located in the Environmental Information Center at following web address: https://eic.pad.pppo.gov/Search.aspx?accession=ENV 1.A-01526.

- SWMU 211-A—Enhanced *In Situ* Bioremediation with Interim Land Use Controls and groundwater sampling.

This RDR contains information regarding design of the EISB system and UCRS and RGA groundwater sampling system to be installed at SWMU 211-A. The following is information included in this document.

SWMU 211-A

- Select bioamendment(s) and bioaugmentation materials for use and evaluate subsurface environmental conditions present or to be created for EISB implementation. (Sections 2.1 and 4.2)
- Design bioamendment(s) mixtures and injection protocols for *in situ* treatment of the saturated UCRS target soils in the selected treatment area to an average depth of approximately 61 ft (maximum 65 ft) below ground surface. (Section 4.3)
- Design and create injection protocols for injection fracturing of the UCRS soils to allow for more effective delivery of injected materials. (Sections 4.3 and 4.4)
- Design and develop injection protocols for bioaugmentation materials and the appropriate sequencing of the injection activities to allow for the best success in stimulating EISB in the SWMU 211-A subsurface (UCRS soils). (Sections 4.3 and 4.4)
- 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. (Section 4.2)
- Select injection equipment and design the injection sequencing protocols. (Sections 4.3, 4.4 and 5)
- Design the monitoring system to be used in assessing the remediation process in the UCRS soils using key testing parameters. (Sections 4.3 and 6 and Appendix A)
- Design the performance and long-term groundwater (UCRS and RGA) sampling networks to monitor the progress of the UCRS remedial action through reduced VOC contaminant levels in the Regional Gravel Aquifer. (Section 6 and Appendix A)

1. INTRODUCTION

This *Certified for Construction Remedial Design Report for SWMU 211-A for Volatile Organic Compound Sources to the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-2435&D2, (RDR) has been prepared for source treatment using enhanced *in situ* bioremediation (EISB) with interim land use controls (LUCs) and Upper Continental Recharge System (UCRS) and Regional Gravel Aquifer (RGA) groundwater sampling as the remedial action for Solid Waste Management Unit (SWMU) 211-A. The remedy planned for the SWMU 211-A is documented in the *Record of Decision for Solid Waste Management Units 1, 211-A, 211-B, and Part of 102 Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-0365&D2 (DOE 2012a) (ROD).

The ROD specified that the remedy to be implemented for SWMU 211-A UCRS soils would be either EISB 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 (RDSI) in 2012–2013; performance of additional RGA groundwater characterization (July 2015); issuance of an Addendum to the Final Characterization Report (DOE 2016); and Letter Notification in December 2015 (DOE 2015a). In August 2017, the FFA parties signed the *Memorandum of Agreement on the C-400 Complex under the Federal Facility Agreement for the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* that agreed that all projects (except Southwest Plume SWMU 211-A) would be resequenced in the fiscal year 2018 Site Management Plan (SMP) (DOE 2017). As a result of that agreement, the planned remedial activity for SWMU 211-B will not be included in this remedial design document. Future activities associated with SWMU 211-B, including developing additional Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) decision documents, if needed, will be reevaluated and resequenced as part of Paducah Gaseous Diffusion Plant (PGDP) SMP process(es).

The interim LUCs that were included in the signed ROD are in place and operating. The LUCs associated with SWMU 211-B will remain in place pending SWMU 211-B future activities determined in SMP development. The LUCs are being implemented through the use of the Paducah Site trenching/excavation/penetration permit (T/E/PP) program and posting of warning signs.

An associated remedial action work plan (RAWP) also will be developed and will be used along with the approved RDR to implement the selected remedial action. The following is the final remedial action for SWMU 211-A as 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.

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 (RDWP) (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 Plan*, DOE/LX/07-1268&D2/R2/A1 (DOE 2015b).

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

- Site description (Section 1)
- Technology description (Section 2)
- Remedial action objectives (RAOs) (Section 3)
- Design requirements (Section 4)
- Process Description (Section 4)
- Construction requirements (Section 5)

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. Bordering PGDP to the northeast, between the PGDP 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.

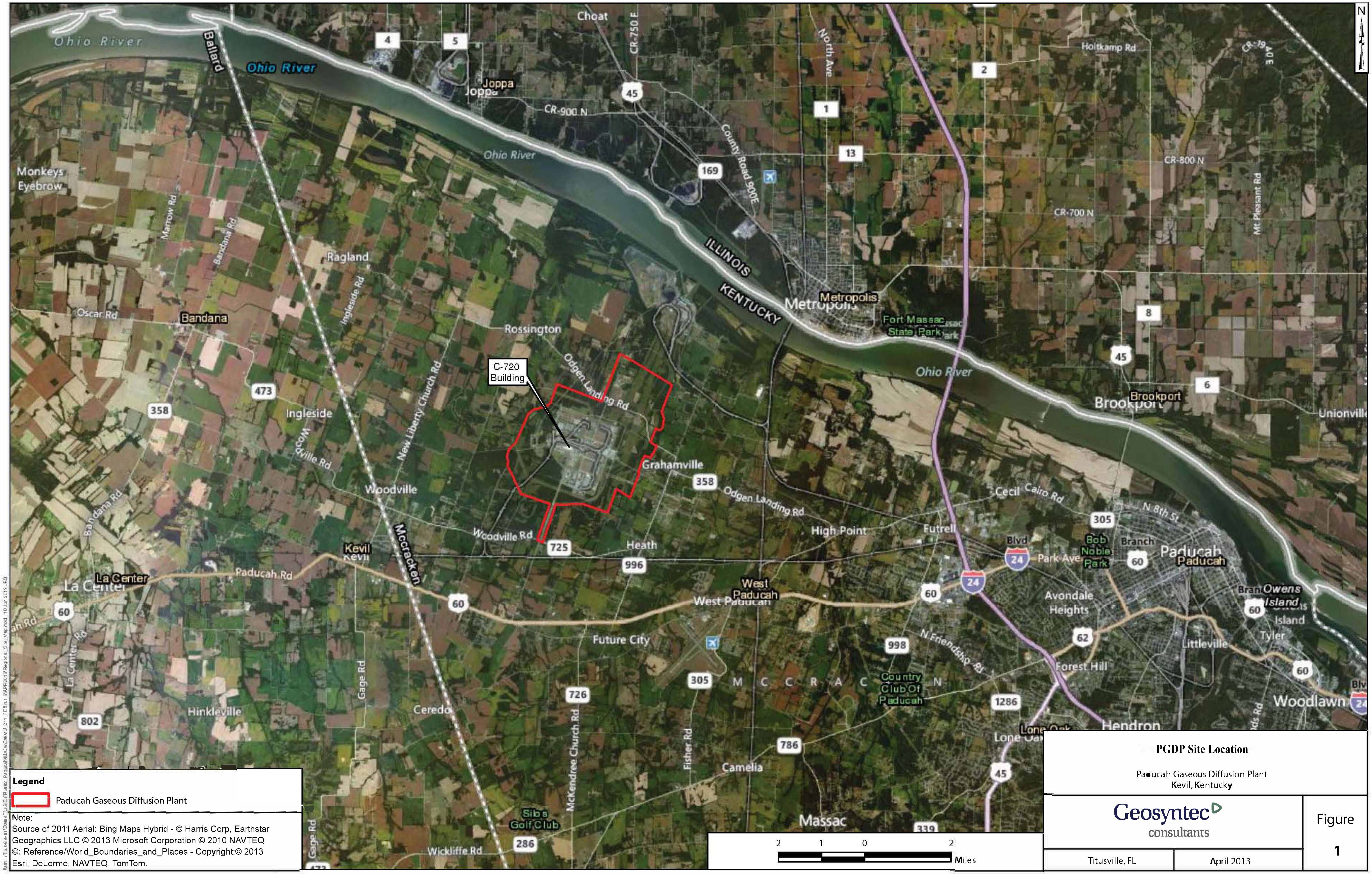
Before PGDP was constructed, a munitions production facility, the Kentucky Ordnance Works, was operated at the current PGDP location and at an adjoining area southwest of the site. Munitions, including trinitrotoluene, were manufactured and stored at Kentucky Ordnance Works between 1942 and 1945. Construction 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 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 Waste Area Grouping (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 (referred to as the Southwest Plume) is trichloroethene (TCE). Other contaminants found in the plume include additional volatile organic compounds (VOCs), metals, and the radionuclide, technetium-99 (Tc-99).

DOE conducted a site investigation (SI) in 2004 to address 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, 211-A, and 211-B Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-0362&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 SWMU 211-A also was performed in 2015 before the FFA parties decided to proceed with implementing the remedial action 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.



Legend

🟥 Paducah Gaseous Diffusion Plant

Note:
Source of 2011 Aerial: Bing Maps Hybrid - © Harris Corp, Earthstar Geographics LLC © 2013 Microsoft Corporation © 2010 NAVTEQ ©; Reference/World_Boundaries_and_Places - Copyright:© 2013 Esri, DeLorme, NAVTEQ, TomTom.

2 1 0 2
Miles

PGDP Site Location

Paducah Gaseous Diffusion Plant
Kevil, Kentucky

Geosyntec consultants

Titusville, FL

April 2013

Figure
1

Figure 1. PGDP Site Location

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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.

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 ft 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 UCD, 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). RGA 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 ft to 351 ft amsl; less prevalent deposits occur at elevations of 337 ft to 341 ft amsl. UCRS groundwater flow is primarily 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, UCRS groundwater flow and contaminant migration through the upper 45 ft to 55 ft of subsurface soil (UCD) is primarily 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 metals and radionuclides, retarding the migration of these contaminants in UCRS 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 or diffusion into fine-grain sediments, if present. To date, none of the investigations in the SWMU 211-A area have identified the presence of any 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 below ground surface (bgs) in depth with a range of 2 ft to 50 ft. Additional discussion for UCRS groundwater is included later in this section as part of the “Study Area Hydrogeology” subsection.

Downward vertical hydraulic gradients generally range from 0.5 ft 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 15 slug tests in a previous investigation (CH2M HILL 1992) in wells across the PGDP site. The field (horizontal) measured hydraulic conductivity of the UCRS sands was 3.4E-05 centimeters per second (cm/s) at the C-720 Building [1.3E-05 inches/second (in/s)] as measured in MW204 located at the northeast corner of the C-720 Building. Measurements of the vertical hydraulic conductivity of the UCRS silt and clay units are not available for the C-720 Building; measurements (laboratory) 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) bgs 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 RGA 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 ft 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%) (DOE 2013).

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 ft 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).

Study Area Hydrogeology. The Southwest Plume SI included soil sampling within the upper 60 ft of SWMU 211-A. 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 borings were terminated at a depth of 60 ft bgs as planned. Although the final interval sampled 55 ft to 60 ft often revealed a noticeable increase in grain size and a significant increase in moisture content, which is consistent with trends near the top of the RGA.

The UCRS has a downward vertical hydraulic gradient that ranges from 0.5 to 1 ft/ft where measured in MWs completed at different depths in the UCRS (DOE 2013). In this setting, measurement of the potentiometric surface requires a good distribution of MWs and piezometers with water and screened at a common elevation or a good distribution of clusters of MWs and piezometers with water to define area-specific vertical hydraulic gradients. A sufficient number of UCRS MWs and piezometers does not exist to measure the UCRS potentiometric surface at the Paducah Site; therefore, it is not realistically feasible to generate a potentiometric map for the UCRS.

Two UCRS wells, MW204 and MW512, and UCRS well cluster, MW511/MW513, are located in the immediate area of SWMU 211-A. Table 1 provides their screen depths and range of measured depth-to-water levels over time. These data indicate water levels in and near the treatment area are shallow (as shallow as 5 ft bgs) and the treatment zone likely is saturated and suitable for EISB.

Table 1. Existing UCRS Monitoring Wells and Water Levels

Monitoring Well Number	Year Constructed	Monitoring Point Elevation, Ft (amsl)	Screened Interval, Ft	Range of Measured Depths to Water, Ft	Number of Measurements
MW204	1992	378.06	49–54	40.2–46.9	25
MW511	2012	376.82	10–15	4.8–7.2	3
MW512	2012	377.59	18–28	26.3–28.3	3
MW513	2012	376.82	37–42	26.0–26.9	3

1.2 TREATMENT SITE LOCATIONS

The treatment location for implementing the remedial action at SWMU 211-A is located in the southwestern portion of the Paducah Site. Specifically, SWMU 211-A is located near the northeast corner of the C-720 Building; it is shown in Figure 2 and is the focus of this RDR.

A number of active and inactive utilities are located in and around SWMU 211-A. See Figure 3 for locations of nearby utilities associated with SWMU 211-A. A currently 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, it is expected that injection points will require field adjustment due to utility infrastructure. If feasible without extensive decontamination, minor infrastructure will be evaluated for removal to assist in implementing the remedial action.

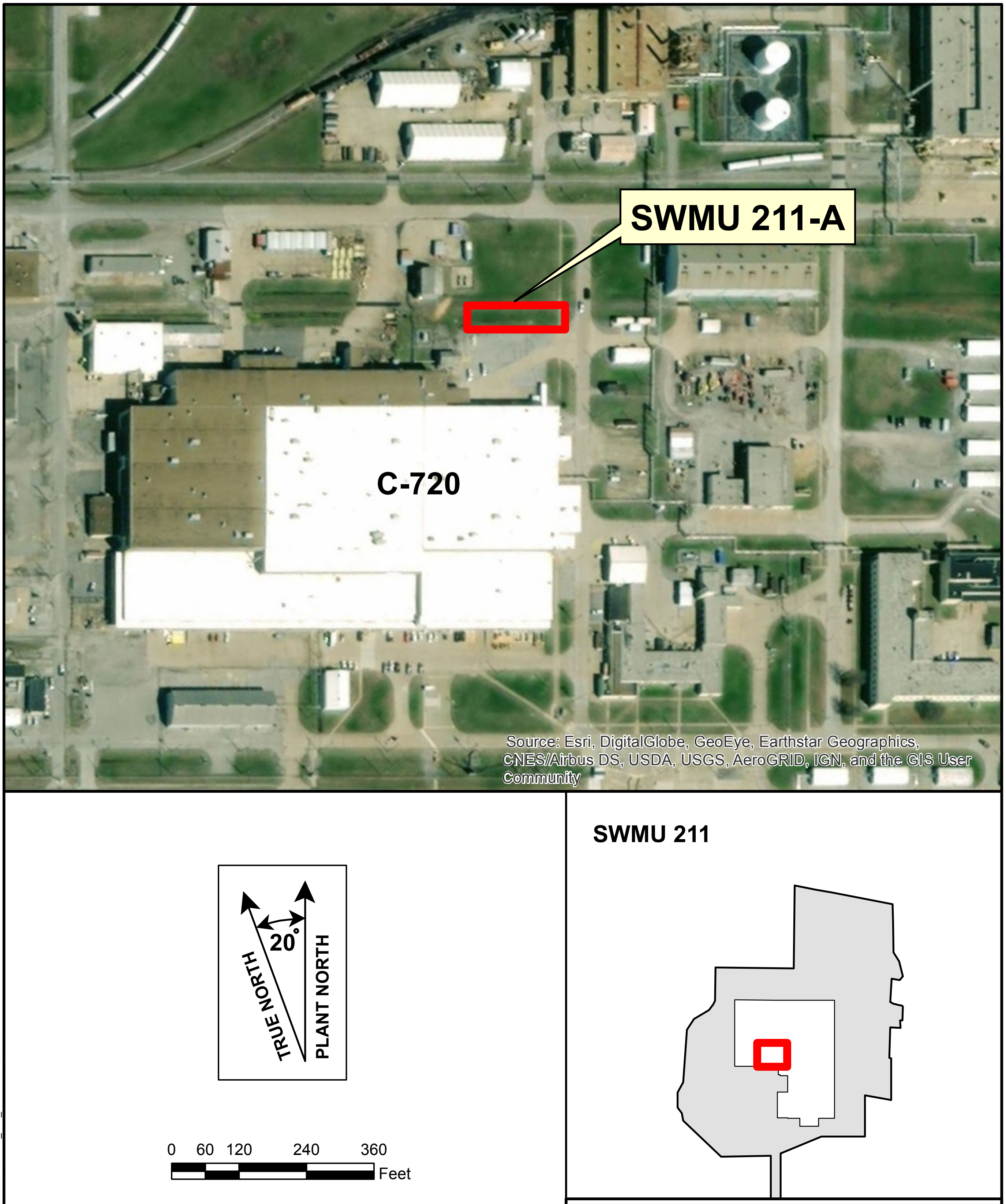
1.3 REMEDIAL DESIGN SUPPORT INVESTIGATION (FINAL CHARACTERIZATION) AND MASS ESTIMATES

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 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 that included SWMU 211-A UCRS soils was performed during the last half of 2012. 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 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 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 action for UCRS soils at SWMU 211-A for this RDR.

- SWMU 211-A—Enhanced *In Situ* Bioremediation with Interim Land Use Controls including groundwater sampling.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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

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Figure 2. SWMU 211-A Location

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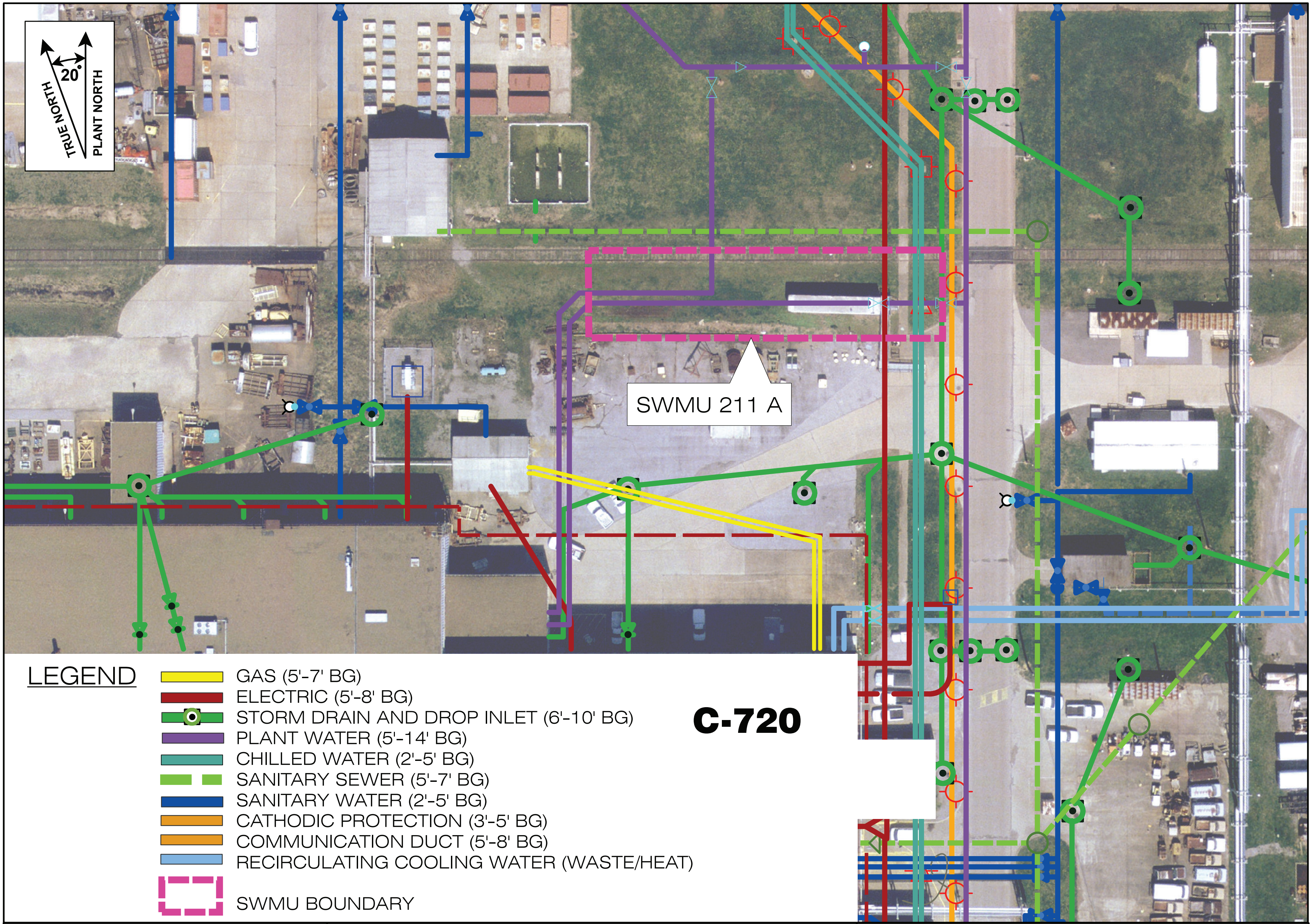

Figure 3. SWMU & Utility Map
C-720
SWMU 211-A

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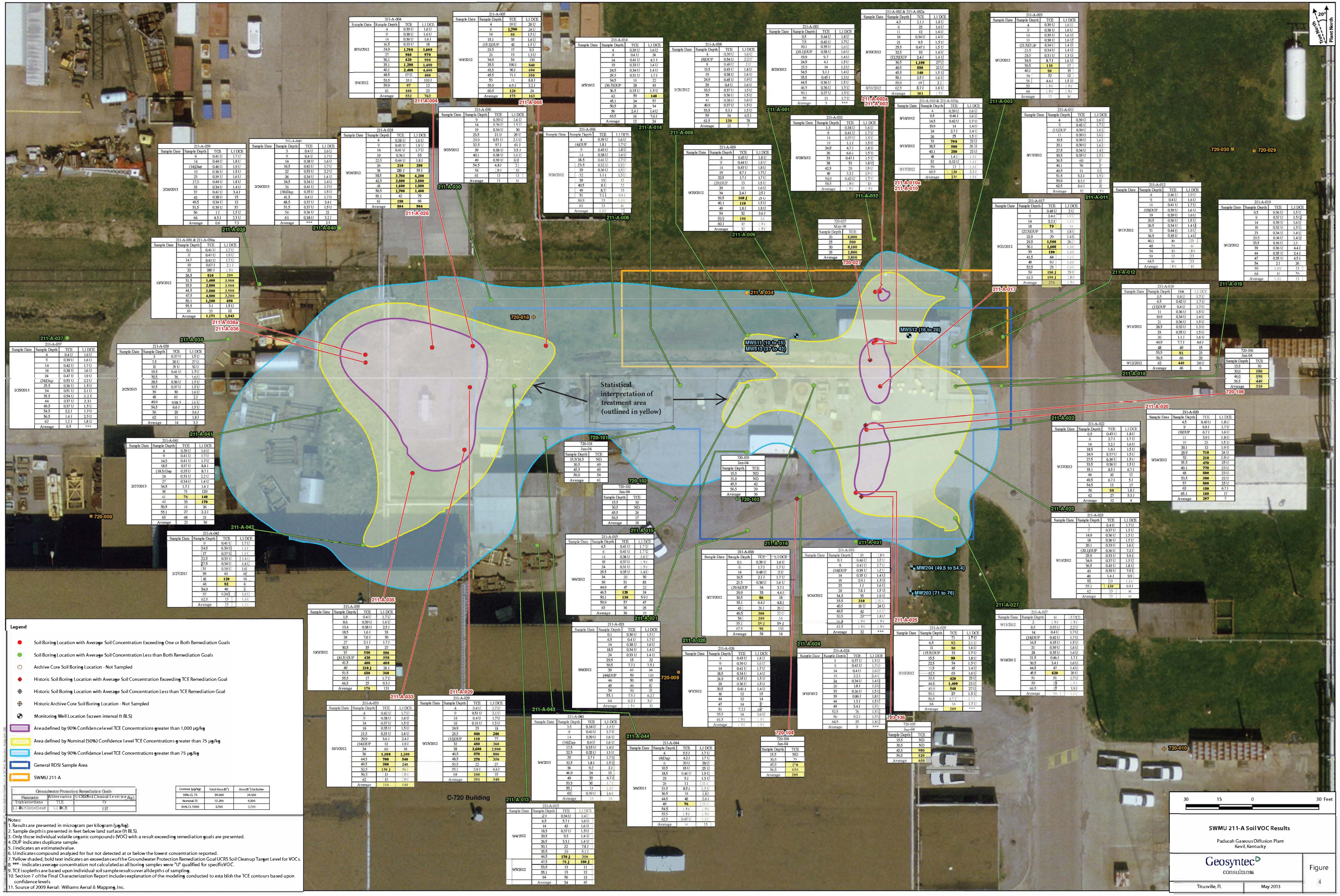
PADUCAH GASEOUS DIFFUSION PLANT

This plan was documented in a presentation to the FFA parties in May 2018 (DOE 2018).

SWMU 211-A

Forty-two direct-push technology (DPT) soil boring locations (30 original, 12 contingency), shown in Figure 4, 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 readings for each 5-ft soil core for VOC analysis. A total of 541 soil samples were collected from the 42 soil boring locations. Figure 4 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 (DOE 2012a)] are noted by yellow highlight. As shown in Figure 4, there are two distinct areas with higher contamination levels. Both areas in SWMU 211-A will be addressed in this RDR and by implementing the EISB remedial action. The source(s) of the VOC contamination, which is the subject of the SWMU 211-A remedial action, is not known. The C-720 Building is a maintenance and machine shop facility, and SWMU 211-A is located outside of the northeast portion of the building. As documented in previous reports concerning SWMU 211-A, the suspected source of the contamination is from spill(s) of TCE that occurred during routine equipment cleaning and rinsing performed in the area (DOE 2013).

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 PGDP 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 impacts for SWMU 211-A are illustrated in Figure 4 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).



Legend

- ● 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
- ▭ General RDSI Sample Area
- ▭ SWMU 211-A

Groundwater Protection Remediation Goals		
Parameter	Abbreviation	UCRS Soil Cleanup Level (µg/kg)
Trichloroethene	TCE	75
1,1-Dichloroethene	1,1 DCE	137

Contour (µg/kg)	Total Area (ft²)	Area (ft²) Exclusive
90% CL 75	34,000	24,500
Nominal 75	13,200	9,500
90% CL 1000	3,700	3,700

Notes:
1. Results are presented in microgram per kilogram (µg/kg).
2. Sample depth is presented in feet below land surface (ft BLS).
3. Only those individual volatile organic compounds (VOC) with a result exceeding remediation goals are presented.
4. DUP indicates duplicate sample.
5. J indicates an estimated value.
6. U indicates compound analyzed for but not detected at or below the lowest concentration reported.
7. Yellow shaded, bold text indicates an exceedance of the Groundwater Protection Remediation Goal UCRS Soil Cleanup Target Level for VOCs.
8. *** - indicates average concentration not calculated as all boring samples were "U" qualified for specific VOC.
9. TCE isopleths are based upon individual soil sample results over all depths of sampling.
10. Section 7 of the Final Characterization Report includes explanation of the modeling conducted to establish the TCE contours based upon confidence levels.
11. Source of 2009 Aerial: Williams Aerial & Mapping, Inc.

SWMU 211-A Soil VOC Results

Paducah Gaseous Diffusion Plant
Kevil, Kentucky

Geosyntec consultants

Titusville, FL | May 2013

Figure 4

Figure 4. SWMU 211-A Soil VOC Results (Adapted from DOE 2013)

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2. TREATMENT TECHNOLOGY

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 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 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 chlorinated 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 chlorinated 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 biodegradation products consisting of dichloroethene (DCE)[1] and vinyl chloride, and then to ethene (i.e., ethene is fully reduced TCE with no chlorine molecules, but it also can be transformed to ethane *in situ*). Ethene is the primary end product of this process and is considered harmless. Figure 5 shows the pathway for reductive dechlorination of TCE; the figure also shows 1,1-DCE reduction, which follows a similar reductive pathway as TCE.

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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.

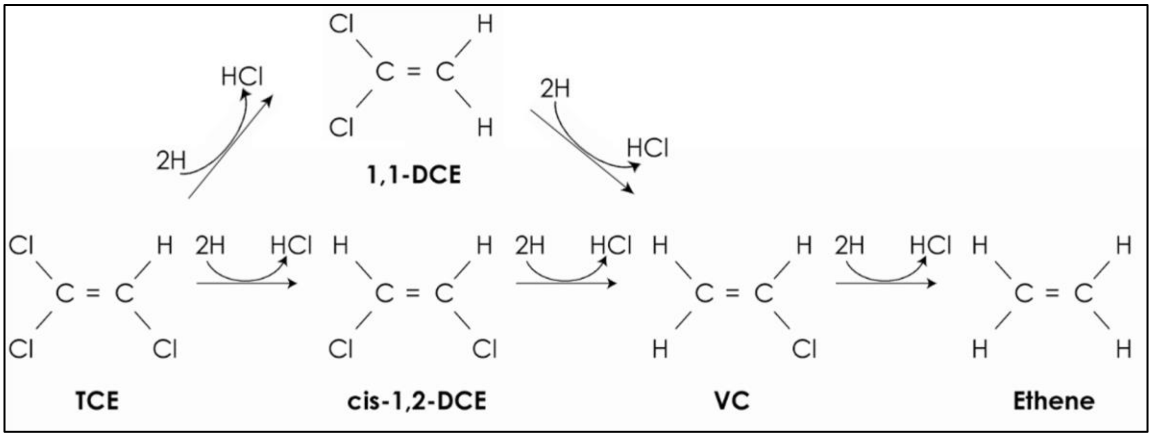

Figure 5. Pathway for Reductive Dechlorination of TCE and 1,1-DCE

EISB involves addition of biostimulants, such as electron donors [e.g., emulsified vegetable oil (EVO), sodium lactate, zero-valent iron (ZVI), etc.], and sometimes 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) and/or robust biodegradation by bacteria added to the aquifer (i.e., bioaugmentation).

The remedial action at SWMU 211-A will be focused on the UCRS; treatment of VOCs in the UCRS is expected 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 using injection 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 an MW network to monitor the progress of the EISB (performance monitoring) and provide for long-term monitoring of the VOCs migrating from the UCRS to RGA groundwater. The performance and long-term monitoring networks will consist of a series of MWs that will be screened in the middle and lower UCRS and in the upper and middle RGA. Historical potentiometric maps prepared and included in the *Trichloroethene and Technetium-99 Groundwater Contamination in the Regional Gravel Aquifer for Calendar Year 2016 at the Paducah Gaseous Diffusion Plant, Paducah Kentucky*, FPDP-RPT-0079, (FPDP 2017) and the *Trichloroethene and Technetium-99 Groundwater Contamination in the Regional Gravel Aquifer for Calendar Year 2018 at the Paducah Gaseous Diffusion Plant, Paducah Kentucky*, FRNP-RPT-0074, (FRNP 2019) are included as Figures 6, 7, and 8. Figures 6, 7, and 8 show the RGA potentiometric surface in the area of SWMU 211-A for the time periods August 2016, August 2017, and August 2018, respectively. These potentiometric maps indicate that RGA groundwater flow from August 2016 to August 2018 varied from north to northeast. As a result of the observed fluctuation in flow

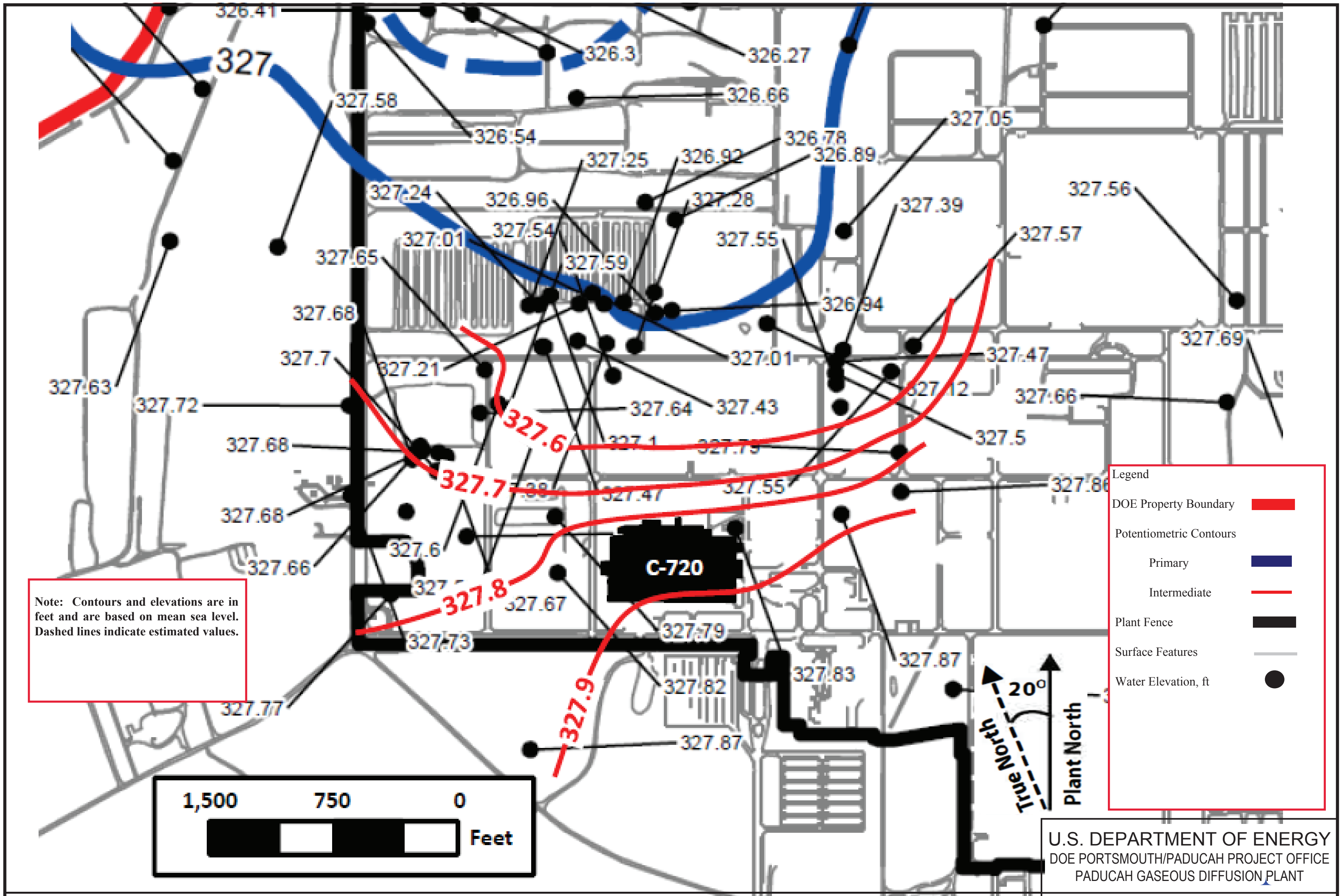

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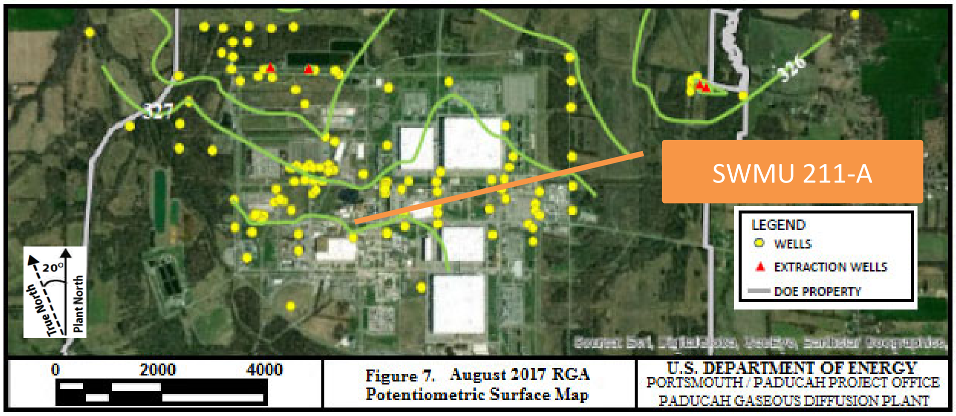
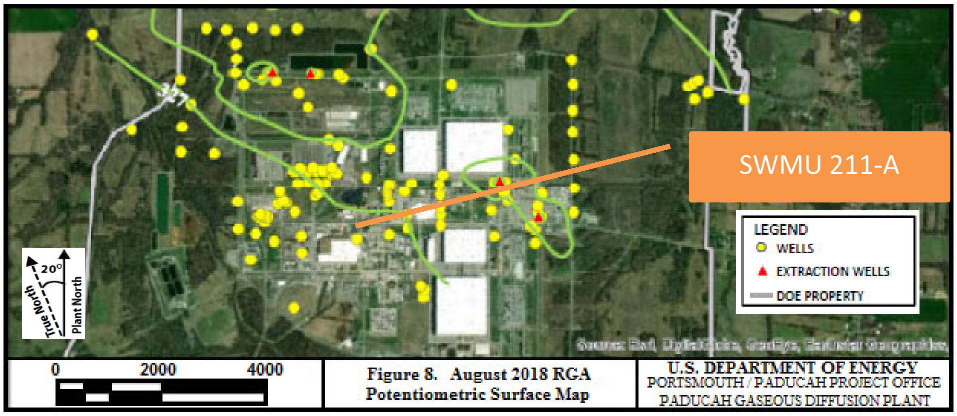
Figure 6. Regional Gravel Aquifer Potentiometric Map in C-720 Building Area (August 2016) – Adapted from Figure 10 of DOE 2017



Adapted from Figure 11, *Trichloroethylene and Technetium-99 Groundwater Contamination in the Regional Gravel Aquifer for Calendar Year 2018 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* FRNP-RPT-0074, June 2019.



Adapted from Figure 12, *Trichloroethylene and Technetium-99 Groundwater Contamination in the Regional Gravel Aquifer for Calendar Year 2018 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* FRNP-RPT-0074, June 2019.

directions and because there is uncertainty in future changes in flow direction (i.e., flow may revert to a more northerly direction), the long-term monitoring network must be designed to address this potential variation in flow direction. The network will provide both upgradient and downgradient groundwater samples at SWMU 211-A. Further details of the network are included in Section 4, and the monitoring program is described in Section 6.

2.1 SWMU 211-A GROUNDWATER GEOCHEMISTRY

EISB via reductive dechlorination is an appropriate technology for remediation of the chlorinated volatile organic compounds (CVOCs) in UCRS groundwater at SWMU 211-A, as indicated by (1) geochemical indicator parameters within the acceptable range for this technology to be effective and (2) existing data that indicates reductive dechlorination already is occurring in groundwater in the UCRS. Historical and recent groundwater data from the UCRS in SWMU 211-A is available for MW204, MW511, MW512, and MW513, and a summary of groundwater data for selected parameters is presented in Table 2. The locations of these MWs are shown on Figure 4. The October 2012 samples presented in Table 2 are the most recent available data collected by DOE for UCRS wells in SWMU 211-A.

Groundwater samples from the UCRS in and around SWMU 211-A show evidence of ongoing reductive dechlorination based on the presence of degradation products of TCE in groundwater. In October 2012, *cis*-1,2-DCE was detected at concentrations up to 18 µg/L at MW204; 1,1-DCE was detected at concentrations up to 810 µg/L at MW513; and *trans*-1,2-DCE was not detected above the reporting limit in samples from these wells. Microbially mediated reductive dechlorination results in primarily *cis*-1,2-DCE, whereas *trans*-1,2-DCE is primarily manufactured for industrial use. A predominance of *cis*- over *trans*-1,2-DCE, as exhibited in samples from MW204, MW511, MW512, and MW513, is an indication that biodegradation is occurring, and that conditions in portions of the UCRS are favorable for biodegradation of TCE. These groundwater data also indicate that complete reductive dechlorination is occurring in some areas in the subsurface due to the presence of ethene and ethane (e.g., 0.32 µg/L ethene and 0.41 µg/L ethane at MW511 in October 2012). Ethene often is the final reductive dechlorination product for chlorinated ethenes and also can be transformed further to ethane *in situ*. Analysis of dissolved gases in UCRS groundwater from MW511, MW512, MW513, and MW204 also detected methane, which indicates the presence of reducing conditions appropriate for reductive dechlorination.

The UCRS groundwater data also indicate that reductive dechlorination currently is incomplete or progressing slowly at SWMU 211-A because the concentrations of ethene and ethane are low, relative to the concentrations of TCE, *cis*-1,2-DCE, and 1,1-DCE. Groundwater sampling for *Dehalococcoides ethenogenes* (DHC), the only known bacterial species that can facilitate complete degradation of TCE to ethene, was conducted in the UCRS in MW511 and MW513 in 2012. DHC bacteria were not detected above the reporting limit; a low DHC population can result in slow or incomplete reductive dechlorination of the CVOCs. This condition is mitigated by bioaugmentation with the KB-1® Plus microbial consortium (or approved[2] equivalent) that contains, among other important organisms, the essential DHC bacteria.

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[2] KB-1® Plus is intended to be the bacterial culture used for this remedial action but flexibility to use an approved equivalent is included in this design if, for an unforeseen reason, KB-1® Plus is unavailable or cannot be used. If an alternate to KB-1® Plus is used, then the change will be discussed with the FFA parties in advance. Throughout this report, when an approved or acceptable substitution is discussed, the FRNP Project Manager will approve or disapprove the recommended equal. A periodic (weekly) teleconference will be scheduled with the FFA parties during the fieldwork period to discuss the status of activities and modifications that may have been made or are being considered. A Field Change Request form (Appendix B) and logbooks will be used to document field changes. The modifications made will be reported in the remedial action completion report.

