Assessment of Corrective Measures TVA Paradise Fossil Plant, Drakesboro, Kentucky

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Prepared for:

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ASSESSMENT OF CORRECTIVE MEASURES TVA PARADISE FOSSIL PLANT, DRAKESBORO, KENTUCKY

This document entitled Assessment of Corrective Measures TVA Paradise Fossil Plant, Drakesboro, Kentucky was prepared by Stantec Consulting Services Inc. ("Stantec") for the account of Tennessee Valley Authority (TVA; the "Client").

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Abbreviations

ACM	Assessment of Corrective Measures
CCR	Coal Combustion Residuals
CFR	Title 40, Code of Federal Regulations
COI	Constituent of interest
CSM	Conceptual Site Model
DOW	Department of Water
EA	Environmental Assessment
EIS	Environmental Impact Statement
EIST	Enhanced In-Situ Treatment
GWPS	Groundwater Protection Standard(s)
HSU	Hydro-stratigraphic unit
KDOW	Kentucky Division of Water
KDWM	Kentucky Department of Waste Management
KY	Kentucky
KYDEP	Kentucky Department for Environmental Protection
mg/L	Milligrams per liter
MNA	Monitored Natural Attenuation
NOI	Notice of Intent
NPDES	National Pollutant Discharge Elimination System
PAF	Paradise Fossil Plant
PRB	Permeable Reactive Barrier
PWB	Process Water Basin
ROD	Record of Decision
SSL	Statistically Significant Level
SSLs	Statistically Significant Levels
TVA	Tennessee Valley Authority
U.S. EPA	United States Environmental Protection Agency
W & S	Water & Sewer

Executive Summary

On April 17, 2015, the United States Environmental Protection Agency (U.S. EPA) published a rule that sets forth national criteria for the management of coal combustion residuals (CCR) produced by electric utilities. The requirements can be found in Title 40, Code of Federal Regulations (CFR) Part 257. The rule includes requirements for monitoring groundwater and assessing corrective measures if constituents listed in Appendix IV of the rule are detected in groundwater samples collected from downgradient monitoring wells at statistically significant levels (SSLs) greater than established groundwater protection standards (GWPS).

In January 2019, the Tennessee Valley Authority (TVA) completed an evaluation of whether there were SSLs over established GWPS as defined in 40 CFR § 257.95(h) for one or more Appendix IV constituents in accordance with 40 CFR § 257.95(g) at the Peabody Ash Pond, Slag Ponds 2A and 2B and Slag Stilling Pond 2C at the Paradise Fossil Plant (PAF). During assessment monitoring, two SSLs for arsenic were reported at monitoring wells PAF-113 and PAF-119. As of the date of this report, TVA has not completed a demonstration that a source other than the CCR units associated with wells PAF-113 and PAF-119 caused the SSLs, as allowed under 40 CFR § 257.95(g)(3)(ii).

In accordance with 40 CFR § 257.96(a), TVA prepared this 2019 Assessment of Corrective Measures (ACM) Report for Slag Ponds 2A and 2B and Slag Stilling Pond 2C (the CCR Multiunit), and the Peabody Ash Pond (the CCR Unit) at the Paradise Fossil Plant (PAF). This ACM Report provides an assessment of the effectiveness of potential corrective measures in achieving the criteria provided in 40 CFR § 257.96(c). The CCR Multiunit is monitored by a CCR Rule multiunit groundwater monitoring well network of three upgradient wells and four downgradient wells. The CCR Unit is monitored by and CCR monitoring well network of four upgradient wells and six downgradient wells.

Three primary strategies have been evaluated to address groundwater exhibiting concentrations of arsenic above the GWPS. These strategies include; Monitored Natural Attenuation (MNA), Hydraulic Containment and Treatment, and Enhanced In-Situ Treatment (EIST).

Following preparation of this ACM Report, the remedy selection process will begin to select a remedy that meets the requirements of 40 CFR § 257.97(b) and § 257.97(c). At least 30 days prior to when the final remedy is selected, a public meeting will be held with interested and affected parties to discuss the results of the corrective measures assessment in accordance with 40 CFR § 257.96(e). Semi-annual reports will be prepared pursuant to 40 CFR § 257.97(a) to document progress toward remedy selection and design. TVA will continue to review new data as it becomes available and implement changes to the groundwater monitoring and corrective action program as necessary to maintain compliance with 40 CFR § 257.90 through § 257.98.

1.0 INTRODUCTION

This Assessment of Corrective Measures (ACM) Report has been prepared to meet the requirements in the United States Environmental Protection Agency (U.S. EPA) Coal Combustion Residuals (CCR) Rule, (40 CFR) § 257.96. During assessment monitoring when at least one constituent listed in Appendix IV of the CCR Rule is detected at a statistically significantly level (SSL) above a site-specific groundwater protection standard (GWPS) established pursuant to 40 CFR § 257.95(h), and the owner/operator has been unable to demonstrate that a source other than the CCR units or an error caused the SSL, the owner/operator must initiate an ACM.

At the Tennessee Valley Authority (TVA) Paradise Fossil Plant (PAF) Slag Ponds 2A, 2B, and Slag Stilling Pond 2C (hereinafter collectively referred to as the CCR Multiunit) and the Peabody Ash Pond (hereinafter referred to as the CCR Unit), groundwater assessment monitoring detected SSLs of arsenic in two monitoring wells (PAF-113 and PAF-119). As a result of these detections, TVA initiated an ACM on April 15, 2019. This report documents the completion of the required ACM and discusses potential corrective measures as required under the CCR Rule. For purposes of this report, any SSL of Appendix IV listed constituents over GWPS will be defined as a constituent of interest (COI).

1.1 OVERVIEW OF CCR RULE REQUIREMENTS FOR ACM IN 40 CFR § 257.96

Section 257.96(a) of the CCR Rule requires that, within 90 days of determining an SSL exceeds a GWPS of an Appendix IV constituent, the owner/operator must initiate an ACM to prevent further releases, to remediate any releases, and to restore the affected area to original conditions. The ACM report must be completed within 90 days of initiating the ACM unless the owner/operator demonstrates that an extension of no longer than 60 days is needed due to site-specific conditions or circumstances. A qualified professional engineer must certify the accuracy of the extension demonstration. The certified demonstration must be included in the annual groundwater monitoring and corrective action report required by 40 CFR § 257.90(e). TVA did not seek an extension for completing the ACM.

The CCR Rule requires that the ACM report under 40 CFR § 257.96(a) must include an analysis of the effectiveness of potential corrective measures in meeting the requirements and objectives of the remedy. More specifically, 40 CFR § 257.96(c) provides that:

The assessment under paragraph (a) of this section must include an analysis of the effectiveness of potential corrective measures in meeting all of the requirements and objectives of the remedy as described under 40 CFR §257.97 addressing at least the following:

(1) The performance, reliability, ease of implementation, and potential impacts of appropriate potential remedies, including; safety impacts, cross-media impacts, and control of exposure to any residual contamination;

(2) The time required to begin and complete the remedy; and

(3) *The institutional requirements such as state and local permit requirements or other environmental or public health requirements that may substantially affect implementation of the remedy(s).*

Potential corrective measures to be considered for the CCR units are generally discussed in Section 4.0, **Appendix A**, and **Appendix B** of this report.

1.2 OVERVIEW OF CCR RULE REQUIREMENTS FOR REMEDY SELECTION IN 40 CFR § 257.97

Once the ACM report is complete, the process for selecting a remedy will commence. The owner/operator must select a remedy that, at a minimum, meets the requirements of 40 CFR § 257.97(b) and must consider the evaluation factors set forth in 40 CFR § 257.97(c). In addition, at least 30 days prior to the selection of the remedy, the owner/operator must discuss the results of the corrective measures assessment in a public meeting required by 40 CFR § 257.96(e). The owner/operator must also provide a schedule for implementing the selected remedy that takes into account the factors set forth in 40 CFR § 257.97(d).

After the ACM report is completed and before the remedy is selected, 40 CFR § 257.97(a) requires semi-annual reports to be prepared describing the progress in selecting and designing the remedy. The CCR Rule contemplates that more investigation and consideration may be needed to evaluate and design the remedy before making the final selection. Once a final remedy is chosen, a final report describing the remedy and how it meets the standards set forth in 40 CFR § 257.97(b) will be prepared.

2.0 BACKGROUND

PAF is located in Drakesboro, Muhlenberg County, Kentucky. The facility is located on the western bank of the Green River. **Figure 2-1** shows an overview map of PAF including its facilities and CCR units. PAF was constructed between 1959 and 1970 and began operations in the 1970s.

2.1 CCR UNIT DESCRIPTIONS

The following is a description of two CCR units at PAF, both CCR units are active CCR disposal impoundments at PAF.

The Peabody Ash Pond is located along the southern edge of the PAF property. This unit is an unlined CCR surface impoundment that encompasses approximately 138 acres. The Peabody Ash Pond was put into service in 1997 and serves as a management facility for the storage and settling of fly ash. Under normal operating conditions, the water surface elevation of the Peabody Ash Pond is 405 feet (AECOM, 2016b). Influent to this impoundment has consisted of sluiced fly ash which flowed into the southwest portion of the impoundment via a ditch to the west. The sluicing of fly ash has ceased in accordance with NPDES permit schedule of compliance. The Peabody Ash Pond also receives decant water flows from the Gypsum Disposal Area Stilling Ponds 1 and 2 and other non-CCR waste waters (AECOM, 2016a). The Peabody Ash Pond provides wastewater treatment and CCR management. Effluent from the stilling impoundment is discharged into Jacobs Creek through permitted KPDES Outfall 001 (AECOM, 2018a). The Peabody Ash Pond is subject to the CCR Rule.

The Slag Pond CCR Multiunit is located in the north eastern area of the PAF property boundary along the Green River. Slag Ponds 2A and 2B are unlined CCR surface impoundments. Slag Pond 2A has a wetted surface area of approximately 16.5 acres and Slag Pond 2B has a wetted surface area of approximately 11.5 acres (AECOM, 2018b).. Slag Ponds 2A and 2B and Slag Stilling Pond 2C serve as an ash pond management facility for the storage and settling of boiler slag. Under normal operating conditions, Slag Pond 2A has a normal water surface elevation of 412.09 feet and Slag Pond 2B has a normal water surface elevation of 411.62 feet (AECOM, 2016d). Influent to this impoundment consists of sluiced boiler slag, which flows into the southeastern portion of Slag Pond 2A via a series of ash inlets. Slag Ponds 2A and 2B also receive process water from many areas surrounding the ponds such as from the Coal Yard Runoff Ponds. Water flows from Slag Pond 2A to Slag Pond 2B to Slag Stilling Pond 2C which discharges to the Green River via permitted Outfall 002 (AECOM, 2018c). Slag Ponds 2A and 2B and Slag Stilling Pond 2C are subject to the CCR Rule.

2.2 OVERVIEW OF OCTOBER 2016 CLOSURE PLAN

TVA began its evaluation of closure options under EPA's CCR rule by developing a programmatic *Ash Impoundment Closure Environmental Impact Statement* (EIS) to address potential environmental risks associated with CCR impoundments. The EIS is divided into two parts – Part 1 is the programmatic analysis that is generally applicable to TVA CCR impoundments, and Part 2 includes an analysis of 10-

site specific ash impoundment closures. The CCR Units discussed in this ACM were not included as part of the site specific analysis; however, the programmatic EIS was designed so that a later study of the closure methodology for Ash Pond 2 could tier off of the programmatic EIS. There were multiple opportunities for the public to comment during this review process.