Table 2.
SWMU 211-A Groundwater Data for Selected Parameters in UCRS Wells

Method Group	Parameter	Units	MW204 9/5/2012	MW204 9/12/2012	MW204 9/18/2012	MW204 10/22/2012	MW511 10/22/2012	MW512 10/23/2012	MW513 10/22/2012
Volatile Organic Compounds									
	1,1-dichloroethene	µg/L	15 D	17	-	16	5 U	5 U	810 D
	cis -1,2-dichloroethene	µg/L	17 D	17	-	18	2.6	1.2	12 D
	trans -1,2-dichloroethene	µg/L	2 U	1 U	-	1 U	1 U	1 U	10 U
	Trichloroethene	µg/L	56 DJY	61	-	76	10	34	220 D
	Vinyl chloride	µg/L	4 U	2 U		2 U	2 U	2 U	20 U
Dissolved Gases									
	Ethane	µg/L	0.039	-	0.022 J	0.012 J	0.41	0.03	0.33
	Ethene	µg/L	0.1	-	0.031	0.02 J	0.32	0.01 J	0.12
	Methane	µg/L	2.6	-	0.47	0.16	0.86	0.48	1.3
Biological									
	Dehalococcoides ethenogenes	cells/mL	-	-	-	-	43 U	-	17 U
Inorganic Ions									
	Chloride	mg/L	88	87	-	90	3.9	-	92
	Iron	mg/L	1.38	1.62	-	1.96	2.35	-	0.77
	Iron, dissolved	mg/L	0.326	0.177	-	0.325	0.115	-	0.1 U
	Nitrate	mg/L	5.4	5.1	-	5.4	3 U	-	3 U
	Sulfate	mg/L	49	47	-	48	66	-	22
Field Geochemical Parameters									
	Dissolved oxygen	mg/L	1.08	2.03	1.6	1.09	3.2	5.14	0.92
	Oxidation reduction potential	mV	285	527	542	323	652	411	389
	pH	SU	6.08	6.12	6.48	5.97	6.19	6.91	6.48

Notes:

1. µg/L = micrograms per liter; cells/mL = cells of *dehalococcoides ethenogenes* per milliliter water; mg/L = milligrams per liter; mV = millivolts; SU = standard units
2. U = Analyte result is less than the reporting limit
3. D = Compounds identified in an analysis at a secondary dilution
4. J = Indicates an estimated value
5. Y = Matrix spike, matrix spike duplicate, and/or relative percent difference failed acceptance criteria

Other important parameters to assess suitability of the groundwater for reductive dechlorination include inorganic ions such as nitrate and sulfate; high concentrations of these ions can result in an excessive electron donor demand in the aquifer, potentially slowing reductive dechlorination. Groundwater pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and dissolved iron concentrations also deserve consideration. The samples collected in September and October 2012 represent the most recent available data collected by DOE for nitrate, sulfate, iron, and field geochemical parameters (e.g., pH, DO, and ORP) from UCRS wells in SWMU 211-A. UCRS Groundwater conditions in SWMU 211-A for these parameters are discussed below.

- The pH range for these wells is in the optimal range for biological activity between 6 and 8.

- Nitrate was not detected in MW511 and MW513, and sulfate concentrations were low—66 mg/L and 22 mg/L, respectively.

- Dissolved iron was less than total iron in these wells, indicating slightly oxidizing conditions. Further evidence for slightly oxidizing conditions is the measured values for DO and ORP. The DO ranged from 0.92 mg/L at MW513 to 5.14 mg/L at MW512. The ORP ranged from 285 mV at MW204 to 652 mV at MW511.

Electron donor and ZVI addition, as proposed in this design, will result in decreasing DO and ORP levels and reducing the iron and sulfate as part of conditioning the aquifer for rapid and complete microbially mediated reductive dechlorination.

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 that are consistent with those contained in the ROD.

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 4 indicates the treatment area for EISB of SWMU 211-A. Table 3 provides the soil protection cleanup levels for SWMU 211-A.

Table 3. UCRS Soil Cleanup Levels for VOCs for Groundwater Protection and Worker Protection at the C-720 Source Area

VOC	Half-Life (year)	Basis for Cleanup Level—Primary MCL (mg/L)	UCRS Soil Cleanup Level (mg/kg)
C-720 Northeast (SWMU 211-A)			
TCE	50	5.00E-03	7.50E-02
1,1-DCE	infinite	7.00E-03	1.37E-01
cis-1,2-DCE	infinite	7.00E-02	6.19E-01
trans-1,2-DCE	infinite	1.00E-01	5.29E+00
Vinyl chloride	infinite	2.00E-03	5.70E-01

Notes:

1. Modified from ROD Tables 17 and 19 for UCRS Soil Cleanup Levels for VOCs for protection of groundwater (DOE 2012a).
2. Analyses show that attaining the cleanup goals for protection of groundwater would yield residual risks (i.e., risks after the cleanup goals are attained) to the worker near the lower end of the EPA acceptable risk range under default rates of exposure. Similarly, residual hazard levels also would be below 1 under default rates of exposure. The cleanup goals that are protective of the groundwater also will protect the worker. The groundwater protection cleanup levels provided were calculated for TCE in UCRS soils with a 50 years half-life to incorporate the effects of degradation on overall remedy time frames (50 years essentially representing no observable degradation). Other VOCs were assumed not to be degraded (DOE 2012a).

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 (DOE 2012a).

4. TECHNICAL DESIGN

4.1 TECHNICAL JUSTIFICATION FOR SELECTION OF REMEDIAL TECHNOLOGY

The following is the selected remedial action technology for SWMU 211-A, as documented in the 2012 ROD and as determined by the FFA parties.

- SWMU 211-A—Enhanced *In Situ* Bioremediation with Interim Land Use Controls and groundwater sampling.

Below are several technical factors that form the basis for selecting bioremediation for SWMU 211-A UCRS soils and groundwater. 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. Reductive dechlorination is a well-established technology for the treatment of CVOCs in soils and groundwater (AFCEE 2004; ITRC 2007; ITRC 2008). As discussed in Section 2, biologically mediated reductive dechlorination is ongoing in portions of SWMU 211-A, as indicated by the presence of *cis*-1,2-DCE and 1,1-DCE in groundwater in the UCRS.

- Investigations at SWMU 211-A have shown that TCE concentrations are acceptable for bioremediation. TCE has been detected in soil in SWMU 211-A at concentrations up to 8,100 µg/kg at historic soil boring 720-027 (Figure 4). In UCRS groundwater, TCE has been detected at concentrations up to 220 µg/L (Table 2), which is approximately 0.02% of solubility (approximately 1,100 mg/L). Bioremediation is a viable technology even for DNAPL concentrations of the CVOCs, although it is a slower process to degrade free product biologically (ITRC 2007; ITRC 2008). The concentrations of TCE in UCRS soil and groundwater indicate TCE concentrations are significantly below DNAPL concentrations and, therefore, bioremediation is expected to proceed rapidly.

- UCRS groundwater at SWMU 211-A is slightly oxidizing, based on field geochemical parameters measured in 2012 (Table 2). Reducing conditions, however, are inferred to exist in some areas because there is evidence of ongoing reductive dechlorination of TCE; for example there is *cis*-1,2-DCE in UCRS groundwater as discussed in Section 2. Amendment delivery will drive the UCRS groundwater to be more reducing and enhance these biodegradation processes by delivering the essential microbial consortium easily and by providing electron donor and ZVI that condition the groundwater geochemistry by reducing DO and ORP and providing a source of carbon for bioremediation. Concentrations of the dissolved gases ethene and ethane detected in groundwater also indicate that reductive dechlorination of the CVOCs is going to completion in some locations in SWMU 211-A. Methane also was detected in UCRS groundwater samples (Table 2), indicating some areas within the UCRS have reducing conditions appropriate for effective reductive dechlorination.

- Bioremediation is a destructive technology, converting TCE (and TCE breakdown products) to ethene and ethane to innocuous products of reductive dechlorination.

Please refer to Section 2.1 for a more detailed discussion of these technical factors and the data supporting the use of bioremediation for CVOCs at SWMU 211-A.

4.2 CRITICAL PARAMETERS

Critical parameters for the remedial actions being implemented at SWMU 211-A 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 Section 4.2.1 describe parameters that are critical to the success of the selected remedial action and the desired outcome of the technology application.

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

Critical parameters for EISB include the physical properties of the geologic formation, the chemical properties of the groundwater system, selection of amendments to inject into the treatment zone, and injection design parameters such as injection well spacing and amendment dosing. 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 uniform distribution of injected amendments and can decrease the radius of influence (ROI) for injection wells. The proposed treatment approach, therefore, includes an initial step of injecting a slurry containing sand and microscale zero-valent iron (mZVI) as proppants using DPT jet injection to create lenses with higher permeability within the UCRS. After injection of the sand-mZVI lenses is complete, injection wells will be installed in contact with the sand-mZVI lenses. This approach will improve the horizontal distribution of EISB amendments. These techniques are described in more detail in Section 4.4.

Groundwater Geochemistry: TCE is treated by EISB when DHC bacteria facilitate an aqueous reduction reaction as described in Section 2.1. 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 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 DO concentrations in groundwater. The transformation of TCE to ethene is a reduction reaction, so a reducing environment (i.e., negative 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 a neutral pH of 7 standard units; the ideal pH for EISB is between approximately 6 and 8 standard units. In addition, the bacteria require an electron donor, which is provided from EVO, to facilitate the reduction process. Field monitoring will measure total organic carbon (TOC) in groundwater, which then will be used as a surrogate measurement for electron donor available to bacteria. The bacteria will facilitate the transfer of electrons from the electron donor to the electron acceptor (for this site, electron acceptors are TCE, *cis*-1,2-DCE, and vinyl chloride). This electron transfer releases chlorine from the electron acceptor, thereby bioremediating the chlorinated compounds (see Figure 5). Table 4 is a matrix that summarizes groundwater parameters, their relation to groundwater geochemistry, and the ideal range for EISB. Additional information about how these parameters will be monitored at SWMU 211-A is provided in Section 4.3.2.

Table 4. Groundwater Parameters Matrix

Parameter	Purpose for Measuring	Ideal Range for EISB
DO	Assess whether groundwater is anaerobic	< 1 mg/L
ORP	Assess whether groundwater is reducing	< -100 mV
pH	Assess whether groundwater is hospitable for bacterial activity	6 to 8 standard units
TOC	Surrogate measurement indicating the amount of electron donor in groundwater that is available to bacteria for EISB	> 10 mg/L
Nitrate, sulfate, dissolved and total iron*	Another measure of groundwater redox as well as the natural demand for the amendments	Low nitrate, sulfate Iron in the dissolved state
DHC population	Count of the number of bacteria in groundwater that can reduce TCE to ethene	> 10^7 cells/liter

Table 4. Groundwater Parameters Matrix (Continued)

Parameter	Purpose for Measuring	Ideal Range for EISB
Dissolved hydrocarbon gases [(DHG) ethene, ethane and methane]	Ethene and ethane are products of complete TCE reduction; methane indicates groundwater redox is in acceptable range for EISB.	Not required for EISB to occur— no target range.

*Nitrate, sulfate, and dissolved and total iron are parameters that typically are measured only before implementing EISB to understand groundwater conditions prior to implementing the remedial action. The oxidized and reduced forms of these parameters are used to track redox conditions in groundwater (e.g., if iron is in the dissolved phase, then groundwater redox is at or below iron reducing condition).

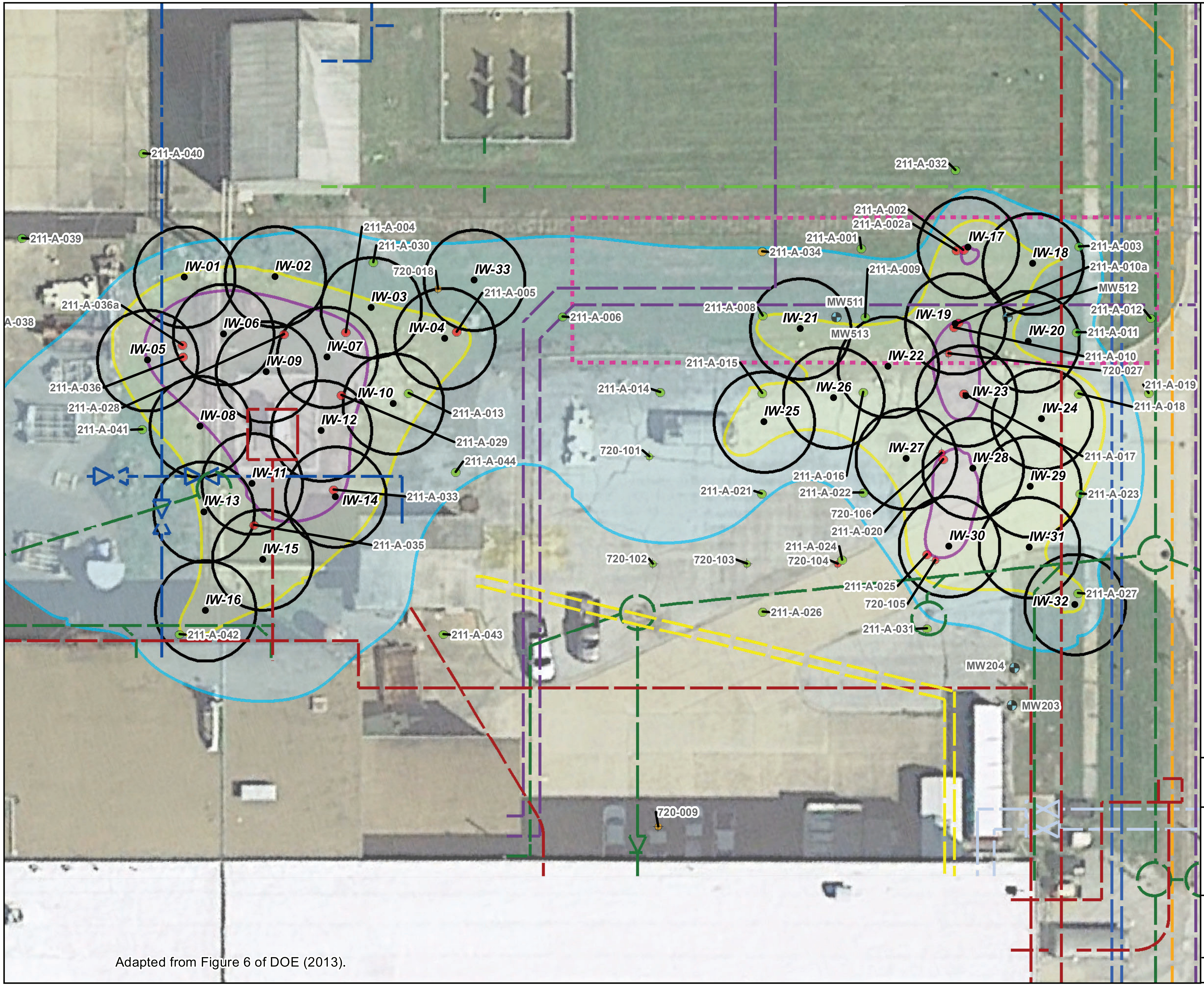
Water Used for EISB Amendment Delivery: The remedial design considers the geochemistry of process water that can affect EISB. This section specifically discusses water that will be used as a carrier fluid for delivering amendments and bacteria. Water used for amendment delivery will be sourced from an on-site potable water supply, as discussed in Section 5.3.

In order to ensure preservation of the bioaugmentation consortium, the carrier fluid ideally should have DO less than 1 mg/L, ORP below -100 mV, and pH between 6 and 8. If necessary, water used for amendment delivery can be treated with a priming agent (e.g., KB-1® Primer or an approved equivalent) that removes DO, decreases ORP, and removes residual chlorine from treated water, thereby making the water more hospitable for the anaerobic bacteria. Batches of anaerobic water will be prepared prior to blending with amendments/bacteria and injection into the injection wells. Sometimes a pH buffer such as sodium bicarbonate is also added to the water used for amendment delivery. The buffer raises the pH into a range ideal for the bacteria and counteract pH decrease that can occur during EISB. The addition of a pH buffer is not proposed for SWMU 211-A because the DPT jet injection component of the design uses a mixture of sand and mZVI as the proppant (described below). The mZVI will counteract pH decreases during EISB because the reaction of mZVI with water creates hydroxide ions that increase pH (Gillham and O'Hannesin 1994; Reardon 1995: ITRC 2011: Luna et al. 2015). Adjustments to this approach will be implemented if the groundwater geochemical parameters (DO, ORP, pH), based on field measurements, indicate that favorable conditions are not being generated under the current approach.

Water Used for Jet Injection: The required chemistry of water used for the jet injection phase of the remedial action is less stringent than the water requirement for the EISB amendment delivery phase of the work because additives used in the jet injection process, mainly mZVI and guar gum, will create anaerobic and reducing conditions rapidly and remove free chlorine. Due to the high surface area of mZVI, it reacts quickly with water to create reducing geochemical conditions. For this reason, there are fewer requirements about the water used for jet injection. An on-site potable water source will be used for water used for jet injection.

Injection Wells ROI and Overlap: The ROI of the injection wells will be enhanced by the sand-mZVI lenses injected in the UCRS. A 15-ft ROI was selected based on the extent of lenses typically achieved using DPT jet injection methods. The injection wells will be placed such that the ROI of adjacent wells overlap, thereby attaining distribution of amendments to the impacted areas. The layout of injection wells in the treatment area is presented in Figure 9 and is based on a 15-ft injection ROI and an average overlap of 30%. Current injection well locations were selected based on current utility maps as shown in Figure 9. Actual field locations may be adjusted, as needed, if additional information becomes available as discussed below.

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 or overhead obstructions and to provide sufficient offset from utilities. Site features such as buildings and railroad tracks may also require minor adjustment to



Adapted from Figure 6 of DOE (2013).

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 (DOE 2013)
- 🟢 Soil Boring Location with Average Soil Concentration Less than Both Remediation Goals (DOE 2013)
- 🟡 Archive Core Soil Boring Location - Not Sampled (DOE 2013)
- ⊕ Historic Soil Boring Location with Average Soil Concentration Exceeding TCE Remediation Goal (DOE 2013)
- ⊕ Historic Soil Boring Location with Average Soil Concentration Less than TCE Remediation Goal (DOE 2013)
- ⊕ Historic Archive Core Soil Boring Location - Not Sampled (DOE 2013)
- ◐ Existing Monitoring Well Location
- 🟪 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
- – – Gas (5'-7' BG)
- – – Electric (5'-8' BG)
- – – Storm Drain (6'-10' BG)
- – – Plant Water (5'-14' BG)
- – – Chilled Water (2'-5' BG)
- – – Sanitary Sewer (5'-7' BG)
- – – Sanitary Water (2'-5' BG)
- – – Cathodic Protection (3'-5' BG)
- – – Recirculating Cooling Water (Waste/Heat)

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 2018 Aerial: Google Earth.
4. Existing monitoring wells MW511, MW512, and MW513 will be abandoned prior to performing injections.

30 15 0 30 Feet

SWMU 211-A Planned Injection Layout

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

FOUR RIVERS NUCLEAR PARTNERSHIP, LLC

October 2019

Figure
9

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Figure 9. SWMU 211-A Planned Injection Layout

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injection well locations. If feasible, aboveground obstructions may be relocated to perform the work. The final placement of injection wells can be adjusted in the field, if needed, to accommodate subsurface obstructions, aboveground site features, and other logistical constraints, while still retaining sufficient coverage of the treatment area with required injectants.

ZVI Dosing Concentration and Slurry Volume: A slurry mixture consisting of sand, mZVI, water, and guar gum will be delivered during the DPT jet injection process. Guar gum is mixed with water to make a more viscous solution that is an effective carrier fluid for the sand-mZVI particles. More detail on the slurry formulation is provided in Section 4.4.2. Viscous slurry injection using these methods is governed by soil mechanics rather than Darcy flow; therefore, this approach is designed to achieve distribution of amendments throughout the target treatment area while limiting short-circuiting into more permeable units. The sand-mZVI will serve as a proppant to keep 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 because the mZVI reacts with groundwater to produce hydrogen, which serves as the ultimate electron donor for the DHC bacteria. The mZVI also will provide pH buffer, as described above in “Groundwater Geochemistry.” The quantity of sand-mZVI slurry to be injected was selected to support a fracture ROI of approximately 15 ft and to achieve a design mass loading between 0.5 and 1.0% ZVI on a dry weight (wt) soil basis (% by wt). The sand-mZVI slurry will be injected prior to delivery of the EISB amendments.

Bioremediation Amendment Dosing Concentrations: EISB amendments will consist of a commercial EVO product mixed with anaerobic water and a bacterial consortium containing DHC bacteria. 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 dissolve slowly into groundwater 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 above subsection entitled “Water Used for EISB Amendment Delivery” provides additional details on the carrier fluid. The mixture of EVO product and anaerobic water is referred to as the EVO solution.

- A bioaugmentation consortium will need to be added into the UCRS to facilitate EISB. This consortium will contain species of DHC bacteria necessary for the full dechlorination of TCE to ethene, plus supporting bacteria such as fermenting bacteria, methanogens, sulfate reducers, etc. DHC is 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 DHC bacteria can complete the degradation process to ethene. For this site, it is important to have a consortium that can function with 1,1,1-TCA in groundwater; the activity of some commercial bioaugmentation consortia can stall in the presence of 1,1,1-TCA. KB-1® Plus, available from SiREM Laboratory, or an approved equivalent, is recommended for this site because it can degrade not only the TCE, but also the 1,1,1-TCA.

The initial delivery of EISB amendments will not include an anti-methanogenic reagent. Anti-methanogenic reagents typically are not needed to achieve reductive dechlorination, and, in many cases, active methanogens are necessary to maintain a high rate of reductive dechlorination (Wen et al. 2015; Loeffler et al. 1997). The reductive dechlorination pathway relies upon a consortium of bacteria, not just the activity of the dechlorinating bacteria. Problems with excessive methane production typically occur only if excessive amounts of electron donor are injected; therefore, the electron donor dosing concentration is designed to prevent this condition. If the dechlorinating bacterial population does not appear to be growing toward the desired concentration (i.e., minimum 10^6 cells/liter), then adjustments such as adding an anti-methanogenic reagent and/or rebioaugmenting with KB-1® Plus may be considered. If such a situation is encountered, performance monitoring groundwater data will inform what corrective action is most appropriate.

The volume and concentration of EVO solution delivered into each well were selected based on a target EVO percentage, assumed pore volume of the targeted injection zone, and number of sand-mZVI fractures intercepted by the screen. The bacterial consortium (i.e., KB-1® Plus or approved equivalent) will be delivered into each of the injection wells 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 will be informed by data collected during the injection activities, including measurement of groundwater geochemistry parameters and water levels at the injection wells and other appropriate monitoring points in or adjacent to the injection zone. Groundwater samples also may be collected for TOC analyses to verify amendment distribution is satisfactory. Visual inspection of the groundwater at select locations (e.g., nearby injection wells) also may be utilized to verify that the EVO solution is meeting the design ROI. Field measurements of geochemical parameters, water levels, and unexpected conditions noticed during visual inspections performed throughout injection activities will be recorded in the field log for inclusion in the RACR. Based on field measurements/observations, the EVO solution and KB-1® Plus or approved equivalent dosing concentrations may be adjusted. Adjustments could include increasing or decreasing the volumes of amendments or potentially installing additional injection points. In the event an injection well 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. Criteria for field-based decisions are discussed in Section 4.4.3.

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. If additional obstructions are encountered, then they 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.

4.3 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 were considered when developing the design approach described in this document.

- Site location, activities, and general site logistics that may restrict locations for invasive work or equipment access:
  - The proposed layout of injection locations is designed to allow access for drilling and injection equipment around existing aboveground structures, including buildings, railroad tracks, and other aboveground structures; and
  - Injection locations may be adjusted in the field in order to provide an appropriate offset from subsurface utilities and other subsurface obstructions.
- Availability of water
  - Up to 500,000 gal of water will be needed. A discussion of water pretreatment requirements and the selected water source is provided in Sections 4.2.1 and 5.3.
- Shape and depth of the treatment area
  - The target treatment area was defined based on the results of soil samples collected during the RDSI in 2012 and 2013 (DOE 2013). The treatment footprint is assumed to be approximately 13,200 ft^2 and consists of two distinct areas (sometimes referred to as lobes) interpreted to contain greater than 75 µg/kg TCE (50% confidence interval). Injection locations are presented in Figure 9 and were selected to provide coverage of the treatment area with a design ROI of 15 ft and an overlap of approximately 30%.
  - The treatment depth interval is approximately 40 ft in thickness, generally extending from approximately 25 ft to 65 ft bgs, which corresponds to an elevation of 350 ft to 310 ft amsl. At each individual injection location, the treatment depth interval was identified based on the results of RDSI soil samples. At each injection location, the top of the target treatment interval was generally selected based on the shallowest detection of TCE or 1,1-DCE above the respective cleanup level in nearby soil samples. The top of the treatment interval ranges from 20 to 45 ft bgs. The bottom of the target treatment interval is defined generally by the lower extent of UCRS soils, approximately 65 ft bgs. The vertical spacing between discrete injection depths for DPT jet injection at each location ranges from 3 ft to 4 ft, with closer spacing selected for locations within areas with higher TCE concentrations, defined by TCE concentrations above 1,000 µg/kg at the 90% confidence level. A cross section showing TCE impacts and approximate locations of target treatment areas is shown in Figure 10, and a detailed table of DPT jet injection locations, injection intervals and depth spacing, design quantities of sand and mZVI, and injection well screen intervals is presented in Table 5.

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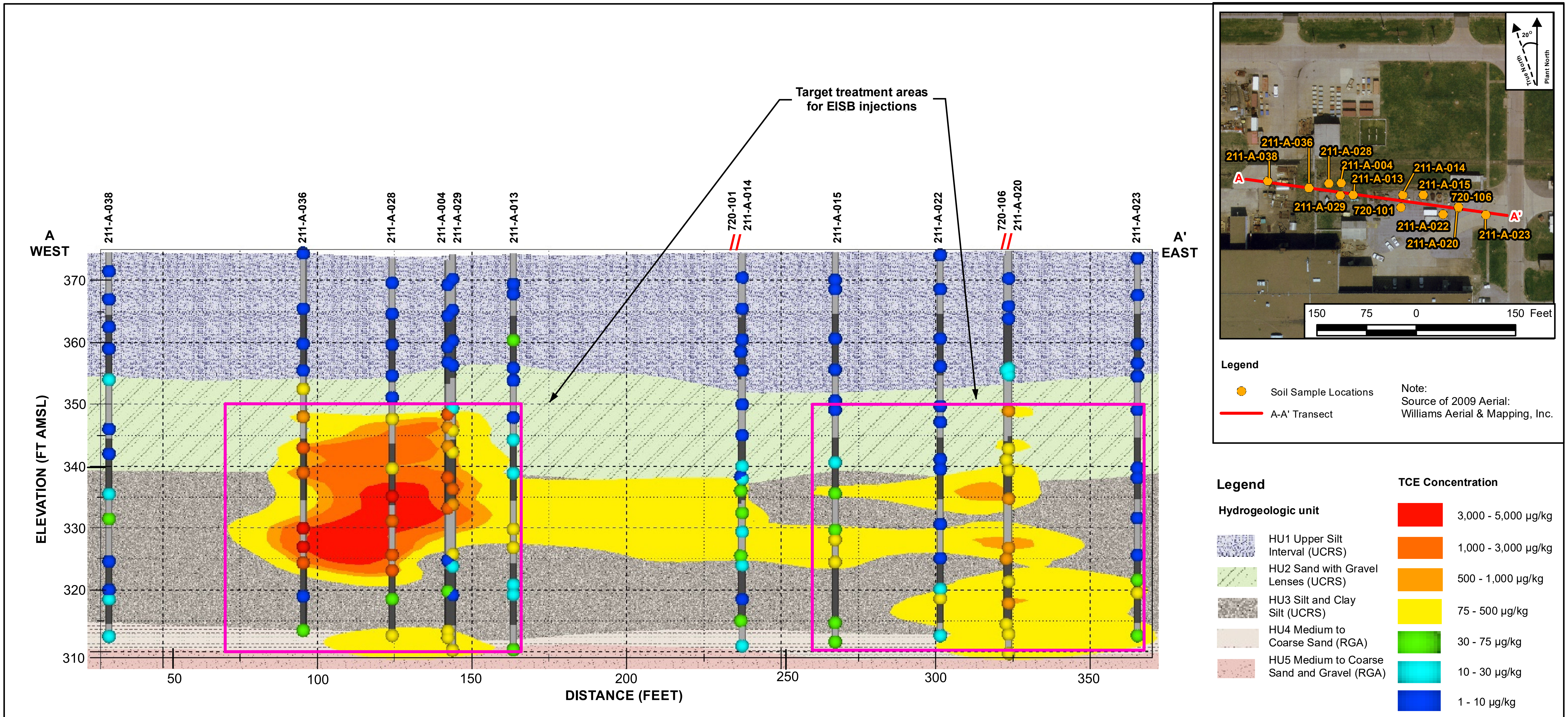

Notes:

1. // indicates location of overlapping soil borings. TCE concentrations for both locations appear graphically superimposed on the soil borings.
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. This cross section shows a slice through the three-dimensional model of TCE distribution in soil. Isopleths were created by interpolation between three-dimensional TCE data (i.e., depth-discrete at boring locations) as opposed to average soil concentrations throughout a boring.
6. C Tech's Environmental Visualization Systems Expert System used to develop TCE isopleths by kriging of three-dimensional data. See DOE, 2013.
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 are 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

Figure
10

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Figure 10. SWMU 211-A Cross Section with TCE Isopleths and Hydrogeologic Units

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Table 5.
Direct-Push Technology Jet Injection Plan

Location ID	Easting (ft)	Northing (ft)	Top of Jet Injection Interval (ft bgs)	Bottom of Jet Injection Interval (ft bgs)	Treatment Interval Thickness (ft)	Jet Injection Spacing (ft)	Number of Jet Injection Depths	Number of EISB Injection Well Screens	1st Screen Interval (ft bgs)	Screen Length (ft)	2nd Screen Interval (ft bgs)	Screen Length (ft)	3rd Screen Interval (ft bgs)	Screen Length (ft)	Amendment Quantity Per Injection		Amendment Quantity Per Location	
															mZVI (lbs)	Sand (lbs)	mZVI (lbs)	Sand (lbs)
IW-01	-5260.76	-2031.79	26.0	62.0	36.0	4	10	3	25-40	15	41-51	10	53-63	10	1,100	550	11,000	5,500
IW-02	-5233.80	-2031.68	24.0	60.0	36.0	4	10	3	23-38	15	39-49	10	51-61	10	1,100	550	11,000	5,500
IW-03	-5205.31	-2040.84	26.0	62.0	36.0	4	10	3	25-40	15	41-51	10	53-63	10	1,100	550	11,000	5,500
IW-04	-5183.39	-2050.00	28.0	60.0	32.0	4	9	3	24-34	10	35-50	15	51-61	10	1,100	550	9,900	4,950
IW-05	-5271.73	-2056.52	21.0	63.0	42.0	3	15	3	18-33	15	34-49	15	50-65	15	1,650	825	24,750	12,375
IW-06	-5249.16	-2048.80	23.0	62.0	39.0	3	14	3	21-36	15	37-52	15	53-63	10	1,650	825	23,100	11,550
IW-07	-5218.36	-2055.56	24.0	63.0	39.0	3	14	3	22-37	15	38-53	15	54-64	10	1,650	825	23,100	11,550
IW-08	-5256.12	-2076.20	25.0	64.0	39.0	3	14	3	23-38	15	39-54	15	55-65	10	1,650	825	23,100	11,550
IW-09	-5236.42	-2059.91	24.0	63.0	39.0	3	14	3	22-37	15	38-53	15	54-64	10	1,650	825	23,100	11,550
IW-10	-5198.75	-2069.42	26.0	62.0	36.0	4	10	3	25-40	15	41-51	10	53-63	10	1,100	550	11,000	5,500
IW-11	-5240.70	-2093.26	30.0	63.0	33.0	3	12	3	27-37	10	38-53	15	54-64	10	1,650	825	19,800	9,900
IW-12	-5220.13	-2077.45	29.0	62.0	33.0	3	12	3	27-42	15	43-53	10	54-64	10	1,650	825	19,800	9,900
IW-13	-5254.98	-2101.60	35.0	63.0	28.0	4	8	2	33-48	15	49-64	15	---	---	1,100	550	8,800	4,400
IW-14	-5215.85	-2097.17	35.0	63.0	28.0	4	8	2	33-48	15	49-64	15	---	---	1,100	550	8,800	4,400
IW-15	-5237.53	-2115.80	33.0	61.0	28.0	4	8	2	31-46	15	47-62	15	---	---	1,100	550	8,800	4,400
IW-16	-5254.51	-2131.02	40.0	52.0	12.0	4	4	1	39-54	15	---	---	---	---	1,100	550	4,400	2,200
IW-17	-5027.73	-2022.91	35.0	59.0	24.0	3	9	2	34-49	15	50-60	10	---	---	1,650	825	14,850	7,425
IW-18	-5008.53	-2027.80	34.0	62.0	28.0	4	8	2	32-47	15	48-63	15	---	---	1,100	550	8,800	4,400
IW-19	-5031.53	-2045.61	31.0	61.0	30.0	3	11	3	30-45	15	46-56	10	57-62	5	1,650	825	18,150	9,075
IW-20	-5009.79	-2050.89	32.0	60.0	28.0	4	8	2	30-45	15	46-61	15	---	---	1,100	550	8,800	4,400
IW-21	-5077.66	-2047.12	39.0	59.0	20.0	4	6	2	38-48	10	50-60	10	---	---	1,100	550	6,600	3,300
IW-22	-5051.57	-2058.41	29.0	61.0	32.0	4	9	3	25-35	10	36-51	15	52-62	10	1,100	550	9,900	4,950
IW-23	-5028.36	-2067.07	20.0	62.0	42.0	3	15	3	17-32	15	33-48	15	49-64	15	1,650	825	24,750	12,375
IW-24	-5005.82	-2073.98	30.0	62.0	32.0	4	9	3	26-36	10	37-52	15	53-63	10	1,100	550	9,900	4,950
IW-25	-5088.45	-2074.85	45.0	61.0	16.0	4	5	2	41-51	10	52-62	10	---	---	1,100	550	5,500	2,750
IW-26	-5067.75	-2067.70	34.0	62.0	28.0	4	8	2	32-47	15	48-63	15	---	---	1,100	550	8,800	4,400
IW-27	-5046.17	-2085.77	27.0	63.0	36.0	4	10	3	26-41	15	42-52	10	54-64	10	1,100	550	11,000	5,500
IW-28	-5026.35	-2088.65	24.0	63.0	39.0	3	14	3	22-37	15	38-53	15	54-64	10	1,650	825	23,100	11,550
IW-29	-5009.24	-2094.16	32.0	64.0	32.0	4	9	3	28-38	10	39-54	15	55-65	10	1,100	550	9,900	4,950
IW-30	-5033.37	-2111.86	28.0	61.0	33.0	3	12	3	25-35	10	36-51	15	52-62	10	1,650	825	19,800	9,900
IW-31	-5009.59	-2112.20	34.0	62.0	28.0	4	8	2	32-47	15	48-63	15	---	---	1,100	550	8,800	4,400
IW-32	-4996.00	-2129.20	45.0	53.0	8.0	4	3	1	44-54	10	---	---	---	---	1,100	550	3,300	1,650
IW-33	-5174.56	-2032.69	30.0	62.0	32.0	4	9	3	26-36	10	37-52	15	53-63	10	1,100	550	9,900	4,950
TOTALS							**325**	**85**									**443,300**	**221,650**

Notes:
1. ft bgs = feet below ground surface
2. mZVI = Microscale Zero-Valent Iron

In general, amendment addition at SWMU 211-A is not needed for the upper 25 ft of the UCRS. At selected locations, injections will be performed at depths shallower than 25 ft bgs to target areas where TCE or 1,1-DCE is present (e.g., up to 20 ft bgs at IW-23). The following are a number of the reasons that support not including the shallow soils in the treatment zone.

- — Utilities exist in SWMU 211-A area that prevent amendment additions to depths shallower than 14 ft bgs. Injection around utilities can result in damage to the utilities. Additionally, the bedding materials placed with the utilities during construction typically have a higher conductivity than the surrounding native soils, and this can result in short circuiting during the injection of the biological amendments.
- — Areas where CVOCs are present in shallow soils are above the EISB treatment areas. Because groundwater flow is downward through the UCRS, dissolved CVOCs from the shallow UCRS contamination will migrate through the underlying EISB and ZVI treatment zones.
- — Shallow injection, even under low pressure, has a greater potential for surfacing than deeper injections because of the proximity of the injection zone to the ground surface. Surfacing of injection can result in worker safety issues. The limited potential value of shallower injections does not justify the associated worker safety and environmental concerns.

The most important of the reasons above is that as this small quantity of contaminant migrates in dissolved phase, it will pass through the EISB and ZVI zone and be remediated. The EISB is expected to be biologically active for up to five years without further amendment injections, and the ZVI will continue to work after that providing protection to the RGA. As documented in the ROD, long-term RGA groundwater monitoring is expected to be required for a number of years (39) following the completion of the injection of the treatment zone. Approximately 5% of the CVOCs are expected to remain following the injections. The long-term monitoring as well as the performance monitoring, which is discussed in Section 6 and Appendix A, will be in place to aid in assessing when the action attains the RAOs and if maintenance injections of amendments may be needed.

Also, consistent with the RAOs contained in the ROD, SWMU 211-A action includes interim LUCs, pending remedy selection as part of the Soils Operable Unit and the Groundwater Operable Unit. The LUCs consist of notification signs of contamination and the inclusion of the PGDP excavation and penetration permit program.

- Site geology and hydrogeology
  - — As discussed in Section 1, the depth to UCRS groundwater in the treatment area ranges from approximately 5 to 28 ft bgs. The target treatment zone likely is saturated and, therefore, suitable for EISB (Table 1).
  - — Hydraulic conductivity of the UCRS is relatively low (Section 1), resulting in a low-predicted achievable injection rate for existing wells at the site. The injection approach described in Section 4.2.1 is designed to accommodate the low hydraulic conductivity of soils in the treatment area.
  - — The direction of groundwater flow in the UCRS is primarily downward. Because EISB amendments will be delivered through horizontal lenses of sand/mZVI across the treatment area,

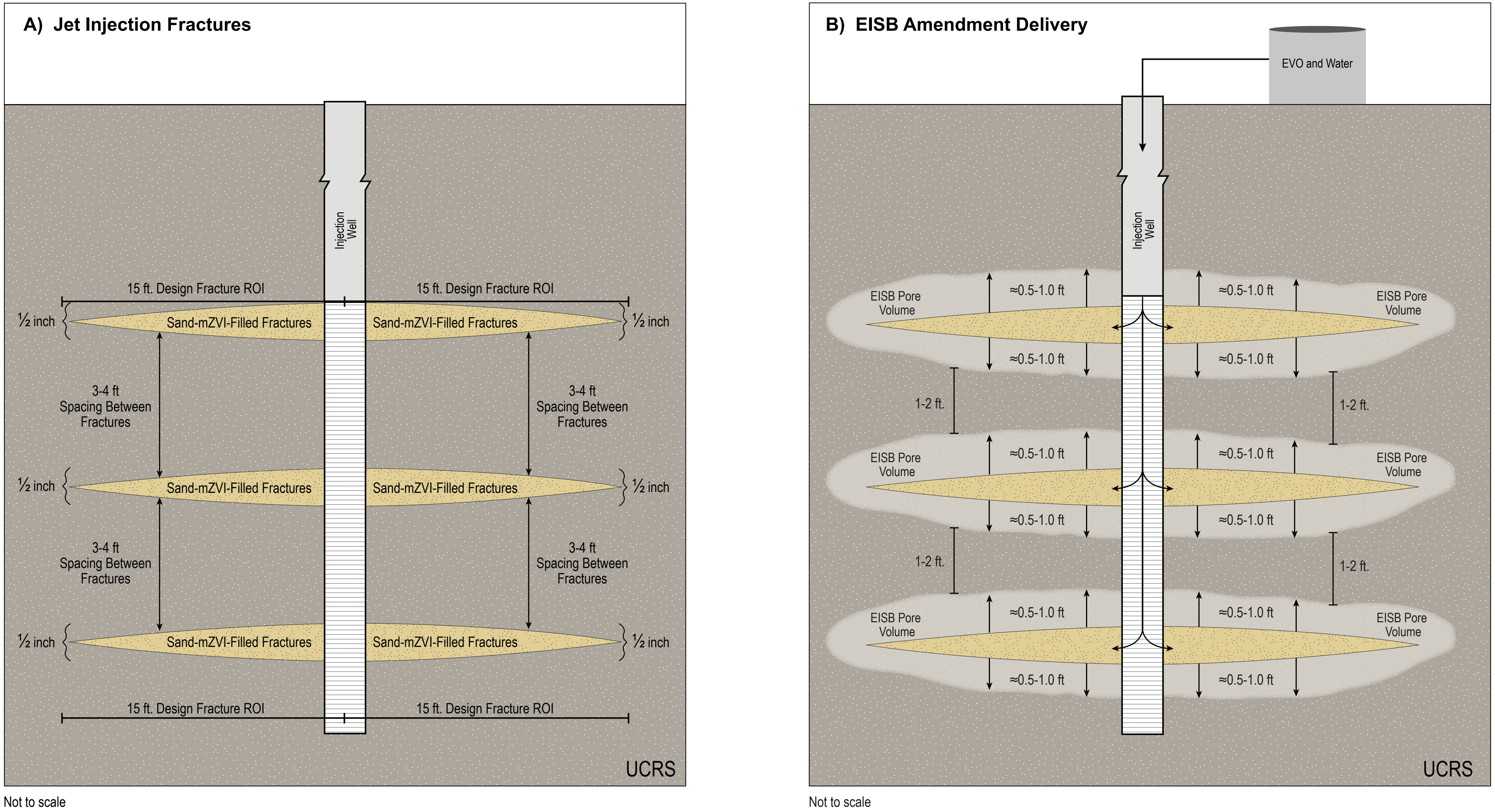
groundwater in the UCRS will flow primarily downward through treatment zones as it migrates toward the RGA.

- Concentrations of Contaminants of Concern
    - — Concentrations of TCE and TCE breakdown products in wells that are screened within the UCRS and RGA are suitable for EISB as described in Section 4.1.
- Contaminant-specific remediation goals defined in the *Focused Feasibility Study for the Southwest Groundwater Plume Volatile Organic Compound Sources (Oil Landfarm and C-720 Northeast and Southeast Sites) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07/0186&D2/R2, (DOE 2010b) and ROD (DOE 2012a) are listed in Table 3.
- 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. A conceptual cross section depicting this approach for a hypothetical location is shown on Figure 11.