The final EIS was posted on June 10, 2016 through July 9, and the Final Record of Decision (ROD) was published on July 28, 2016. Through a site-specific environmental assessment (EA) and a supplemental EA, TVA informed decision makers, regulators and the public about the environmental consequences of closing the Peabody Ash Pond and the Slag Ponds. As a result of the environmental reviews, Slag Ponds 2A and 2B will be closed in place and CCR volume will be recovered from Slag Stilling Pond 2C so that it can be repurposed and used for stormwater discharges. Peabody Ash Pond will be closed in place in a reduced footprint.

2.3 CONCEPTUAL SITE MODEL SUMMARY

The geologic and hydrogeologic conceptual site model (CSM) is one of the primary tools that can be used to support decisions on corrective measures.

2.3.1 Geology and Hydrogeology

The subsurface geology at PAF is characterized by three hydro-stratigraphic units (HSUs) and the following sections provide a summary of the geologic and hydrogeologic CSM to provide context for the ACM. An HSU is defined as “a body of rock distinguished and characterized by its porosity and permeability” (Seaber, 1988). The HSUs relevant to this report are Mine Soils/ Fill, Alluvium/Residuum (Clay), and Carbondale Formation/Sturgis Formation. A generalized cross-section showing the primary lithologic features is presented on **Figure 2-2**.

2.3.1.1 Mine Spoils/Fill

Due to surface mining for coal, a large portion of PAF is covered by mine spoils. **Figure 2-3** shows the extent of surface mining at PAF. Mine spoils/fill is the uppermost layer at PAF and consists of sandy, silty, gravelly clay, mixed with coal. The surface mine spoils can be up to 100 feet in thickness and contain large rock fragments and the surface mine spoil distribution is variable at PAF.

2.3.1.2 Alluvium/Residuum

The Alluvium is formed from river deposits and is found in the floodplains of large streams or rivers. The alluvium is described as consisting of sands, silts, and clays. The alluvium deposits are limited to the floodplain of the Green River. The residuum is formed from the weathering of the underlying bedrock. It can be composed of silt, clay, and sand, usually with rock fragments (Kentucky Geological Survey, 2019). The alluvium/residuum layer lies between the mine spoils/fill layer and the Carbondale Formation. Residuum may have historically been present over a larger area, but much of the unconsolidated deposits and part of the Carbondale Formation have been removed by surface mining.

2.3.1.3 Carbondale Formation

Geologic mapping indicates that PAF and the surrounding areas are underlain by the Sturgis and Carbondale Formations. The Carbondale Formation sequence consists of alternating layers of sandstone, siltstone, coal, silty shale, and limestone, and is between 295 to 410 feet in thickness.

2.3.2 Groundwater Flow Direction

The predominant groundwater flow direction at PAF is east toward the Green River and its tributary, Jacobs Creek. **Figure 2-4** presents the groundwater flow direction at PAF that was developed from sampling data obtained during the November 28, 2016 sampling event.

2.3.3 Potential Receptor Review

The existing potable water supply near PAF is primarily surface water obtained through the Muhlenberg Co. Water District. The Muhlenberg Co. Water District obtains water from the Central City Water and Sewer (W & S) System which withdraws its water from the Green River.

Although the exact locations from which the Central City W & S System withdrawals water from the Green River were not located, **Figure 2-5** presents a map identifying Kentucky Department of Water (DOW) permitted surface water withdrawal locations near PAF. All of the DOW Permitted Water Withdrawals identified on **Figure 2-5** have a use classification of either industrial or mining.

3.0 GROUNDWATER ASSESSMENT MONITORING PROGRAM

Groundwater assessment monitoring has been conducted at PAF in accordance with 40 CFR § 257.95. This section of the report summarizes the results of the groundwater assessment monitoring program.

3.1 GROUNDWATER MONITORING NETWORK

In compliance with 40 CFR § 257.91, groundwater monitoring networks were certified for both the CCR Unit and CCR Multiunit. The CCR Unit uses background wells 10-5, 95-48A, PAF-105, and PAF-106 and downgradient wells 10-4, 10-6, PAF-107, PAF-117, PAF-118, and PAF-119. The CCR Multiunit uses background wells 95-48A, PAF-108, and PAF-109 and downgradient wells 95-47C, PAF-110, PAF-112, and PAF-113. The location of CCR units, background wells, and downgradient wells are presented on **Figure 2-1**.

3.2 GROUNDWATER ASSESSMENT

Groundwater assessment monitoring was conducted during 2018. This section provides a summary of the assessment monitoring results with a focus on those constituents that exhibited SSLs above the GWPS. The results of the assessment monitoring are summarized below:

CCR Unit

- An SSL for arsenic was identified at monitoring well PAF-119;
    - The maximum concentration of arsenic detected in 2018 was 0.101 milligrams per liter (mg/L); and
    - The GWPS for arsenic is 0.013 mg/L.

CCR Multiunit

- An SSL for arsenic was identified at monitoring well PAF-113;
    - The maximum concentration of arsenic detected in 2018 was 0.092 milligrams per liter (mg/L); and
    - The GWPS for arsenic is 0.013 mg/L.

3.3 GROUNDWATER CHARACTERIZATION

CCR Unit

Assessment monitoring of the CCR Unit identified an SSL for arsenic in monitoring well PAF-119. Groundwater data obtained from monitoring wells proximal to monitoring well PAF-119 were used as the basis to initially characterize the horizontal and vertical extents of arsenic in groundwater. Data from both

CCR and non-CCR monitoring wells were considered in this initial characterization. The horizontal extent of arsenic concentrations above the SSL observed at PAF-119 are defined to the west by PAF-105 and to the east by 10-6. The potential treatment zone to address the extent of arsenic along the unit perimeter above GWPS is illustrated on **Figure 3-1**.

CCR Multiunit

Assessment monitoring of the CCR Multiunit identified an SSL for arsenic in monitoring well PAF-113. Groundwater data obtained from monitoring wells proximal to monitoring well PAF-113 were used as the basis to initially characterize the horizontal and vertical extents of arsenic in groundwater. Data from both CCR and Non-CCR monitoring wells were considered in this initial characterization. The horizontal extent of arsenic concentrations above the SSL observed at PAF-113 are defined to the southeast by 95-47C and to the northwest by PAF-112. The potential treatment zone to address the extent of arsenic along the unit perimeter above GWPS is illustrated on **Figure 3-1**.

Supplemental site characterization will be conducted to further refine the characterization of the nature and extent of arsenic above the GWPS to support the design and selection of a remedy for both the CCR Multiunit and the CCR Unit. Specifically, supplemental characterization may include the following:

- Installation of additional monitoring wells as needed to refine definition of the extent of Appendix IV constituents greater than the GWPS;
- Supplemental investigation will further inform understanding of the nature and estimated quantity of material released including concentrations of Appendix IV constituents in the material released; and
- Sampling of any wells installed for purpose of evaluating and designing a remedy.

3.4 SUMMARY OF ALTERNATE SOURCE DEMONSTRATION

At this time, an alternate source demonstration has not been completed at PAF for the arsenic SSL detections over GWPS for the CCR Unit and CCR Multiunit.

4.0 ASSESSMENT OF CORRECTIVE MEASURES

Section 257.96(a) of the CCR Rule requires that, within 90 days of determining an SSL exceeding a GWPS of an Appendix IV constituent, the owner/operator must initiate an ACM to prevent further releases, to remediate any releases, and to restore the affected area to original conditions.

Groundwater assessment monitoring conducted for the CCR Unit and CCR Multiunit has determined that arsenic was present at an SSL above the GWPS as defined in 40 CFR § 257.95(h) at monitoring wells PAF-113 and PAF-119. As discussed in Section 3.3, additional groundwater characterization will be conducted during the remedy selection and design process.

This section of the report provides an ACM to address groundwater exhibiting arsenic above the GWPS.

4.1 ANALYSIS OF CORRECTIVE MEASURES

The objective of the ACM is defined in 40 CFR § 257.96(a) and consists preventing further releases, remediating any releases, and restoring the affected area to original conditions. An assessment of corrective measures to address Appendix IV SSLs has been initiated in accordance with 40 CFR § 257.96 (a), and an analysis of potential corrective measures is being conducted in accordance with 40 CFR § 257.96(c).

4.2 PLAN FOR CLOSING CCR UNITS

The objectives of corrective measures under 40 CFR § 257.96(a) are to “prevent further releases [from the CCR Unit], to remediate any releases, and to restore affected areas to original conditions. Ultimately, in accordance with 40 CFR § 257.97(b)(3), the selected corrective measure must at a minimum “[c]ontrol the source(s) of releases so as to reduce or eliminate, to the maximum extent feasible, further releases of constituents of Appendix IV to this part into the environment.” The Preamble (80 Fed. Reg. 21302, 21406) to the CCR Rule discusses that source control measures may include modifying operational procedures.

To achieve TVA’s commitment to comply with CCR Rule and other regulatory requirements, TVA will close both the CCR Unit and CCR Multiunit at PAF in the future, and closure regardless of the method selected will control the source. Stopping flows to ponds and dewatering the ponds will lead to further control of the source and prevention of releases.

CCR Unit

Current closure plans anticipate capping and closing in place the CCR Unit in accordance with 40 CFR § 257.102. Closure of the CCR Unit will control the source and prevent releases to the groundwater. Capping the CCR Unit will limit water infiltration through the CCR and will reduce releases since rainwater will not come into contact with the CCR.

CCR Multiunit

Current closure plans anticipate capping and closing in place Slag Ponds 2A and 2B and recovering CCR volume from Stilling Pond 2C in accordance with 40 CFR § 257.102. Closure of the CCR Multiunit will control the source and prevent releases to the groundwater. Capping the CCR Multiunit will limit water infiltration through the CCR and will reduce releases since rainwater will not come into contact with the CCR.

Since closure of the CCR Unit and CCR Multiunit will serve as a source control measure, the remedial technologies considered in the following sections are focused on addressing the area of groundwater exhibiting arsenic at concentrations above the GWPS. Furthermore, the process for selecting a remedy includes continued evaluation of groundwater monitoring data that will be collected after closure of the CCR Multiunit. These data findings will inform decision making related to timing, scope, and necessity of both potential interim actions, if necessary, and the selection of a groundwater remedy.

Annual reports will be generated pursuant to 40 CFR § 257.90(e) to summarize the results of the groundwater assessment monitoring and semi-annual reports will be prepared pursuant to 40 CFR § 257.97(a) to document progress toward remedy selection and design. Interim groundwater corrective measures will be considered if the results of the groundwater assessment monitoring indicate that off-site receptors could be impacted by the release of arsenic from the CCR Unit and CCR Multiunit.

4.3 POTENTIAL REMEDIAL TECHNOLOGIES

This ACM provides an evaluation of potential remedial technologies to address the SSL observed at monitoring wells PAF-113 and PAF-119. As discussed in Section 4.2, closure of the CCR units will serve as the primary source control measure. In addition to this source control measure, three primary strategies have been evaluated to address groundwater exhibiting concentrations above the GWPS including the following:

- Monitored Natural Attenuation (MNA);
- Hydraulic Containment and Treatment; and
- Enhanced In-Situ Treatment (EIST).

Appendix A provides a detailed summary of each of these corrective measures.

The hydraulic containment and treatment and the EIST corrective measure both require treatment of groundwater (either in-situ or ex-situ).