- DPT Jet Injection
    - — Hydraulic fracturing, using DPT jet injection will deliver sand-mZVI as proppants to create more permeable (lateral) zones within the UCRS; these will be used to enhance delivery of EISB amendments.
    - — mZVI delivered using DPT jet injection also will serve as an electron donor source and will be injected at the quantity needed to reach between 0.5 and 1.0% by weight within the target treatment zone.
- Injection of the EISB amendments
    - — Anaerobic water will be prepared by adding KB-1® Primer or approved equivalent to water from a potable water source (Section 5.3).
    - — 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 a 2% dosage of EVO in the treatment zone targeted for EISB (i.e., 2% EVO by volume in the estimated pore space of a zone surrounding each sand-mZVI lens as shown on Figure 11). In order to promote distribution of EISB amendments throughout the vertical thickness of the treatment zone, a maximum injection well screen length of 15 ft will be used. The relatively high permeability of the sand-mZVI lenses will support distribution of EISB amendments into each of the lenses intersected by each injection well. The design volume of EVO solution injected in each well is based on a volume of 400 gal of EVO solution per each lens intercepted by the well screen. This volume assumes a soil porosity of approximately 30% and that the injected solution displaces approximately 25% of the pore volume in a 1-ft thick layer surrounding each sand-mZVI lens. While this approach may deliver a higher volume of EVO solution preferentially to sand-mZVI lenses in more permeable soil within each well screen interval, the EISB amendments in each sand-mZVI lens will create a zone that will be conducive



Acronyms

EISB = Enhance *In Situ* Bioremediation
ROI = Radius of influence
UCRS = Upper Continental Recharge System
mZVI = microscale Zero-Valent Iron
EVO = Emulsified Vegetable Oil

Conceptual Cross Section Depicting Sand-mZVI Fractures and EISB Injections

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Figure 11

Figure 11. Conceptual Cross Section Depicting Sand-mZVI Fractures and EISB Injections

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to reductive dechlorination as UCRS groundwater migrates through the treatment zone. Further, because the more permeable soils are potential pathways for migration of impacted UCRS groundwater to the RGA, delivery of larger amendment volumes to these individual zones is acceptable and desirable.

— KB-1® Plus microbial consortium or approved equivalent will be injected into each injection well. Between 1 and 3 liters of KB-1® Plus or approved equivalent will be injected in each injection well.

— Injection pressures and rates will be kept to the lowest effective levels required to distribute the EISB amendments efficiently throughout the UCRS.

— Injection pressures during delivery of EISB amendments will be targeted between approximately 15 and 40 lb per square inch (psi).

— Target injection rates will exceed 0.5 gal per minute (gpm) per injection well (ideally greater than 1 gpm) to facilitate completion of the injection program within a time frame that is practical.

4.3.2 SWMU 211-A—Monitoring

The selected remedy includes both a performance monitoring program and a long-term monitoring program. Performance monitoring will provide data on the bioremediation action, while the long-term monitoring will provide data on the remedial action's impact at reducing VOC migration from the UCRS to the underlying RGA groundwater.

Groundwater monitoring at SWMU 211-A will consist of a pre-EISB event (i.e., baseline monitoring) to understand initial conditions, and two monitoring programs that will begin after amendments are delivered. Monitoring after EISB implementation will be used to assess the performance of EISB in the UCRS (i.e., performance monitoring) and conditions in the RGA relative to the remedial objectives in the ROD[3] (i.e., long-term monitoring).

Baseline Monitoring: Baseline monitoring will be performed in and around SWMU 211-A at the locations of performance MWs described below. Baseline monitoring is needed to characterize pre-EISB UCRS groundwater conditions at performance monitoring locations that will aid in assessing changes resulting from EISB.

Performance Monitoring: A performance monitoring program will be used to understand groundwater conditions in the UCRS where EISB will be occurring. The well network for performance monitoring will have triplets of MWs[4] at the locations shown on Figure 12. Each triplet will have an MW screened in the middle UCRS, an MW screened in the lower UCRS, and an MW screened in the upper RGA. Because groundwater flows primarily vertically through the UCRS and then discharges into the RGA, these screen depths are selected to collect data along a groundwater flow path (from middle UCRS to lower UCRS to RGA). The following include the parameters analyzed in groundwater collected from performance MWs.

---

[3] See Section 3.1 and DOE 2012a for a complete listing of the RAOs for this remedial action.

[4] Existing wells, MW511, MW512 and MW513, located in the EISB treatment area will be abandoned before EISB is implemented so these wells are not included in performance monitoring.

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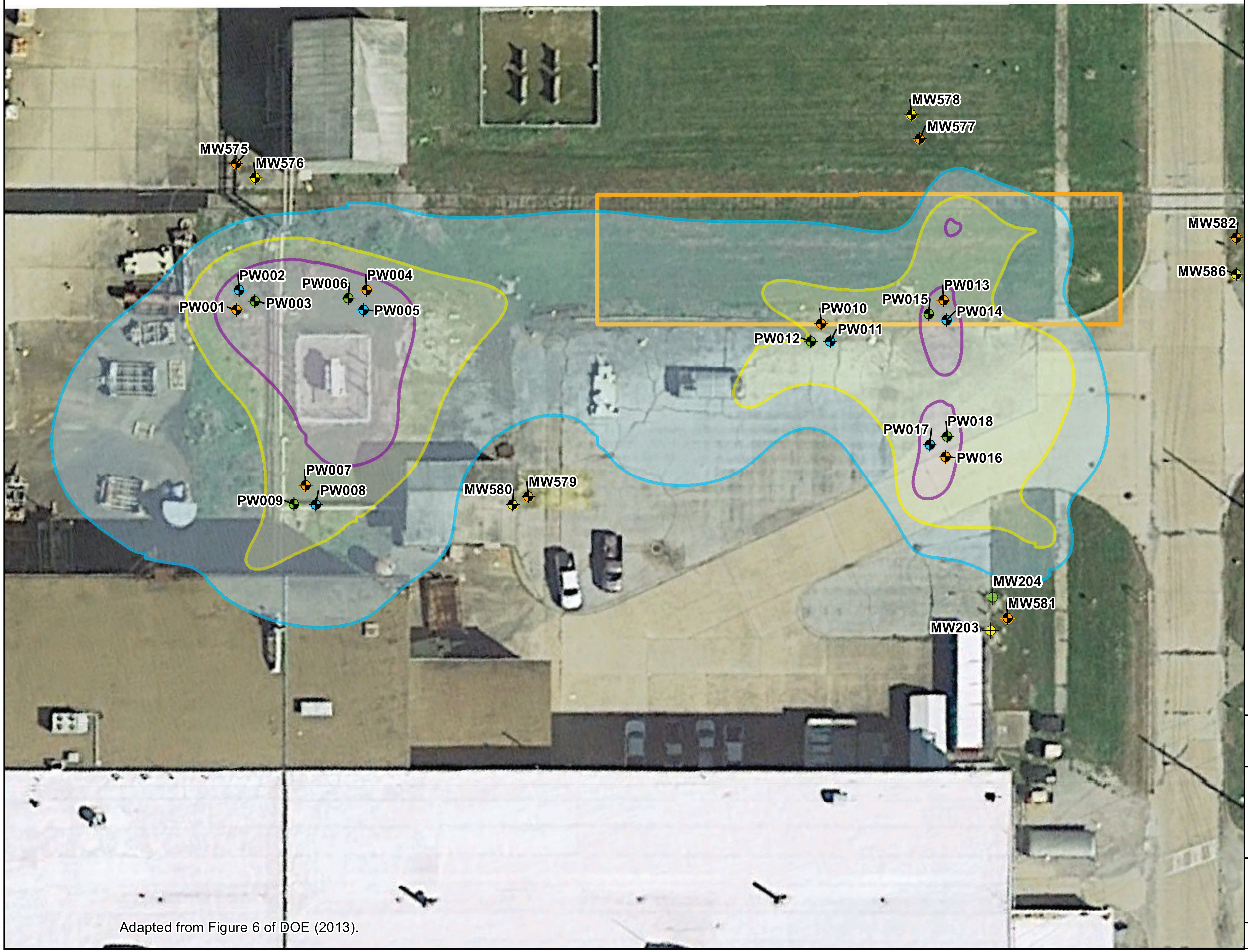

Adapted from Figure 6 of DOE (2013).

20°
True North
Plant North

Legend

Existing Monitoring Well Locations That Will Remain

- ⊕ Well screened within the middle UCRS
- ⊕ Well screened within the middle RGA

Proposed Monitoring Well Locations

- ⊕ Well screened within the middle UCRS
- ⊕ Well screened within the lower UCRS
- ⊕ Well screened within the upper RGA
- ⊕ Well screened within the middle RGA
- 🟪 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. Section 7 of the Final Characterization Report includes explanation of the modeling conducted to establish the TCE contours based upon confidence levels.
2. Source of 2018 Aerial: Google Earth.

30 15 0 30 Feet

SWMU 211-A Monitoring Well Layout

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Figure 12

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Figure 12. SWMU 211-A Monitoring Well Layout

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- Field parameters will be collected during low-flow groundwater sampling (e.g., DO, ORP, pH, etc.) to provide information on the geochemistry of UCRS and RGA groundwater and particularly whether conditions ideal for EISB are maintained.[5]

  VOC concentrations (full list for EPA Method 8260C) will be measured at performance MWs. This information will be used to track changes in TCE concentration and in the concentration of TCE breakdown products (e.g., *cis*-1,2-DCE and VC). The concentrations of other VOCs, such as 1,1,1-TCA, also will be tracked.

- TOC will be measured and used as surrogate for available electron donor in the UCRS to support EISB.

- DHG (i.e., ethene, ethane, and methane). Ethene and ethane concentrations will be monitored because these are the end products of TCE reduction. Methane will be tracked and used as an indicator of groundwater geochemistry since methane-producing bacteria typically are active under the same geochemical conditions as dechlorinating bacteria.

- DHC will be measured periodically to determine if TCE-reducing bacteria are growing in the UCRS to a population capable of robust TCE degradation.

Long-Term Monitoring: Long-term monitoring will be used in and around SWMU 211-A to track the long-term effects of implementing EISB on RGA groundwater contamination to support RAO 3 and to support development of five-year review reports. MWs that make up the long-term and performance monitoring network in SWMU 211-A are shown on Figure 12. Nine new long-term wells are planned (MW575 through MW582 and MW586), and the project will utilize one existing well, MW203. Details for the new and existing long-term MWs are shown in Figure 12 and in Table 6. RGA groundwater samples from long-term MWs will be analyzed for the five key VOCs to track changes in concentrations in the RGA over time as EISB degrades TCE in the UCRS. The presence of contamination located upgradient of SWMU 211-A will increase the difficulty in monitoring the positive impacts to RGA groundwater resulting from SWMU 211-A UCRS remediation. The SWMU 211-A upgradient MWs, which are planned to be located between the C-720 Building and the SWMU 211-A bioremediation treatment area, will exhibit VOC contamination from contaminant upgradient. For long-term monitoring, positive impacts from the bioremedial action will result in reductions of VOC contamination in downgradient wells to levels below those contained in the upgradient MWs.

Details about the baseline, performance and long-term monitoring program are provided in the OM&M Plan included as Appendix A. The OM&M Plan includes information such as well locations, screened intervals, and construction details, in addition to planned sampling locations, parameters, and frequency for each of the monitoring programs.

---

[5] Field parameters will be collected only if performance MWs can yield sufficient groundwater for purging. See the Operations, Maintenance, and Environmental Monitoring (OM&M) Plan (Appendix A) for information on groundwater sampling at wells that have insufficient yield to perform low-flow sampling.

Table 6. Monitoring Well Network for Long-Term Monitoring of SWMU 211-A

MW Number	New/Existing Well	Targeted Screen Location*	Expected Bottom of Screen, ft bgs*	Estimated Screen Length, ft	Monitoring Position with Respect to SWMU, Gradient
MW575	New	Upper RGA	70	5	Down
MW576	New	Middle RGA	75	5	Down
MW577	New	Upper RGA	75	5	Down
MW578	New	Middle RGA	70	5	Down
MW579	New	Upper RGA	70	5	Up
MW580	New	Middle RGA	75	5	Up
MW581	New	Upper RGA	70	5	Up
MW582	New	Upper RGA	70	5	Down
MW586	New	Middle RGA	75	5	Down
MW203	Existing	Middle RGA	76 (As-Built)	5 (As-Built)	Up

*Actual screened interval and soil boring total depth may be adjusted by the field geologist based on geological analysis of the obtained soil core.

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 water 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 delivery of amendments. As mentioned above, the inclusion of 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. Panel A of Figure 11 provides a conceptual depiction of a sand-mZVI-filled fracture.

2. Install injection wells at each DPT jet injection location using screened intervals selected to hydraulically connect the well with the fractures.

3. Inject EISB amendments and DHC into the formation via injection wells and fractures. Panel B of Figure 11 provides a conceptual depiction of the delivery of EISB amendments.

4. Monitor to measure the performance of EISB.

Figure 13 illustrates the sequence of these field activities with respect to the monitoring programs described in Section 4.3.2.

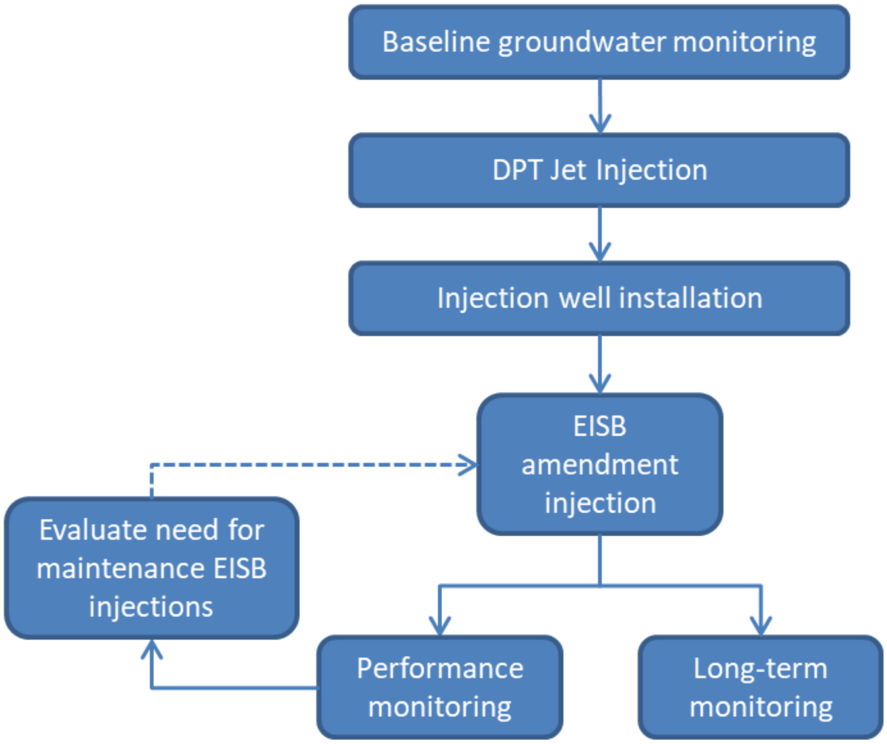

Figure 13. Flow Diagram for EISB Remedy in SWMU 211-A

4.4.1 Equipment Summary

A description of the equipment used for DPT jet injection and EISB amendment injection is provided in the following sections.

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 injection system; and (3) the amendment mixing and injection system. A process flow diagram illustrating the equipment used for DPT jet injection is presented in Figure 14, and photographs illustrating typical configurations of equipment used by injection contractors are presented in Figure 15. A detailed description of the DPT jet injection process is provided in Section 4.4.2.

- An appropriately sized DPT drill rig (e.g., Geoprobe® 8040 with GH80 hammer, 3230DT with GH70 hammer, 3200 with GH70 hammer, or approved equivalent) will be used to advance 3.5-inch DPT drilling rods fitted with custom dual-fluid injection tooling to the target injection depth for a given fracture. The DPT jet injection method requires use of specialized injection tooling which creates sand-mZVI-filled hydraulic fractures using high-pressure water jetting followed by slurry injection. After the injection tooling is driven to a target injection depth, a temporary injection wellhead is installed at the top of the direct-push drill rods that allow the high-pressure water line and the slurry injection line to be connected to the injection tooling.

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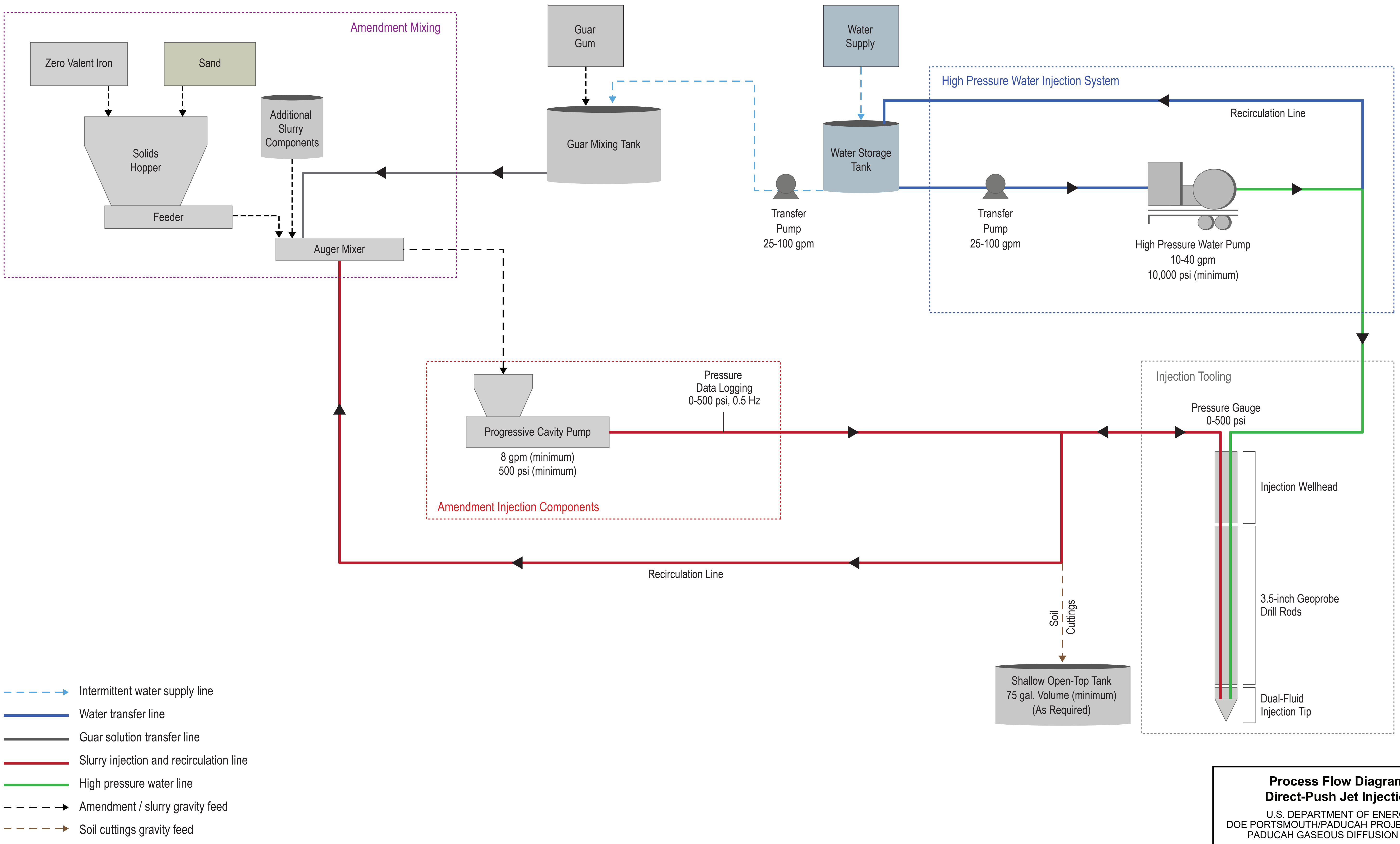

Note:

1. Except for water storage tanks, vendors will stage mixing and injection equipment for liquids on plastic sheeting with artificial berms to contain drips, spills, and leaks.

Process Flow Diagram-
Direct-Push Jet Injection

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Figure
14

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Figure 14. Process Flow Diagram - Direct-Push Jet Injection

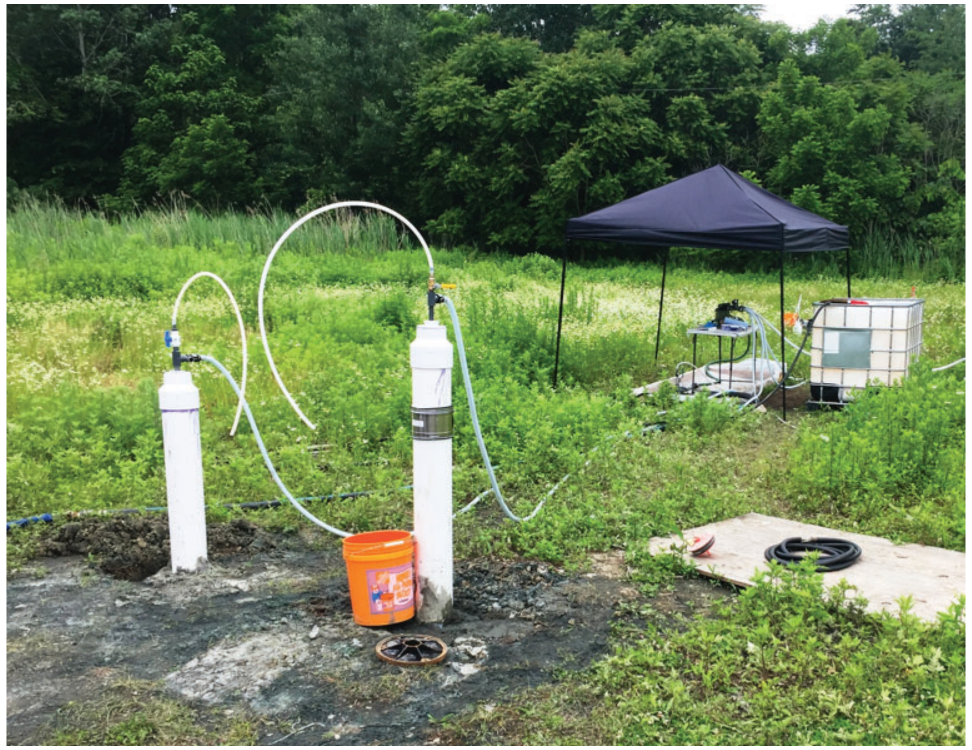
An injection contractor's amendment mixing and injection rig, equipped with a hopper for granular solid amendments, a guar mixing tank, an auger mixer, and a progressive cavity pump.

A DPT jet injection wellhead with a high-pressure water line (top) and a slurry injection line (bottom).

A dual-fluid injection tip for DPT jet injection attached to 3.5-inch Geoprobe rods.

An EISB injection manifold attached to a KB-1® Plus vessel and scale. The blue injection lines on the manifold deliver EVO solution and KB-1® Plus to individual injection wells.

A Jetstream Waterblaster high-pressure water pump used to perform the water jetting phase of DPT jet injection.



Injection of EVO solution from a stock tank into injection wells.

DPT Jet Injection and EISB Injection - Example Field Photos

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Figure

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Figure 15. DPT Jet Injection and EISB Injection – Example Field Photos

- The high-pressure water injection system is used to deliver water to the injection tooling lines for high-pressure jetting. The high-pressure water pump will be capable of producing a flow rate of 10 to 40 gpm at a pressure of 10,000 psi (690 bar).

- The amendment mixing and injection system includes equipment to stage and meter the granular solid (i.e., sand and mZVI) and liquid components of the slurry, an auger mixer to prepare the slurry for injection, and a slurry injection pump to inject the highly viscous amendment slurry. The slurry injection pump will be a progressing cavity positive displacement pump capable of injecting at a minimum flow rate of 8 gpm at 500 psi. The slurry injection line will be equipped with a pressure gauge to monitor the pressure during slurry injection and a data logging pressure transducer to record the slurry injection pressure over time.

The DPT jet injection method and associated custom tooling were developed by FRx, Inc., to deliver proppants, such as sand-mZVI, into low-permeability formations. This injection method and tooling have been used successfully to implement EISB in low-permeability formations at other sites. Other successful projects provide a level of confidence that the same approach will promote successful delivery and distribution of sand-mZVI at SWMU 211-A needed for EISB.

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

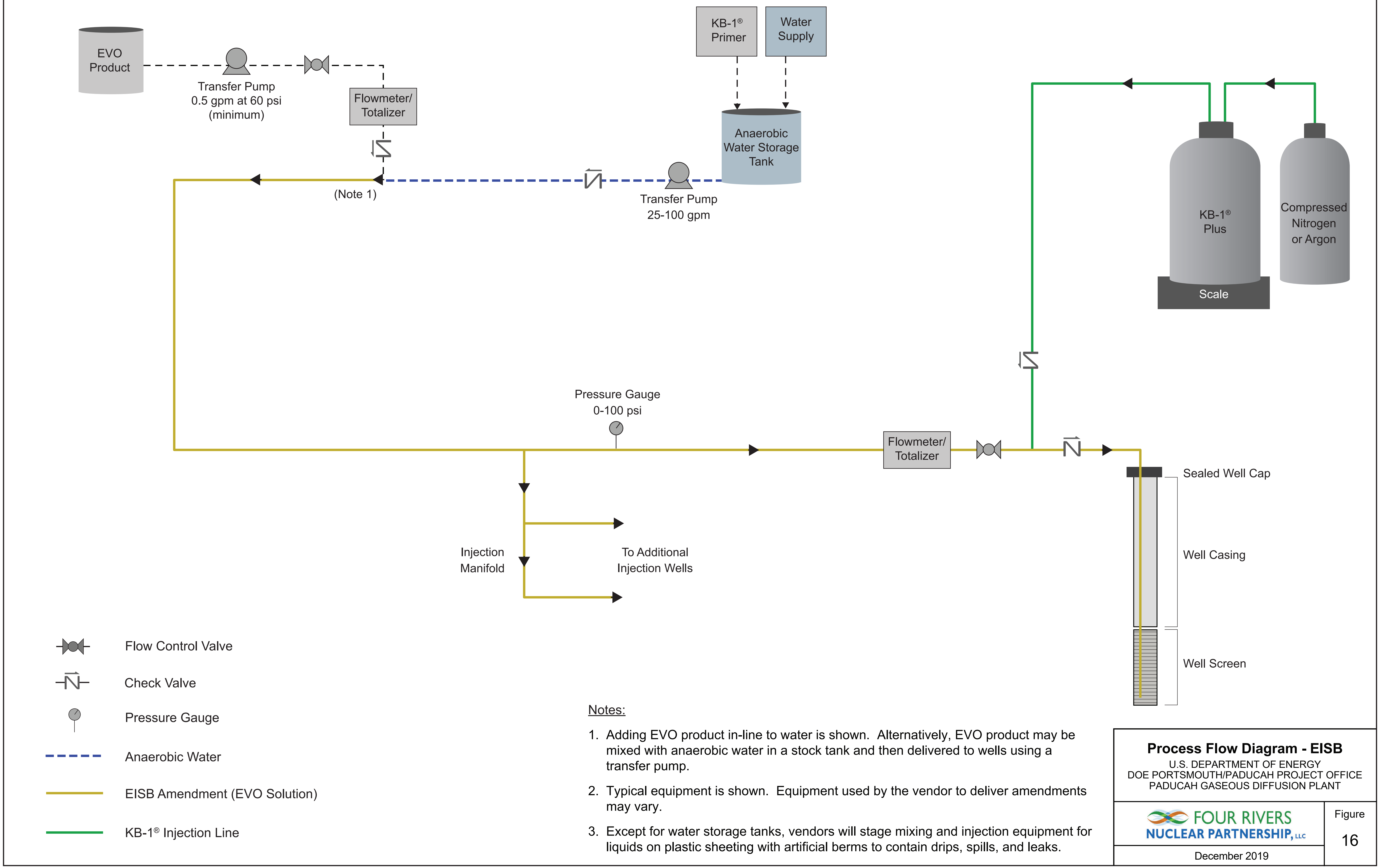
4.4.1.2 EISB injection equipment

EISB injection amendments will be gravity-fed and/or pumped into injection wells from a stock tank(s) containing anaerobic water and a commercial EVO product. A transfer pump (capable of injecting at a minimum flowrate of 0.5 gpm at 60 psi) may be used if flow under gravity-feed is lower than about 1 gpm/well. EVO solution will be injected through an injection manifold equipped with flow meters and pressure gauges for each well head connection. A process flow diagram for EISB injections in shown in Figure 16, and photographs illustrating typical configurations of equipment used by injection contractors are presented in Figure 15.

Bioaugmentation with a DHC consortium (i.e., KB-1® Plus or approved equivalent) typically is performed via a port on the injection manifold. The consortium is supplied by the vendor in sealed vessels. Compressed inert gas (e.g., argon or nitrogen) is used to push the consortium from the vessel and into the manifold. A scale is used frequently to measure the amount of consortium delivered (i.e., the volume added is determined by the change in weight of the vessel divided by the density of KB-1® Plus). A photograph of a vendor’s injection manifold and KB-1® Plus vessel is provided in Figure 15. 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® Plus vessel is the stainless-steel cylinder that is on a scale. The white tubing from the KB-1® Plus vessel to one of the channels of the manifold is used to transfer KB-1® Plus into that line where it is carried to the injection well.

4.4.2 Implementation Sequence

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 DHC consortium into the subsurface through the injection wells (Figure 13). The sequence for each of these steps is described in the following sections. Figure 11 provides a conceptual depiction of an injection well installed in sand-mZVI lenses and subsequent injection of EISB amendments.



Notes:

1. Adding EVO product in-line to water is shown. Alternatively, EVO product may be mixed with anaerobic water in a stock tank and then delivered to wells using a transfer pump.
2. Typical equipment is shown. Equipment used by the vendor to deliver amendments may vary.
3. Except for water storage tanks, vendors will stage mixing and injection equipment for liquids on plastic sheeting with artificial berms to contain drips, spills, and leaks.

Process Flow Diagram - EISB
U.S. DEPARTMENT OF ENERGY
DOE PORTSMOUTH/PADUCAH PROJECT OFFICE
PADUCAH GASEOUS DIFFUSION PLANT

FOUR RIVERS NUCLEAR PARTNERSHIP, LLC

December 2019

Figure
16

Figure 16. Process Flow Diagram - EISB

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4.4.2.1 DPT Jet Injection

The general steps for creating fractures with DPT jet injection include (1) advancing the injection tooling to the desired fracture depth; (2) using high-pressure jetting to inscribe a horizontal disc shape (kerf) into the wall of the borehole to focus injection stresses; (3) injecting a viscous slurry containing proppant (i.e., sand-mZVI) to initiate the formation of a hydraulic fracture; and (4) continued injection of the viscous slurry to propagate the hydraulic fracture to the desired extent (i.e., ROI). Fractures created using DPT jet injection are relatively thin, sheet-like structures with a horizontal attitude. Fractures typically have a design ROI of 15 ft from the injection boring and an average aperture of approximately one centimeter. Because the sand-mZVI slurry is injected with relatively low volumes to form lenses, displacement of UCRS groundwater within the injection ROI and potential migration of impacted UCRS groundwater out of the treatment area are minimal.

The slurry injected via DPT jet injection will be composed of a mixture of sand and mZVI (approximately 67% ZVI and 33% sand by weight) in a cross-linked, hydrated guar gum (guar gel) slurry. Hydrated guar gum is made by mixing guar gum and water. Prior to injection, sand and mZVI will be mixed with hydrated guar gum, which will be cross-linked using borax. The addition of the borax will form guar gel, creating a viscous sand-mZVI slurry to suspend sand and mZVI, thereby promoting delivery and limit aggregation of the sand-mZVI within the aquifer matrix. An enzymatic breaker (e.g., Rantec LEB-H^{TM} or approved equivalent) also will be added to the sand-mZVI slurry prior to injection at a concentration based on the manufacturer's instructions. The enzymatic breaker will break down the guar gel after the slurry is injected to increase the permeability of the sand-mZVI lenses. Requirements for makeup water used during jet injection are discussed in Section 5.3. Design quantities of sand and mZVI to be injected at each discrete injection depth are presented in Table 5. The quantity of mZVI to be injected at each location is designed to yield a mass loading in soil of approximately 1% by weight in areas with higher TCE concentrations (above 1,000 µg/kg at the 90% confidence interval) and a mass loading of approximately 0.5% by weight in the remaining portions of the treatment area with TCE concentrations above 75 µg/kg.

DPT jet injection of sand-mZVI will consist of the following steps for a single depth-discrete injection. Injections are recommended to begin at locations around the outside of the treatment area and work toward locations in the middle of the treatment area to reduce the potential for lateral migration of impacted UCRS groundwater.

- A DPT drill rig of appropriate size is used to advance 3.5-inch DPT drill rods equipped with specialized injection tooling into the subsurface to the first (i.e., shallowest) target injection depth. Injections are performed using a top down approach to prevent an open borehole below the injection tooling from acting as a preferential pathway for remediation amendments to short-circuit into deeper injection zones. A top-down approach is critical to the success of this injection technique in low-permeability soils because this approach, compared to a bottom up approach minimizes the chance for preferential vertical pathways for remediation amendments to short circuit downward.

- After the injection tooling is advanced to depth, high-pressure water jetting (i.e., up to 10,000 psi) is used to erode a horizontal disc shape (kerf) in the formation surrounding the injection tooling.

- The sand-mZVI slurry is mixed just prior to the start of injection at each depth interval. The design quantities of sand and mZVI for each depth-discrete injection are presented in Table 5.

- After the water jetting step is complete, the sand-mZVI slurry is injected under sufficient pressures (typically between 75 and 400 psi) to create sand-mZVI-filled horizontal fractures with a target ROI of 15 ft. Refer to Figure 11 for a conceptual depiction of an injection well and sand-mZVI-filled fractures.

- The slurry injection rate typically is 8 to 15 gpm, and each depth-discrete injection is estimated to require between 30 and 90 minutes to complete, depending on the actual slurry flow rate.
- After the target volume of slurry has been injected, the tooling is advanced to the next injection interval, and the steps detailed above are repeated until injections have been completed over the full treatment depth interval specified in Table 5.

During injections at a given location, pressure may build up in the formation and take several hours to dissipate. After completion of injections at a given location, withdrawal of drill rods before pressure dissipates may result in backflow of sand-mZVI slurry up the borehole. Pressure on the drill rods will be monitored with a pressure gauge installed at the point where the injection lines connect to the drill rods. If backpressure is observed after completing injections at a location, the temporary injection wellhead will be capped while pressure dissipates, and spare drill rods and injection tooling may be used to allow for immediate drill rod/tooling advancement at the next injection location.

4.4.2.2 Injection Well Installation

After DPT jet injection is completed at an injection location, between one and three injection wells will be installed with well screens intersecting the lenses created during DPT jet injection. 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). Because treatment depth intervals are 40 ft on average, multiple screened intervals are required at most locations to facilitate injection across the entire treatment depth interval. After injection pressure has dissipated and the drill rods have been removed at an injection location, the deepest well at that location will be installed in the existing borehole. Additional wells with shallower screen intervals at each injection location will be installed with lateral offsets less than 5 ft from the DPT jet injection location. The number of injection wells to be installed at each DPT jet injection location and the estimated well screen depths are presented in Table 5.

Injection wells will be installed using methods designed to place the sand filter pack surrounding the well screen in contact with the sand-mZVI-filled fractures. Injection wells should be installed using DPT or sonic drilling methods. The use of drilling methods that increase the likelihood of compromising the hydraulic connection between the well screen and the sand-mZVI-filled fractures by smearing these zones with clay (e.g., rotary drilling with hollow-stem augers) must be avoided. Wells will be constructed using 2-inch schedule 40 PVC, and wells will have 10-slot PVC well screens.

4.4.2.3 EISB Amendment Injection

Following DPT jet injection of sand-mZVI and installation of the injection wells, EISB amendments will be injected into the target treatment interval in the UCRS via injection wells. Prior to injection, anaerobic water will be prepared in a stock tank. Water for the EISB amendment injections will be obtained from an on-site potable water source, and the water will be pre-treated to remove oxygen and residual chlorine and create a negative ORP (e.g., using KB-1® Primer or approved equivalent). Section 4.2.1 provides a discussion on requirements of water for EISB injections. A commercially available EVO product will be mixed with the anaerobic water to create an EVO solution at the design concentration. Most commercial EVO products contain approximately 50% vegetable oil, 50% water, and minor amounts of sodium lactate, stabilizers/emulsifying agents, and nutrient additives. The EVO solution may be prepared by injecting the EVO product in-line with the anaerobic water (as shown in Figure 15) or alternatively by preparing batches of EVO solution in stock tank(s).

EVO solution then will be injected in each injection well utilizing a temporary aboveground piping network. The target volume of EVO solution to be injected in each injection well is presented in Table 7. Panel B on Figure 11 provides a conceptual depiction of amendment delivery to the formation through an injection well and sand-mZVI fractures. Injections will begin by plumbing the stock tank to the well heads through an injection manifold. Each injection well header will be fitted with a pressure gauge and a flow meter to document that the required volume of EVO solution that is added to each injection well. Initially, the injection fluid will be allowed to flow directly into the injection wells under gravity. If flowrates are below about 1 gpm, then a transfer pump may be connected inline between the stock tank and the injection wells to create sufficient pressure for faster delivery. Pressures and flowrates will be monitored throughout the injection period, and pressures will not be allowed to exceed 60 psi at the well heads. Additional real-time process monitoring during EISB injection is described in Section 4.4.3.

Bioaugmentation will be performed at each injection well after approximately half of the design volume of EVO solution has been injected. Prior to bioaugmentation, geochemistry of the anaerobic water and/or the EVO solution will be assessed using field equipment (e.g., a YSI 600 sonde) to confirm that it is appropriate for the bacteria (e.g., DO < 1 mg/L, and ORP < -100 mV, and pH between 6 and 8). This will ensure that the bioaugmentation consortium is injected within a pocket of water with geochemistry conducive to bacteria survival. The design quantity of bioaugmentation consortium (see Table 7) will be added to each injection well using methods designed to prevent exposure of KB-1® Plus or approved equivalent, to oxygen. If the bioaugmentation consortium is supplied by the vendor in vessels, then the bioaugmentation consortium vessel integrity will be verified by injection personnel upon receipt (in the field). The bioaugmentation consortium 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 bioaugmentation consortium will be metered into the injection well using compressed gas to transfer it from the vessel into the well. Alternatively, the bioaugmentation consortium 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® Plus (or approved equivalent) recently has become available in Fast Injection Tubes (FIT tubes), which are small, sealed containers used to deliver a premeasured dose of KB-1® Plus (or approved equivalent) without the need for line purging. Whether the bioaugmentation consortium will be provided in vessels or FIT tubes will be determined as part of field implementation based on cost, vendor capability, and the EISB contractor’s equipment; the delivery of bioaugmentation consortium will follow manufacturer’s standard procedures.

After bioaugmentation is complete, the remaining volume of EVO solution will be injected into the injection well to distribute the bacterial consortium into the formation. After the design volume of EVO solution is injected, a flush of 100 gal of anaerobic water (without EVO) will be performed to clear the EVO solution out of the well screen and sand pack. This step is designed to reduce potential biofouling of the wells due to residual EVO in the well screen and sand pack.