4.4 EFFECTIVENESS OF PROPOSED CORRECTIVE MEASURES

The effectiveness of each corrective measure discussed in Section 4.3 was analyzed in accordance with 40 CFR § 257.96(c). A qualitative approach was used to compare the effectiveness of the proposed corrective measures. The following qualitative scoring system was used:

- *Performance, Reliability, and Ease of Implementation*: These criteria were scored as High, Medium or Low. A High ranking indicates a corrective measure performs comparatively well in that evaluation category;
- *Potential Impacts of Potential Remedies to Safety, Cross Media Impacts, and Exposure to residual COIs*: These criteria were scored as Low Risk, Medium Risk, or High Risk. A Low Risk ranking indicates a corrective measure performs comparatively well in that evaluation category.
- *The Time Required to Begin and Completed the Remedy*: An estimate of the time frame required to begin and complete the remedy is discussed in **Appendix B**; and
- *Institutional Requirements:* State and local permit requirements and other public health requirements that may substantially affect implementation of the remedy are also discussed in **Appendix B**.

The results of the qualitative evaluation of corrective measures completed for the CCR Unit and CCR Multiunit are presented in **Appendix B** and **Table B-1**.

5.0 SELECTION OF GROUNDWATER REMEDIAL ACTION

A remedy to address SSLs in groundwater will be selected in accordance with 40 CFR § 257.97. This section of the report summarizes additional information that will be obtained and reviewed prior to selection of a groundwater remedy.

5.1 DATA REQUIREMENTS FOR DESIGN OF GROUNDWATER REMEDIAL ACTION

The groundwater remedy selection process will include the collection of supplemental data to fill data gaps. In addition, groundwater modeling, as appropriate will also be conducted to further evaluate the applicability of groundwater containment and treatment alternatives. The following discussion provides an overview of additional data collection and analysis to be conducted to support remedy selection.

The extent of arsenic concentrations above the GWPS has been initially characterized in accordance with 40 CFR § 257.95(g)(1) and will be further refined as additional data is obtained. The results of will assist in the selection of a groundwater remedy in accordance with 40 CFR § 257.97(b) and 257.97(c).

Groundwater assessment monitoring will be conducted in accordance with 40 CFR § 257.96(b) until the remedy is selected and the corrective action groundwater monitoring program is initiated under 40 CFR § 257.98(a)(1). Continued assessment monitoring will generate data to evaluate groundwater concentrations and trends. These data will inform evaluation of the effectiveness of source control measures in controlling the source and preventing further releases. The scope and necessity of additional groundwater remedies and potential interim actions will be determined based upon analysis of data collected as part of the groundwater assessment monitoring program and supplemental activities.

Groundwater modeling, as appropriate, will be conducted to support the basis of design for any potential remedy that involves groundwater containment and treatment. A groundwater model will be developed to define basis of design requirements for potential groundwater remedies. The basis of design parameters defined through groundwater modeling, as appropriate, can include:

- Groundwater flow velocities and flow direction;
- Groundwater extraction rates for containment remedies;
- Groundwater mounding potential resultant from installation of EIST;
- Changes in groundwater flow directions resulting from EIST installation;
- Lengths of EIST to contain release; and
- Estimated time frame to reduce concentrations of arsenic to levels necessary to achieve GWPS.

Groundwater modeling can also be useful for estimating the time frame for restoring groundwater to concentration levels less than the GWPS.

As shown in **Table 1**, treatment technologies that are effective for arsenic can include:

- Advanced Filtration;
- Chemical Precipitation;
- Co-Precipitation;
- Redox Manipulation – Oxidation/Reduction Treatment;
- Absorption (Chemical Fixation); and
- Ion Exchange.

The groundwater chemistry is site-specific and therefore bench-scale treatability testing can be used to identify the best methodology to address arsenic at PAF. Bench-scale treatability studies may be conducted on representative groundwater samples prior to selecting a groundwater corrective measure for implementation.

5.2 SEMI-ANNUAL REPORTING, PUBLIC MEETING, REMEDY SELECTION, AND FINAL REPORT

Following completion of this ACM, the owner/operator must select a remedy as soon as feasible to comply with 40 CFR § 257.97(a). Progress toward the selection and design of the remedy will be documented in semi-annual reports in accordance with 40 CFR § 257.97(a).

At least 30-days prior to selecting a remedy, a public meeting to discuss the results of the corrective measures assessment will be conducted as required by 40 CFR § 257.96(e).

A final report will be generated after the remedy is selected. This final report will describe the remedy and how it meets the standards specified in 40 CFR § 257.97(b) and 257.97(c).

Recordkeeping requirements specified in 40 CFR § 257.105(h), notification requirements specified in 40 CFR § 257.106(h), and internet requirements specified in 40 CFR § 257.107(h) will be complied with as required by 40 CFR § 257.96(f).

6.0 REFERENCES

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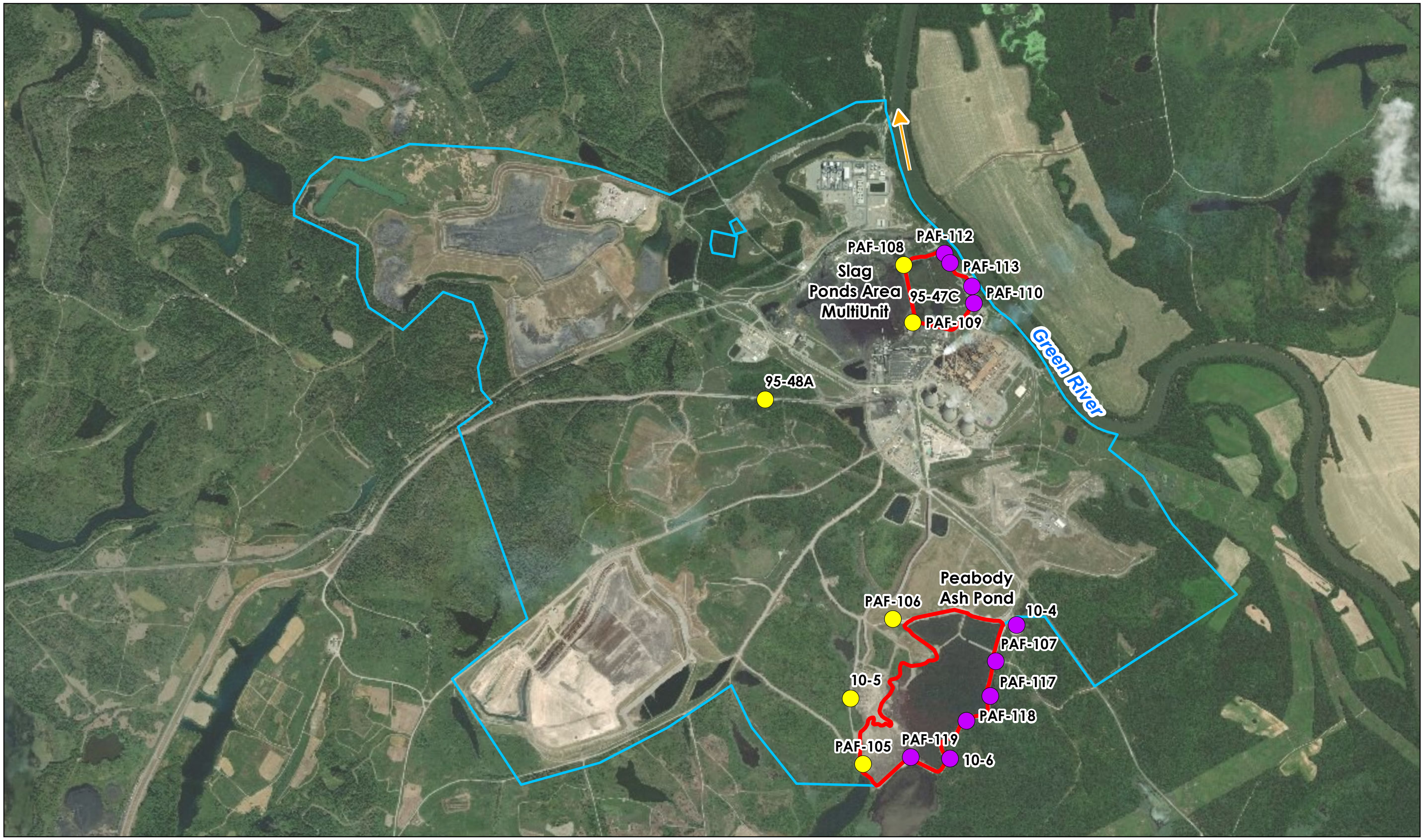
TABLES

TABLE 1.	
WATER TREATMENT TECHNOLOGIES FOR CONSTITUENTS TENNESSEE VALLEY AUTHORITY - PARADISE FOSSIL PLANT CCR UNIT	
Water Treatment Technology	**COI***
	Arsenic
Advanced Filtration	X
Chemical Precipitation	X
Co-Precipitation	X
Redox Manipulation	X
Absorption (Chemical Fixation)	X
Ion Exchange	X

*Constituent of Interest

Figures



- Downgradient Well
- Background or Upgradient Well
- CCR Unit Subject to CCR Rule Under § 257.96
- TVA Property Boundary

N

0 1,500 3,000 Feet

(At original document size of 8.5x11)
1:36,000

Notes
1. Coordinate System: NAD 1983 StatePlane Kentucky South FIPS 1602 Feet
2. Background: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Project Location
Drakesboro
Muhlenberg County, KY

Prepared by LMB on 2019-07-10
Technical Review by EP on 2019-07-10
Independent Review by JB on 2019-07-10

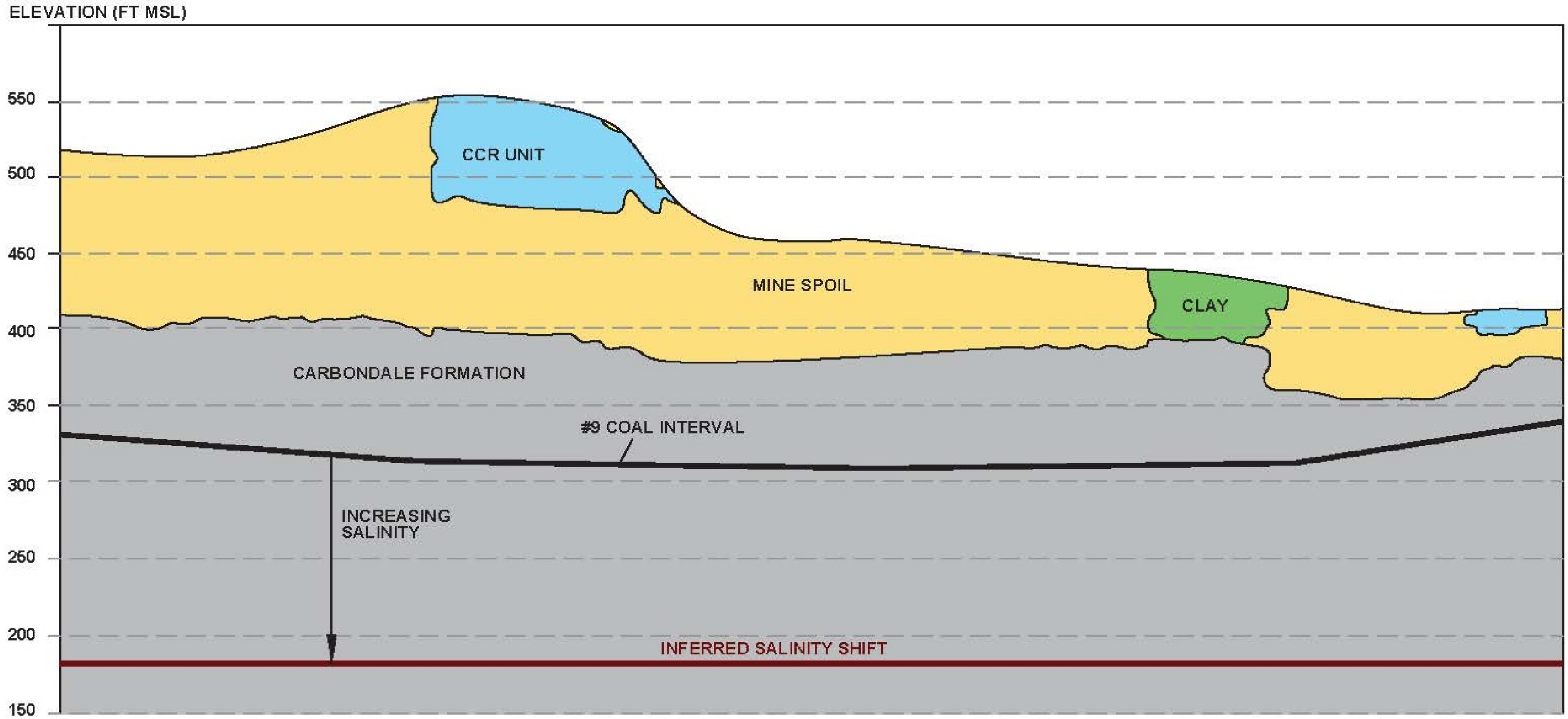
Client/Project
Tennessee Valley Authority
Paradise Fossil Plant
CCR Rule