Table 7.
EISB Injection Plan

Injection Location	Injection Well ID	Top of Screen (ft bgs)	Bottom of Screen (ft bgs)	Screen Length (ft)	EVO Solution Volume (gal)	KB-1® Plus Volume (L)
IW-01	IW-01A	25.0	40.0	15	1600	3
	IW-01B	41.0	51.0	10	1200	2
	IW-01C	53.0	63.0	10	1200	2
IW-02	IW-02A	23.0	38.0	15	1600	3
	IW-02B	39.0	49.0	10	1200	2
	IW-02C	51.0	61.0	10	1200	2
IW-03	IW-03A	25.0	40.0	15	1600	3
	IW-03B	41.0	51.0	10	1200	2
	IW-03C	53.0	63.0	10	1200	2
IW-04	IW-04A	24.0	34.0	10	800	2
	IW-04B	35.0	50.0	15	1600	3
	IW-04C	51.0	61.0	10	1200	2
IW-05	IW-05A	18.0	33.0	15	2000	3
	IW-05B	34.0	49.0	15	2000	3
	IW-05C	50.0	65.0	15	2000	3
IW-06	IW-06A	21.0	36.0	15	2000	3
	IW-06B	37.0	52.0	15	2000	3
	IW-06C	53.0	63.0	10	1600	2
IW-07	IW-07A	22.0	37.0	15	2000	3
	IW-07B	38.0	53.0	15	2000	3
	IW-07C	54.0	64.0	10	1600	2
IW-08	IW-08A	23.0	38.0	15	2000	3
	IW-08B	39.0	54.0	15	2000	3
	IW-08C	55.0	65.0	10	1600	2
IW-09	IW-09A	22.0	37.0	15	2000	3
	IW-09B	38.0	53.0	15	2000	3
	IW-09C	54.0	64.0	10	1600	2
IW-10	IW-10A	25.0	40.0	15	1600	3
	IW-10B	41.0	51.0	10	1200	2
	IW-10C	53.0	63.0	10	1200	2
IW-11	IW-11A	27.0	37.0	10	1200	2
	IW-11B	38.0	53.0	15	2000	3
	IW-11C	54.0	64.0	10	1600	2
IW-12	IW-12A	27.0	42.0	15	2000	3
	IW-12B	43.0	53.0	10	1600	2
	IW-12C	54.0	64.0	10	1200	2
IW-13	IW-13A	33.0	48.0	15	1600	3
	IW-13B	49.0	64.0	15	1600	3
IW-14	IW-14A	33.0	48.0	15	1600	3
	IW-14B	49.0	64.0	15	1600	3
IW-15	IW-15A	31.0	46.0	15	1600	3
	IW-15B	47.0	62.0	15	1600	3
IW-16	IW-16A	39.0	54.0	15	1600	3
IW-17	IW-17A	34.0	49.0	15	2000	3
	IW-17B	50.0	60.0	10	1600	2
IW-18	IW-18A	32.0	47.0	15	1600	3
	IW-18B	48.0	63.0	15	1600	3

Table 7.
EISB Injection Plan (Continued)

Injection Location	Injection Well ID	Top of Screen (ft bgs)	Bottom of Screen (ft bgs)	Screen Length (ft)	EVO Solution Volume (gal)	KB-1® Plus Volume (L)
IW-19	IW-19A	30.0	45.0	15	2000	3
	IW-19B	46.0	56.0	10	1600	2
	IW-19C	57.0	62.0	5	800	1
IW-20	IW-20A	30.0	45.0	15	1600	3
	IW-20B	46.0	61.0	15	1600	3
IW-21	IW-21A	38.0	48.0	10	1200	2
	IW-21B	50.0	60.0	10	1200	2
IW-22	IW-22A	25.0	35.0	10	800	2
	IW-22B	36.0	51.0	15	1600	3
	IW-22C	52.0	62.0	10	1200	2
IW-23	IW-23A	17.0	32.0	15	2000	3
	IW-23B	33.0	48.0	15	2000	3
	IW-23C	49.0	64.0	15	2000	3
IW-24	IW-24A	26.0	36.0	10	800	2
	IW-24B	37.0	52.0	15	1600	3
	IW-24C	53.0	63.0	10	1200	2
IW-25	IW-25A	41.0	51.0	10	800	2
	IW-25B	52.0	62.0	10	1200	2
IW-26	IW-26A	32.0	47.0	15	1600	3
	IW-26B	48.0	63.0	15	1600	3
IW-27	IW-27A	26.0	41.0	15	1600	3
	IW-27B	42.0	52.0	10	1200	2
	IW-27C	54.0	64.0	10	1200	2
IW-28	IW-28A	22.0	37.0	15	2000	3
	IW-28B	38.0	53.0	15	2000	3
	IW-28C	54.0	64.0	10	1600	2
IW-29	IW-29A	28.0	38.0	10	800	2
	IW-29B	39.0	54.0	15	1600	3
	IW-29C	55.0	65.0	10	1200	2
IW-30	IW-30A	25.0	35.0	10	1200	2
	IW-30B	36.0	51.0	15	2000	3
	IW-30C	52.0	62.0	10	1600	2
IW-31	IW-31A	32.0	47.0	15	1600	3
	IW-31B	48.0	63.0	15	1600	3
IW-32	IW-32A	44.0	54.0	10	1200	2
IW-33	IW-33A	26.0	36.0	10	800	2
	IW-33B	37.0	52.0	15	1600	3
	IW-33C	53.0	63.0	10	1200	2
TOTALS				**1,075**	**130,000**	**215**

Note:

1. The volume of bacterial consortium assumes KB-1® Plus which has a *dehalococcoides ethenogenes* (DHC) concentration of approximately $5\text{x}10^{10}$ cells/liter. If another culture that has a different DHC concentration is used, then the amount of bacterial consortium should be adjusted.

4.4.3 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. Example field forms for recording measurements during DPT jet injection and EISB amendment injection are provided in Appendix B. Additionally, field changes also will be captured using a form contained in Appendix B.

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

- During DPT jet injection to create fractures
  - Quantities of materials injected, and injection pressures and flow rates at each injection interval.
- During EISB amendment delivery
  - Quantities of materials injected, volume of KB-1® Plus (or approved equivalent) added, and 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 DPT jet injection and EISB injections for surficial breakthrough of injection materials. Potential pathways for surficial breakthrough, including injection wells that already have been installed, will be identified and inspected during injections. Existing MWs, MW511, MW512, and MW513, are planned for plugging and abandonment because their grout seal is suspected of being compromised. Completed injection wells will be capped with a temporary well plug or finished with a sealed injection wellhead prior to performing DPT jet injection at nearby locations to minimize the likelihood of being preferential pathways for surfacing. Potential receiving areas for fluids during surficial breakthrough during injections, such as a catch basins, etc., will be identified prior to commencing the injections. If a breakthrough does occur, injection activities at locations suspected of causing the breakthrough will be paused and spill containment/cleanup processes will be implemented (e.g., deployment of sorbent booms, pumping of EVO solution, containment of sand-mZVI slurry).
- If surface breakthrough occurs during DPT jet injection prior to injecting the target volume of sand-mZVI slurry at a given depth interval, additional injection volume equivalent to the volume remaining to be injected at the injection depth where breakthrough occurred will be injected into one of the following, in order of preference:
  - The next injection depth at that location; or
  - An adjacent injection location at the injection depth closest to the depth where surface breakthrough occurred.
- Check equipment and tooling to ensure proper functioning during injections. Deficient equipment will be repaired or replaced prior to starting work. For critical equipment, backup units may be mobilized to the site to prevent work delays.
- Check water levels in nearby monitoring and/or injection wells periodically. If observed conditions are not as expected (e.g., a rising water level during injections), corrective actions, such as decreasing injection pressures or adjusting the injection layout, will be taken.

- Measure geochemical parameters at MWs and/or injection wells near the treatment area.

- Measure geochemical parameters (including pH, DO, and ORP) of each batch of anaerobic water prepared for EISB injections after initial preparation and periodically during injections (at least once daily). If these parameters are not within recommended ranges, corrective actions, such as the addition of amendments, will be implemented to bring the parameters back into range, If necessary, the injection work will be paused until acceptable parameters are achieved.

- Injection monitoring will be recorded in daily field forms (Appendix B). Injection pressures, flowrates, and depths will be recorded as appropriate to determine relative differences between injection locations and changes over time.

- Conditions may warrant changes from the intended implementation approach. These changes will be documented on the Field Change Request Form included in Appendix B. Certain changes, as indicated on the Field Change Request form, will be communicated to the FFA parties as soon as feasible after approval by the FRNP Project Manager.

4.4.4 EISB Maintenance

Generally, EISB persists provided groundwater geochemistry is conducive to the survival of DHC, and there are VOCs and electron donor to support DHC. If EVO is consumed by the bacteria and further VOC degradation is needed, then more EVO can be added by performing maintenance EISB injections in existing wells. The need for maintenance EISB injections will be assessed based on the results of post-injection groundwater monitoring [described in Section 6 and in the OM&M Plan (Appendix A)]. Factors that will be evaluated when assessing the need and potential schedule for maintenance EISB injections include concentration trends of VOCs and degradation/end products; concentration of TOC; and geochemical parameters (including ORP, DO and pH). For example, if VOC concentration trends in performance MWs suggest that higher VOC concentrations are persisting over time with a coincident reduction in degradation product, then maintenance EISB injections may be needed to support ongoing EISB. EISB maintenance injections also may be needed if additional VOC treatment is needed, TOC concentrations are low (e.g., < 10 mg/L),[6] and groundwater geochemical parameters in the UCRS are outside the optimal ranges for EISB (Table 4). Evaluation about whether maintenance EISB injections are needed, however, should be based on multiple lines of evidence, considering the factors listed above and other factors such as ratios of parent and degradation products, spatial and temporal variability in groundwater sample results, and the overall treatment progress. These factors will be analyzed, and the need for additional EVO injections will be assessed. The OM&M Plan has additional discussion on EISB maintenance (Appendix A). Performance and long-term monitoring data and a discussion of EISB maintenance, if necessary, will be reported to the FFA parties as described in Section 6.2.

At SWMU 211-A, maintenance EISB injections will be performed via injection wells installed during the initial amendment delivery described above or new injections wells with screens that intercept fractures can be installed if needed. The process for maintenance EISB injections is essentially the same as the initial EISB injection approach described above in Section 4.4.2, except that bacterial consortium (i.e., bioaugmentation) generally is unnecessary during maintenance EISB injection. Additional information regarding the need for maintenance EISB injections delivering more EVO and the process for addressing biofouling of the injection wells, if necessary, is provided in the OM&M Plan (Appendix A).

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[6] A 10 mg/L threshold is a general metric for the concentration of TOC needed to support robust bioremediation based on experience implementing and monitoring bioremediation of TCE at numerous sites over a range of geochemical and hydrogeologic conditions.

4.4.5 Post-Injection Monitoring

After amendments have been injected into the subsurface, a groundwater performance monitoring program will be initiated to assess treatment occurring in the UCRS within amended zones, and a long-term monitoring program will be initiated to observe changes in VOC concentration in the underlying RGA as a result of bioremediation in the UCRS. Monitoring within and below the bioremediation zone will be performed using a series of nested MWs with screened intervals in the upper and lower UCRS and upper RGA. Monitoring also will be performed in the upper and middle RGA upgradient and downgradient of the treatment areas to evaluate the performance of the remedy by assessing changes in VOC concentrations in the RGA across SWMU 211-A. A detailed description of the monitoring program is provided in Section 6 and the OM&M Plan that is enclosed as Appendix A.

5. CONSTRUCTION REQUIREMENTS

5.1 MONITORING WELL DRILLING EQUIPMENT

MW construction will be performed at SWMU 211-A as part of implementing the remedial action. As planned, 9 new long-term MWs will be installed for SWMU 211-A, and 18 new performance MWs will be installed in and around SWMU 211-A. Section 4 and Appendix A provide additional information on the planned placement of MWs. The MWs will be constructed and completed consistent with engineering drawings in Appendix C:

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

MWs 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 or approved equivalent 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 drill pipe, 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 amendment 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:

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

- A fractionation tank used to store water temporarily and create batches of anaerobic water that will be used to create EVO solution;
- Multiple 200 to 2,500-gal storage tanks to store water temporarily and to prepare hydrated guar gum, guar gel slurry, anaerobic water, and EVO solution in batches;
- Pumps for transferring water, slurry, EVO product, 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.

The selection of specific equipment listed above will be left to the discretion of the contractor selected to implement the remedy. The selection will be performed and approved consistent with contract documentation.

5.3 WATER REQUIREMENTS

This section describes the source and pre-treatment requirements for water that will be needed to implement the remediation action at SWMU 211-A. Stages of the remedial action that require water include high-pressure water jetting during DPT jet injection, preparation of the sand-mZVI slurry, and preparation of the EVO solution for EISB injections. The total volume of water required is expected to be up to 500,000 gal. Requirements for the water used for remedy implementation are outlined in Section 4.2.1. Water that will be used for these stages of the work is expected to be obtained from the potable water system at PGDP via a fire hydrant or spigot near SWMU 211-A. Potable water is sourced from the Ohio River, and the water is treated on-site at the C-611 water treatment facility. The need for additional pretreatment for water used for remedy implementation was assessed based on a review of recent samples collected from the treatment system and at various distribution points throughout the facility.

As noted in Section 4.2.1, pretreatment is not planned for water used for DPT jet injection or sand-mZVI slurry preparation. The water used to prepare EVO solution will be treated with KB-1® Primer (or approved equivalent) to reduce DO and residual chlorine in the water and promote anaerobic conditions before the water is mixed with other EISB amendments. Water will be obtained from a distribution point (e.g., a spigot or fire hydrant) near SWMU 211-A. Prior to remedy implementation, a sample will be collected from the proposed water distribution point for laboratory analysis. A pre-implementation sampling plan for the proposed water source will be included as part of the RAWP to verify the chemistry of the water source, refine the amount of KB-1® Primer (or approved equivalent) that will be needed. Preimplementation testing of the water source is expected to include analysis for VOCs and RCRA 8 metals. During remedy implementation, the geochemistry of water after pretreatment with KB-1® Primer (or equivalent) will be monitored periodically and recorded, as described in Section 4.4.3.

5.4 SITE PREPARATION

It is expected that bioremediation amendments will be introduced to the UCRS soils through injection. These placement points are spaced closely (see Figure 9**)**. The SWMU 211-A eastern lobe is covered mostly with concrete or asphalt pavement and the western treatment lobe generally is soil covered with a limited area of gravel covering. Both the east and west lobes 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 T/E/PPs to allow working around the utilities that are present. Areas with concrete or asphalt pavement will be core drilled to allow access to soil below the pavement for deeper drilling.

It is expected that nine long-term MWs will be installed around the SWMU 211-A treatment area. Based on the planned 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. Drilling locations may be adjusted in the field to accommodate site features or subsurface or overhead obstructions. The western portion of SWMU 211-A treatment area contains a couple of permanent small buildings around which work will have to be performed because their removal is not feasible as part of this the remedial action. Other parking lot fencing and guardrails will be removed as feasible to decrease obstructions to drilling and equipment. The use of best management practices related to storm-water management is required for drilling and construction within the SWMU 211-A area. Accordingly, it is planned that silt fence or similar equipment may be installed in the site construction area as needed.

5.5 PERMITTING

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

- T/E/PP
- Lockout/tagout permit
- Hot work permit

6. SAMPLING, MONITORING, AND REPORTING

6.1 SAMPLING AND MONITORING POSTREMEDIAL ACTION

Implementation of this remedial action includes both a performance monitoring program and a long-term monitoring program. Performance monitoring will provide data on the bioremediation action, while the long-term monitoring will provide data on the remedial action’s impact at reducing VOC migration from the UCRS to the underlying RGA groundwater.

The performance monitoring program includes a baseline groundwater sampling program that will collect groundwater samples in the UCRS and upper RGA prior to EISB implementation; then a groundwater sampling program that will be initiated following delivery of amendments into the UCRS at SWMU 211-A. Evaluation of EISB requires sampling for parameters that provide an indication of the efficacy and continuity of the remedial action. Bioremediation, once active, can be self-sustaining as long as geochemical and chemical parameters in the subsurface remain supportive. Baseline and performance monitoring is needed in the UCRS to assess the progress of EISB. Long-term monitoring in the RGA also is planned for SWMU 211-A to assess changes in TCE concentrations in the RGA after implementing EISB in the UCRS.

This will be achieved through implementation of the sampling and monitoring programs described below and in Appendix A. The performance and long-term monitoring programs will be performed concurrently.

- A performance monitoring program will be implemented to assess groundwater conditions and bioremediation activity in the UCRS within the treatment zone. The performance monitoring program also will include wells in the upper RGA that underlie the UCRS to track concentrations in the upper RGA as VOCs migrate primarily downward through the UCRS. Performance monitoring will be preceded by a baseline groundwater sampling event in the UCRS and upper RGA at performance monitoring locations. Baseline sampling will provide an understanding of groundwater geochemistry and VOC concentrations at performance monitoring locations prior to the EISB remedial action.

- A long-term monitoring program will be implemented after EISB amendments have been delivered. The long-term monitoring program will be used to assess VOC concentrations in RGA groundwater against remedial objectives from the ROD. This will include MWs located upgradient and downgradient of SWMU 211-A. Wells for long-term monitoring will be screened in the upper and middle RGA and sampled periodically for analysis of the five key site chlorinated VOCs.

Section 4 provides RDR information used to develop the MW network. Specific information on MW locations, screened intervals for MWs, sampling parameters, and sampling frequencies are provided in the OM&M Plan (Appendix A).

6.2 REPORTING

Results from performance and long-term monitoring will be submitted to the FFA parties in Five-Year Reviews. Progress utilizing data from groundwater monitoring will be communicated to the FFA parties, as necessary, between Five-Year Reviews as interim updates, particularly during the initial five years of EISB implementation.

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. Safety data sheets for materials to support EISB implementation are provided in Appendix D.

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 CERCLA, 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.

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APPENDIX A

OPERATIONS, MAINTENANCE, AND ENVIRONMENTAL MONITORING PLAN

Prepared for

Four Rivers Nuclear Partnership, LLC
Paducah, KY

Operations, Maintenance, and Environmental Monitoring Plan

Paducah Gaseous Diffusion Plant

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ACRONYMS

1,1-DCE	1,1-dichloroethene
cis-1,2 DCE	*cis*-1,2-dichloroethene
DHC	*dehalococcoides ethenogenes*
DO	dissolved oxygen
DOE	U.S. Department of Energy
EISB	enhanced *in-situ* bioremediation
EVO	emulsified vegetable oil
FFA	Federal Facility Agreement
ft bgs	feet below ground surface
HASP	health and safety plan
IDW	investigative-derived waste
MW	monitoring well
mZVI	microscale zero-valent iron
NTU	nephelometric turbidity units
OM&M	operations, maintenance, and environmental monitoring
ORP	oxidation-reduction potential
PGDP	Paducah Gaseous Diffusion Plant
PPE	personal protective equipment
RAO	remedial action objective
RDR	remedial design report
RGA	Regional Gravel Aquifer
SMO	Sample Management Office
SWMU	solid waste management unit
TCE	trichloroethene
TOC	total organic carbon
trans-1,2-DCE	*trans*-1,2-dichloroethene
UCRS	Upper Continental Recharge System
USEPA	United States Environmental Protection Agency
VOC	volatile organic compound

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1. INTRODUCTION

This Operation, Maintenance, and Environmental Monitoring (OM&M) Plan was prepared as a component of the Remedial Design Report (RDR) for the Solid Waste Management Unit 211-A (SWMU 211-A) portion of the Paducah Gaseous Diffusion Plant (PGDP or Paducah Site) located approximately 10 miles west of Paducah, Kentucky. Prior to the PGDP construction, the land was occupied by a munitions production facility that manufactured and stored munitions, including trinitrotoluene. The PGDP supplied enriched uranium for reactors from 1955 to 2013. The local geology at the Paducah Site includes the Upper Continental Recharge System (UCRS), a layer primarily composed of silt and clay with some sand and gravel lenses. Beneath the UCRS lies the Regional Gravel Aquifer (RGA), which is composed predominantly of gravel and sand. Groundwater flows vertically through the UCRS downward into the RGA with little horizontal movement. Groundwater flow is predominantly horizontal in the RGA and northward toward the Ohio River.

This OM&M Plan focuses on the section of the Southwest Groundwater Plume in and around SWMU 211-A, consisting of a western and an eastern lobe which have been impacted with chlorinated volatile organic compounds (chlorinated VOCs). The Southwest Groundwater Plume was identified in a previous investigation and lies within the RGA around SWMU 211-A. The primary contaminant of concern within the Southwest Groundwater Plume is trichloroethene (TCE), though other VOCs, metals, and technetium-99 are also found in the plume. The TCE contaminant source for this action lies in the UCRS and travels to the RGA through vertical groundwater migration.

Enhanced *in situ* bioremediation (EISB) is the selected remedy for TCE in the UCRS. The RDR provides a description of the EISB process and means for implementing EISB at SWMU 211-A. In summary, EISB will be implemented by (1) emplacing a network of lateral lenses filled with sand and microscale zero-valent iron (mZVI) as proppants throughout the UCRS and then (2) injecting electron donor in the form of an aqueous solution of emulsified vegetable oil (EVO) along with a bacterial consortium capable of reductively dechlorinating TCE to ethene. The bacteria will use the electron donor as a source of carbon (food) and respire the TCE as an electron acceptor, fostering a reduction reaction that will convert TCE in groundwater to ethene.

This OM&M plan presents activities that will be performed to operate, maintain, and monitor the performance of EISB that will occur in the UCRS and resulting in changes to RGA groundwater quality in and around SWMU 211-A.

The objectives of this OM&M Plan are as follows:

- Identify groundwater monitoring locations (i.e., monitoring wells or temporary groundwater monitoring points) for the EISB remedy in and around SWMU 211-A;
- Identify for the groundwater monitoring program, locations in and around SWMU 211-A for water level monitoring to evaluate groundwater flow characteristics in and around SWMU 211-A and groundwater sampling to assess EISB performance;

- Identify the monitoring program for contaminant concentrations and other groundwater parameters in the RGA to evaluate progress towards achieving performance standards; and
- Provide instructions for periodic maintenance which may be needed for the EISB remedy.

The following sections outline the details of the OM&M program designed to achieve these objectives.

2. HEALTH AND SAFETY

Staff performing OM&M activities at and around SWMU 211-A are exposed to several potential hazards. Activities to be performed during implementation and monitoring of the remedy include drilling, hydraulic fracturing, well installation, amendment mixing and injection, soil and water management, and groundwater sampling. Potential risks associated with these activities include, but are not limited to, physical hazards such as work near rotating equipment and machinery, working with pressurized lines, lifting, and slips, trips and falls, exposure to contaminated soil and groundwater and other chemical products, insects, and potentially adverse weather conditions.

A Health and Safety Plan (HASP) for the project will be prepared as part of the Remedial Action Work Plan as described in Section 8 of the RDR. The HASP will have guidance for mitigating risk while on the Paducah Site, including wearing proper personal protective equipment (PPE), following contractor procedures for tasks, engineering controls, etc. All Paducah Site personnel and visitors are required to read the HASP before entering or performing work at SWMU 211-A during the remedial action, as well as follow all protocols set forth in the HASP.

3. EISB MAINTENANCE

During the initial EISB implementation at SWMU 211-A, high-pressure jet injections will be used to first install sand-mZVI filled lenses within the UCRS to create zones with enhanced permeability in the subsurface. Injection wells will then be installed with screened intervals across the sand-mZVI lenses to enhance the delivery of EISB amendments (i.e., EVO solution and a bacterial consortium) into the UCRS via the sand-mZVI lenses. This implementation is described in the RDR. After EISB is initiated, EVO is consumed by the biodegradation process. If EVO is consumed and further treatment is needed, additional EVO injection events (i.e., maintenance EISB injections) may be necessary to support ongoing EISB. If maintenance EISB injections are needed, it is planned that they will be performed using the injection wells and sand-mZVI lenses installed for the initial EISB injections.

3.1 Schedule for EISB Maintenance

If EVO is consumed by the bacteria prior to attaining project remedial action objectives (RAOs), then additional EVO may need to be delivered into the UCRS. The need for and schedule for EISB maintenance injections will be a decision made at the discretion of the Federal Facility Agreement (FFA) parties and the project team based on the results of performance monitoring groundwater samples. The performance monitoring plan for groundwater in and around SWMU 211-A is described in Section 4.

The table below identifies parameters that will be considered when determining whether the aquifer may need additional amendments to support on-going EISB. No single parameter should be used for decision-making; rather these parameters should be considered collectively by the technical team to assess whether EISB maintenance is needed. Section 2.1 and Table 4 of the RDR provide supporting discussion on how to interpret these parameters for an EISB remedy.

Parameter	**Consideration for Maintenance EISB Injections**
Dissolved Oxygen (DO)	An increasing trend in DO towards aerobic conditions might indicate a change in groundwater geochemistry due to depleted electron donor. Higher DO can potentially decrease the efficiency of EISB.
pH	Ideal pH for EISB is between approximately 5 and 8.
Oxidation-Reduction Potential (ORP)	Increasing ORP, particularly above 0 mV, may indicate need to add electron donor.
Total Organic Carbon (TOC) (see table note 1)	TOC > 10 mg/L is typically sufficient to support robust bioremediation, although EISB can sometimes persist when TOC is < 10 mg/L (e.g., if mZVI is creating hydrogen). Low TOC may indicate a need to add electron donor.
VOC concentration trends and speciation	Slower VOC degradation or a lack of degradation intermediates and/or end products may indicate EISB is stalling (see table note 2).
VOC concentrations in the RGA groundwater	If groundwater in the RGA is meeting standards, then additional EISB in the UCRS may be unnecessary.
KB-1® Plus Population	A decreasing population of *dehalococcoides* (DHC) bacteria may indicate a poor environment for survival of the bacteria and/or need to add additional bacterial consortium.
Ethene concentration	Cessation of ethene production, following a period of robust EISB, may indicate a slowdown in EISB and need for more electron donor (see Table note 2).
Methane concentration	Decreasing methane concentration may indicate more electron donor is needed, since methanogenic bacteria, like DHC, prosper under reducing conditions in the presence of organic carbon.

Notes:

(1) TOC can be used as a surrogate for available electron donor in groundwater. The 10 mg/L threshold for TOC is an approximate level recommended by Geosyntec based on experience.

(2) It is recommended that concentration ratios for parent, intermediate and end products of EISB are considered when evaluating the need for EISB maintenance as opposed to only considering absolute concentrations.

The factors above should be evaluated using a multiple lines of evidence approach to assess the need for additional EVO injections. For example, if groundwater performance monitoring shows that the bioremediation process has stalled because EVO has been consumed, and further groundwater treatment is needed based on long-term monitoring, then EISB maintenance may be necessary. On the other hand, EISB maintenance may not be necessary, even if EISB has stalled, if monitoring data show RGA groundwater quality has met remedial goals. While the injection of additional bacterial consortium is not typically needed after the initial round of bioaugmentation, it might be recommended during a maintenance event based on the results of performance monitoring.

3.2 Process for Maintenance EISB Injections

This section describes a general process for maintenance EISB injections in the UCRS using existing wells; this process may be modified based on Paducah Site conditions at the time and judgement of the project team. Maintenance EISB injections can be performed via injection wells installed during the initial amendment delivery described in the RDR. The amendment delivery process for EISB maintenance injections will generally follow the process for EVO injections described in the RDR. It is not planned that additional sand-mZVI injections or injection well installation will be needed after the initial remedy implementation.

In some cases, biofouling of the injection well screens may occur after the initial round of EISB injections. Biofouling is typically caused by residual electron donor in the immediate vicinity of the well screen after injection and can decrease the permeability of the well screen and the sand pack. The EISB injection process described in the RDR is designed to mitigate biofouling, because injection of EISB amendments is followed by flushing the injection well screen with anaerobic water. If wells are found to be affected by biofouling during an EISB maintenance event (based on flow rates less than 0.5 gpm), then standard well development techniques such as surging and pumping will be used. In rare cases, if physical well development is not sufficient to remove biofouling from the well screen, then a chemical additive such as bleach or glycolic acid may be used.

General steps for maintenance EISB injections are provided below. These steps may be adjusted as needed depending on Paducah Site conditions when a maintenance event is needed (for example, maintenance EISB injections may be performed only over a portion of the treatment area or in a subset of the injection wells).

- Anaerobic water will be prepared by adding KB-1® Primer or an approved equivalent to water obtained from the on-site potable water supply (expected to be a fire hydrant near SWMU 211-A) to remove DO and residual chlorine and create negative ORP.

- EVO will be mixed with anaerobic water (to create an EVO solution) and the solution injected at the quantities specified in the RDR for each injection well where maintenance EISB injections are performed. Maintenance EISB injections may be needed only in a subset of the SWMU 211-A injection wells.

- EVO solution can be injected into the injection wells that were installed previously during the initial amendment delivery, or into newly installed injection wells that intercept the fracture zone if the previously-installed injection wells are damaged or otherwise unusable. EVO solution should be delivered relatively uniformly throughout the target treatment volume.

- It is unlikely that additional KB-1® Plus microbial consortium or an approved equivalent will be needed because bacteria should persist in the treatment zone once populated after the initial amendment delivery event.
- Injection pressures and rates should be kept to the lowest effective levels required to distribute EVO solution through the UCRS.
- Injection pressures within these zones are estimated to range between 15 to 40 pounds per square inch (psi). Target injection rates should be between 0.5 to 2 gallons per minute per injection point to facilitate completion of the injection program within a time frame that is practical.
- Groundwater monitoring at the long-term and performance monitoring wells will continue following EISB maintenance according to the methods discussed in Section 4.3.

4. EISB MONITORING

EISB monitoring will consist of routine collection and analysis of groundwater samples from monitoring wells in and around SWMU 211-A. This section describes three types of EISB monitoring: baseline monitoring, performance monitoring, and long-term monitoring. Baseline groundwater monitoring will be performed to assess groundwater characteristics prior to the delivery of EISB amendments. Performance monitoring will be used to track the progress of EISB in the UCRS and the impact of EISB on groundwater in the shallow RGA directly beneath the treatment areas. Long-term monitoring will be used to assess the impact of EISB on groundwater quality in the RGA surrounding SWMU 211-A and progress toward achieving performance standards and attaining the RAOs.

Baseline groundwater sampling will be performed by collecting groundwater samples from temporary points at proposed performance monitoring locations and collecting groundwater samples from long-term monitoring wells <u>prior</u> to implementation of EISB. Performance monitoring will occur at wells installed within and below the treatment area. Long-term monitoring will be performed at wells installed upgradient and downgradient of the treatment area to determine the effectiveness of EISB in the RGA. Wells for performance and long-term monitoring will be constructed according to the well construction table (Table 1).

4.1 Baseline Sampling

Baseline groundwater sampling will occur prior to EISB implementation. The purpose of the baseline sampling is to assess the initial conditions at the Paducah Site prior to the delivery of EVO and other amendments. At future performance monitoring well locations, baseline groundwater samples will be collected at temporary sample points using a direct-push drilling rig (e.g., using GeoProbe equipment and a SP-16 sampler or equivalent) because installation of wells in the treatment zone prior to sand-mZVI injection may increase the likelihood of the sand-mZVI slurry short-circuiting to the ground surface. Baseline samples at future performance monitoring well locations will be collected by advancing a temporary sampling device (following contractor procedure CP4-ES-1020), purging the sampler, and collecting a groundwater sample using a bladder pump (see contractor procedure CP4-ES-2101). If possible, baseline samples will be collected using low-flow methods after parameter stabilization.[1] Criteria for field parameter stabilization over three consecutive readings are based on the US Environmental Protection Agency (EPA) low-flow purging and sampling procedure and are provided below:

- Turbidity: within 10%; or less than 5 nephelometric turbidity units (NTUs)
- DO: within 10%; or less than 0.5 mg/L
- Specific conductance: within 3%
- Temperature: within 3%
- pH: within 0.1 unit
- ORP: within 10 mV

Samples will be submitted to an environmental laboratory for analysis, following contractor procedure CP4-ES-2708. Sample collection locations, depths and analyses performed are listed in Table 2. Sample collection locations are shown on Figures 1 and 2.

Long-term monitoring wells will be installed before implementing the remedial action because they will be located outside of the treatment area. Baseline samples collected from long-term monitoring wells will be collected using low-flow methods after parameter stabilization. Samples from long-term monitoring wells will be analyzed at a laboratory contracted by the U.S. Department of Energy (DOE) Sample Management Office (SMO) laboratory for five VOCs by EPA method 8260C: TCE, *cis*-1,2-dichloroethene (*cis*-1,2-DCE), *trans*-1,2-dichloroethene (*trans*-1,2-DCE), 1,1-dichloroethene (1,1-DCE), and vinyl chloride. All samples collected from performance monitoring wells will be analyzed at a laboratory contracted by the DOE SMO.

A subset of the baseline samples collected from performance monitoring well locations also will be analyzed for the presence of DHC bacteria as indicated in Table 2, including two locations in the middle UCRS and two locations in the lower UCRS. The locations to be sampled for DHC were selected to provide spatially distributed samples (i.e., in the eastern and western portions of the treatment area) and to assess DHC concentrations at multiple depths.

One duplicate sample will be collected for every ten samples; therefore, three duplicates will be collected during the baseline sampling event. One matrix spike and matrix spike duplicate will be collected for every twenty samples; therefore, two matrix spikes and matrix spike duplicates will be collected during the baseline sampling event. One trip blank will be submitted for each day that sampling will occur. One equipment blank will be collected for the baseline sampling

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[1] Because of the low yield within the UCRS, parameter stabilization may not be feasible at points within the UCRS. If parameter stabilization is not feasible due to slow recharge, the sampler and drill rods will be purged dry. The apparatus will then be left in place until it has recharged (e.g., 24 hours later). The sample will then be collected from the water that refills the sampling apparatus.

event. Trip and equipment blanks should be prepared according to contractor procedure CP4-ES-2704. See Table 2 for the Baseline Sampling and Analysis Plan and Figures 1 and 2 for baseline sampling locations. Section 5 provides instructions for managing waste (e.g., purge water) from baseline sampling.

Sample bottles shall be labeled either before or immediately after sample collection (see sample naming convention provided in Table 2). Once a sample is collected, it will be immediately logged on the chain of custody and placed in coolers on ice. Coolers containing samples shall be shipped to the environmental laboratory using chain-of-custody procedures. Coolers may be shipped using FedEx (or an approved equivalent shipping service), or they can be picked up by the laboratory courier. Chains of custody that include sample names and collection date and time, what analyses will be performed, and contact and project information, will be completed by sampling staff and signed by those who are transporting coolers. A copy of the chain of custody should be retained in the field notes. Additional information is provided in contractor procedures CP4-ES-0104 and CP4-ES-2708.

4.2 Performance and Long-Term Monitoring Well Installation

Eighteen performance monitoring wells, arranged as six (nested) triplets of wells, will be installed in and around the treatment area to monitor EISB effectiveness in the UCRS and upper RGA. Locations for these wells are shown on Figure 1 and details on the construction of performance monitoring wells are provided in Table 1. Performance monitoring wells will be installed after EISB implementation to avoid damage to well casings and screens due to the high-pressure jet injections. All monitoring wells will be outfitted with a dedicated bladder pump.

Nine long-term monitoring wells will be installed in and around SWMU 211-A but exterior to the treatment area, three upgradient and six downgradient, to determine the effectiveness of EISB in attaining the RAOs for the RGA groundwater. Long-term monitoring wells will be installed prior to EISB implementation. Long-term monitoring well locations are shown on Figure 2. A fourth upgradient long-term monitoring well (MW203) was installed previously and will be utilized for long-term monitoring. Each well will be a standard stick-up well (see Figure 3 for stick-up schematic for the Paducah Site) and constructed from 4-inch diameter polyvinyl chloride (PVC) with 5-ft PVC screened intervals. Bollards may be placed adjacent to the wells to prevent damage. Wells will be installed according to the contractor procedure CP4-ES-0069. Following installation, the wells will be developed according to contractor procedure CP4-ES-0069 and surveyed according to the installer’s general practices.

4.3 Performance and Long-Term Groundwater Sampling and Analysis

Routine groundwater monitoring will occur at performance monitoring wells and long-term monitoring wells according to the program provided in Table 3. A sampling event will include the following steps:

1. Inspecting the well for damage and/or maintenance needs;
2. Measurement of depth to groundwater; and

3. Collection of groundwater samples.

These steps are described in the sections below.

4.3.1 Inspection

Monitoring wells will be visually inspected for damage prior to sample collection as outlined in contractor procedure CP4-ES-0074. Damage will be documented on the water level field form (or other field form as appropriate) and photographs can be taken if needed. The field staff performing the inspection may investigate the well damage and stabilize the well to prevent further damage or impacts to groundwater if the conditions are safe to do so. A report of the damage should be provided to the Project Manager so repairs can be assessed.

4.3.2 Water Level Measurement

The depth to water at each long-term and performance monitoring well will be measured prior to collecting groundwater samples. Depths to groundwater will be converted to groundwater elevations which will then be analyzed to characterize the horizontal and vertical groundwater gradients in and around SWMU 211-A.

The preferred method for measuring water levels is to use an electronic water level tape. Prior to measuring the water level at each well, the well cap will be opened to allow the water level to equilibrate with the atmosphere prior to measurement. Field staff shall also decontaminate the probe prior to use at each well. The water level probe then will be inserted into the well riser slowly until the meter sounds. The depth to water will be measured from the highest point of the riser around the well or a designated/marked measuring point on the casing. The measuring point should coincide with the surveyed top of casing for the well. This ensures that consistent measurements are made between sampling events. At each well, a series of at least three water level measurements should be taken until the same reading is obtained for at least two consecutive measurements to confirm the accuracy of the measurement and demonstrate that the water level is stable. The full water level measurement procedure is outlined in contractor procedure CP4-ES-2100. Water levels will be recorded in field notes or on a field form after each measurement is collected and before proceeding to the next well. The water level tape will be decontaminated in the field between wells according to contractor procedure CP4-ES-2702. The field team shall endeavor to collect all water level measurements for each monitoring event during a single day.

4.3.3 Performance Monitoring

4.3.3.1 Well Locations

Eighteen performance monitoring wells will be installed within the treatment area in and around SWMU 211-A as described in Section 4.2, with nine wells in the eastern lobe and nine wells in the western lobe. The eastern lobe at SWMU 211-A will have three triplets of performance monitoring wells, with each triplet consisting of one well screened in the upper UCRS, the lower UCRS, and the upper RGA. Three well triplets will also be installed in the eastern lobe at SWMU 211-A with similar screened intervals. These wells will be used to monitor VOC concentrations to track the effectiveness of EISB, as well as groundwater geochemistry, to ensure suitable conditions for EISB persist (e.g., reducing ORP and low DO). Performance monitoring well locations are shown on Figure 1.

4.3.3.2 Groundwater Sampling and Analysis

Groundwater samples will be collected from each performance monitoring well according to the sampling plan provided in Table 3. For the first year following an injection, samples will be collected one month, three months, six months, and twelve months after EISB implementation. A higher sampling frequency is specified for the first six months after EISB implementation in order to assess the initiation of bioremediation, as indicated by the start of reductive dechlorination and the growth of *dehaloccocoides* in the subsurface. After the first six months of monitoring, performance monitoring groundwater samples will be collected every six months.

Prior to each day of sampling, the meters used to measure field parameters will be calibrated according to manufacturer guidelines and documented by field staff on calibration forms or field logbooks. Groundwater samples from performance monitoring wells will be collected using the low flow/minimal drawdown sampling approach (see contractor procedure CP4-ES-2101) using bladder pumps. In some cases, bailers or other sampling devices may be used to purge and obtain groundwater samples from UCRS wells. When a bladder pump is used, the intake for the bladder pump should be located in the middle of the screened interval when sampling. The total depth of the wells, the initial and final depths to water, as well as intermediate measurements during purging should be recorded during sampling (see contractor procedure CP4-ES-2100 for the full water level measurement procedure). Because of the low yield within the UCRS, parameter stabilization may not be feasible at wells within the UCRS. If there is significant drawdown during purging prior to parameter stabilization, the well will be purged dry and allowed to recharge. The sample then will be collected after the well has recharged.

While purging the wells, field parameters including pH, ORP, temperature, conductivity, DO, and turbidity should be recorded in field logbooks or on a sampling form. Purged water will be collected and disposed of following the guidelines provided in Section 5. Pumps and field probes must be decontaminated according to the contractor procedure CP4-ES-2702 before sampling the next well.

All groundwater samples collected from performance monitoring wells will be analyzed at a laboratory contracted by the DOE SMO for VOCs by EPA method 8260C with the full list of VOCs reported. Groundwater samples should also be analyzed for dissolved hydrocarbon gasses by EPA method 8015 and total organic carbon by EPA method 9060A as specified in Table 3. A subset of the performance monitoring wells also will be sampled for DHC bacteria; these wells are indicated in Table 3 and are co-located with the baseline sample locations where DHC sampling will be performed. As discussed in Section 4.1, locations for DHC sampling were selected to provide spatially distributed samples within the treatment area.

One duplicate sample will be collected for every ten samples collected at performance monitoring locations. This results in two duplicates collected per sampling event. One matrix spike and matrix spike duplicate will also be collected for every twenty samples; therefore, one matrix spike and matrix spike duplicate will be collected per sampling event. One trip blank will be prepared for each day of sampling. Trip blanks should be prepared following contractor procedure CP4-ES-2704.

Sample bottles shall be labeled either before or immediately after sample collection (see sample naming convention provided in Table 3). Once a sample is collected, it will be immediately logged on the chain of custody and placed in coolers on ice. Coolers containing samples shall be shipped to the environmental laboratory using chain-of-custody procedures. Coolers may be shipped using FedEx (or an approved equivalent shipping service), or they can be picked up by the laboratory courier. Chains of custody that include sample names and collection date and time, what analyses will be performed, and contact and project information, will be completed by sampling staff and signed by those who are transporting coolers. A copy of the chain of custody should be retained in the field notes. Refer to contractor procedures CP4-ES-0104 and CP4-ES-2708 for more information.

4.3.4 Long-Term Monitoring

4.3.4.1 Well Locations

Six monitoring wells, oriented as two couplets, will be installed downgradient of SWMU 211-A [i.e., a couplet north of the western lobe (MW575 and MW576), a couplet north of the eastern lobe (MW577 and MW578), and a couplet northeast of the eastern lobe (MW582 and MW586)]. These wells will be used to monitor VOC concentrations in the RGA to determine progress towards achieving performance standards for SWMU 211-A. Each couplet will each have one well screened in the upper RGA and a well screened in the middle RGA. The locations of these wells are provided in Figure 2.

Three additional long-term monitoring wells will be installed in the RGA upgradient of the EISB treatment area. These wells will consist of one well couplet located southeast of the western lobe (MW579 and MW580) and a well located south of the eastern lobe at SWMU 211-A (MW581). The well couplet will have one well screened within the upper RGA and the other screened within the middle RGA. The single well installed south of the eastern lobe (MW581) will be screened in the upper RGA and located close to the existing wells MW203 (screened within the middle RGA) and MW204 (screened within the lower UCRS). Upgradient long-term monitoring wells will be used to assess concentrations of VOCs in groundwater migrating toward SWMU 211-A.

4.3.4.2 Groundwater Sampling and Analysis

The proposed and existing wells will be used to monitor EISB effectiveness and to assess compliance. Groundwater samples will be collected from each long-term monitoring well listed on the sampling plan every six months for the first five years following EISB implementation and then once per year after five years.

Prior to each day of sampling, the meters used to measure field parameters will be calibrated according to manufacturer guidelines and documented by field staff on calibration forms or in field logbooks. All groundwater samples from long-term monitoring wells will be collected using the low flow/minimal drawdown sampling approach (see contractor procedure

CP4-ES-2101) using bladder pumps. The intake for the bladder pump should be located in the middle of the screened interval when sampling. The total depth of the wells, the initial and final depths to water, as well as intermediate measurements during purging should be recorded during sampling (see contractor procedure CP4-ES-2100 for the full water level measurement procedure). If there is significant drawdown during purging prior to parameter stabilization, the well will be purged dry and allowed to recharge. The sample then will be collected after the well has recharged.

While purging the wells, field parameters including pH, ORP, temperature, conductivity, DO, and turbidity should be recorded in field logbooks or on a sampling form. Purged water will be collected in buckets and disposed of following the guidelines provided in Section 5. Pumps and field probes must be decontaminated according to the contractor procedure CP4-ES-2702 before sampling the next well.