182603473

Figure No.
Figure 2-1

Title
CCR Units with Background and Downgradient Wells

U:\TVA-ACM\PAF\gis\mxd\TVA_ACM_PAF_Figure2-1.mxd Revised: 2019-07-11 By: LBlackman



Project Location
Drakesboro
Muhlenberg County, KY

Prepared by LMB on 2019-07-11
Technical Review by EP on 2019-07-11
Independent Review by JB on 2019-07-11

Client/Project
182603473
Tennessee Valley Authority
Paradise Fossil Plant
CCR Rule

Figure No.
Figure 2-2

Title
Geologic Cross-Section

CCR Unit Subject to CCR Rule Under § 257.96

TVA Property Boundary

Strip Mining Extent

N

0 1,500 3,000 Feet

(At original document size of 8.5x11)
1:36,000

Notes

1. Coordinate System: NAD 1983 StatePlane Kentucky South FIPS 1602 Feet

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

Project Location
Drakesboro
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Prepared by LMB on 2019-07-11
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Independent Review by JB on 2019-07-11

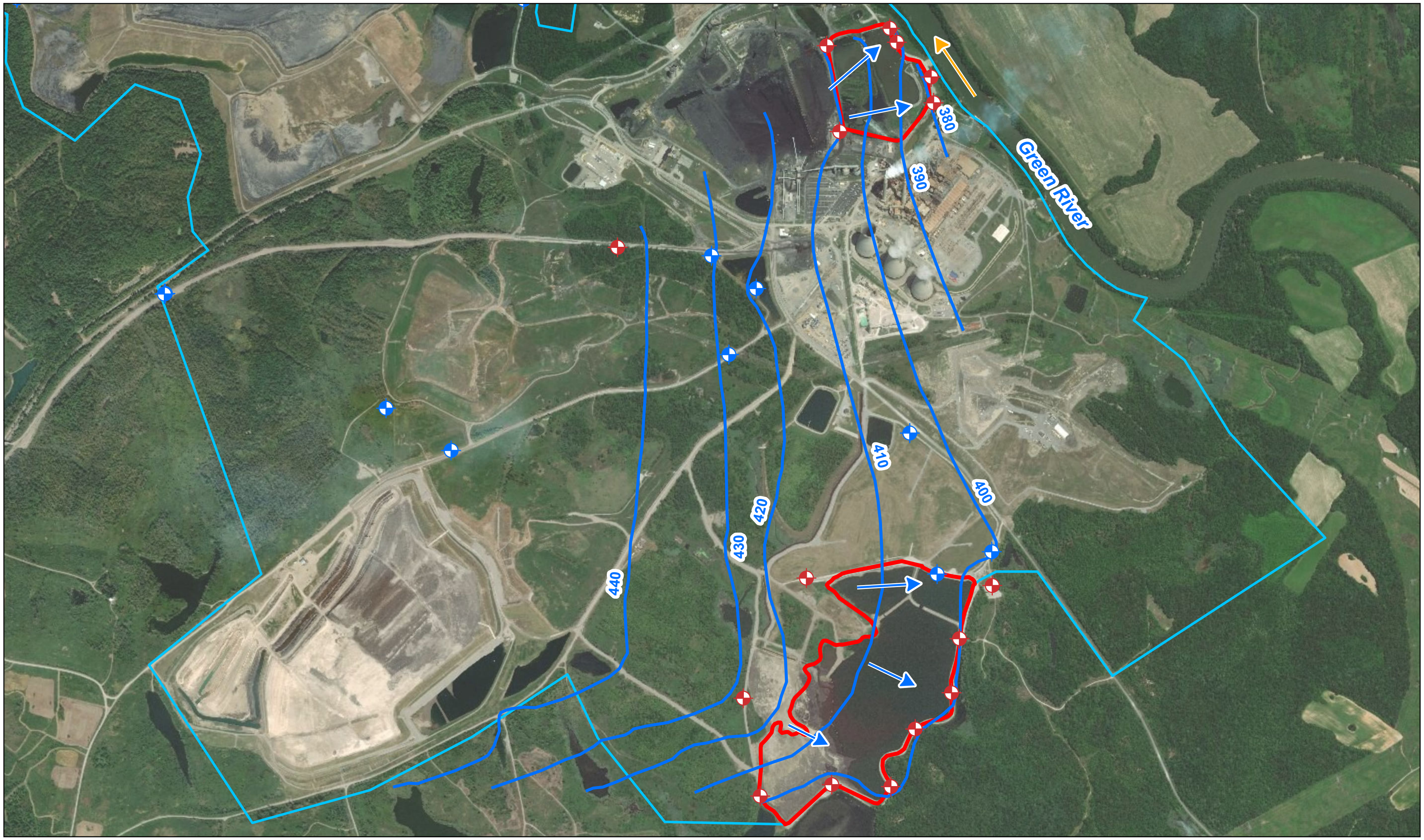
Client/Project
Tennessee Valley Authority
Paradise Fossil Plant
CCR Rule