All samples will be analyzed at a laboratory contracted by the DOE SMO for VOCs by EPA method 8260C although the laboratory should be instructed to only report five VOCs: TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, 1,1-DCE, and vinyl chloride. One duplicate sample will be collected for every 20 samples; therefore, 1 duplicate will be collected per long-term monitoring well sampling event. One matrix spike and matrix spike duplicate will be collected for every twenty samples; therefore, one matrix spike and matrix spike duplicate will be collected per sampling event. One trip blank will be prepared for each cooler used to contain VOC samples and submitted during each day of sampling when collecting groundwater samples for VOC analysis. Trip blanks should be prepared as outlined in contractor procedure CP4-ES-2704.

Table 3 provides specifics on sampling and analysis of long-term monitoring wells.

Sample bottles shall be labeled either before or immediately after sample collection (see sample naming convention provided in the sampling plan). Once a sample is collected, it will be immediately logged on the chain of custody and placed in coolers on ice. Coolers containing samples shall be shipped to the environmental laboratory using chain-of-custody procedures. Coolers may be shipped using FedEx (or an approved equivalent shipping service), or they can be picked up by the laboratory courier. Chains of custody that include sample names and collection date and time, what analyses will be performed, and contact and project information will be completed by sampling staff and signed by those transporting the coolers. A copy of the chain of custody should be retained in the field notes. Refer to contractor procedure CP4-ES-0104 and CP4-ES-2708 for more information.

4.4 Maintenance

Maintenance of the long-term and performance monitoring wells may be needed and could include routine and non-routine (as needed) activities. These activities may include mowing around wells, clearing vegetation to allow for safe and easy access to wells, or ensuring the wells are locked prior to leaving the Paducah Site. Wells may also need periodic repairs if damage is noted during inspections. Maintenance/repair activities should be recorded on Daily Field Reports and reported according to Paducah Site protocols.

Monitoring wells may need to be rehabilitated periodically to remove fine particles that enter the well and settle to the bottom and/or to improve the connectivity between the well screen, filter pack and formation. Rehabilitation activities will follow the same general process as well development performed upon installation of the well. The well development contractor procedure CP4-ES-0069 should be referenced for well rehabilitation.

Maintenance related to EISB is discussed in Section 3 of this OM&M Plan.

5. WASTE GENERATION

Investigation-derived waste (IDW) will be generated as part of SWMU 211-A remedy implementation and OM&M activities. IDW may include the following:

- Soil, water and residual amendments generated during fracturing and amendment emplacement;
- Soil generated during the installation of monitoring wells;
- Soil and groundwater generated during well development or well rehabilitation;
- Groundwater generated during performance and long-term sampling; and
- Trash and general construction refuse generated during field work (e.g., gloves, empty containers, etc.).

More information about IDW management is provided in Section 9 of this RDR.

TABLES

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Table 1
Well Construction Details
Paducah Gaseous Diffusion Plant
Paducah, Kentucky

Well ID	New/Existing Well	Targeted Screen Location	Well Diameter (in)	Total Depth (ft bgs)*	Screened Interval (ft bgs)**	Filter Pack Interval (ft bgs)**	Bentonite Seal Interval (ft bgs)***	Surface Completion	Monitoring Position with Respect to SWMU 211-A (gradient)
Performance Monitoring Wells									
PW001	New	RGA (Upper)	4	71.5	65-70	63-71.5	59-63	Stick-Up	Within
PW002	New	UCRS (Lower)	4	61.5	55-60	53-61.5	49-53	Stick-Up	Within
PW003	New	UCRS (Middle)	4	51.5	45-50	43-51.5	39-43	Stick-Up	Within
PW004	New	RGA (Upper)	4	71.5	65-70	63-71.5	59-63	Stick-Up	Within
PW005	New	UCRS (Lower)	4	61.5	55-60	53-61.5	49-53	Stick-Up	Within
PW006	New	UCRS (Middle)	4	51.5	45-50	43-51.5	39-43	Stick-Up	Within
PW007	New	RGA (Upper)	4	71.5	65-70	63-71.5	59-63	Stick-Up	Within
PW008	New	UCRS (Lower)	4	61.5	55-60	53-61.5	49-53	Stick-Up	Within
PW009	New	UCRS (Middle)	4	51.5	45-50	43-51.5	39-43	Stick-Up	Within
PW010	New	RGA (Upper)	4	71.5	65-70	63-71.5	59-63	Stick-Up	Within
PW011	New	UCRS (Lower)	4	61.5	55-60	53-61.5	49-53	Stick-Up	Within
PW012	New	UCRS (Middle)	4	51.5	45-50	43-51.5	39-43	Stick-Up	Within
PW013	New	RGA (Upper)	4	71.5	65-70	63-71.5	59-63	Stick-Up	Within
PW014	New	UCRS (Lower)	4	61.5	55-60	53-61.5	49-53	Stick-Up	Within
PW015	New	UCRS (Middle)	4	51.5	45-50	43-51.5	39-43	Stick-Up	Within
PW016	New	RGA (Upper)	4	71.5	65-70	63-71.5	59-63	Stick-Up	Within
PW017	New	UCRS (Lower)	4	61.5	55-60	53-61.5	49-53	Stick-Up	Within
PW018	New	UCRS (Middle)	4	51.5	45-50	43-51.5	39-43	Stick-Up	Within
Long-Term Monitoring Wells									
MW575	New	RGA (Upper)	4	71.5	65-70	63-71.5	59-63	Stick-Up	Down Gradient
MW576	New	RGA (Middle)	4	76.5	70-75	68-76.5	64-68	Stick-Up	Down Gradient
MW577	New	RGA (Upper)	4	71.5	65-70	63-71.5	59-63	Stick-Up	Down Gradient
MW578	New	RGA (Middle)	4	76.5	70-75	68-76.5	64-68	Stick-Up	Down Gradient
MW579	New	RGA (Upper)	4	71.5	65-70	63-71.5	59-63	Stick-Up	Up Gradient
MW580	New	RGA (Middle)	4	76.5	70-75	68-76.5	64-68	Stick-Up	Up Gradient
MW581	New	RGA (Upper)	4	71.5	65-70	63-71.5	59-63	Stick-Up	Up Gradient
MW203	Existing	RGA (Middle)	2	80	71-76	68-80	63-68	Stick-Up	Up Gradient
MW582	New	RGA (Upper)	4	71.5	65-70	63-71.5	59-63	Stick-Up	Down Gradient
MW586	New	RGA (Middle)	4	76.5	70-75	68-76.5	64-68	Stick-Up	Down Gradient

Notes:

1. * Monitoring wells constructed with a 1.5-foot sump below the screened interval.
2. ** Actual screened interval and total depth of well may be adjusted by the Field Geologist based on geological analysis of the obtained soil core.
3. *** A high-solids (~30% solids) bentonite slurry shall be placed from the top of the seal to the ground surface.
4. All wells will be constructed from schedule 40 PVC.
5. RGA = Regional Gravel Aquifer
6. UCRS = Upper Continental Recharge System
7. ft bgs = feet below ground surface

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Table 2
Baseline Sampling and Analysis Plan
Paducah Gaseous Diffusion Plant
Paducah, Kentucky

Locations Near Future Performance Monitoring Wells[1]

Sample Location	Geologic Unit	Screened Interval (ft bgs)	Sample Depth (ft bgs)	Sample Analysis
PW001	RGA (Upper)	N/A	67	8260C, RSK-175, TOC
PW002	UCRS (Lower)	N/A	57	8260C, RSK-175, TOC, Dhc + DUP
PW003	UCRS (Middle)	N/A	47	8260C, RSK-175, TOC, Dhc + DUP
PW004	RGA (Upper)	N/A	67	8260C, RSK-175, TOC
PW005	UCRS (Lower)	N/A	57	8260C, RSK-175, TOC
PW006	UCRS (Middle)	N/A	47	8260C, RSK-175, TOC
PW007	RGA (Upper)	N/A	67	8260C, RSK-175, TOC
PW008	UCRS (Lower)	N/A	57	8260C, RSK-175, TOC
PW009	UCRS (Middle)	N/A	47	8260C, RSK-175, TOC
PW010	RGA (Upper)	N/A	67	8260C, RSK-175, TOC
PW011	UCRS (Lower)	N/A	57	8260C, RSK-175, TOC
PW012	UCRS (Middle)	N/A	47	8260C, RSK-175, TOC
PW013	RGA (Upper)	N/A	67	8260C, RSK-175, TOC
PW014	UCRS (Lower)	N/A	57	8260C, RSK-175, TOC
PW015	UCRS (Middle)	N/A	47	8260C, RSK-175, TOC
PW016	RGA (Upper)	N/A	67	8260C, RSK-175, TOC + MS/MSD
PW017	UCRS (Lower)	N/A	57	8260C, RSK-175, TOC, Dhc
PW018	UCRS (Middle)	N/A	47	8260C, RSK-175, TOC, Dhc
Long-Term Monitoring Wells				
MW575	RGA (Upper)	65-70	67	8260C** + DUP
MW576	RGA (Middle)	70-75	72	8260C**
MW577	RGA (Upper)	65-70	67	8260C**
MW578	RGA (Middle)	70-75	72	8260C** + MS/MSD
MW579	RGA (Upper)	65-70	67	8260C**
MW580	RGA (Middle)	70-75	72	8260C**
MW581	RGA (Upper)	65-70	67	8260C**
MW203	RGA (Middle)	71-76	73	8260C**
MW582	RGA (Upper)	65-70	67	8260C**
MW586	RGA (Middle)	70-75	72	8260C**
Quality Control Samples				
Equipment Blank	N/A	N/A	N/A	8260C, RSK-175, TOC
Trip Blank	N/A	N/A	N/A	8260C

Notes:
1. Groundwater samples from locations near future performance monitoring wells shall be collected from temporary points using GeoProbe equipment such as a SP-16 with a 2-foot screen.
2. Samples will be collected using low-flow methods after parameter stabilization if possible. If a sample point does not yield sufficient water for low-flow sampling, groundwater samples will be collected by purging the well, and then returning within one week to collect groundwater samples.
3. Temporary sample collection points shall be grouted (using bentonite grout) from the bottom up after groundwater has been collected.
4. Sample ID will be constructed consistent with the project RAWP.
5. 8260C = VOCs by Method 8260C (GC/Mass Spec)
6. 8260C** = VOCs by Method 8260C (GC/Mass Spec), laboratory reports concentrations for only TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, 1,1-DCE and vinyl chloride
7. RSK-175 = analysis for dissolved hydrocarbon gasses (ethene, ethane and methane) by RSK SOP 175 Modified
8. TOC = total organic carbon
9. Dhc = analysis for presence of *dehalococcoides* bacteria
10. DUP = duplicates of the analyses at this well will be performed
11. MS/MSD = Matrix Spike and Matrix Spike Duplicate performed for this sample
12. RGA = Regional Gravel Aquifer
13. UCRS = Upper Continental Recharge System
14. ft bgs = feet below ground surface
15. N/A = Not Applicable

Table 3
Post-Injection Sampling and Analysis Plan
Paducah Gaseous Diffusion Plant
Paducah, Kentucky

Sample Location	Geologic Unit	Screened Interval (ft bgs)	Sample Depth (ft bgs)	Initial Year after EISB Implementation								Years 1-5 after EISB Implementation		Years >5 after EISB Implementation			
				Completion of EISB Implementation +1 Month		Completion of EISB Implementation +3 Month		Completion of EISB Implementation +6 Month		Completion of EISB Implementation +12 Month		Semiannual Years 1-5 after EISB Implementation		Semiannual Years >5 after EISB Implementation		Annual Years >5 after EISB Implementation	
				Water Level	Sample Analysis	Water Level	Sample Analysis	Water Level	Sample Analysis	Water Level	Sample Analysis	Water Level	Sample Analysis	Water Level	Sample Analysis	Water Level	Sample Analysis
Performance Monitoring Wells																	
PW001	RGA (Upper)	65-70	67	x	8260C, RSK-175, TOC + DUP	x	8260C, RSK-175, TOC + DUP	x	8260C, RSK-175, TOC + DUP	x	8260C, RSK-175, TOC + DUP	x	8260C, RSK-175, TOC + DUP	x	8260C, RSK-175, TOC + DUP	N/A	N/A
PW002	UCRS (Lower)	55-60	57	x	8260C, RSK-175, TOC, Dhc + DUP	x	8260C, RSK-175, TOC, Dhc + DUP	x	8260C, RSK-175, TOC, Dhc + DUP	x	8260C, RSK-175, TOC, Dhc + DUP	x	8260C, RSK-175, TOC, Dhc + DUP	x	8260C, RSK-175, TOC, Dhc + DUP	N/A	N/A
PW003	UCRS (Middle)	45-50	47	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	N/A	N/A
PW004	RGA (Upper)	65-70	67	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	N/A	N/A
PW005	UCRS (Lower)	55-60	57	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	N/A	N/A
PW006	UCRS (Middle)	45-50	47	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	N/A	N/A
PW007	RGA (Upper)	65-70	67	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	N/A	N/A
PW008	UCRS (Lower)	55-60	57	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	N/A	N/A
PW009	UCRS (Middle)	45-50	47	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	N/A	N/A
PW010	RGA (Upper)	65-70	67	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	N/A	N/A
PW011	UCRS (Lower)	55-60	57	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	N/A	N/A
PW012	UCRS (Middle)	45-50	47	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	N/A	N/A
PW013	RGA (Upper)	65-70	67	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	N/A	N/A
PW014	UCRS (Lower)	55-60	57	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	N/A	N/A
PW015	UCRS (Middle)	45-50	47	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	x	8260C, RSK-175, TOC	N/A	N/A
PW016	RGA (Upper)	65-70	67	x	8260C, RSK-175, TOC + MS/MSD	x	8260C, RSK-175, TOC + MS/MSD	x	8260C, RSK-175, TOC + MS/MSD	x	8260C, RSK-175, TOC + MS/MSD	x	8260C, RSK-175, TOC + MS/MSD	x	8260C, RSK-175, TOC + MS/MSD	N/A	N/A
PW017	UCRS (Lower)	55-60	57	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	N/A	N/A
PW018	UCRS (Middle)	45-50	47	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	x	8260C, RSK-175, TOC, Dhc	N/A	N/A
Long-Term Monitoring Wells																	
MW575	RGA (Upper)	65-70	67	x	N/A	x	N/A	x	8260C** + DUP	x	8260C** + DUP	x	8260C** + DUP	N/A	N/A	x	8260C** + DUP
MW576	RGA (Middle)	70-75	72	x	N/A	x	N/A	x	8260C**	x	8260C**	x	8260C**	N/A	N/A	x	8260C**
MW577	RGA (Upper)	65-70	67	x	N/A	x	N/A	x	8260C**	x	8260C**	x	8260C**	N/A	N/A	x	8260C**
MW578	RGA (Middle)	70-75	72	x	N/A	x	N/A	x	8260C** + MS/MSD	x	8260C** + MS/MSD	x	8260C** + MS/MSD	N/A	N/A	x	8260C** + MS/MSD
MW579	RGA (Upper)	65-70	67	x	N/A	x	N/A	x	8260C**	x	8260C**	x	8260C**	N/A	N/A	x	8260C**
MW580	RGA (Middle)	70-75	72	x	N/A	x	N/A	x	8260C**	x	8260C**	x	8260C**	N/A	N/A	x	8260C**
MW581	RGA (Upper)	65-70	67	x	N/A	x	N/A	x	8260C**	x	8260C**	x	8260C**	N/A	N/A	x	8260C**
MW203	RGA (Middle)	71-76	73	x	N/A	x	N/A	x	8260C**	x	8260C**	x	8260C**	N/A	N/A	x	8260C**
MW582	RGA (Upper)	65-70	67	x	N/A	x	N/A	x	8260C**	x	8260C**	x	8260C**	N/A	N/A	x	8260C**
MW586	RGA (Middle)	70-75	72	x	N/A	x	N/A	x	8260C**	x	8260C**	x	8260C**	N/A	N/A	x	8260C**
Quality Control Samples																	
Trip Blank	N/A	N/A	N/A	N/A	8260C	N/A	8260C	N/A	8260C	N/A	8260C	N/A	8260C	N/A	8260C	N/A	N/A

Notes:
1. Wells not listed will not be sampled.
2. Prior to sample collection, water levels shall be measured at designated wells.
3. Sample ID will be constructed consistent with the project RAWP.
4. Samples will be collected using low-flow methods after parameter stabilization if possible. If a sample point does not yield sufficient water for low-flow sampling, groundwater samples will be collected by purging the well, and then returning within one week to collect groundwater samples.
5. 8260C = VOCs by Method 8260C (GC/Mass Spec), laboratory reports the full list of VOCs
6. 8260C** = VOCs by Method 8260C (GC/Mass Spec), laboratory reports concentrations for only TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, 1,1-DCE and vinyl chloride
7. RSK-175 = analysis for dissolved hydrocarbon gasses (ethene, ethane and methane) by Method RSK SOP 175 Modified
8. TOC = total organic carbon
9. Dhc = analysis for presence of *dehalococcoides* bacteria
10. DUP = duplicates of the analyses at this well will be performed
11. MS/MSD = Laboratory matrix spike and laboratory matrix spike duplicate performed for this sample
12. RGA = Regional Gravel Aquifer
13. UCRS = Upper Continental Recharge System
14. ft bgs = feet below ground surface
15. N/A = Not Applicable

FIGURES

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Adapted from Figure 6 of DOE (2013).

Legend

Existing Monitoring Well Locations That Will Remain

⊕ Well screened within the middle UCRS

⊕ Well screened within the middle RGA

Proposed Monitoring Well Locations

⊕ Well screened within the middle UCRS

⊕ Well screened within the lower UCRS

⊕ Well screened within the upper RGA

⊕ Well screened within the middle RGA

🟪 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. Section 7 of the Final Characterization Report includes explanation of the modeling conducted to establish the TCE contours based upon confidence levels.
2. Source of 2018 Aerial: Google Earth.

30 15 0 30 Feet

SWMU 211-A Performance Monitoring Well Layout

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

FOUR RIVERS NUCLEAR PARTNERSHIP, LLC

September 2019

Figure 1

Document Path: Q:\GISProjects\KX6467A_Paducah\MXDs\ACTON_2018\SWMU 211-A Performance MW.mxd

Adapted from Figure 6 of DOE (2013).

Legend

Existing Monitoring Well Locations That Will Remain

⊕ Well screened within the middle UCRS

⊕ Well screened within the middle RGA

Proposed Monitoring Well Locations

⊕ Well screened within the upper RGA

⊕ Well screened within the middle RGA

🟪 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. Section 7 of the Final Characterization Report includes explanation of the modeling conducted to establish the TCE contours based upon confidence levels.
2. Source of 2018 Aerial: Google Earth.

30 15 0 30 Feet

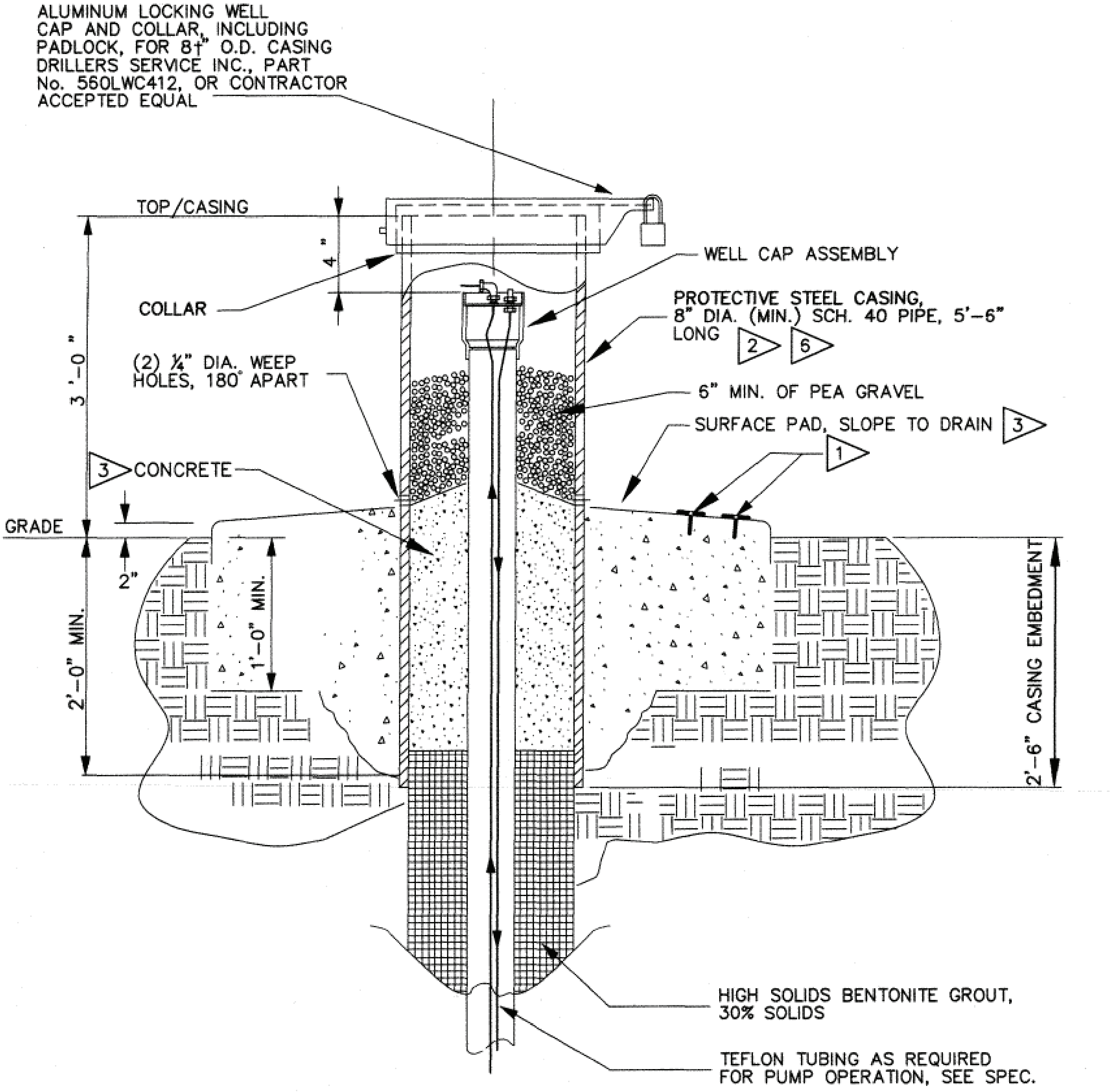
SWMU 211-A Long-Term Monitoring Well Layout

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

FOUR RIVERS NUCLEAR PARTNERSHIP, LLC

September 2019

Figure 2



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 ½" 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

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.

Suggested Well Schematic

Paducah Gaseous Diffusion Plant
Paducah, Kentucky

Geosyntec
consultants

ACTON, MASSACHUSETTS | FEBRUARY 2019

FIGURE
3

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APPENDIX B

EXAMPLE FIELD FORMS

DPT Jet Injection Log

Project Name: ____________________ Page ____ of ____

Project Number: ____________________ **Date:** ____________________

Field Personnel: ____________________ **Weather:** ____________________

Location ID	Injection Depth (ft bgs)	Date	Time Injection Started	Time Injection Completed	Guar Gel (gal)	ZVI (lbs)	Sand (lbs)	Water Blaster Injection Pressure (psi)	Average Slurry Injection Pressure (psi)	Comments
				Totals						

Anaerobic Water Batch Preparation Log

Project Name: ____________________ Page ____ of ____
Project Number: ____________________ **Field Personnel:** ____________________
Date: ____________________ **Weather** ____________________

Batch #	Tank Fill			KB-1® Primer		Geochemical Parameters						Comments
	Start Time (hr:mm)	End Time (hr:mm)	Volume (gallons)	Time (hr:mm)	Amount (kg)	Time (hr:mm)	Temp (°C)	pH (SU)	Sp. Cond (μs/cm^3)	DO (mg/L)	ORP (mV)	

EVO Solution Injection Log

Project Name: ______________________________ **Date:** _____________________ Page ____ of ____
Project Number: ______________________________ **Weather:** _____________________
Field Personnel: ______________________________ **Activity:** _____________________
______________________________ _____________________

Location:______________________	**Start: Date**__________ **Time**__________	**Finish: Date**__________ **Time**__________

Well ID	**Start Time (hr:mm)**	**Stop Time (hr:mm)**	**Volume Water (gal)**	**Volume EVO Solution (gal)**	**Flowrate (GPM)**	**Total Volume Injected (gal)**	**Notes**

KB-1® Plus Injection Log

Project Name: ______________________________ **Date:** ______________________________ Page ____ of ____
Project Number: ______________________________ **Weather:** ______________________________
Field Personnel: ______________________________ **Activity:** ______________________________
______________________________ ______________________________

Vessel ID#:_________
Vessel size (L):______
Start Time:___________
Initial Pressure:_______ **Initial Weight:**_______
End Time:___________
Final Pressure:_______ **Final Weight:**________

Well ID	Start Time (hr:mm)	Stop Time (hr:mm)	Vessel Start Weight (kg)	Vessel End Weight (kg)	Volume (Liters)	Notes

SWMU 211-A REMEDIAL ACTION

Field Change Request Form

Project Name: ________________________________ **Subcontractor:** ____________________________

Field Activity: ________________________________ **Request Number:** __________________________

To: ____ **Date:**_____________________________________

Field Change Request (FCR) Title:____

Description:____

____

____

Recommended Change: ____

____

____

____

____

____

____

____

____

______________________________	________________________	________________
Respondent Field Coordinator (or Designee) (Print)	**Signature**	**Date**

Approval:

______________________________	________________________	________________
FRNP Project Manager (Print)	**Signature**	**Date**

Comments:

____

____

____

____

____

NOTES:

- FCR forms will be included as an appendix to the remedial action completion report.
- FCR forms for the following items will be communicated to the FFA parties as soon as feasible after approval by the FRNP Project Manager and prior to implementation:
    - Applying a different bioaugmentation consortium or electron donor than planned,
    - Eliminating a planned injection well location,
    - Eliminating a planned injection screen in an injection well,
    - Eliminating a DPT jet injection sand/ZVI injection location, and
    - Moving a planned Performance or Monitoring Well location by more than 10 ft from its original planned location.

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APPENDIX C

MONITORING WELL ENGINEERING DRAWINGS

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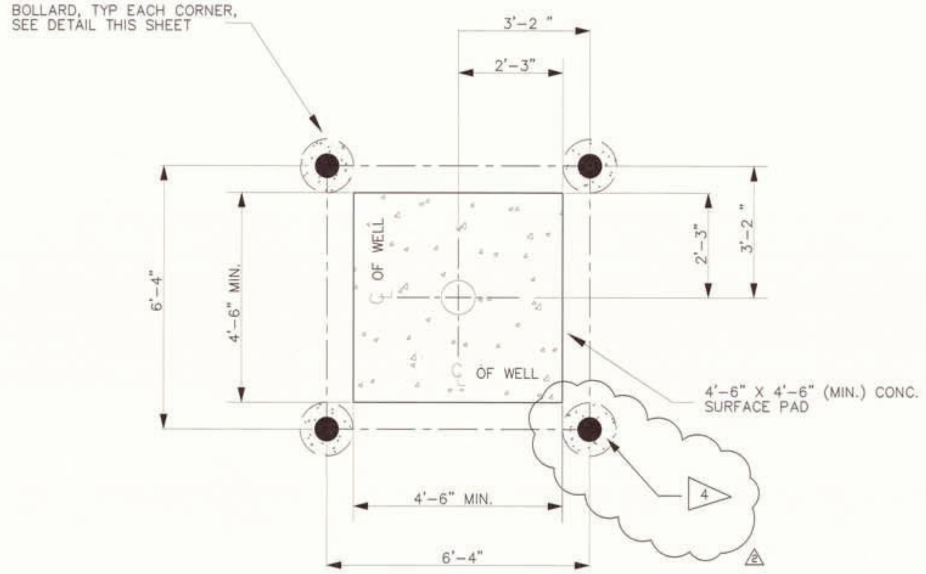
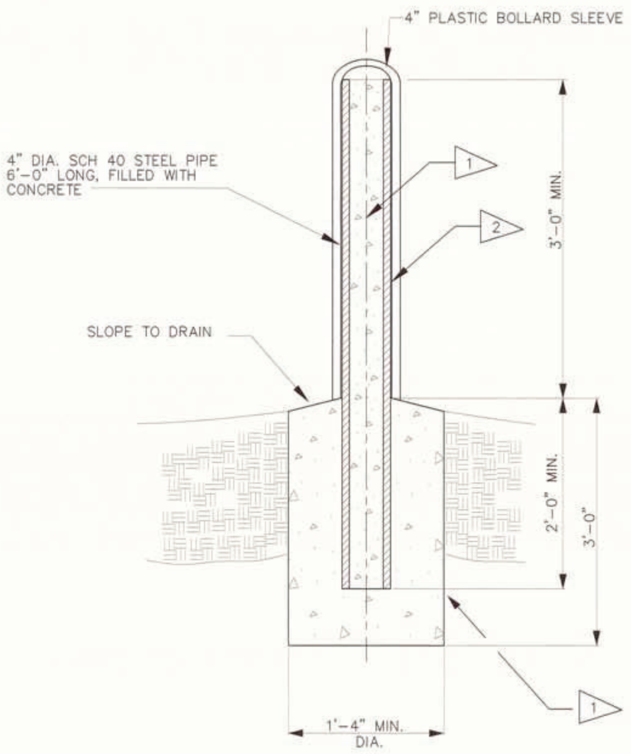


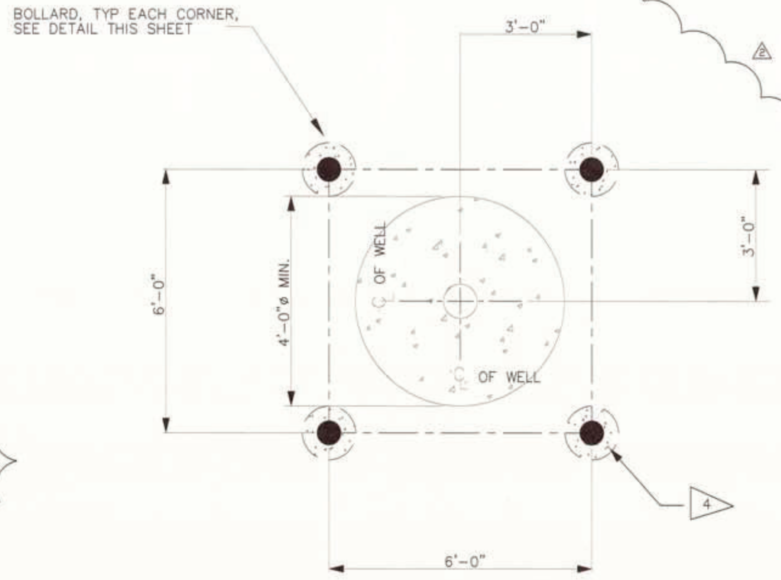
SQUARE CONCRETE PAD AND BOLLARD LOCATION PLAN



TYPICAL BOLLARD DETAIL

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 (¼" 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.



CIRCULAR CONCRETE PAD AND BOLLARD LOCATION PLAN

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

THIS DRAWING PRODUCED ON AUTOCAD
DO NOT REVISE MANUALLY

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

[Aug 22, 2018]

LPE
KAREN A. SIZEMORE
21059
Karen A. Sizemore
8/30/18
DATE
PROFESSIONAL SEAL

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

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS ± 1/16"
XX DECIMALS
XXX DECIMALS
ANGLES
BREAK SHARP EDGES MAX.
FINISH

"NO REPRESENTATION OR WARRANTY, EXPRESSED OR IMPLIED, IS MADE THAT THE USE OR DISCLOSURE OF ANY INFORMATION, APPARATUS, METHOD OR PROCESS DISCLOSED IN THESE DRAWINGS MAY NOT INFRINGE PRIVATE RIGHTS OF OTHERS. NO LIABILITY IS ASSUMED WITH RESPECT TO THE USE OF, OR FOR DAMAGES RESULTING FROM THE USE ANY INFORMATION, APPARATUS, METHOD OR PROCESS DISCLOSED IN THESE DRAWINGS. THE DRAWINGS ARE BEING MADE FOR INFORMATION TO BIDDER AND ARE NOT TO BE USED FOR OTHER PURPOSES, AND ARE TO BE RETURNED UPON REQUEST OF THE FORWARDING CONTRACTOR."

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

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

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

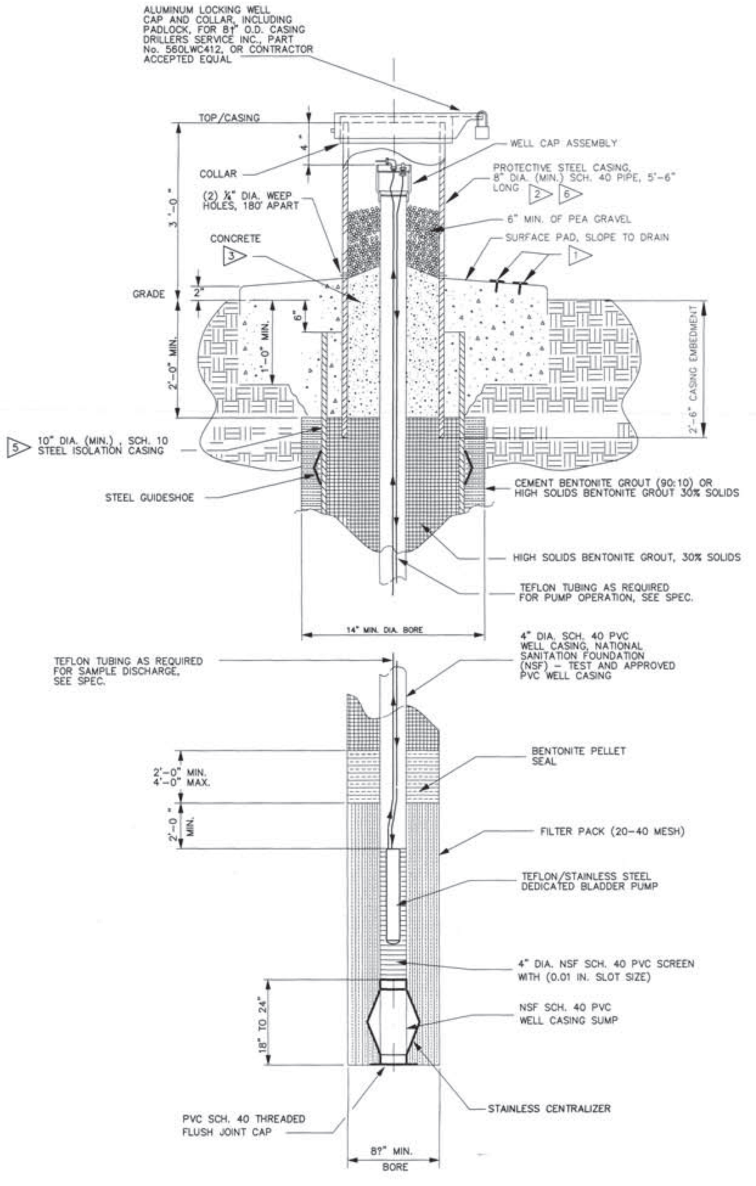
GROUND WATER MONITORING WELLS TYPICAL WELL DETAILS

NON-ESSENTIAL

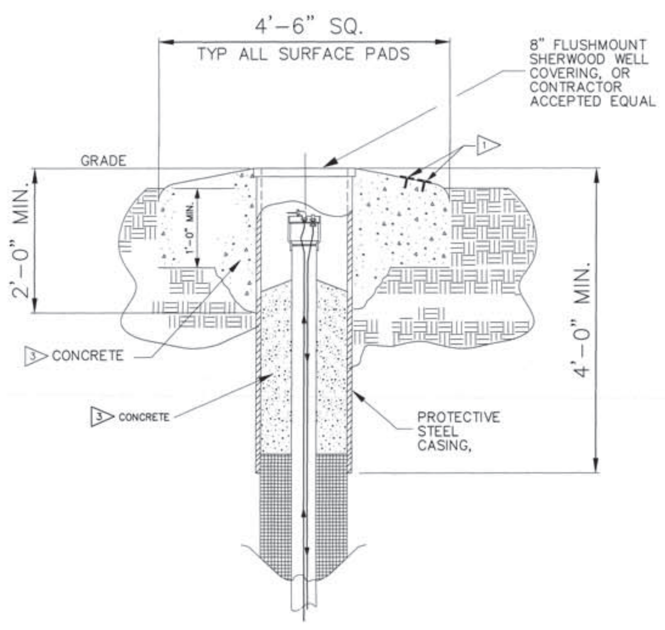
SCALE	PLANT	BLDG	FL	CLASS
NONE	PGDP	N/A	N/A	U

ID		REV
FA1950	C7DCWELLSA002	2

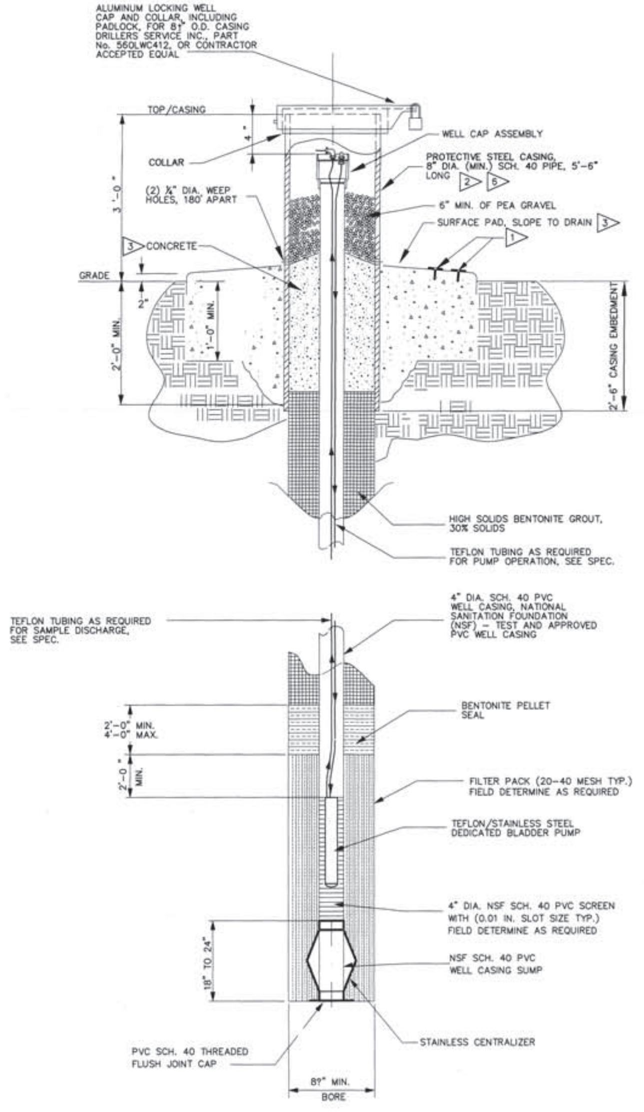
NEXT ASS'Y: FINAL ASS'Y:



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 ½" 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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FOUR RIVERS NUCLEAR PARTNERSHIP, LLC

LPE

KAREN A. SIZEMORE
21050

Karen A. Sizemore
9/25/17

DATE

PROFESSIONAL SEAL

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

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS ± 1/16"
XX DECIMALS
XXX DECIMALS
ANGLES
BREAK SHARP EDGES MAX.
FINISH

"NO REPRESENTATION OR WARRANTY, EXPRESSED OR IMPLIED, IS MADE THAT THE USE OR DISCLOSURE OF ANY INFORMATION, APPARATUS, METHOD OR PROCESS DISCLOSED IN THESE DRAWINGS MAY NOT INFRINGE PRIVATE RIGHTS OF OTHERS. NO LIABILITY IS ASSUMED WITH RESPECT TO THE USE OF, OR FOR DAMAGES RESULTING FROM THE USE ANY INFORMATION, APPARATUS, METHOD OR PROCESS DISCLOSED IN THESE DRAWINGS. THE DRAWINGS ARE BEING MADE FOR INFORMATION TO BIDDER AND ARE NOT TO BE USED FOR OTHER PURPOSES, AND ARE TO BE RETURNED UPON REQUEST OF THE FORWARDING CONTRACTOR."

REV. NO.	ISSUE / REVISION DESCRIPTION	DATE	DRW	CHKR	RE	TR	APPD
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

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

APPENDIX D

SAFETY DATA SHEETS

CONTENTS

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1. IDENTIFICATION OF THE SUBSTANCE OR MIXTURE AND OF THE SUPPLIER

Product identifier used on the label: 20 Mule Team Borax

Recommended use of the chemical and restrictions on use: Universal

Name, address and telephone number of the chemical manufacturer:
Henkel Consumer Goods Inc.
7201 E. Henkel Way
Scottsdale, AZ 85255

Telephone: For medical emergencies 1-888-689-9082

CHEMTREC: 1-800-424-9300
Internet: www.henkel-northamerica.com

2. HAZARDS IDENTIFICATION

The hazards described in this Globally Harmonized System Safety Data Sheet (SDS) are not intended for consumers, and does not address consumer use of the product. For information regarding consumer applications of this product, refer to the product label.

Classification of the substance or mixture in accordance with paragraph (d) of §1910.1200

HAZARD CLASS	HAZARD CATEGORY
SKIN IRRITATION	2
EYE IRRITATION	2A
REPRODUCTIVE TOXICITY	2

Signal word, hazard statement(s), symbol(s) and precautionary statement(s) in accordance with paragraph (f) of §1910.1200

Signal word: WARNING
Hazard Statement(s):
Causes skin irritation.
Causes serious eye irritation.
Suspected of damaging fertility or the unborn child.

Symbol(s):

Precautionary Statements:

Prevention:	Obtain special instructions before use. Do not handle until all safety precautions have been read and understood. Wash thoroughly after handling. Wear eye and face protection. Wear protective gloves. Use personal protective equipment as required.
Response:	IF ON SKIN: Wash with plenty of water. IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. IF exposed or concerned: Get medical attention. If skin irritation occurs: Get medical attention. If eye irritation persists: Get medical attention. Take off contaminated clothing.
Storage:	Store locked up.
Disposal:	Dispose of contents and/or container according to Federal, State/Provincial and local governmental regulations.

Hazards not otherwise classified:	None known

Classification complies with OSHA Hazard Communication Standard (29 CFR 1910.1200) and is consistent with the provisions of the United Nations Globally Harmonized System of Classification and Labeling of Chemicals (GHS).

See Section 11 for additional toxicological information.

3. COMPOSITION / INFORMATION ON INGREDIENTS

The following chemicals are classified as health hazards in accordance with paragraph (d) of § 1910.1200.

Chemical Name*	CAS Number (Unique Identifier)	Concentration
Sodium tetraborate decahydrate	1303-96-4	60 - 100 %

*The specific chemical identity and/or exact percentage (concentration) of composition has been withheld because a trade secret is claimed in accordance with paragraph (i) of §1910.1200.

4. FIRST AID MEASURES

Description of necessary measures

Inhalation:	Remove from exposure area to fresh air. Treat symptomatically and supportively.
Skin contact:	Rinse affected area with large amounts of water until no evidence of product remains. Get medical attention if irritation persists.
Eye contact:	Immediately rinse eyes with plenty of water for at least 15 minutes while holding eyelids open. Get medical attention if pain or irritation develops.
Ingestion:	Dilution by rinsing the mouth and giving water or milk to drink is generally recommended. Contact physician or local poison control center.

Most important symptoms and effects, both acute and delayed

After eye contact: Moderate to strong irritation of the eyes (redness, swelling, burning, watering eyes), the occurrence of these symptoms may be delayed.

After skin contact: May cause moderate to severe irritation. After Ingestion: Ingestion may cause pain, burning, swelling and redness in the mouth and throat. Nausea and vomiting may occur. After inhalation: Dust may cause mucous membrane irritation with coughing and shortness of breath.

Indication of any immediate medical attention and special treatment needed

After eye contact: Rinse eyes immediately with plenty of water, occasionally lifting upper and lower lids, until no evidence of product remains. After skin contact: Rinse affected area with large amounts of water until no evidence of product remains. After ingestion: May be fatal if swallowed and enters airways. Dilution by rinsing the mouth and giving a glass of water to drink is generally recommended. After inhalation: Remove from exposure area to fresh air. Contact physician or local poison control center.

5. FIRE FIGHTING MEASURES

Suitable (and unsuitable) extinguishing media

Suitable extinguishing media:	Extinguish using agent suitable for type of surrounding fire. Product is fire retardant.
Unsuitable extinguishing media:	None known

Specific hazards arising from the chemical

Thermal decomposition products may include toxic oxides of sodium and boron.

Special protective equipment and precautions for fire-fighters

In case of fire, wear a full-face positive-pressure self-contained breathing apparatus and protective suit. Apply cooling water to sides of containers that are exposed to flames until well after fire is out. Avoid breathing vapors, keep upwind. Isolate area. Keep unnecessary personnel away.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions, protective equipment and emergency procedures

Wear skin, eye and respiratory protection as recommended in Section 8. Stop leak if you can do it without risk. Spills present a slipping hazard. Keep unnecessary personnel away. Ensure clean-up is conducted by trained personnel only. Ventilate spill area if possible. Make sure area is slip-free before re-opening to traffic.

Environmental precautions

Small or household quantities may be disposed in regular domestic trash. For larger quantities check with your local disposal authorities.

Methods and materials for containment and cleaning up

SMALL SPILLS: Sweep or scoop up and place into containers for later disposal. Wash site of spillage thoroughly with water.
LARGE SPILLS: Sweep or scoop up and place into suitable clean, dry containers for reclamation or later disposal. Dispose in suitable waste container. Keep unnecessary people away from spill.

7. HANDLING AND STORAGE

Precautions for safe handling

Do not get in eyes, on skin, on clothing Do not take internally. Use with adequate ventilation.

Conditions for safe storage, including any incompatibilities

Store in original containers in a cool dry area. Storage areas for large quantities (warehouse) should be well ventilated. Keep the containers tightly closed when not in use.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

OSHA permissible exposure limit (PEL), American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV), and any other exposure limit used or recommended by the chemical manufacturer, importer, or employer preparing the safety data sheet, where available.

Hazardous Component(s)	ACGIH TLV	OSHA PEL	AIHA WEEL	OTHER
Sodium tetraborate decahydrate	2 mg/m3 TWA Inhalable fraction. 6 mg/m3 STEL Inhalable fraction.	None	None	None

Appropriate engineering controls

Provide local exhaust or general dilution ventilation to keep exposure to airborne contaminants below the permissible exposure limits where mists or vapors may be generated.

Individual protection measures

Respiratory:	If respiratory protection is required, it must be based on the contamination levels found in the workplace, must not exceed the working limits of the respirator and be jointly approved by the National Institute for Occupational Safety and Health and the Mine Safety and Health Administration (NIOSH-MSHA).
Eye:	Safety glasses are required to prevent eye contact where dusty conditions may occur.
Hand/Body:	Protective gloves are required where repeated or prolonged skin contact may occur. Protective clothing is required where repeated or prolonged skin contact may occur.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance:	solid white
Odor:	odourless
Odor threshold:	Not available.
pH:	9.3 Aqueous solution
Melting point/ range:	Not available.
Boiling point/range:	Not available.
Flash point:	Not applicable
Evaporation rate:	Not available.
Flammable/Explosive limits - lower:	Not available.
Flammable/Explosive limits - upper:	Not available.
Vapor pressure:	Not available.
Vapor density:	Not available.
Solubility in water:	Not available.
Partition coefficient (n-octanol/water):	Not available.
Autoignition temperature:	Not available.
Decomposition temperature:	Not available.
Viscosity:	Not available.
VOC content:	Not available.

10. STABILITY AND REACTIVITY

Reactivity:	This product may react with strong oxidizing agents.
Chemical stability:	Stable under normal ambient temperature (70°F, 21°C) and pressure (1 atm).
Possibility of hazardous reactions:	Hazardous polymerization has not been reported to occur under normal temperatures and pressures.
Conditions to avoid:	Avoid storing in direct sunlight and avoid extremes of temperature.
Incompatible materials:	Strong oxidizers, acids, zirconium.
Hazardous decomposition products:	Thermal decomposition products may include toxic oxides of sodium and boron.

11. TOXICOLOGICAL INFORMATION

Likely routes of exposure including symptoms related to characteristics

Inhalation:	Dust may cause mucous membrane irritation with coughing, dryness and sore throat.
Skin contact:	Prolonged and/or repeated skin contact with this product may cause irritation.
Eye contact:	May cause moderate to severe irritation, with possibility of corneal injury if not removed promptly.
Ingestion:	May cause mild gastrointestinal irritation with nausea, vomiting, diarrhea and abdominal pain.
Physical/Chemical:	The product is irritant to skin and mucous membranes.
Other relevant toxicity information:	This product is a laundry care product. The use of this product by consumers is safe under normal and reasonable foreseen use.

Numerical measures of toxicity, including delayed and immediate effect

Hazardous Component(s)	LD50s and LC50s	Immediate and Delayed Health Effects
Sodium tetraborate decahydrate	Oral LD50 (RAT) = 396 - 689 mg/kg Oral LD50 (RAT) = 5,660 mg/kg Oral LD50 (RAT) = 396 mg/kg Oral LD50 (RAT) = 5.66 g/kg Dermal LD50 (RABBIT) = > 10,000 mg/kg Inhalation LC50 (RAT, 4 h) = > 0.002 mg/l	Irritant, Reproductive, Skin, Less weight gain and food intake.

Carcinogenicity information

Hazardous Component(s)	NTP Carcinogen	IARC Carcinogen	OSHA Carcinogen
Sodium tetraborate decahydrate	No	No	No

Carcinogenicity	None of the ingredients in this product are listed as carcinogens by the International Agency for Research on Cancer (IARC), the National Toxicology Program (NTP) or the Occupational Safety and Health Administration (OSHA).
Mutagenicity	None of the ingredients in this product are known to cause mutagenicity.
Toxicity for reproduction	Sodium borate and boric acid interfere with sperm production, damage the testes and interfere with male fertility when given to animals by mouth at high doses.

12. ECOLOGICAL INFORMATION

Aquatic Toxicity:

This product is anticipated to be safe for the environment at concentrations predicted in household settings under normal use conditions. The following toxicity information is available for the hazardous ingredient(s) when used as technical grade and is provided as reference for the occupational settings.

Toxicity to fish:

The aquatic toxicity profile of this product has not been determined.

Toxicity to aquatic invertebrates:

The aquatic toxicity profile of this product has not been determined.

Toxicity to algae:

The aquatic toxicity profile of this product has not been determined.

Persistence and degradability

The persistence and degradability of this product has not been determined.

Bioaccumulative potential

The bioaccumulation potential of this product has not been determined.

Mobility in soil

The mobility of this product (in soil and water) has not been determined.

13. DISPOSAL CONSIDERATIONS

Description of waste residues:

Hazardous waste number:	Not regulated

Safe handling and disposal methods:

Recommended method of disposal:	This product is not a RCRA hazardous waste and can be disposed of in accordance with federal, state and local regulations.
Disposal of uncleaned packages:	Place in trash.

14. TRANSPORT INFORMATION

The information in this section is for reference only and should not take the place of a shipping paper (bill of lading) specific to an order. Please note that the proper shipping classification may vary by packaging, properties, and mode of transportation.

U.S. Department of Transportation Ground (49 CFR)

Proper shipping name:	Not regulated
Hazard class or division:	None
Identification number:	None
Packing group:	None

International Air Transportation (ICAO/IATA)

Proper shipping name:	Not regulated
Hazard class or division:	None
Identification number:	None
Packing group:	None

Water Transportation (IMO/IMDG)

Proper shipping name:	Not regulated
Hazard class or division:	None
Identification number:	None
Packing group:	None

15. REGULATORY INFORMATION

Occupational safety and health act: Hazard Communication Standard, 29 CFR 1910.1200(g) Appendix D: The Occupational Safety and Health Administration (OSHA) require that the Safety Data Sheets (SDSs) are readily accessible to employees for all hazardous chemicals in the workplace. Since the use pattern and exposure in the workplace are generally not consistent with those experienced by consumers, this SDS may contain health hazard information not relevant to consumer use.

United States Regulatory Information

TSCA 8 (b) Inventory Status:	All components are listed or are exempt from listing on the Toxic Substances Control Act Inventory.
TSCA 12 (b) Export Notification:	
CERCLA/SARA Section 302 EHS:	None above reporting de minimis.
CERCLA/SARA Section 311/312:	Not available.
CERCLA/SARA Section 313:	None above reporting de minimis.
California Proposition 65:	No California Proposition 65 listed chemicals are known to be present.

Canada Regulatory Information

CEPA DSL/NDSL Status:	All components are listed on or are exempt from listing on the Canadian Domestic Substances List.

16. OTHER INFORMATION

DISCLAIMER: The data contained herein are furnished for information only and are believed to be reliable. However, Henkel Corporation and its affiliates (“Henkel”) does not assume responsibility for any results obtained by persons over whose methods Henkel has no control. It is the user’s responsibility to determine the suitability of Henkel’s products or any production methods mentioned herein for a particular purpose, and to adopt such precautions as may be advisable for the protection of property and persons against any hazards that may be involved in the handling and use of any Henkel’s products. In light of the foregoing, Henkel specifically disclaims all warranties, express or implied, including warranties of merchantability and fitness for a particular purpose, arising from sale or use of Henkel’s products. Henkel further disclaims any liability for consequential or incidental damages of any kind, including lost profits.

This safety data sheet contains changes from the previous version in sections: New Safety Data Sheet format.

Prepared by:	R&D Support Services
Issue date:	07/24/2017

Revision Date 6/23/2016

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name	:	Ferox Flow zero valent iron powder
Brand	:	Hepure
CAS-No.	:	7439-89-6

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses	:	Environmental remediation, water treatment, various

1.3 Details of the supplier of the safety data sheet

Company	:	Hepure Technologies, Inc. 63 Main Street, Suite 203B Flemington, NJ 08822
Telephone	:	877-727-4776

1.4 Emergency telephone number

Emergency Phone #	:	Chemtrec 800-424-9300 CCN234339

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Not classified as hazardous

2.2 GHS Label elements, including precautionary statements

Signal Word: not applicable
Hazard Statements: not applicable
Precautionary Statements: not applicable

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS – none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula: Fe
Molecular Weight: 55.85 g/mol
CAS-No.: 7439-89-6
EC-No.: 231-096-4

Carbon:	2 to 2.5%
Sulfur:	0.050%
Silicon :	1.5 to 2%
Iron:	Balance

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Move out of dangerous area. Consult a physician. Show this safety data sheet to the doctor in attendance.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

No data available

4.3 Indication of any immediate medical attention and special treatment needed

No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use Class D or other metal extinguishing agent.

5.2 Special hazards arising from the substance or mixture

These materials, as coarse particles, are non-flammable and do not react with water or other materials used for extinguishing fire. Fine metal dust may pose a risk of fire or explosion if accumulated, mixed and confined with an ignition source. When handling fine particles generated from this material, avoid creating dust clouds and ignition sources. May release iron oxide fume if involved in a fire.

5.3 Advice for firefighters

Wear self-contained breathing apparatus for fire fighting if necessary.

5.4 Further information

Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Avoid dust formation. Avoid breathing vapors, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas.
For personal protection see section 8.

6.2 Environmental precautions

Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up

Sweep up and shovel. Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13). Keep in suitable, closed containers for disposal. Contain spillage, pick up with an electrically protected vacuum cleaner or by wet-brushing and transfer to a container for disposal according to local regulations (see section 13).

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

Avoid formation of dust and aerosols.
Provide appropriate exhaust ventilation at places where dust is formed. Keep away from sources of ignition - No smoking. Take measures to prevent the build up of electrostatic charge.

7.2 Conditions for safe storage, including any incompatibilities

Keep container tightly closed in a dry and well-ventilated place.

Store under inert gas. Moisture sensitive. Keep in a dry place.

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Safety glasses with side-shields conforming to EN166 Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Impermeable gloves, protective work clothing as necessary.

Respiratory Protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face particle respirator type N100 (US) or type P3 (EN 143) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a) Appearance	Form: powder
b) Odor	no data available
c) Odor Threshold	no data available
d) pH	no data available
e) Melting point/freezing point	Melting point/range: 1,535 °C (2,795 °F) - lit.
f) Initial boiling point and boiling range	2,750 °C (4,982 °F) - lit.
g) Flash point	no data available

h)	Evaporation rate	no data available
i)	Flammability (solid, gas)	not flammable as a course particle; Fine metal dust may pose a risk of fire or explosion if accumulated, mixed and confined with an ignition source
j)	Upper/lower flammability or explosive limits	no data available
k)	Vapor pressure	no data available
l)	Vapor density	no data available
m)	Relative density	7.86 g/cm3 at 25 °C (77 °F)
n)	Water solubility	insoluble
o)	Partition coefficient: n-octanol/water	no data
p)	Auto-ignition temperature	available no
q)	Decomposition temperature	data available
		no data available
r)	Viscosity	no data available
s)	Explosive properties	no data available
t)	Oxidizing properties	no data available

9.2 Other safety information

Bulk density	2,500.0 - 3,500.0 kg/m3

10. STABILITY AND REACTIVITY

10.1 Reactivity

No data available

10.2 Chemical stability

Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions

No data available

10.4 Conditions to avoid

Heat, flames and sparks. Extremes of temperature and direct sunlight.

10.5 Incompatible materials

Acids, Oxygen, Strong oxidizing agents, Halogens, Phosphorus

10.6 Hazardous decomposition products

Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - rat - 30,000 mg/kg
Remarks: Nutritional and Gross Metabolic: Weight loss or decreased weight

gain. Inhalation: no data available

Dermal: no data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitization
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data

available No

data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: NO4565500

Overdose of iron compounds may have a corrosive effect on the gastrointestinal mucosa and be followed by necrosis, perforation, and stricture formation. Several hours may elapse before symptoms that can include epigastric pain, diarrhea, vomiting, nausea, and hematemesis occur. After apparent recovery a person may experience metabolic acidosis, convulsions, and coma hours or days later. Further complications may develop leading to acute liver necrosis that can result in death due to hepatic coma. Long term inhalation exposure to iron (oxide fume or dust) can cause siderosis. Siderosis is considered to be a benign pneumoconiosis and does not normally cause significant physiologic impairment. Siderosis can be observed on x-rays with the lungs having a mottled appearance.

12. ECOLOGICAL INFORMATION

Non-hazardous

13. DISPOSAL CONSIDERATIONS

Waste Disposal Method:

Product: Dispose of in accordance with Federal, State and Local regulations.
Packaging: Dispose of in accordance with Federal, State and Local regulations.

14. TRANSPORT INFORMATION

Shipping Regulations:	Not regulated
UN Number:	N/A
UN Proper Shipping Name:	N/A
Transport Hazard Class:	N/A
Packing Group:	N/A
Marine Pollutant:	No

15. REGULATORY INFORMATION

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components	CAS-No.	Revision Date
Iron, Powder	7439-89-6	

New Jersey Right To Know Components	CAS-No.	Revision Date
Iron, Powder	7439-89-6	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Hepure Technologies, Inc. and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product.

Version: 2.3 Revision Date: 6/23/2016

Safety Data Sheet

SECTION 1: IDENTIFICATION

Product Identifier
Trade Name: **G150 Guar Gum**

Recommended Use of the Chemical and Restrictions on Use
Product Use:
Uses Advised Against: None identified

Manufacturer/Supplier: **Rantec Corporation**
Address: 17 Kukuchka Lane
Ranchester, WY 82839

Phone Number: (307) 655-9565
Fax Number: (307) 655-9528
e-mail: rantec@ranteccorp.com

SDS Date of Preparation: December 15, 2014

SECTION 2: HAZARDS IDENTIFICATION

GHS Classification:
Combustible Dust
Respiratory Sensitizer Category 1

Label Elements:
Danger!

May form combustible dust concentrations in air.
May cause allergy or asthma symptoms or breathing difficulties if inhaled.

Avoid breathing dust or fume.
In case of inadequate ventilation, wear respiratory protection.
IF INHALED: If breathing is difficult, remove victim to fresh air and keep at rest in a position comfortable for breathing.
If experiencing respiratory symptoms: Remove victim to fresh air and call POISON CENTER or doctor.
Dispose of contents in accordance with local, regional and national regulations.

Other Hazards: None

SECTION 3: COMPOSITION/INFORMATION ON INGREDIENTS

Chemical Name	CAS#	%
Guar Gum	9000-30-0	100

SECTION 4: FIRST AID MEASURES

Description of First Aid Measures

Eye: Flush thoroughly with water. If irritation persists get medical attention.

Skin: No first aid should normally be needed. Wash exposed skin with soap and water after use. If irritation or rash develops, get medical attention. Use skin lotion if dryness occurs.

Inhalation: If symptoms of irritation or allergy develop, remove person from source of exposure to fresh air. Get immediate medical attention if asthmatic symptoms develop.

Ingestion: DO NOT INGEST. While this product is not toxic by ingestion, swallowing small amounts could cause complete blockage of the mouth, pharynx, trachea, esophagus and/or gastrointestinal system which may cause choking, suffocation and/or other life threatening medical conditions. Get medical attention immediately.

Most Important symptoms and effects, both acute and delayed:

May cause mechanical eye and skin irritation. Inhalation of dust may cause nose and throat irritation, coughing and sneezing. Inhalation may cause sensitization and difficulty breathing. Ingestion may cause gastric upset and nausea.

Indication of any immediate medical attention and special treatment needed: If inhaled and causes allergic reaction, seek prompt medical attention. Seek immediate medical attention if any amount is ingested.

SECTION 5: FIRE FIGHTING MEASURES

Extinguishing Media:

Use water fog, dry chemical, carbon dioxide or foam. Do not use solid water jet as that may create a dust cloud that can present an explosion hazard. Guar gum is very slippery when wet.

Specific Hazards Arising from the Chemical

High concentrations of dust suspended in air may present a potential explosion hazard. Settled dust presents a fire hazard. Re-suspension of the dust into the air by vibration, traffic, material handling, etc. in high concentrations in the presence of an ignition source could result in a dust explosion. Minimize the generation and accumulation of dust. Slip hazard: product is very slippery when wet.

Hazardous Decomposition Products: Combustion may produce oxides of carbon and nitrogen.

Special Protective Equipment and Precautions for Fire-Fighters:

Firefighters should wear positive pressure self-contained breathing apparatus and full protective clothing.

SECTION 6: ACCIDENTAL RELEASE MEASURES

Personal Precautions, Protective Equipment and Emergency Procedures:

Wear appropriate protective equipment. Avoid creating and breathing dust. Eliminate ignition sources. Combustible Dust in Industry: Preventing and Mitigating the Effects of Fire and Explosions. Safety and Health Information Bulletin. SHIB 07-31-2005; updated 11-12-2014. https://www.osha.gov/dts/shib/shib073105.html

Environmental Precautions:

Avoid unintentional release to the environment.

Methods and Material for Containment and Cleaning Up:

Do not use water or water based solvents. Collect dry and in a manner to minimize the generation of airborne dust or vacuum with a high vacuum cleaner. If a vacuum is used, explosion proof equipment is required. Non-sparking tools should be used. Dust deposits should not be allowed to accumulate on surfaces, as these may form an explosive mixture if they are released into the atmosphere in sufficient concentrations. Avoid dispersal of dust in the air (i.e., clearing dust surfaces with compressed air.)

Reference to Other Sections:

Refer to Section 8 for protective equipment. Refer to Section 13 for disposal guidance.

SECTION 7: HANDLING AND STORAGE

Precautions for Safe Handling:

Avoid contact with eyes and clothing. Avoid creating and breathing dusts. Wear protective clothing and equipment as described in Section 8. Use only with adequate ventilation. Wash thoroughly with soap and water after handling. Minimize the generation and accumulation of dust. Keep dust away from open flames, hot surfaces and sources of ignition. Follow good housekeeping practices to keep surfaces, including areas overhead such as piping, drop ceilings, ductwork, etc. free from settled dust. Dry powders can build static electricity charges when subjected to friction of transfer and in mixing operations. Provide adequate precautions, such as electrical grounding and bonding, or inert atmospheres.

Empty containers retain product residues. Follow all SDS precautions in handling empty containers.

Conditions for Safe Storage, Including any Incompatibilities

Keep containers closed when not in use.

SECTION 8: EXPOSURE CONTROLS/PERSONAL PROTECTION

Exposure Limits:

Chemical Name	Exposure Limits
Guar Gum (as PNOR)	5 mg/m3 TWA OSHA PEL (respirable), 15 mg/m3 TWA (total dust)

Note: The OSHA limits may not adequately protect workers from respiratory sensitization. Exposure levels should be maintained as low as possible for the workers' protection.

Refer to local regulations for specific requirements.

Exposure Controls:

Engineering Controls: Use explosion proof local exhaust ventilation as needed to maintain exposure concentrations below the recommended limits.
Eye and Face: Follow facility requirements. Dust goggles recommended for dusty conditions.
Skin: None required. Work gloves may be used to protect against mechanical irritation.
Respiratory: If the concentrations exceed the Threshold Value Limit (TLV), a NIOSH approved dust respirator, supplied air respirator or self-contained breathing apparatus is recommended. Select appropriate respiratory protection for respirable particulates based on consideration of the airborne workplace concentrations and duration of exposure. Select and use respirators in accordance with 29 CFR 1910.134, ANSI Z88.2, the NIOSH Respirator Decision Logic and good

industrial hygiene practice.
Protective Clothing: Appropriate protective clothing as needed to minimize skin contact.
Work Hygienic Practices: Wash thoroughly after handling.

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

Physical State: Solid	**Appearance:** Creamy white powder
Odor: Bean-like odor	**Odor Threshold**: Not applicable
pH: Not applicable	**Relative Density:** Not applicable
Boiling Point: Not applicable	**Melting Point:** Decomposes
Vapor Pressure: Not applicable	**Water Solubility:** complete solubility
Vapor Density: Not applicable	**Evaporation Rate:** Not applicable
Viscosity: Not applicable	**Pour Point**: Not applicable
Flash Point: Not applicable	**Flammable Limits: LEL:** 0.04 oz/cf
Autoignition Temperature: None	**Flammable Limits: UEL:** Not applicable
Percent Volatile: Not applicable	**Flammability (solid/gas):** Not applicable
Partition Coefficient: n-octanol/water: Not applicable	**Decomposition Temperature:** None
Explosive Properties: Combustible dust	**Oxidizing Properties:** None

SECTION 10: STABILITY AND REACTIVITY

Reactivity: Not reactive.

Chemical Stability: Stable under normal conditions.

Possibility of Hazardous Reactions: Reactions with strong oxidizers may generate heat.

Conditions to Avoid: Keep away ignition sources. Combustible Dust in Industry: Preventing and Mitigating the Effects of Fire and Explosions. Safety and Health Information Bulletin. SHIB 07-31-2005; updated 11-12-2014. https://www.osha.gov/dts/shib/shib073105.html

Incompatible Materials: Avoid strong acids and oxidizing agents.

Hazardous Decomposition Products: Thermal decomposition may produce carbon and nitrogen oxides.

SECTION 11: TOXICOLOGICAL INFORMATION

Information on Toxicological Effects:

Eye Contact: Contact may cause irritation based on studies with laboratory animals.

Skin Contact: Contact may cause dryness.

Inhalation: Inhalation of dust may cause irritation of the nose, throat and respiratory passages. Symptoms include coughing, sore throat, nasal congestion, sneezing wheezing and shortness of breath. May cause allergic reaction in susceptible individuals.

Ingestion: Ingesting small amounts could cause complete blockage of the mouth, pharynx, trachea, esophagus and/or gastrointestinal system which may cause choking, suffocation and/or other life threatening medical conditions.

Acute Toxicity Data:
Guar Gum: Oral rat LD50: 9.4g/kg

Guar gum is a natural food additive, although direct use in powder or pill form is banned by the FDA due to the risk of respiratory or gastrointestinal blockage.

Chronic Health Effects: Prolonged overexposure to any nuisance dust may cause lung injury. Symptoms include cough, shortness of breath and reduced pulmonary function.

Germ Cell Mutagenicity: No data available. This product is not expected to cause mutagenic activity.

Carcinogenicity: None of the components of this product are listed as carcinogens or suspected carcinogens by OSHA, IARC or NTP.

Developmental / Reproductive Toxicity: No data available. This product is not expected to cause adverse effects on reproduction or development.

Specific Target Organ Toxicity (Single Exposure): No data available.

Specific Target Organ Toxicity (Repeated Exposure): Prolonged overexposure to any nuisance dust may cause lung injury. Symptoms include cough, shortness of breath and reduced pulmonary function.

SECTION 12: ECOLOGICAL INFORMATION

Toxicity:
No data available. This product is not expected to be toxic to aquatic organisms.

Persistence and Degradability:
No data available.

Bioaccumulative Potential:
Not expected to bioaccumulate.

Mobility in Soil:
No mobility in soil is expected.

Other Adverse Effects: None known.

SECTION 13: DISPOSAL INFORMATION

Waste Treatment Methods

Disposal Method: Dispose in accordance with all local, state and federal regulations.
Empty Container: No special handling or disposal is required.
General Comments: It is the responsibility of the user of this product to characterize wastes generated to determine if the waste meets the definition of hazardous waste. The product uses, transformations, synthesis, mixtures, etc., may render the resulting end product subject to regulation.

SECTION 14: TRANSPORT INFORMATION

	UN Number	UN Proper Shipping Name	Transport Hazard Class(s)	Packing Group	Environmental Hazards
US DOT	None	Not regulated	None	None	Not applicable
EU ADR/RID	None	Not regulated	None	None	Not applicable
IMDG	None	Not regulated	None	None	Not applicable

Special Precautions for User: None

SECTION 15: REGULATORY INFORMATION

Safety, Health and Environment Regulations:

US Regulations:
EPA SARA 311/312 Hazard Classification: Fire Hazard, Acute Health

EPA SARA 313: This Product Contains the Following Chemicals Subject to Annual Release Reporting Requirements Under SARA Title III, Section 313 (40 CFR 372): None

Protection Of Stratospheric Ozone: This product is not known to contain or to have been manufactured with ozone depleting substances as defined in 40 CFR Part 82, Appendix A to Subpart A.

CERCLA Section 103: This product is not subject to CERCLA spill reporting requirements. Many states have more stringent release reporting requirements. Report spills when required under federal, state and local regulations.

California Proposition 65: This product is not known to contain chemicals regulated under Proposition 65.

Canadian Regulations:
Canadian WHMIS: D-2-A
This product has been classified in accordance with the hazard criteria in the CPR and the SDS contains all the information required by the CPR.

Chemical Inventories:
US TSCA All of the components of this material are listed on the Toxic Substances Control Act (TSCA) Chemical Substances Inventory or are exempt.
Canadian CEPA: All of the components are listed on the Canadian DSL or are exempt.
Australia: All of the components are listed on the AICS inventory or are exempt.
China: All the components are listed on the Chinese chemical inventory or are exempt.
Philippines: All the components are listed in the Philippine Inventory.
New Zealand: All of the components are listed on the New Zealand Inventory of Chemicals.
Korea: All of the components are listed on the Korean Existing Chemicals Inventory
Japan: All the components are listed on the Japan Inventory of existing chemicals.

SECTION 16: OTHER INFORMATION

NFPA Ratings:

Health: 1	Flammability: 2	Reactivity: 0

HMIS Ratings:

Health: 1	Flammability: 2	Reactivity: 0

SDS Date of Preparation/Revision: December 15, 2014

Revision History: Conversion to GHS format. Changes in all Sections.

==

SAFETY DATA SHEET

1. CHEMICAL IDENTIFICATION AND COMPANY INFORMATION

Product Name: **KB-1®**

Company Info: SiREM
130 Stone Rd. W., Guelph, Ontario, Canada, N1G 3Z2
Phone: 519-822-2265
Toll Free, North America: 1-866-251-1747
Fax: 888-635-3470
www.siremlab.com

Emergency Phone Number: 519-822-2265 (for 24/7 assistance, contact poison center hotline in your jurisdiction).

Description: Microbial inoculum (non-pathogenic, non-hazardous) in growth media consisting of a dilute aqueous solution of mineral salts and nutrients.

Recommended Use: Bioremediation of contaminated groundwater.

Restrictions on Use: KB-1® product intended for laboratory research and field applications for cleanup of contaminated groundwater. Products are not intended to be used as human or animal therapeutics, cosmetics, agricultural or pesticide products, food additives, or as household chemicals.

2. HAZARDS IDENTIFICATION

GHS Classification: Not classified as “hazardous” per OSHA 29 CFR 1910.1200, “Hazard Communication”.

GHS Label elements, including hazard and precautionary statements: Not Applicable.

HMIS Rating:	**Health**	**Flammability**	**Physical Hazard**	**Personal Protection**
	1	0	0	B*
NFPA Rating:	**Health**	**Flammability**	**Reactivity**	**Special Hazard**
	1	0	0	N/A

* B = Safety Glasses, Gloves.

A review of available data indicates minimal potential for health effects related to normal use of this product. Microbial components are non-pathogenic. The product is not expected to be a health hazard as a result of inhalation of mists, ingestion or skin contact. Eye contact may result in mild irritation/redness. Normal hygiene precautions should be observed, including eye protection, skin protection, and hand washing. The potential exists for individuals with hypersensitivity to biological materials to exhibit allergic sensitivity to biological components of this product (see Section 4, “First Aid Measures”).

3. COMPOSITION/INFORMATION ON INGREDIENTS

KB-1® is a microbial culture grown in an aqueous dilute solution of mineral salts and nutrients classified as non-hazardous in accordance with provisions of OSHA 29 CFR 1910.1200, “Hazard Communication.”

The microbial composition of KB-1®, as determined by phylogenetic analysis, includes:

Dehalococcoides sp.
Geobacter sp.
Methanomethylovorans sp.

Identification of organisms was obtained by matching 16S rRNA gene sequence of organisms in KB-1® to other known organisms. The characteristics of related organisms can be used to identify potential or likely characteristics of organisms in KB-1®.

4. FIRST AID MEASURES

Avoid direct contact with skin and eyes. In any case of any exposure which elicits a response, a physician should be consulted immediately.

Route of Entry	Symptoms	First Aid Procedures
Ingestion	Upset stomach, irritation of digestive tract.	Do not induce vomiting. Drink several cups of water. Seek medical attention.
Skin contact	Skin irritation – reddening, itching or inflammation.	Remove contaminated clothes. Wash skin with plenty of water and soap. Seek medical attention if irritation develops or open wounds are present.
Eye contact	Eye irritation – redness, tearing, blurred vision.	Rinse immediately with plenty of water for 15 – 20 minutes, lifting lower and upper eyelids occasionally (remove contact lenses if easily possible). Seek medical attention if undue irritation or redness occurs.
Inhalation of mist	Respiratory irritation, coughing, breathing difficulty.	Remove victim to fresh air. Administer first aid as appropriate for symptoms. Seek medical attention if serious symptoms occur.

5. FIRE FIGHTING MEASURES

General:	This material is non-flammable, consisting primarily of water, and poses no special hazards if involved in a fire situation.
Suitable extinguishing media:	If material is involved in fire situation, use extinguishing media suitable for surrounding fire.
Special protective equipment and precautions for firefighters:	No special equipment necessary; use equipment appropriate for surrounding fire.
Hazardous combustion products:	Not applicable.
Toxic gases produced:	Not applicable.
Shock/impact sensitivity:	Not shock sensitive.

6. ACCIDENTAL RELEASE MEASURES

Method of containment and cleanup:	Spilled KB-1® should be soaked up with sorbent and saturated with a 10% bleach solution (prepared by making a one in ten dilution of diluted standard bleach [normally sold at a strength of 5.25% sodium hypochlorite] to disinfect affected surfaces. Sorbent should be double bagged and disposed of as indicated in Section 13. After removal of sorbent, area should be washed with 10% bleach solution to disinfect. If liquid from the culture vessel is present on the fittings, non-designated tubing or exterior of the stainless steel pressure vessel liquid should be wiped off and the area washed with 10% bleach solution.
Ventilation:	No special ventilation is required in the event of the spill, as the material consists of water and non-volatile constituents. If the potential for generation of mist exists, open windows and provide adequate ventilation. If high levels of mist are encountered, use personal protective equipment indicated below.
Eye/skin protection:	Have eye-washing facilities readily available where eye contact can occur. Wash skin with soap and water. Use appropriate protective gloves when handling. Showering and changing into street clothes after work is recommended.
Protective equipment for airborne mist:	A NIOSH/MSHA approved dust mask or air purifying respirator with dust/mist filter is recommended where elevated concentrations of airborne mist are expected.

7. HANDLING AND STORAGE

Handling and storage precautions:	Use personal protective equipment (eye & skin protection) and hygiene measures (hand washing) to minimize contact with the material. KB-1® is shipped in stainless steel pressure vessels and connected to injection lines and inert gas is used to pressurize the vessel to displace the contents. KB-1® should be handled with care to avoid any spillage. Vessels are shipped with 1 to 5 pound per square inch (psi) pressure; valves should not be opened until connections to appropriate lines for subsurface injection are in place. During storage, avoid exposing stainless steel pressure vessels to undue temperature extremes (i.e., temperatures less than 0°C or greater than 30°C may result in harm to the microbial cultures and damage to the vessels). All valves should be in the closed position when the vessel is not pressurized to prevent the escape of gases and to maintain anaerobic conditions in the vessel.
Incompatibilities:	Avoid exposure of the culture to air as the presence of oxygen will kill the microbes.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

OSHA Permissible Exposure Limits (PELs): ACHIH Threshold Limit Values (TLVs):	No occupational exposure limits are established for microbial constituents. Mixture is not classified as “hazardous” in accordance with 29 CFR 1910.1200 “Hazard Communication,” exceedance of exposure limits is not anticipated either under normal conditions of use, or as the result of an accidental release.
Engineering controls:	Generally not required under normal conditions of use. If method of use will result in significant mist generation, use under conditions of adequate ventilation.
Work practices:	Use good hygiene practices, avoid mist generation, and minimize contact with the material as a general precautionary measure.
Personal protective equipment:	Under normal conditions of use, wear safety glasses, protective gloves (latex, vinyl or nitrile) and steel toed footwear as general precautionary measures, particularly when opening pressure vessel valves or when pressurizing vessels to inject contents into the subsurface environment. For laboratory use, also wear lab coat. For higher risk of eye contact, wear safety goggles or face shield, as appropriate. Respiratory protection is not required under normal conditions of use (see Section 6, “Accidental Release Measures.”

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance, physical state:	Aqueous liquid, dark grey, slightly turbid under anaerobic conditions, pink if exposed to air (oxygen).
Odor:	Pungent (“skunky”) odor.
Solubility:	Soluble in water.
pH:	6.5 – 7.5
Melting range	Not determined, approximately equivalent to water.
Vapor density:	Not determined, approximately equivalent to water.
Vapor pressure:	Not determined, approximately equivalent to water.
Relative density:	Not determined, approximately equivalent to water.
Evaporation rate:	Not determined, approximately equivalent to water.
Initial Boiling point, boiling range	Not determined, approximately equivalent to water.
Flammability	Not flammable.
Partition coefficient	Not applicable
Auto-ignition temperature	Not applicable
Decomposition temperature:	No data, bacterial contents will decompose by heating.
Flash point	N/A

10. STABILITY AND REACTIVITY

Chemical stability and reactivity:	Stable and non-reactive.
Possibility of hazardous reactions:	Stable. Spontaneous hazardous chemical reactions / decomposition will not occur.
Conditions to avoid:	Maintain under anaerobic conditions to preserve product integrity (exposure to air/oxygen will kill microbes).
Incompatible materials:	Strong oxidizers, acids, water reactive materials.
Hazardous decomposition products:	Not applicable.
Shock sensitivity:	Not shock sensitive; will not decompose and form shock sensitive compounds.

11. TOXICOLOGICAL INFORMATION

Potential for pathogenicity: KB-1$^{®}$ has tested **negative** (i.e., the organisms are not present) for a variety of pathogenic organisms indicated below:

Pathogenic Organisms	Disease(s) Caused	Test Results
Salmonella sp.	*Typhoid fever, gastroenteritis*	Not Detected
Listeria monocytogenes	*Listerioses*	“
Vibrio sp.,	*Cholera, gastroenteritis*	“
Campylobacter sp.,	*Bacterial diarrhea*	“
Clostridia sp.,	*Food poisoning, botulism, tetanus, gas gangrene*	“
Bacillus anthracis	*Anthrax*	“
Pseudomonas aeruginosa	*Wound infection*	“
Yersinia sp.,	*Bubonic plague, intestinal infection*	“
Yeast and Mold	*Candidiasis, yeast infection etc.*	“
Fecal coliforms	*Indicator organisms for many human pathogens diarrhea, urinary tract infections*	“
Enterococci	*Various opportunistic infections*	“

While there is no evidence that virulent pathogenic organisms are present in KB-1$^{®}$, there is potential that certain organisms in KB-1$^{®}$ may have the potential to act as opportunistic (mild) pathogens, particularly in individuals with open wounds and/or compromised immune systems. For this reason standard hygienic procedures such as hand washing after use should be observed.

12. ECOLOGICAL INFORMATION

This product is not rated as “hazardous” as either an acute or chronic ecological hazard, in accordance with the OSHA Hazard Communication standard, 29 CFR 1910.1200.

13. DISPOSAL CONSIDERATION

Material must be disinfected or sterilized prior to disposal. Consult local regulations prior to disposal.

14. TRANSPORT INFORMATION

U.S. (D.O.T.):	Proper Shipping Name:	Culture of Micro-organisms
	Hazard Class:	Not applicable
	UN/NA:	Not applicable
	Labels:	Not applicable
Canada (T.D.G.)	Proper Shipping Name:	Culture of Micro-organisms
	Hazard Class:	Not applicable
	UN/NA:	Not applicable
	Labels:	Not applicable
International: IMDG:	Proper Shipping Name:	Culture of Micro-organisms
	Hazard Class:	Not applicable
	UN/NA:	Not applicable
	Labels:	Not applicable
IATA:	Proper Shipping Name:	Culture of Micro-organisms
	Hazard Class:	Not applicable
	UN/NA:	Not applicable
	Labels:	Not applicable

15. REGULATORY INFORMATION

TSCA:	No
SARA TITLE III	
Section 302 (EHS) Ingredients:	No
Section 313 Ingredients:	No
Section 304 (EHS/CERCLA) Ingredients:	No
SARA TITLE III NOTIFICATION INFORMATION	
Acute Health Hazard:	No
Chronic Health Hazard:	No
Fire Hazard:	No
Sudden Release of Pressure Hazard:	No

16. OTHER INFORMATION

SiREM provides the information contained herein for hazard communication and safety planning purposes, based on existing information on each of the product components available in the literature; no independent testing was conducted on the final product. The above information is intended to be used only as a guide to the appropriate precautionary handling of this material by a properly trained person.

SAFETY DATA SHEET

Issuing date 28-Oct-2010 **Revision Date** 20-Mar-2015 **Version** 1

1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY/UNDERTAKING

1.1 Product identifier

Product name	LEB-H

1.2 Relevant identified uses of the substance or mixture and uses advised against

Recommended use	Oilfield Chemical
Uses advised against	No information available

1.3 Details of the supplier of the safety data sheet

Supplier

Rantec Corporation
PO Box 729
Ranchester, WY 82839
Phone 307-655-9565

For further information, please contact:

E-mail Address	No information available

1.4 Emergency telephone number

Emergency telephone	1-307-655-9565

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

REGULATION (EC) No 1272/2008

Classification according to EU Directives 67/548/EEC or 1999/45/EC

For the full text of the R-phrases mentioned in this Section, see Section 16

Symbol(s)

Not dangerous

2.2 Label Elements

2.3 Other information

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

For the full text of the R-phrases mentioned in this Section, see Section 16

Additional information

Not Hazardous (OSHA 29 CFR 1910.1200)

4. FIRST AID MEASURES

4.1 Description of first-aid measures

Eye contact

Rinse immediately with plenty of water, also under the eyelids, for at least 15 minutes. Keep eye wide open while rinsing. If symptoms persist, call a physician.

Skin contact
Wash off immediately with soap and plenty of water while removing all contaminated clothes and shoes. If skin irritation persists, call a physician.

Ingestion
Call a physician or Poison Control Center immediately. Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth.

Inhalation
Move to fresh air. If breathing is difficult, give oxygen. If not breathing, give artificial respiration. If symptoms persist, call a physician.

Protection of First-aiders
Remove all sources of ignition. Use personal protective equipment.

4.2 Most important symptoms and effects, both acute and delayed

4.3 Indication of any immediate medical attention and special treatment needed.

Notes to physician
Treat symptomatically.

5. FIRE-FIGHTING MEASURES

5.1 Extinguishing media

Suitable Extinguishing Media
Use CO2, dry chemical, or foam.

Extinguishing media which shall not be used for safety reasons
No information available.

5.2 Special hazards arising from the substance or mixture

Special Hazard
None in particular.

5.3 Advice for firefighters

Special protective equipment for fire-fighters
As in any fire, wear self-contained breathing apparatus pressure-demand, MSHA/NIOSH (approved or equivalent) and full protective gear.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Remove all sources of ignition. Evacuate personnel to safe areas. Ensure adequate ventilation. Use personal protective equipment.

See Section 12 for additional Ecological information.

6.2 Environmental precautions

Prevent product from entering drains. Do not flush into surface water or sanitary sewer system.

6.3 Methods and materials for containment and cleaning up

Prevent further leakage or spillage if safe to do so. Dike far ahead of liquid spill for later disposal.

Soak up with inert absorbent material. Clean up promptly by sweeping or vacuum. Keep in suitable, closed containers for disposal. Do not flush into surface water or sanitary sewer system.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

Handle in accordance with good industrial hygiene and safety practice. Ensure adequate ventilation. Do not breathe vapors or spray mist. Keep away from open flames, hot surfaces and sources of ignition. Avoid contact with skin, eyes and clothing. Wear personal protective equipment. When using, do not eat, drink or smoke.

7.2 Conditions for safe storage, including any incompatibilities

Keep in properly labeled containers. Keep containers tightly closed in a dry, cool and well-ventilated place.

7.3 Specific end uses

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Exposure Guidelines	Contains no substances with occupational exposure limit values
Exposure limits	Contains no substances with occupational exposure limit values
Derived No Effect Level (DNEL)	No information available
Predicted No Effect Concentration (PNEC)	No information available

8.2 Exposure controls

Engineering Measures	Ensure adequate ventilation, especially in confined areas. Ensure that eyewash stations and safety showers are close to the workstation location.
Personal protective equipment	
Eye Protection	Safety glasses with side-shields. Goggles.
Hand Protection	Impervious gloves.
Skin and body protection	Wear suitable protective clothing.
Respiratory protection	If exposure limits are exceeded or irritation is experienced, NIOSH/MSHA approved respiratory protection should be worn.
Hygiene measures	Handle in accordance with good industrial hygiene and safety practice. When using, do not eat, drink or smoke. Provide regular cleaning of equipment, work area and clothing.
Environmental Exposure Controls	Do not allow material to contaminate ground water system.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

Physical State	Liquid	**Appearance**	clear
Odor	Mild - Musty	**Color**	amber - brown

Property	Values	Remarks/ Method
pH	7.0-7.5	
Freezing Point	-10 °C / 14 °F	
Boiling point/boiling range		
Flash Point	Not applicable	
Evaporation rate		No data available
Flammability (solid, gas)		No data available
Flammability Limits in Air		No data available
upper flammability limit		
lower flammability limit		
Vapor pressure		No data available
Vapor density		No data available
Relative density	1.090-1.110	
Water solubility	completely soluble	
Solubility in other solvents		No data available
Partition coefficient: n-octanol/water		No data available
Autoignition temperature		No data available
Decomposition temperature		No data available

Viscosity, kinematic	No data available
Explosive properties	No data available
Oxidizing Properties	No data available
Softening point	
Molecular Weight	
VOC Content	No data available
Density Bulk Density	9.10-9.26 lbs/gal

10. STABILITY AND REACTIVITY

10.1 Reactivity

No data available.

10.2 Chemical stability

Stable under normal conditions.

10.3 Possibility of hazardous reactions

Hazardous polymerization does not occur.

10.4 Conditions to Avoid

Heat, flames and sparks.

10.5 Incompatible Materials

Strong oxidizing agents.

10.6 Hazardous Decomposition Products

None known based on information supplied.

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
Product Information

Inhalation	May cause irritation.
Eye contact	May cause irritation.
Skin contact	May cause irritation.
Ingestion	May cause irritation.

Chronic toxicity

Carcinogenicity	Contains no ingredient listed as a carcinogen >0.1%
Sensitization	May cause sensitization of susceptible persons
Reproductive toxicity	No information available
Mutagenic effects	No information available
Developmental Toxicity	No information available
Teratogenicity	No information available
Target Organ Effects	No information available.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Ecotoxicity effects	The environmental impact of this product has not been fully investigated.

12.2 Persistence and degradability

No information available.

12.3 Bioaccumulative potential

No information available.

12.4 Mobility in soil

No information available.

12.5 Results of PBT and vPvB assessment

No information available

12.6 Other adverse effects

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Waste from Residues / Unused Products	Dispose of in accordance with local regulations.
Contaminated packaging	Do not re-use empty containers.
EWC Waste Disposal No:	According to the European Waste Catalogue, Waste Codes are not product specific, but application specific. Waste codes should be assigned by the user based on the application for which the product was used

14. TRANSPORT INFORMATION

DOT	Not regulated
IMDG/IMO	Not regulated
ADR/RID	Not regulated
ICAO/IATA	Not regulated

15. REGULATORY INFORMATION

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

International Inventories

TSCA	Complies
EINECS/ELINCS	Complies
DSL/NDSL	Complies
PICCS	-
ENCS	-
IECSC	-
AICS	-
KECL	-

Legend

TSCA - United States Toxic Substances Control Act Section 8(b) Inventory
EINECS/ELINCS - European Inventory of Existing Commercial Chemical Substances/EU List of Notified Chemical Substances

DSL/NDSL - Canadian Domestic Substances List/Non-Domestic Substances List
PICCS - Philippines Inventory of Chemicals and Chemical Substances
ENCS - Japan Existing and New Chemical Substances
IECSC - China Inventory of Existing Chemical Substances
AICS - Australian Inventory of Chemical Substances
KECL - Korean Existing and Evaluated Chemical Substances

15.2 Chemical Safety Assessment

U.S. Federal Regulations

SARA 313

Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA). This product does not contain any chemicals which are subject to the reporting requirements of the Act and Title 40 of the Code of Federal Regulations, Part 372.

SARA 311/312 Hazard Categories

Acute Health Hazard	Yes
Chronic Health Hazard	Yes
Fire Hazard	No
Sudden Release of Pressure Hazard	No
Reactive Hazard	No

Clean Water Act

This product does not contain any substances regulated as pollutants pursuant to the Clean Water Act (40 CFR 122.21 and 40 CFR 122.42).

CERCLA

This material, as supplied, does not contain any substances regulated as hazardous substances under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) (40 CFR 302) or the Superfund Amendments and Reauthorization Act (SARA) (40 CFR 355). There may be specific reporting requirements at the local, regional, or state level pertaining to releases of this material.

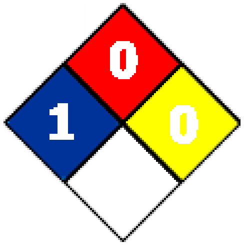
Canada

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all the information required by the CPR.

16. OTHER INFORMATION

NFPA	**Health Hazard** 1	**Flammability** 0	**Stability** 0	**Physical and chemical hazards** -
	HMIS	**Health Hazard** 1	**Flammability** 0	**Physical Hazard** 0

Personal protection - .



Full text of R-phrases referred to under sections 2 and 3

Full text of H-Statements referred to under sections 2 and 3

Prepared By HSE Department

Issuing date	28-Oct-2010
Revision Date	20-Mar-2015
Revision Note	Not Applicable.

This safety data sheet complies with the requirements of Regulation (EC) No. 1907/2006.

US Only: This safety data sheet complies with the requirements of the OSHA Hazard Communication Standard 29 CFR 1910.1200.

Disclaimer

While the information and data contained herein are presented in good faith and believed to be reliable, nothing herein shall be deemed to constitute a warranty, express or implied, that the information or data is reliable, accurate, or complete or that the products described herein are merchantable or fit for a particular purpose or that said information, data, or products can be used without infringing the intellectual property rights of third parties. Individuals who receive the products or the information or data relating to the products described herein, must use their own judgment in determining fitness for a particular purpose. Unless otherwise stated, the information or data contained herein relates to the products when not used in conjunction with any other products or materials. We disclaim all express and implied warranties of merchantability, fitness for a particular purpose, and non-infringement. We shall not be liable for any loss or damage that may occur from the use of the products described herein, including the use of the products in conjunction with other products or materials, or reliance on the data or information described herein.

Safety Data Sheet

Date: February 24, 2016 **Supersedes:** September 30, 2015

Section 1: Product Identification

Trade Name: Foundry & Recreation: Silica, Lake and Bank Sand All Grades; Proppant: 16/30, 20/35, 20/40, 30/50, 40/70 and 100 Mesh; All Grades

Chemical Name: Crystalline Silica (Quartz)

Application: Foundry, Proppant, Recreation

Manufacturer:
Fairmount Santrol
3 Sugar Creek Center Blvd
Suite 550
Sugar Land, TX 77478
Phone: 1.800.255.7263 Website: FairmountSantrol.com

Emergency Telephone Number: CHEMTREC
Within USA and Canada: 1.800.424.9300
Outside USA and Canada: +1.703.741.5970 (collect calls accepted)
For emergency calls only. Non-emergency calls cannot be serviced at this number.

"This product is not intended for and is strictly prohibited for sandblasting"

Section 2: Hazard Identification

Hazard Overview

Product is a chemically inert, non-combustible mineral. Long-term exposure can cause silicosis. Silicosis is a respiratory disease, which can result in delayed, disabling and sometimes fatal lung injury. IARC and NTP have determined that respirable crystalline silica inhaled from occupational sources can cause cancer in humans. Risk of injury is dependent on the duration and level of exposure. A single exposure will likely not result in serious adverse effects.

GHS Classification:

Physical:
Not Classified

Health:
Category 1A Carcinogen
Category 1 Specific Target Organ Systemic Toxicity (Repeated Exposure)

Environmental:
Not Classified

Signal Word
Danger

Hazard Statements
H372: Causes damage to lungs and/or kidneys through prolonged or repeated exposure by inhalation.
H350: May cause lung cancer.

Precautionary Statements
P260: Do not breathe dust.
P314: Get medical advice/attention if you feel unwell.

Section 3: Composition/Information on Ingredients

CAS#	Component	Percentage	GHS Classification
14808-60-7	Silicon Dioxide in the form of Crystalline Silica (Quartz)	>99%	STOST (Repeat Exposure) Category 1

See Section 8 for occupational exposure limit information.

Section 4: First Aid Measures

Inhalation (Gross): No specific first aid is necessary since the adverse health effects associated with inhalation of respirable crystalline silica result from chronic exposures. If there is a gross inhalation of product, remove the person immediately to fresh air. Get medical attention if persons feels unwell.

Ingestion: If large amounts of product are swallowed, get immediate medical attention.

Eye Contact: Immediately wash eyes with large amounts of water, lifting the upper and lower lids occasionally. If irritation persists or for imbedded foreign body, get immediate medical attention.

Skin Contact: Dermal contact with this product should not affect the skin. Wash exposed skin with soap and water before breaks and at the end of the work shift.

Section 5: Fire Fighting Measures

Extinguishing Media: Product is not flammable or combustible. It is compatible with all extinguishing media. Use any media that is appropriate for the surrounding fire.

Special Fire Fighting Procedures: Wear standard turnout gear and NIOSH-approved self-contained breathing apparatus (SCBA) with full facepiece in pressure demand or positive pressure demand mode.

Unusual Fire and Explosion Hazards: None known.

Hazardous Combustion Products: None known.

Section 6: Accidental Release Measures

Use personal protective equipment recommended in Section 8.
Avoid generating dust. If material is uncontaminated, collect using dustless method (HEPA vacuum) and place in appropriate container for use. Do not use compressed air to clean spilled sand or ground silica. If contaminated: a) use appropriate method for the nature of contamination, and b) consider possible toxic or fire hazards associated with the contaminating substances. Collect material in appropriate containers for recovery and recycling or disposal; see Section 12.

Section 7: Handling and Storage

Handling: Avoid generating dust. Do not breathe dust. *Use of this product may generate elevated airborne levels of crystalline silica dust that may not be visible to the unaided eye.* Use normal precautions against bag breakage or spills of bulk material. Use proper work practices and adequate ventilation with dust collection to maintain airborne levels of respirable crystalline silica to below the OSHA Permissible Exposure Limit (PEL). If airborne levels of crystalline silica exceed the PEL, wear respiratory protection and protective clothing when handling this product. Refer to Section 8 for additional information on personal protective equipment. See also American Society for Testing and Materials (ASTM) Standard Practice E1132-99a, "*Standard Practice for Health Requirements Relating to Occupational Exposure to Respirable Crystalline Silica.*"

Storage: Use good housekeeping in storage and use areas to prevent accumulation of dust in work areas. Quartz is incompatible with strong oxidizers such as hydrofluoric acid, fluorine, chlorine trifluoride, or oxygen difluoride.

The OSHA Hazard Communication Standard 29 CFR §1910.1200 and state and local worker or community "Right to Know" laws and regulations should be strictly followed, which includes training employees on the content of this SDS. *Warn your employees (and your customer users in case of resale) by posting and other means of the potential health risks associated with use of this product and train them in the appropriate personal protective equipment, work practices, and engineering controls, which will reduce their risk of exposure***.**

Crystalline silica is listed by the State of California (under Proposition 65) as requiring the following warning:

> *Detectable amounts of chemicals known by the state of California to cause cancer, birth defects, or other reproductive harm may be found in this product.*

Section 8: Exposure Control/Personal Protection

Local Exhaust: Use process enclosure, local exhaust ventilation, or other engineering controls to control airborne levels of dust. See ACGIH "*Industrial Ventilation, A Manual of Recommended Practice*" (latest edition).

Eye Protection: Wear appropriate protective eyeglasses or chemical safety goggles where particles could cause injury to the eye as described by OSHA's eye and face protection regulations in 29 CFR §1910.133.

Skin Protection: Follow good personal hygiene practices including cleansing of exposed skin with soap and water, and laundering work clothing that has become dusty. Wash exposed skin with soap and water before breaks and at the end of work shift.

Respiratory Protection: When effective engineering controls are not feasible to control exposures to respirable crystalline silica below the OSHA PEL (or other exposure limit), use the following table to assist in selecting respiratory protection. This table was obtained from the NIOSH Respirator Selection Logic (2004). Assigned protection factor (APF) is the minimum expected level of respiratory protection provided by a properly functioning respirator. Maximum use concentration (MUC) for a respirator is determined by multiplying a contaminant exposure limit by the protection factor assigned to the respirator. Respiratory protection for respirable crystalline silica is based on the airborne exposure concentration and duration of exposure for the particular use of the respirator. A respiratory protection program in accordance with OSHA Standard 29 CFR §1910.134 must be implemented whenever workplace conditions warrant use of a respirator. ANSI Standard Z88.2 (recent revision) "*American National Standard for Respiratory Protection*" also should be considered. All tight-fitting respirators must be fit-tested either qualitatively or quantitatively for each respirator user. Use only NIOSH-certified respirators.

Assigned Protection Factor	Type of Respirator (NIOSH-Certified Respirator)
10	Any air-purifying elastomeric half-mask respirator equipped with appropriate type of particulate filter. [1] Appropriate filtering facepiece respirator. [1,2] Any air-purifying full facepiece respirator equipped with appropriate type of particulate filter. [1] Any negative pressure (demand) supplied-air respirator equipped with a half-mask.
25	Any powered air-purifying respirator equipped with a hood or helmet and a high efficiency (HEPA) filter. Any continuous flow supplied-air respirator equipped with a hood or helmet.
50	Any air-purifying full facepiece respirator equipped with N-100, R-100, or P-100 filter(s). Any powered air-purifying respirator equipped with a tight-fitting facepiece (half or full facepiece) and a HEPA filter. Any negative pressure (demand) supplied-air respirator equipped with a full facepiece. Any continuous flow supplied-air respirator equipped with a tight-fitting facepiece (half or full facepiece). Any negative pressure (demand) self-contained respirator equipped with a full facepiece.
1000	Any pressure-demand supplied-air respirator equipped with a full facepiece.

[1] Appropriate means that the filter medium will provide protection against the particulate in question.
[2] APF of 10 can only be achieved if the respirator is qualitatively or quantitatively fit tested on individual workers.

Occupational Exposure Limits:

Chemical	Percent (by wt.)	Exposure Limits						Unit
		OSHA		NIOSH		ACGIH		
		TWA	STEL	TWA	STEL	TWA	STEL	
Crystalline Silica (Quartz)	>99%	$\frac{10\ mg/m^{3a,b}}{\%\ SiO_2 + 2}$	N.E.	0.05^a	N.E.	0.025^a	N.E.	mg/m^3

N.E. = Not Established. mg/m^3 = milligrams per cubic meter of air.
[a] = Respirable Fraction.
[b] = OSHA PEL for crystalline silica as cristobalite or trdymite is ½ the value calculated from the respirable dust formula for quartz.

OSHA Permissible Exposure Limits (PEL) and ACGIH Threshold Limit Values (TLV) are an 8-hour time-weighted average (TWA) concentration during a 40-hour workweek. NIOSH Recommended Exposure Limit (REL) is a time-weighted average concentration for up to a 10-hour workday during a 40-hour workweek. STEL denotes a Short Term Exposure Limit, 15-minutes.

Section 9: Physical and Chemical Properties

Appearance: Free-flowing sand; white to tan
pH: Not applicable
Specific Gravity (water = 1): 2.65
Solubility in Water: Insoluble
Vapor Density: Not applicable
Vapor Pressure: Not applicable

Odor: Odorless
Melting Point: 2930 °F (1610 °C)
Evaporation Rate: None
Boiling Point: 4046 °F (2230 °C)
Autoignition Temp: Will not burn
Flammable Limits (LEL/UEL): Not applicable

Section 10: Stability and Reactivity

Stability: Stable under normal handling and storage conditions.

Hazardous Polymerization: Will not occur.

Chemical Incompatibility: Strong oxidizing agents such as fluorine, chlorine trifluoride, manganese trioxide, and oxygen difluoride, may cause fire.

Hazardous Decomposition Products: Silica will dissolve in hydrofluoric acid producing a corrosive gas, silicon tetrafluoride.

Section 11: Toxicological Information

Inhalation of respirable silica dust may not cause noticeable injury or illness even though permanent lung damage may be occurring. Inhalation of silica dust may have the following serious chronic health effects:

Silicosis: The major concern is silicosis, caused by the inhalation and retention of respirable crystalline silica dust. Silicosis can exist in several forms, chronic (or ordinary), accelerated, or acute.

Chronic or Ordinary Silicosis (often referred to as Simple Silicosis) is the most common form of silicosis, and can occur after many years of exposure to relatively low concentrations of airborne respirable crystalline silica dust. It is further defined as either simple or complicated silicosis. Lung lesions (shown as radiographic opacities) less than 1 centimeter in diameter characterize simple silicosis, primarily in the upper lung zones. Often, simple silicosis is not associated with symptoms, detectable changes in lung function or disability. Simple silicosis may be progressive and may develop into complicated silicosis or progressive massive fibrosis (PMF). Complicated silicosis or PMF is characterized by lung lesions (shown as radiographic opacities) greater than 1 centimeter in diameter. Although there may be no symptoms associated with complicated silicosis or PMF, the symptoms, if present, are shortness of breath, wheezing, cough and sputum production. Complicated silicosis or PMF may be associated with decreased lung function and may be disabling. Advanced complicated silicosis or PMF may lead to death. Advanced complicated silicosis or PMF can result in heart disease secondary to the lung disease.

Accelerated Silicosis can occur with exposure to high concentrations of respirable crystalline silica over a relatively short period; the lung lesions can appear within five years of the initial exposure. The progression can be rapid. Accelerated silicosis is similar to chronic or ordinary silicosis, except that the lung lesions appear earlier and the progression is more rapid.

Acute Silicosis can occur with exposures to very high concentrations of respirable crystalline silica over a very short time period, sometimes as short as a few months. The symptoms of acute silicosis include progressive shortness of breath, fever, cough and weight loss. Acute silicosis can be fatal.

Cancer:

IARC: The International Agency for Research on Cancer ("IARC") concluded that there was *"sufficient evidence* in humans for the carcinogenicity of crystalline silica in the forms of quartz or cristobalite from occupational sources", and that there is *"sufficient evidence* in experimental animals for the carcinogenicity of quartz and cristobalite." The overall IARC evaluation was that "crystalline silica inhaled in the form of quartz or cristobalite from occupational sources is *carcinogenic to humans (Group* 1)." The IARC evaluation noted "carcinogenicity was not detected in all industrial circumstances studies. Carcinogenicity may be dependent on inherent characteristics of the crystalline silica or on external factors affecting its biological activity or distribution of its polymorphs." For further information on the IARC evaluation, see IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 68, "Silica, Some Silicates..." (1997).

NTP: The National Toxicology Program (NTP), in its Ninth Annual Report on Carcinogens, classified "silica, crystalline (respirable)" as a known human carcinogen.

OSHA: Crystalline silica (quartz) is not regulated by the Occupational Safety and Health Administration (OSHA) as a human carcinogen.

There have been many articles published on the carcinogenicity of crystalline silica, which the reader should consult for additional information. The following are examples of recently published articles:

"*Crystalline Silica and Lung Cancer: The Problem of Conflicting Evidence*", Indoor Built Environ, Volume 8: 121-126 (1998).
"*Crystalline Silica and the Risk of Lung Cancer on the Potteries,*" Occup. Environ. Med., Vol. 55: 779-785 (1998).
"*Is Silicosis Required for Silica-Associated Lung Cancer*?" American Journal of Industrial Medicine, Vol. 37: 252- 259 (2000).
"*Silica, Silicosis, and Lung Cancer: A Risk Assessment,*" American Journal of Industrial Medicine, Vol. 38: 8-18 (2000).
"*Silica, Silicosis, and Lung Cancer: A Response to a Recent Working Group Report,*" Journal of Occupational and Environmental Medicine, Vol. 42: 704-720 (2000).
"*NIOSH Hazard Review: Health Effects of Occupational Exposure to Respirable Crystalline Silica.* DDHS (NIOSH) Publication No. 2002-129 (2002).

Autoimmune Diseases: There is evidence that exposure to respirable crystalline silica (without silicosis) or that the disease silicosis is associated with the increased incidence of several autoimmune disorders, -- scleroderma, systemic lupus erythematosus, rheumatoid arthritis and diseases affecting the kidneys. For a review of the subject, the following articles may be consulted:

"*Occupational Exposure to Crystalline Silica and Autoimmune Disease*", Environmental Health Perspectives, Vol. 107, Supplement 5, pp. 793-802 (1999).
"*Occupational Scleroderma*", Current Opinion in Rheumatology, Vol. 11: 490-494 (1999).

Tuberculosis: Individuals with silicosis are at increased risk to develop pulmonary tuberculosis, if exposed to persons with tuberculosis. The following may be consulted for further information:

Occupational Lung Disorders, 3rd Ed., Chapter 12, "Silicosis and Related Diseases," Parkes, W. (1994).
"*Risk of pulmonary tuberculosis relative to silicosis and exposure to silica dust in South African gold miners*," Occup. Environ. Med., Vol. 55: 496-502 (1998).

Kidney Disease: There is evidence that exposure to respirable crystalline silica (without silicosis) or that the disease silicosis is associated with the increased incidence of kidney diseases, including end stage renal disease. For additional information on the subject, the following may be consulted:
"*Kidney Disease and Silicosis*", Nephron, Vol. 85: 14-19 (2000).

Skin Contact: No adverse effects expected.

Eye Contact: Contact may cause mechanical irritation and possible injury.

Ingestion: No adverse effects expected for normal, incidental ingestion.

Chronic Health Effects: See "Inhalation" subsection above with respect to silicosis, cancer status and other data with possible relevance to human health.

Medical Conditions Aggravated by Exposure: Individuals with respiratory disease, including but not limited to asthma and bronchitis, or subject to eye irritation, should not be exposed to respirable silica dust.

Signs and Symptoms of Exposure: Exposure to dust may cause mucous membrane and respiratory irritation, cough, sore throat, nasal congestion, sneezing and shortness of breath. However, there may be no immediate signs or symptoms of exposure to hazardous concentrations of respirable crystalline silica (quartz). See "Inhalation" subsection above for symptoms of silicosis. The absence of symptoms is not necessarily indicative of safe conditions.

Acute Toxicity: Crystalline Silica
Oral, rat: LD50 = 22,500 mg/kg

Section 12: Ecological Information

Crystalline Silica:
LC50 carp >10,000 mg/L/72 hr.

This product is not expected to present an environmental hazard.

Section 13: Disposal Considerations

General: If uncontaminated, dispose as an inert, non-metallic mineral. If contaminated, dispose in accordance with all applicable local, state/provincial and federal regulations in light of the contamination present. Local regulations may be more stringent than regional and national requirements. It is the responsibility of the waste generator to determine the toxicity and physical characteristics of the material to determine the proper waste identification and disposal in compliance with applicable regulations.

RCRA: This product as sold by Fairmount Santrol is not classified as hazardous wastes under the Resource Conservation and Recovery Act, or its regulations, 40 CFR §261 et seq.

Section 14: Transport Information

This product is not regulated for transportation under the U.S. DOT, Canadian TDG, IMDG, or IATA Regulations.

Section 15: Regulatory Information

United States (Federal and State):

TSCA: Crystalline silica (CAS #14808-60-7) is listed on the EPA Toxic Substance Control Act (TSCA) Section 8(b) inventory.

RCRA: Crystalline silica is not classified as hazardous waste under the Resource Conservation and Recovery Act (RCRA), or its regulations, 40 CFR §261 et seq.

CERCLA Section 103 Reportable Quantity: None.

SARA 311/312: Hazard Categories for SARA Section 311/312 Reporting: Crystalline silica (Acute and Chronic Health Hazard).

SARA 313: Product contains no chemicals that are subject to Annual Release Reporting Requirements under SARA Section 313 (40 CFR 372).

Clean Air Act: Product was not processed with or does not contain Class I or II ozone depleting substances.

Clean Water Act: Not listed as a hazardous substance in Section 311.

NTP: Crystalline silica (quartz) is classified as a Known to be a Human Carcinogen.

OSHA: Crystalline silica (quartz) is listed under 29 CFR 1910.1000 as a toxic and hazardous substance.

California Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65): Crystalline silica (respirable) is classified as a substance known by the State of California to cause cancer.

Canada:

Domestic Substances List (DSL): Crystalline silica (quartz) is a naturally occurring substance on the DSL.

WHMIS Classification: Crystalline silica - Class D, Division 2, Subdivision A (Very Toxic Material causing other Toxic Effects).

Other:

IARC: Crystalline silica (quartz) is classified in IARC Group 1 Carcinogen.

European Inventory of Commercial Chemical Substances: Crystalline silica (quartz) is listed on EINECS Inventory; the EINECS number for quartz: 238-878-4.

European Community Labeling:

Harmful Xn
Contains crystalline silica, quartz (238-878-4)
R48/20 Harmful: Danger of serious damage to health by prolonged exposure by inhalation
S22 Do not breathe dust
S38 In case of insufficient ventilation, wear suitable respiratory protection

National, state, provincial or local emergency planning, community right-to-know or other laws, regulations or ordinances may be applicable--consult applicable national, state, provincial or local laws.

Section 16: Other Information

Web Sites with information about health effects from occupational exposure to the chemical substances contained in this product and associated engineering controls and personal protective equipment:

OSHA Website:
https://www.osha.gov/dsg/topics/silicacrystalline/index.html
NIOSH Website:
http://www.cdc.gov/niosh/topics/silica
NIOSH Hazard Review – Health Effects of Occupational Exposure to Respirable Crystalline Silica
http://www.cdc.gov/niosh/docs/2002-129/
IARC Monograph concerning crystalline silica, Volume 100C:
http://monographs.iarc.fr/ENG/Monographs/PDFs/index.php.

NFPA Hazard Rating:	Health: 1	Fire: 0	Reactivity: 0
HMIS Hazard Rating:	Health: *	Fire: 0	Reactivity: 0

* Warning – Chronic health effect possible – inhalation of silica dust may cause lung injury/disease (silicosis). Take appropriate measures to avoid breathing dust. See Section 8.

EU Classes and Risk Phrases for Reference
Xn Harmful
R48/20 Harmful: Danger of serious damage to health by prolonged exposure by inhalation.

User's Responsibility: The OSHA Hazard Communication Standard 29 CFR 1910.1200 require that this Safety Data Sheet be made available to your employees who handle or may be exposed to this product. Educate and train your employees regarding applicable precautions. Instruct your employees to handle this product properly.

Disclaimer: The information contained in this document applies to this specific material as supplied. It may not be valid for this material if it is used in combination with other materials. It is the user's responsibility to satisfy oneself as to the suitability and completeness of this information for one's own particular use. Since the actual use of the product described herein is beyond our control, Fairmount Santrol assumes no liability arising out of the use of the product by others. Appropriate warnings and safe handling procedures should be provided to handlers and users.

Foundry and Recreation: Silica, Lake and Bank Sand All Grades; Proppant: 16/30, 20/35, 20/40, 30/50, 40/70 & 100 Mesh; All Grades
Crystalline Silica (Quartz)
Fundición y Recreación: Sílice, Lago y el Banco de arena todos los grados; Proppant: 16/30, 20/35, 20/40, 30/50, 40/70 y 100 de malla; Todos los grados
La sílice cristalina (cuarzo)
Fonderie et loisirs : silice, lac et de sable de la Banque toutes les qualities ; Proppant : 16/30, 20/35, 20/40, 30/50, 40/70 et 100 Mesh ; Toutes les qualités
Silice cristalline (quartz)

DANGER/PELIGRO/DANGER

HAZARD STATEMENTS
Causes damage to lungs through prolonged or repeated inhalation exposure.
May cause lung cancer.
May cause damage to kidneys.
INDICACIONES DE PELIGRO
Provoca daños en los pulmones tras exposiciones prolongadas o repetidas por inhalación.
Puede causar cáncer de pulmón.
Puede causar daños a los riñones.
MENTIONS DE DANGER
Cause des lésions pulmonaires par des expositions répétées ou prolongées par inhalation.
Peut causer un cancer du poumon.
Peut endommager les reins.
PRECAUTIONARY STATEMENTS
Minimize dust generation and accumulation during handling and use.
Do not breathe dust.
Use with adequate capture ventilation.
Clean up spills and dust accumulation using dustless methods (HEPA vacuum or water) to minimize dust generation.
Avoid contact with strong oxidizing agents; may cause fire.
Wash hands after handling.
No specific disposal method is required. Dispose of in accordance with Federal, State, and Local regulations.
Do not handle product until Safety Data Sheet has been read and understood.
CONSEJOS DE PRUDENCIA
Reduzca al mínimo la generación y acumulación de polvo durante la manipulación y uso.
No hay respirar el polvo.
Use con la ventilación adecuada de captura.
Limpie los derrames y la acumulación de polvo utilizando métodos sin polvo (aspiradora HEPA o agua) para minimizar la generación de polvo.
Evite el contacto con agentes oxidantes; esto puede causar incendios
Lave sus manos despues de usarse
No se requiere un metodo especifco para su disposcion. Eliminar desecho acorde a las regulaciones Federales, Estatales y locales.
No use el producto hasta que la hoja de seguridad haya sido leida y comprendida
CONSEILS DE PRUDENCE
Minimiser la production et l'accumulation de poussière lors de la manipulation et de l'utilisation.
Ne pas respirer la poussière.
Utiliser avec une ventilation de captage adéquate.
Nettoyer les déversements et l'accumulation de poussière à l'aide de méthodes sans poussière (aspirateur HEPA ou de l'eau) pour minimiser la production de poussière.
Éviter un contact avec des agents oxydants puissants ; il pourrait provoquer un incendie.
Se laver les mains après une manipulation.
Il n'existe aucune exigence relative à une méthode d'élimination particulière. L'élimination se fait conformément aux règlements fédéraux, étatiques et locaux.
S'abstenir de manipuler le produit tant que la fiche de données de sécurité n'a pas été lue et comprise.

Fire: Product will not burn. Product is compatible with all extinguishing media.
Fuego: El producto no se quemará. El producto es compatible con todos los medios de extinción.
Incendie: Ce produit ne brûle pas. Il est compatible avec tous les agents d'extinction.

First Aid: Gross inhalation, remove person immediately to fresh air. Get medical attention if person feels unwell. Gross ingestion, get immediate medical attention.
Primeros Auxilios: Inhalación Bruto, retire persona inmediatamente al aire fresco. Busque atención médica si la persona se siente mal. La ingestión bruta, busque atención médica inmediata.
Premiers soins : Forte inhalation : amener immédiatement la personne à l'air frais. Si elle ne sent pas bien, consulter un médecin. Ingestion massive : consulter un médecin immédiatement

For additional information, read **Safety Data Sheet** for product.
Para más información, lea la **hoja de datos de seguridad** para el producto.
Pour de plus amples informations, lire la **fiche de données de sécurité** du produit.

This product is not intended for and is strictly prohibited for sandblasting.
Este producto no está dirigido a la limpieza con chorro de arena (sandblasting) y está estrictamente prohibido para tal fin.
Ce produit n'est pas conçu pour le sablage au jet et il est formellement interdit de l'utiliser à cette fin.

24-hour Emergency Phone Number
24 horas Número de teléfono de emergencia
Numéro de téléphone d'urgence (24 heures)
CHEMTREC
Within USA and Canada/Dentro de EE.UU. y Canadá/États-Unis et Canada: **1.800.424.9300**
Outside USA and Canada/Fuera de EE.UU. y Canadá/Hors États-Unis et Canada: **+1.703.741.5970** (collect calls accepted)/(se aceptan llamadas por cobrar)/(appels en PCV acceptés)
For emergency calls only. Non-emergency calls cannot be serviced at this number./Para llamadas de emergencia solamente. Llamadas no de emergencia no pueden ser atendidas en este número./Pour les appels urgents uniquement. Les appels non urgents ne peuvent pas être traités à ce numéro.

Manufacturer/Fabricante/Fabricant:
Fairmount Santrol
3 Sugar Creek Center Blvd
Suite 550
Sugar Land, TX 77478
Phone/Teléfono/Nº de telephone: 1.800.255.7263
Website: FairmountSantrol.com

February 24, 2016/24 de febrero de 2016/24 février 2016

SAFETY DATA SHEET

RioTinto

Section 1. Identification

Product name : H2OMET 28, 56, 57, 58, 68, 86, 414

Chemical name : iron

Product code : 2000

Other means of identification : Iron powder

Product type : Powder.

Relevant identified uses of the substance or mixture and uses advised against

Material uses : Industrial applications: Powder metallurgy

Identified uses
Powder metallurgy. SU 8,9,10,14,15/ PC 7,14,20,24,25,37,38/ PROC 1,2,3,5,7,8b,9,14,21,22,23,24,25,26,27a,27b/ AC 7/ ERC 1,2,5,6a,6b,12a,12b.

Supplier's details :

Rio Tinto Fer et Titane Inc,
1625 Route Marie-Victorin
Sorel-Tracy, Quebec J3R 1M6
Canada

Tel: +1-450-746-3000

e-mail address of person responsible for this SDS : rtit.msds@riotinto.com

Emergency telephone number : +1 215 207 0061 (Rio Tinto Fer et Titane Inc)
For advice on chemical emergencies, spillages, fires or first aid.

Section 2. Hazards identification

OSHA/HCS status : While this material is not considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200), this SDS contains valuable information critical to the safe handling and proper use of the product. This SDS should be retained and available for employees and other users of this product.

Classification of the substance or mixture : Not classified.

GHS label elements

Signal word : No signal word.

Hazard statements : No known significant effects or critical hazards.

Precautionary statements

Prevention : Not applicable.

Response : Not applicable.

Storage : Not applicable.

Disposal : Not applicable.

Hazards not otherwise classified : Handling and/or processing of this material may generate a dust which can cause mechanical irritation of the eyes, skin, nose and throat. Fine dust clouds may form explosive mixtures with air. Repeated or prolonged inhalation of dust may lead to chronic respiratory irritation and pneumoconiosis.

Section 3. Composition/information on ingredients

Substance/mixture : Substance

Chemical name : iron

CAS number/other identifiers

CAS number : 7439-89-6

Product code : 2000

Ingredient name	%	CAS number
Iron	>90	7439-89-6
carbon alloyed	<4	7440-44-0

Any concentration shown as a range is to protect confidentiality or is due to batch variation.

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Additional information

For more details on the composition, refer to Certificate of Analysis.

Occupational exposure limits, if available, are listed in Section 8.

Section 4. First aid measures

Description of necessary first aid measures

Eye contact : Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Get medical attention if irritation occurs.

Inhalation : Move exposed person to fresh air. Get medical attention if symptoms occur.

Skin contact : Wash with soap and water. Get medical attention if symptoms occur.

Ingestion : Wash out mouth with water. Get medical attention if symptoms occur.

Most important symptoms/effects, acute and delayed

Potential acute health effects

Eye contact : Exposure to airborne concentrations above statutory or recommended exposure limits may cause irritation of the eyes.

Inhalation : Exposure to airborne concentrations above statutory or recommended exposure limits may cause irritation of the nose, throat and lungs.

Skin contact : No known significant effects or critical hazards.

Ingestion : No known significant effects or critical hazards.

Over-exposure signs/symptoms

Eye contact : Adverse symptoms may include the following:
irritation
redness

Inhalation : Adverse symptoms may include the following:
respiratory tract irritation
coughing

Skin contact : No specific data.

Ingestion : No specific data.

Indication of immediate medical attention and special treatment needed, if necessary

Notes to physician : No specific treatment. Treat symptomatically.

Specific treatments : No specific treatment.

Protection of first-aiders : No special protection is required. See Section 8 for information on appropriate personal protective equipment.

See toxicological information (Section 11)

Section 5. Fire-fighting measures

Extinguishing media

Suitable extinguishing media : Use a fog nozzle to spray water.

Unsuitable extinguishing media : Do not use water jet.

Specific hazards arising from the chemical : Fine dust clouds may form explosive mixtures with air. As with any finely granulated product, (i.e flour) a risk of fire is present should the material be dispersed in air and exposed to a source of ignition.

Hazardous thermal decomposition products : Decomposition products may include the following materials:
carbon dioxide
carbon monoxide
metal oxide/oxides

Special protective actions for fire-fighters : Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training.

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions, protective equipment and emergency procedures

For non-emergency personnel : No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Do not touch or walk through spilled material. Avoid breathing dust. Put on appropriate personal protective equipment.

For emergency responders : If specialized clothing is required to deal with the spillage, take note of any information in Section 8 on suitable and unsuitable materials. See also the information in "For non-emergency personnel".

Environmental precautions : Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods and materials for containment and cleaning up

Small spill : Recycle, if possible. Waste must be disposed of according to applicable regulations.

Large spill : Avoid creating dusty conditions and prevent wind dispersal. Note: see Section 1 for emergency contact information and Section 13 for waste disposal. Waste must be disposed of according to applicable regulations. Recycle, if possible.

Section 7. Handling and storage

Precautions for safe handling

Protective measures : Put on appropriate personal protective equipment (see Section 8). Avoid breathing dust.

Advice on general occupational hygiene : Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. See also Section 8 for additional information on hygiene measures.

Conditions for safe storage, including any incompatibilities : Store in accordance with local regulations. Store so as to avoid dust generation and dispersal. Store in a segregated and approved area. Do not store in unlabeled containers. Separate from oxidizing materials. Use appropriate containment to avoid environmental contamination.

Section 8. Exposure controls/personal protection

Control parameters

Occupational exposure limits

Ingredient name	Exposure limits
Iron	**ACGIH TLV (United States).** TWA: 5 mg/m³, (as iron oxide) 8 hours. Form: Dust and fumes **NIOSH REL (United States).** TWA: 5 mg/m³, (as iron oxide) 10 hours. Form: Dust and fumes **OSHA PEL (United States).** TWA: 10 mg/m³, (as iron oxide) 8 hours. Form: Fume
carbon alloyed	None.

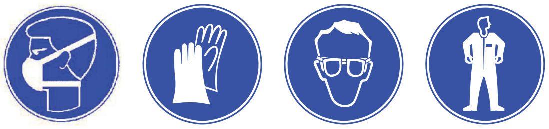
Recommended monitoring procedures	: If this product contains ingredients with exposure limits, personal, workplace atmosphere or biological monitoring may be required to determine the effectiveness of the ventilation or other control measures and/or the necessity to use respiratory protective equipment.
Appropriate engineering controls	: Good general ventilation should be sufficient to control worker exposure to airborne contaminants. If user operations generate dust, fumes, gas, vapor or mist, use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits.
Environmental exposure controls	: Avoid creating dusty conditions and prevent wind dispersal.

Individual protection measures

Hygiene measures	: Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.
Eye/face protection	: Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, gases or dusts. If contact is possible, the following protection should be worn, unless the assessment indicates a higher degree of protection: safety glasses with side-shields. If operating conditions cause high dust concentrations to be produced, use dust goggles. Recommended: Safety glasses.

Skin protection

Hand protection	: Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary.
Body protection	: Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product. Recommended: overall
Other skin protection	: Appropriate footwear and any additional skin protection measures should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Respiratory protection	: Based on the hazard and potential for exposure, select a respirator that meets the appropriate standard or certification. Respirators must be used according to a respiratory protection program to ensure proper fitting, training, and other important aspects of use.
Personal protective equipment (Pictograms)	:



Section 9. Physical and chemical properties

Appearance	
Physical state	Solid. [Powder.]
Color	Gray.
Odor	Odorless.
Odor threshold	Not applicable.
pH	Not applicable.
Melting point	1535°C (2795°F)
Boiling point	2861°C (5181.8°F)
Flash point	Not applicable.
Evaporation rate	Not applicable.
Flammability (solid, gas)	Non-flammable.
Lower and upper explosive (flammable) limits	Not available.
Vapor pressure	Not applicable.
Vapor density	Not available.
Bulk density	2.4 - 3.2 [g/cm³]
Granulometry	<1.5 mm
Relative density	7.8
Solubility	Insoluble in the following materials: cold water and hot water.
Solubility in water	0 g/l
Partition coefficient: n-octanol/water	Not applicable.
Auto-ignition temperature	Not applicable.
Decomposition temperature	Not applicable.
Viscosity	Not applicable.

Section 10. Stability and reactivity

Reactivity	No specific test data related to reactivity available for this product or its ingredients.
Chemical stability	The product is stable.
Possibility of hazardous reactions	Under normal conditions of storage and use, hazardous reactions will not occur.
Conditions to avoid	Reactive or incompatible with the following materials: oxidizing materials and acids. Emits toxic fumes when heated. Avoid the creation of dust when handling and avoid all possible sources of ignition (spark or flame). Take precautionary measures against electrostatic discharges. To avoid fire or explosion, dissipate static electricity during transfer by grounding and bonding containers and equipment before transferring material. Prevent dust accumulation.
Incompatible materials	Reactive or incompatible with the following materials: oxidizing materials and acids. Emits toxic fumes when heated.
Hazardous decomposition products	Under normal conditions of storage and use, hazardous decomposition products should not be produced.

Section 11. Toxicological information

Information on toxicological effects

Acute toxicity

Product/ingredient name	Result	Species	Dose	Exposure
Iron	LCLo Inhalation Dusts and mists LD50 Oral	Rat Rat	250 mg/m³ 7500 mg/kg	6 hours -

Conclusion/Summary : No known significant effects or critical hazards.

Irritation/Corrosion

Conclusion/Summary

Skin : Non-irritating to the skin.

Eyes : Non-irritating to the eyes.

Respiratory : Non-irritating to the respiratory system.

Sensitization

Conclusion/Summary

Skin : Non-sensitizer to skin.

Mutagenicity

Conclusion/Summary : No known significant effects or critical hazards.

Carcinogenicity

Conclusion/Summary : No known significant effects or critical hazards.

Reproductive toxicity

Conclusion/Summary : No known significant effects or critical hazards.

Teratogenicity

Conclusion/Summary : No known significant effects or critical hazards.

Specific target organ toxicity (single exposure)

Not available.

Specific target organ toxicity (repeated exposure)

Not available.

Aspiration hazard

Not available.

Information on the likely routes of exposure : Routes of entry anticipated: Oral, Dermal, Inhalation.

Potential acute health effects

Eye contact : Exposure to airborne concentrations above statutory or recommended exposure limits may cause irritation of the eyes.

Inhalation : Exposure to airborne concentrations above statutory or recommended exposure limits may cause irritation of the nose, throat and lungs.

Skin contact : No known significant effects or critical hazards.

Ingestion : No known significant effects or critical hazards.

Symptoms related to the physical, chemical and toxicological characteristics

Eye contact : Adverse symptoms may include the following:
irritation
redness

Inhalation : Adverse symptoms may include the following:
respiratory tract irritation
coughing

Skin contact : No specific data.

Ingestion : No specific data.

Delayed and immediate effects and also chronic effects from short and long term exposure

Section 11. Toxicological information

Short term exposure

Potential immediate effects : No known significant effects or critical hazards.

Potential delayed effects : No known significant effects or critical hazards.

Long term exposure

Potential immediate effects : No known significant effects or critical hazards.

Potential delayed effects : No known significant effects or critical hazards.

Potential chronic health effects

Product/ingredient name	Result	Species	Dose	Exposure
Iron	Sub-chronic LOAEL Oral Sub-chronic NOAEL Inhalation Dusts and mists	Rat Rat	26 mg/kg 5 mg/m³	12 weeks 4 weeks

Conclusion/Summary : Repeated or prolonged inhalation of dust may lead to chronic respiratory irritation and pneumoconiosis.

General : Repeated or prolonged inhalation of dust may lead to chronic respiratory irritation.

Carcinogenicity : No known significant effects or critical hazards.

Mutagenicity : No known significant effects or critical hazards.

Teratogenicity : No known significant effects or critical hazards.

Developmental effects : No known significant effects or critical hazards.

Fertility effects : No known significant effects or critical hazards.

Numerical measures of toxicity

Acute toxicity estimates

Not available.

Section 12. Ecological information

Toxicity

Product/ingredient name	Result	Species	Exposure
Iron	Chronic NOEC 100 mg/l Marine water	Algae - Glenodinium halli	72 hours

Conclusion/Summary : Not classified.

Persistence and degradability

Conclusion/Summary : Inorganic: Not readily biodegradable.

Bioaccumulative potential

Product/ingredient name	LogP$_{ow}$	BCF	Potential
Iron	-	-	-

Mobility in soil

Soil/water partition coefficient (K$_{OC}$) : Not available.

Other adverse effects : No known significant effects or critical hazards.

Section 13. Disposal considerations

Disposal methods : The generation of waste should be avoided or minimized wherever possible. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers. Recycle, if possible.

Section 14. Transport information

	DOT Classification	TDG Classification	Mexico Classification	ADR/RID	IMDG	IATA
UN number	Not regulated.	Not regulated.	Not regulated.	Not regulated.	Not regulated.	Not regulated.
UN proper shipping name	-	-	-	-	-	-
Transport hazard class(es)	-	-	-	-	-	-
Packing group	-	-	-	-	-	-
Environmental hazards	No.	No.	No.	No.	No.	No.
Additional information	-	-	-	-	-	-

Special precautions for user : Not applicable.

Transport in bulk according to Annex II of MARPOL and the IBC Code : Not applicable.

Section 15. Regulatory information

U.S. Federal regulations : **TSCA 8(a) CDR Exempt/Partial exemption**: Not determined

United States inventory (TSCA 8b): All components are listed or exempted.

Clean Air Act Section 112 (b) Hazardous Air Pollutants (HAPs) : Not listed

Clean Air Act Section 602 Class I Substances : Not listed

Clean Air Act Section 602 Class II Substances : Not listed

DEA List I Chemicals (Precursor Chemicals) : Not listed

DEA List II Chemicals (Essential Chemicals) : Not listed

SARA 302/304

Composition/information on ingredients

No products were found.

SARA 304 RQ : Not applicable.

SARA 311/312

Section 15. Regulatory information

Classification : Not applicable.

Composition/information on ingredients

No products were found.

State regulations

Massachusetts : None of the components are listed.
New York : None of the components are listed.
New Jersey : None of the components are listed.
Pennsylvania : None of the components are listed.

International regulations

Chemical Weapon Convention List Schedules I, II & III Chemicals

Not listed.

International lists

National inventory

Australia inventory (AICS) : All components are listed or exempted.
Canada inventory : All components are listed or exempted.
China inventory (IECSC) : All components are listed or exempted.
Europe inventory : All components are listed or exempted.
Korea inventory : All components are listed or exempted.
New Zealand Inventory of Chemicals (NZIoC) : All components are listed or exempted.
Philippines inventory (PICCS) : All components are listed or exempted.
United States inventory (TSCA 8b) : All components are listed or exempted.

Canada

WHMIS (Canada) : Not controlled under WHMIS (Canada).
Canadian NPRI : None of the components are listed.

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all the information required by the Controlled Products Regulations.

Section 16. Other information

Hazardous Material Information System (U.S.A.)

Health	1
Flammability	3
Physical hazards	1

Caution: HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks Although HMIS® ratings are not required on SDSs under 29 CFR 1910. 1200, the preparer may choose to provide them. HMIS® ratings are to be used with a fully implemented HMIS® program. HMIS® is a registered mark of the National Paint & Coatings Association (NPCA). HMIS® materials may be purchased exclusively from J. J. Keller (800) 327-6868.

The customer is responsible for determining the PPE code for this material.

National Fire Protection Association (U.S.A.)

Section 16. Other information

Reprinted with permission from NFPA 704-2001, Identification of the Hazards of Materials for Emergency Response Copyright ©1997, National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association, on the referenced subject which is represented only by the standard in its entirety.

Copyright ©2001, National Fire Protection Association, Quincy, MA 02269. This warning system is intended to be interpreted and applied only by properly trained individuals to identify fire, health and reactivity hazards of chemicals. The user is referred to certain limited number of chemicals with recommended classifications in NFPA 49 and NFPA 325, which would be used as a guideline only. Whether the chemicals are classified by NFPA or not, anyone using the 704 systems to classify chemicals does so at their own risk.

Procedure used to derive the classification

Classification	Justification
Not classified.	

History

Date of issue/Date of revision : 12/15/2015

Date of previous issue : No previous validation

Version : 1

Key to abbreviations : ATE = Acute Toxicity Estimate
BCF = Bioconcentration Factor
GHS = Globally Harmonized System of Classification and Labelling of Chemicals
IATA = International Air Transport Association
IBC = Intermediate Bulk Container
IMDG = International Maritime Dangerous Goods
IMSBC = International Maritime Solid Bulk Cargoes Code
LogPow = logarithm of the octanol/water partition coefficient
MARPOL = International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978. ("Marpol" = marine pollution)
UN = United Nations

References : Not available.

◤ **Indicates information that has changed from previously issued version.**

United States / 4.6 / EN-US

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.
Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

Safety Data Sheet

Electron Donor Solution Extended Release

SDS Revision Date: **06/02/2015**

1. Identification

1.1. Product identifier

Product Identity	Electron Donor Solution Extended Release
Alternate Names	EDS-ER

1.2. Relevant identified uses of the substance or mixture and uses advised against

Intended use	See Technical Data Sheet.
Application Method	See Technical Data Sheet.

1.3. Details of the supplier of the safety data sheet

Company Name	Tersus Environmental, LLC 1116 Colonial Club Rd. Wake Forest, NC 27587
Emergency	
CHEMTREC (USA)	(800) 424-9300
24 hour Emergency Telephone No.	1-703-527-3887
Customer Service: Tersus Environmental, LLC	(919) 453-5577 info@tersusenv.com

2. Hazard(s) identification

2.1. Classification of the substance or mixture

No applicable GHS categories.

2.2. Label elements

Using the Toxicity Data listed in section 11 and 12 the product is labeled as follows.

.

[Prevention]:

No GHS prevention statements

[Response]:

No GHS response statements

[Storage]:

No GHS storage statements

[Disposal]:

No GHS disposal statements

3. Composition/information on ingredients

This product contains the following substances that present a hazard within the meaning of the relevant State and Federal Hazardous Substances regulations.

Ingredient/Chemical Designations	Weight %	GHS Classification	Notes
Soybean Oil **CAS Number: 8001-22-7**	**93**		
Vegetable Oil Derived Fatty Acid Esters **CAS Number: Proprietary**	**7**	**Not Classified**	**[1]**

In accordance with paragraph (i) of §1910.1200, the specific chemical identity and/or exact percentage (concentration) of composition has been withheld as a trade secret.
[1] Substance classified with a health or environmental hazard.
[2] Substance with a workplace exposure limit.
[3] PBT-substance or vPvB-substance.
*The full texts of the phrases are shown in Section 16.

4. First aid measures

4.1. Description of first aid measures

General	In all cases of doubt, or when symptoms persist, seek medical attention. Never give anything by mouth to an unconscious person.
Inhalation	Remove to fresh air, keep patient warm and at rest. If breathing is irregular or stopped, give artificial respiration. If unconscious place in the recovery position and obtain immediate medical attention. Give nothing by mouth.
Eyes	Irrigate copiously with clean water for at least 15 minutes, holding the eyelids apart and seek medical attention.
Skin	Remove contaminated clothing. Wash skin thoroughly with soap and water or use a recognized skin cleanser.
Ingestion	If swallowed obtain immediate medical attention. Keep at rest. Do NOT induce vomiting.

4.2. Most important symptoms and effects, both acute and delayed

Overview	Inhalation Health Risks and Symptoms of Exposure: Excessive inhalation of oil mist may affect the respiratory system. Oil mist is classified as a nuisance particulate by ACGIH. Skin Absorption Health Risks and Symptoms of Exposure: Not classified as a primary skin irritant or corrosive material. Sensitive individuals may experience dermatitis after long

exposure of oil on skin.

Health Hazards (Acute and Chronic):
Acute: None observed by inhalation.
Chronic: None reported.

5. Fire-fighting measures

5.1. Extinguishing media

CO2, dry chemical, foam, sand.

5.2. Special hazards arising from the substance or mixture

Hazardous decomposition: No hazardous decomposition data available.

5.3. Advice for fire-fighters

Special Firefighting Procedures: Avoid use of water as it may spread fire by dispersing oil. Use water to keep fire-exposed containers cool. Water spray may be used to flush spills away from fire.

Unusual Fire and Explosion Hazards: Rags soaked with any oil or solvent can present a fire hazard and should always be stored in UL Listed or Factory Mutual approved, covered containers. Improperly stored rags can create conditions that lead to oxidation. Oxidation, under certain conditions can lead to spontaneous combustion.

ERG Guide No. ----

6. Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

Put on appropriate personal protective equipment (see section 8).

6.2. Environmental precautions

Do not allow spills to enter drains or waterways.

Use good personal hygiene practices. Wash hands before eating, drinking, smoking or using toilet. Promptly remove soiled clothing and wash thoroughly before reuse.

6.3. Methods and material for containment and cleaning up

Wear appropriate respiratory protection and protective clothing as described in Section 8. Depending on quantity of spill: (a) Small spill: Add solid adsorbent, shovel into disposable container and wash the area. Clean area with detergent. (b) Large spill: Squeegee or pump into holding container. Clean area with detergent. In the event of an uncontrolled release of this material, the user should determine if this release is reportable under applicable laws and regulations.

All recovered material should be packaged, labeled, transported, and disposed or reclaimed in accordance with local, state, and federal regulations and good engineering practices.

7. Handling and storage

7.1. Precautions for safe handling

Handle containers carefully to prevent damage and spillage.

7.2. Conditions for safe storage, including any incompatibilities

Incompatible materials: No data available.

Store away from flame, fire, and excessive heat.

7.3. Specific end use(s)

No data available.

8. Exposure controls and personal protection

8.1. Control parameters

Exposure

CAS No.	Ingredient	Source	Value
Proprietary	Vegetable Oil Derived Fatty Acid Esters	OSHA	No Established Limit
		ACGIH	No Established Limit
		NIOSH	No Established Limit
		Supplier	No Established Limit

Carcinogen Data

CAS No.	Ingredient	Source	Value
Proprietary	Vegetable Oil Derived Fatty Acid Esters	OSHA	Select Carcinogen: No
		NTP	Known: No; Suspected: No
		IARC	Group 1: No; Group 2a: No; Group 2b: No; Group 3: No; Group 4: No;

8.2. Exposure controls

Respiratory	Not normally needed. A qualified health specialist should evaluate whether there is a need for respiratory protection under specific conditions.
Eyes	Eye protection is always recommended when handling chemicals. Wear safety glasses meeting the specifications established in ANSI Standard Z87.1.

Skin	Not normally needed. However, protective clothing is always recommended when handling chemicals.
Engineering Controls	Provide adequate ventilation. Where reasonably practicable this should be achieved by the use of local exhaust ventilation and good general extraction. If these are not sufficient to maintain concentrations of particulates and any vapor below occupational exposure limits suitable respiratory protection must be worn.
Other Work Practices	Use good personal hygiene practices. Wash hands before eating, drinking, smoking or using toilet. Promptly remove soiled clothing and wash thoroughly before reuse.

9. Physical and chemical properties

Appearance	Pale Yellow Liquid
Odor	Faint
Odor threshold	Not determined
pH	Not Measured
Melting point / freezing point	Not Measured
Initial boiling point and boiling range	Not Measured
Flash Point	Greater than 550F (288C)
Evaporation rate (Ether = 1)	Not Measured
Flammability (solid, gas)	Not Applicable
Upper/lower flammability or explosive limits	**Lower Explosive Limit:** Not Measured **Upper Explosive Limit:** Not Measured
Vapor pressure (Pa)	Not Measured
Vapor Density	Exceeds 1.0
Specific Gravity	0.92 - 0.925
Solubility in Water	Miscible
Partition coefficient n-octanol/water (Log Kow)	Not Measured
Auto-ignition temperature	Not Measured
Decomposition temperature	Not Measured
Viscosity (cSt)	Not Measured
% Volatile (by volume)	0%
Weight per gallon	7.7lbs at 60F

9.2. Other information

No other relevant information.

10. Stability and reactivity

10.1. Reactivity

Hazardous Polymerization will not occur.

10.2. Chemical stability

Stable under normal circumstances.

10.3. Possibility of hazardous reactions

No data available.

10.4. Conditions to avoid

No data available.

10.5. Incompatible materials

No data available.

10.6. Hazardous decomposition products

No hazardous decomposition data available.

11. Toxicological information

Acute toxicity

Ingredient	Oral LD50, mg/kg	Skin LD50, mg/kg	Inhalation Vapor LC50, mg/L/4hr	Inhalation Dust/Mist LC50, mg/L/4hr	Inhalation Gas LC50, ppm
Vegetable Oil Derived Fatty Acid Esters - (Proprietary)	No data available	No data available	No data available	No data available	No data available

Note: When no route specific LD50 data is available for an acute toxin, the converted acute toxicity point estimate was used in the calculation of the product's ATE (Acute Toxicity Estimate).

Classification	Category	Hazard Description
Acute toxicity (oral)	---	Not Applicable
Acute toxicity (dermal)	---	Not Applicable
Acute toxicity (inhalation)	---	Not Applicable
Skin corrosion/irritation	---	Not Applicable
Serious eye damage/irritation	---	Not Applicable
Respiratory sensitization	---	Not Applicable

Skin sensitization	---	Not Applicable
Germ cell mutagenicity	---	Not Applicable
Carcinogenicity	---	Not Applicable
Reproductive toxicity	---	Not Applicable
STOT-single exposure	---	Not Applicable
STOT-repeated exposure	---	Not Applicable
Aspiration hazard	---	Not Applicable

12. Ecological information

12.1. Toxicity

No additional information provided for this product. See Section 3 for chemical specific data.

Aquatic Ecotoxicity

Ingredient	96 hr LC50 fish, mg/l	48 hr EC50 crustacea, mg/l	ErC50 algae, mg/l
Vegetable Oil Derived Fatty Acid Esters - (Proprietary)	Not Available	Not Available	Not Available

12.2. Persistence and degradability

There is no data available on the preparation itself.

12.3. Bioaccumulative potential

Not Measured

12.4. Mobility in soil

No data available.

12.5. Results of PBT and vPvB assessment

This product contains no PBT/vPvB chemicals.

12.6. Other adverse effects

No data available.

13. Disposal considerations

13.1. Waste treatment methods

Observe all federal, state and local regulations when disposing of this substance.

14. Transport information

	DOT (Domestic Surface Transportation)	IMO / IMDG (Ocean Transportation)	ICAO/IATA
14.1. UN number	Not Applicable	Not Regulated	Not Regulated
14.2. UN proper shipping name	Not Regulated	Not Regulated	Not Regulated
14.3. Transport hazard class(es)	**DOT Hazard Class:** Not Applicable	**IMDG:** Not Applicable **Sub Class:** Not Applicable	**Air Class:** Not Applicable
14.4. Packing group	Not Applicable	Not Applicable	Not Applicable

14.5. Environmental hazards

IMDG Marine Pollutant: No

14.6. Special precautions for user

No further information

15. Regulatory information

Regulatory Overview	The regulatory data in Section 15 is not intended to be all-inclusive, only selected regulations are represented.
Toxic Substance Control Act (TSCA)	All components of this material are either listed or exempt from listing on the TSCA Inventory.
WHMIS Classification	Not Regulated

US EPA Tier II Hazards

Fire: No

Sudden Release of Pressure: No

Reactive: No

Immediate (Acute): No

Delayed (Chronic): No

EPCRA 311/312 Chemicals and RQs:
To the best of our knowledge, there are no chemicals at levels which require reporting under this statute.

EPCRA 302 Extremely Hazardous:
To the best of our knowledge, there are no chemicals at levels which require reporting under this statute.

EPCRA 313 Toxic Chemicals:
To the best of our knowledge, there are no chemicals at levels which require reporting under this statute.

Proposition 65 - Carcinogens (>0.0%):
To the best of our knowledge, there are no chemicals at levels which require reporting under this statute.

Proposition 65 - Developmental Toxins (>0.0%):
To the best of our knowledge, there are no chemicals at levels which require reporting under this statute.

Proposition 65 - Female Repro Toxins (>0.0%):
To the best of our knowledge, there are no chemicals at levels which require reporting under this statute.

Proposition 65 - Male Repro Toxins (>0.0%):
To the best of our knowledge, there are no chemicals at levels which require reporting under this statute.

New Jersey RTK Substances (>1%) :
To the best of our knowledge, there are no chemicals at levels which require reporting under this statute.

Pennsylvania RTK Substances (>1%):

Soybean oil

16. Other information

The information and recommendations contained herein are based upon data believed to be correct. However, no guarantee or warranty of any kind, expressed or implied, is made with respect to the information contained herein. We accept no responsibility and disclaim all liability for any harmful effects which may be caused by exposure to our products. Customers/users of this product must comply with all applicable health and safety laws, regulations, and orders.

The full text of the phrases appearing in section 3 is: Not applicable

This is the first version in the GHS SDS format. Listings of changes from previous versions in other formats are not applicable.

We suggest that containers be either professionally reconditioned for re-use by certified firms or properly disposed of by certified firms to help reduce the possibility of an accident. Disposal of containers should be in accordance with applicable federal, state and local laws and regulations. "Empty" drums should not be given to individuals.

The conditions of handling, storage, use and disposal of the product are beyond our control and may be beyond our knowledge. For this and other reasons, we do not assume responsibility and expressly disclaim liability for loss, damage or expense arising out of or in any way connected with the handling, storage, use or disposal of the product.

The information above is believed to be accurate and represents the best information currently available to us. However, we make no warranty of merchantability or any other warranty, express or implied, with respect to such information, and we assume no liability resulting from its use. Users should make their own investigations to determine the suitability of the information for their particular purposes. In no event shall Tersus Environmental be liable for any claims, losses, or damages of any third party or for lost profits or any special, indirect, incidental, consequential or exemplary damages, howsoever arising, even if Tersus Environmental has been advised of the possibility of such damages.

End of Document

SAFETY DATA SHEET

KB-1® Primer

Prepared according to U.S. OSHA, CMA, ANSI, Canadian WHMIS, Australian WorkSafe, Japanese Industrial Standard JIS Z 7250:2000, and European Union REACH Regulations

SECTION 1 - PRODUCT AND COMPANY IDENTIFICATION

1.1 PRODUCT NAME:	**KB-1® Primer**
PRODUCT CODE:	N/A
CHEMICAL FAMILY NAME:	Mixture
U.N. NUMBER:	None
U.N. DANGEROUS GOODS CLASS:	Not Regulated
1.2 PRODUCT USE:	For preparation of anaerobic water for use in groundwater remediation. KB-1® products are intended for laboratory research and field applications for groundwater remediation, and are not intended to be used as human or animal therapeutics, cosmetics, agricultural or pesticidal products, food additives, or as household chemicals.
1.3 SUPPLIER/MANUFACTURER'S NAME:	**SiREM**
ADDRESS:	130 Stone Road, West, Guelph, Ontario Canada N1G 3Z2
1.4 EMERGENCY PHONE:	519-515-0840
BUSINESS PHONE:	519-515-0840 (Product Information)
WEB SITE:	www.siremlab.com
1.5 DATE OF PREPARATION:	December 05, 2018
DATE OF LAST REVISION:	New

SECTION 2 - HAZARDS IDENTIFICATION

2.1 Classification of the mixture:

This product does meet the definition of a hazardous substance or preparation as defined by 29 CFR 1910. 1200 AND the European Union Council Directives 67/548/EEC, 1999/45/EC, 1272/2008/EC, 2015/830/EU and subsequent Directives.

Component(s) Contributing to Classification(s)

L-Cysteine

2.2 GHS Label elements, including precautionary statements:

Pictogram(s):

None applicable.

Signal Word:

Warning!

GHS Hazard Classification(s):

Acute Toxicity Category 5 (Oral)

Hazard Statement(s):

H303: May be harmful if swallowed

Prevention Statement(s):

None Applicable

Response Statement(s):

P312: Call a POISON CENTER/doctor if you feel unwell.

Storage Statement(s):

None Applicable

Disposal Statement(s):

None Applicable.

2.3 Other Hazards:

This mixture does not meet the criteria for PBT or vPvB in accordance with Annex VII.

SECTION 3 - COMPOSITION and INFORMATION ON INGREDIENTS

3.1 Substances: Not applicable

3.2 Mixtures:

HAZARDOUS INGREDIENTS:	CAS #	EINECS #	Index #	WT %	GHS CLASSIFICATION
L-Cysteine	52-90-4	200-158-2	Not Listed	1-10%	ACUTE TOX. CAT 4 (ORAL)
Balance of other ingredients are non-hazardous or hazardous below the applicable cut-off level.					

Additional Information: See SECTION 16 for full classification phrases.

SECTION 4 - FIRST-AID MEASURES

4.1 Description of first aid measures:

Contaminated individuals of chemical exposure must be taken for medical attention if any adverse effect occurs. Rescuers should be taken for medical attention, if necessary. Take copy of label and SDS to health professional with contaminated individual.

EYE CONTACT: If product enters the eyes, open eyes while under gentle running water for at least 15 minutes. Seek medical attention if irritation persists.

SKIN CONTACT: Wash skin thoroughly after handling. Seek medical attention if irritation develops and persists. Remove contaminated clothing. Launder before re-use.

INHALATION: If breathing becomes difficult, remove victim to fresh air. If necessary, use artificial respiration to support vital functions. Seek medical attention.

INGESTION: If product is swallowed, call physician or poison control center for most current information. If professional advice is not available, do not induce vomiting. Never induce vomiting or give diluents (milk or water) to someone who is unconscious, having convulsions, or who cannot swallow. Seek medical advice. Take a copy of the label and/or SDS with the victim to the health professional.

4.2 Most important symptoms and effects, both acute and delayed:

May be harmful if swallowed. See section 11 for additional information.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: Pre-existing skin problems may be aggravated by prolonged or repeated contact.

4.3 Indication of immediate medical attention and special treatment needed:

Treat symptoms and reduce over-exposure.

SECTION 5 - FIRE-FIGHTING MEASURES

5.1 Extinguishing media:

Use media suitable for surrounding area. Carbon dioxide, foam, dry chemical, halon, water spray.

5.2 Specific hazards arising from the chemical:

No data available for this product.

Explosion Sensitivity to Mechanical Impact:	Not Sensitive.
Explosion Sensitivity to Static Discharge:	Not Sensitive
Minimum Ignition Energy (M.I.E.)	No Data at this time

5.3 Special firefighting Procedure:

Incipient fire responders should wear eye protection. Structural firefighters must wear Self-Contained Breathing Apparatus and full protective equipment. Isolate materials not yet involved in the fire and protect personnel. Move containers from fire area if this can be done without risk; otherwise, cool with carefully applied water spray. If possible, prevent runoff water from entering storm drains, bodies of water, or other environmentally sensitive areas.

SECTION 6 - ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures:
No action shall be taken involving any personal risk or without suitable training. Do not touch or walk through spilled material. Avoid breathing dust. Provide adequate ventilation. Use appropriate respirator when ventilation is inadequate and use personal protective clothing as described in Section 8 of this safety data sheet. See section 11 for additional information on health hazards.

6.2 Environmental precautions:
No specific data available for this product.

6.3 Methods and material for containment and cleaning up:
Wear suitable protective clothing. Avoid dust formation. Avoid breathing dust. Carefully sweep up and remove. Place material in a dry container and cover. Remove from the area. Flush spill area with water. Do not let products enter drains. Dispose of in accordance with applicable Federal, State, and local procedures (see Section 13, Disposal Considerations).

SECTION 7 - HANDLING and STORAGE

7.1 Precautions for safe handling:
As with all chemicals, avoid getting this product ON YOU or IN YOU. Wash thoroughly after handling this product. Do not eat, drink, smoke, or apply cosmetics while handling this product. Use in a well-ventilated location. Remove contaminated clothing immediately

7.2 Conditions for safe storage, including any incompatibilities:
Store in a tightly sealed container in a cool, dry and well-ventilated place. Store away from direct light. Avoid generation of dust. Do not breathe dust. Wash thoroughly after handling. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. Wear suitable protective clothing. Segregate from strong oxidizing agents, acids, bases.

7.3 Specific end uses:
See section 1.2.

SECTION 8 - EXPOSURE CONTROLS - PERSONAL PROTECTION

8.1. Control parameters:

EXPOSURE LIMITS/GUIDELINES: None established for this product.

8.2 Exposure Controls:
Currently, International exposure limits are not established for the components of this product. Please check with competent authority in each country for the most recent limits in place.

VENTILATION AND ENGINEERING CONTROLS: Generally not required under normal conditions of use. If method of use will result in significant dust generation, use in lab hood or under conditions of adequate ventilation.

The following information on appropriate Personal Protective Equipment is provided to assist employers in complying with OSHA regulations found in 29 CFR Subpart I (beginning at 1910.132) or equivalent standard of Canada, or standards of EU member states (including EN 149 for respiratory PPE, and EN 166 for face/eye protection), and those of Japan. Please reference applicable regulations and standards for relevant details.

RESPIRATORY PROTECTION: Maintain airborne contaminant concentrations below guidelines listed above, if applicable. If necessary, use only respiratory protection authorized in the U.S. Federal OSHA Respiratory Protection Standard (29 CFR 1910.134), equivalent U.S. State standards, Canadian CSA Standard Z94.4-93, the European Standard EN149, or EU member states.

EYE PROTECTION: Safety glasses or chemical goggles as appropriate to prevent eye contact. If necessary, refer to U.S. OSHA 29 CFR 1910.133 or appropriate Canadian Standards.

HAND PROTECTION: Use chemical resistant gloves to prevent skin contact. If necessary, refer to U.S. OSHA 29 CFR 1910.138 or appropriate Standards of Canada.

BODY PROTECTION: Use body protection appropriate to prevent contact (e.g. lab coat, overalls). If necessary, refer to appropriate Standards of Canada, or appropriate Standards of the EU, Australian Standards, or relevant Japanese Standards.

SECTION 9 - PHYSICAL and CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties:

PHYSICAL STATE:	Solid (Granules)
APPEARANCE:	White to off-white powder or granules
ODOR:	Odorless
ODOR THRESHOLD (PPM):	Not Available
pH:	6-8 (aqueous solution)
MELTING / FREEZING POINT (C°):	Not Available
BOILING POINT (C°):	Not Available
FLASH POINT:	Not Available
EVAPORATION RATE (nBuAc = 1):	Not Available
FLAMMABILITY (solid, gas):	Not Available
FLAMMABLE LIMITS (in air by volume, %):	Not Available
VAPOR PRESSURE (mmHg):	Not Available
VAPOR DENSITY (AIR=1):	Not Available
RELATIVE DENSITY	2.4 to 2.6 g/cm3, depending on formulation
SOLUBILITY IN WATER (%)	Soluble
PARTITION COEFFICIENT: N-OCTANOL/WATER:	Not Available
AUTOIGNITION TEMPERATURE:	Not Available
DECOMPOSITION TEMPERATURE:	Not Available
VISCOSITY:	Not Available
EXPLOSIVE PROPERTIES:	Not Available
OXIDISING PROPERTIES:	Not Available

9.2 Other Information:

PACKING DENSITY:	Not Available
VOC:	Not Available

SECTION 10 - STABILITY and REACTIVITY

10.1 Reactivity: See section 10.5.
10.2 Chemical Stability: Product is stable.
10.3 Possibility of Hazardous Reactions: Under normal conditions of storage and use, hazardous reactions will not occur.
10.4 Conditions to avoid: Contact with incompatibles, exposure to light, and moist air.
10.5 Incompatible materials: Strong oxidizing agents, bases.
10.6 Hazardous Decomposition Products: Carbon monoxide, carbon dioxide, nitrogen oxides, sulfur oxides, potassium oxides.

SECTION 11 - TOXICOLOGICAL INFORMATION

11.1 Information on Toxicological Effects:

TOXICITY DATA:

L-Cysteine CAS# 52-90-4

Oral LD50 1890 mg/kg Rat

Oral LD50 660 mg/kg Mouse

11.1.2 Mixtures:

Acute toxicity	Acute Toxicity Category 5 (Oral)
Skin corrosion / irritation	Based on available data, the classification criteria are not met
Serious eye damage / irritation	Based on available data, the classification criteria are not met
Respiratory or skin sensitization	Based on available data, the classification criteria are not met
Germ cell mutagenicity	Based on available data, the classification criteria are not met
Carcinogenicity	Based on available data, the classification criteria are not met
Reproductive toxicity	Based on available data, the classification criteria are not met
STOT-single exposure	Based on available data, the classification criteria are not met
STOT-repeated exposure	Based on available data, the classification criteria are not met
Aspiration hazard	Based on available data, the classification criteria are not met

Other Information

POTENTIAL HEALTH HAZARDS OR RISKS FROM EXPOSURE:

ACUTE:

EYE CONTACT: Eye exposure may produce irritation.
SKIN CONTACT: Prolonged or repeated skin exposure may cause irritation.
INHALATION HAZARDS: Inhalation of dusts may cause irritation.
INGESTION HAZARDS: May be harmful if swallowed. May cause gastrointestinal tract irritation.

CHRONIC: None Known

TARGET ORGANS: ACUTE: Organs CHRONIC: None Known

CARCINOGENICITY: None of the ingredients are found on the following lists: FEDERAL OSHA Z LIST, NTP, CAL/OSHA, IARC and therefore are not considered to be, nor suspected to be a cancer-causing agent by these agencies.

IRRITANCY OF PRODUCT: Contact with this product can be irritating to skin and eyes.

SENSITIZATION OF PRODUCT: This product is not considered a skin sensitizer.

REPRODUCTIVE TOXICITY INFORMATION: No information concerning the effects of this product and its components on the human reproductive system.

MUTAGENICITY INFORMATION: This product does not contain a component that is suspected to be a mutagenicity hazard.

SPECIFIC TARGET ORGAN TOXICITY – SINGLE EXPOSURE: Data not sufficient for classification.

SPECIFIC TARGET ORGAN TOXICITY – REPEATED EXPOSURE: Data not sufficient for classification.

ASPIRATION HAZARD: Not applicable

SECTION 12 - ECOLOGICAL INFORMATION

ALL WORK PRACTICES MUST BE AIMED AT ELIMINATING ENVIRONMENTAL CONTAMINATION.

12.1 Toxicity:

No specific data available on this product.

12.2 Persistence and Degradability:

No specific data available on this product.

12.3 Bioaccumulative Potential:

No specific data available on this product.

12.4 Mobility in Soil:

No specific data available on this product.

12.5 Results of PBT and vPvB Assessment:

No specific data available on this product.

12.6 Other Adverse Effects:

No specific data available on this product.

12.7 Water Endangerment Class:

Not believed to be water endangering in accordance with EU Guideline 91/155-EWG. At present there are no ecotoxicological assessments for this product.

SECTION 13 - DISPOSAL CONSIDERATIONS

13.1 Waste Treatment Methods:
Waste disposal must be in accordance with appropriate Federal, State, and local regulations, those of Canada, Australia, EU Member States and Japan.

SECTION 14 - TRANSPORTATION INFORMATION

14.1 Transport Information:

US DOT; IATA; IMO; ADR:

THIS PRODUCT IS NOT CLASSIFIED AS DANGEROUS GOODS AS DEFINED BY 49 CFR 172.101 BY THE U.S. DEPARTMENT OF TRANSPORTATION.

PROPER SHIPPING NAME: None

HAZARD CLASS NUMBER and DESCRIPTION: Not Regulated

UN IDENTIFICATION NUMBER: None

PACKING GROUP: None

DOT LABEL(S) REQUIRED: None

NORTH AMERICAN EMERGENCY RESPONSE GUIDEBOOK NUMBER (2016): None

MARINE POLLUTANT: This product does not contain ingredients that are classified by the DOT as a Marine Pollutant (as defined by 49 CFR 172.101, Appendix B)

TRANSPORT CANADA, TRANSPORTATION OF DANGEROUS GOODS REGULATIONS:

This product is not classified as Dangerous Goods, per regulations of Transport Canada

INTERNATIONAL AIR TRANSPORT ASSOCIATION (IATA):

This product is not classified as Dangerous Goods, by rules of IATA:

INTERNATIONAL MARITIME ORGANIZATION SHIPPING and MARITIME DANGEROUS GOODS CODE SHIPPING INFORMATION (IMO / IMDG):

This product is not classified as Dangerous Goods.

EUROPEAN AGREEMENT CONCERNING THE INTERNATIONAL CARRIAGE OF DANGEROUS GOODS BY ROAD (ADR):

This product is not classified by the United Nations Economic Commission for Europe to be dangerous goods.

SECTION 15 - REGULATORY INFORMATION

15.1 Safety, Health and Environmental Regulations/Legislation Specific for the Substance or Mixture:

UNITED STATES REGULATIONS

SARA REPORTING REQUIREMENTS: This product is not subject to the reporting requirements of Sections 302, 304 and 313 of Title III of the Superfund Amendments and Reauthorization Act., as follows: None

TSCA: All components in this product are listed on the US Toxic Substances Control Act (TSCA) inventory of chemicals.

SARA 311/312:

Acute Health:	No	Chronic Health:	No	Fire:	No	Reactivity:	No

U.S. SARA THRESHOLD PLANNING QUANTITY: There are no specific Threshold Planning Quantities for this product. The default Federal SDS submission and inventory requirement filing threshold of 10,000 lb (4,540 kg) may apply, per 40 CFR 370.20.

U.S. CERCLA REPORTABLE QUANTITY (RQ): None

CALIFORNIA SAFE DRINKING WATER AND TOXIC ENFORCEMENT ACT (PROPOSITION 65): None of the ingredients are on the California Proposition 65 lists.

CANADIAN REGULATIONS:

CANADIAN DSL/NDSL INVENTORY STATUS: All of the components of this product are on the DSL Inventory

CANADIAN ENVIRONMENTAL PROTECTION ACT (CEPA) PRIORITIES SUBSTANCES LISTS: No component of this product is on the CEPA First Priorities Substance Lists.

CANADIAN WHMIS CLASSIFICATION and SYMBOLS: This product is categorized as per WHMIS 2015 Hazardous Product Regulations.

EUROPEAN ECONOMIC COMMUNITY INFORMATION:

EU LABELING AND CLASSIFICATION:

Classification of the mixture according to Regulation (EC) No1272/2008. See section 2 for details**.**

AUSTRALIAN INFORMATION FOR PRODUCT:

AUSTRALIAN INVENTORY OF CHEMICAL SUBSTANCES (AICS) STATUS: Components of this product are listed on the AICS.

STANDARD FOR THE UNIFORM SCHEDULING OF DRUGS AND POISONS: Not applicable.

JAPANESE INFORMATION FOR PRODUCT:

JAPAN INDUSTRIAL SAFETY AND HEALTH LAW: This product has been classified per the Japan Industrial Safety and Health Law. See Section 2 for the GHS Classification.

KOREA ACT ON REGISTRATION AND EVALUATION OF CHEMICAL SUBSTANCES (K-REACH): This product has been classified per K-REACH. See Section 2 for the GHS Classification.

INTERNATIONAL CHEMICAL INVENTORIES:

Listing of the components on individual country Chemical Inventories is as follows:

Asia-Pac:	Listed
Australian Inventory of Chemical Substances (AICS):	Listed
Korean Existing Chemicals List (ECL):	Listed
Japanese Existing National Inventory of Chemical Substances (ENCS):	Listed
Philippines Inventory if Chemicals and Chemical Substances (PICCS):	Listed
Swiss Giftliste List of Toxic Substances:	Listed
U.S. TSCA:	Listed

15.2 Chemical Safety Assessment:

A chemical safety assessment has not been performed on this product.

SECTION 16 - OTHER INFORMATION

HMIS Rating (Scale 0-4)	**NFPA Rating (Scale 0-4)**
Health hazard: 1	Health hazard: 1
Flammability: 0	Flammability: 0
Physical Hazard: 0	Physical Hazard: 0

Caution: HMIS and NFPA ratings are based on a 0-4 rating scale

0= Minimal Hazard
1= Slight
2= Moderate
3= High
4= Extreme

Abbreviations and acronyms

ACGIH	*American Conference of Governmental Industrial Hygienists*
CFR	*Code of Federal Regulations*
DOT	*Federal Department of Transportation*
GHS	*The Globally Harmonized System of Classification and Labelling of Chemicals*
HMIS	*Hazardous Material Identification System*
HCS	*Hazard Communication Standard*
IARC	*International Agency for Research on Cancer*
IATA	*The International Air Transport Association*
ICAO	The *International Civil Aviation Organization*
IMDG	*International Maritime Dangerous Goods*
IMO	*International Maritime Organization*
LD50/LC50	*Lethal Concentration/Dose, 50 percent*
NFPA	*National Fire Protection Association*
NIOSH	*National Institute for Occupational Safety and Health*

NTP	*National Toxicology Program*
OSHA	*Occupational Safety and Health*
PEL	*OSHA Permissible Exposure Limit*
SARA	*Superfund Amendments and Reauthorization Act*
TLV	*ACGIH Threshold Limit Value*
TWA	*Time-Weighted Average*
Acute Tox	*Acute Toxicity*
Skin Corr	*Skin Corrosion*

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MSDS to GHS Compliance

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End of SDS Sheet