182603473

Figure No.
Figure 2-3

Title
Surface Mine Map

U:\TVA-ACM\PAF\gis\mxd\TVA_ACM_PAF_Figure2-3.mxd Revised: 2019-07-11 By: LBlackman



CCR Compliance Well

CCR Observation Well

Groundwater Flow Direction

Groundwater Contour November 28, 2016 sampling event

CCR Unit Subject to CCR Rule Under § 257.96

TVA Property Boundary

N

0 1,000 2,000 Feet

(At original document size of 8.5x11)
1:24,000

Notes

1. Coordinate System: NAD 1983 StatePlane Kentucky South FIPS 1602 Feet

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

TVA

Project Location
Drakesboro
Muhlenberg County, KY

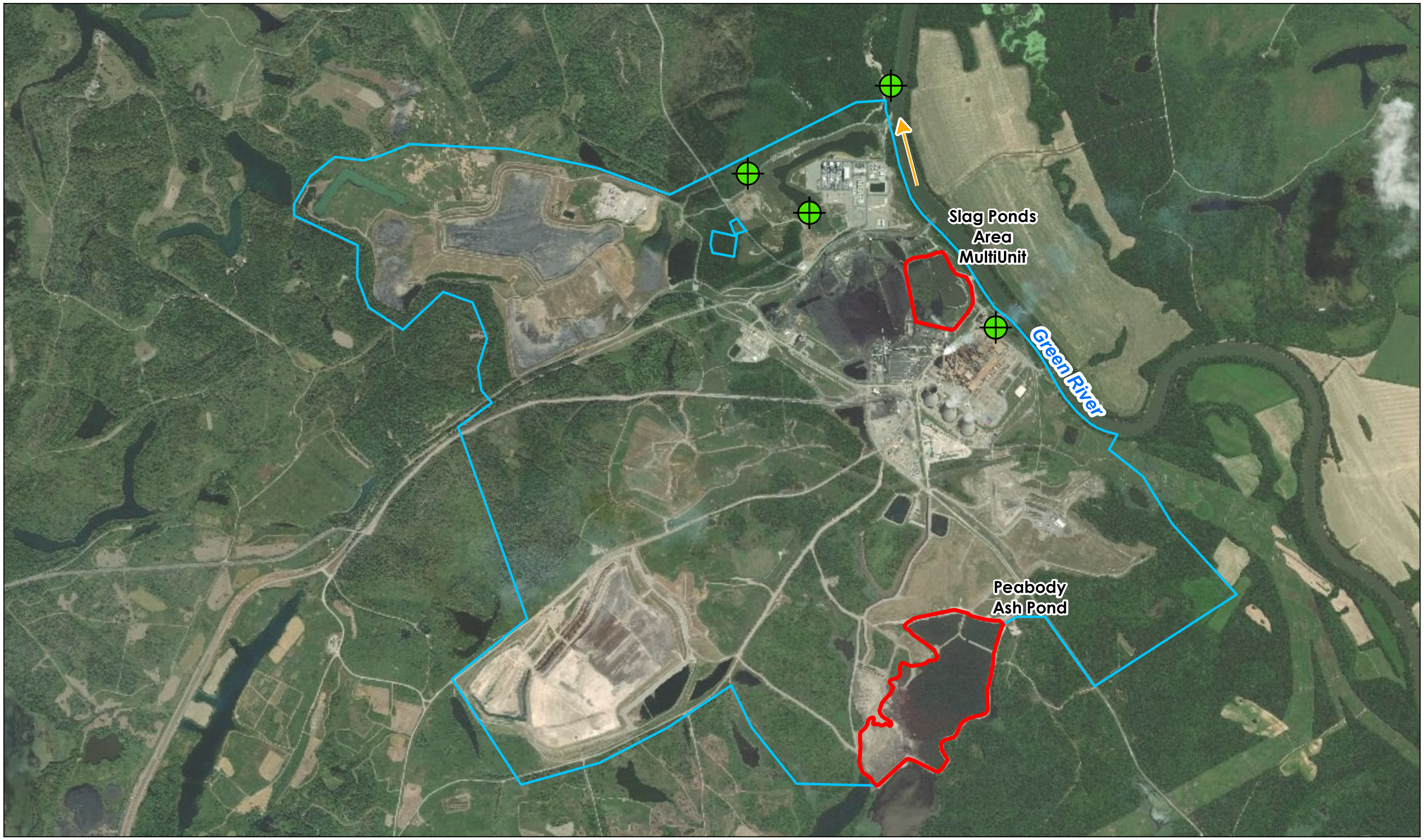
Prepared by LMB on 2019-07-11
Technical Review by EP on 2019-07-11
Independent Review by JB on 2019-07-11

Client/Project
182603473
Tennessee Valley Authority
Paradise Fossil Plant
CCR Rule

Figure No.
Figure 2-4

Title
Groundwater Flow Direction

U:\TVA-ACM\PAF\gis\mxd\TVA_ACM_PAF_Figure2-4.mxd Revised: 2019-07-11 By: LBlackman



DOW Permitted Withdrawals

CCR Unit Subject to CCR Rule Under § 257.96

TVA Property Boundary

N

0 1,500 3,000 Feet

(At original document size of 8.5x11)
1:36,000

Notes

1. Coordinate System: NAD 1983 StatePlane Kentucky South FIPS 1602 Feet

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

Project Location
Drakesboro
Muhlenberg County, KY

Prepared by LMB on 2019-07-11
Technical Review by EP on 2019-07-11
Independent Review by JB on 2019-07-11

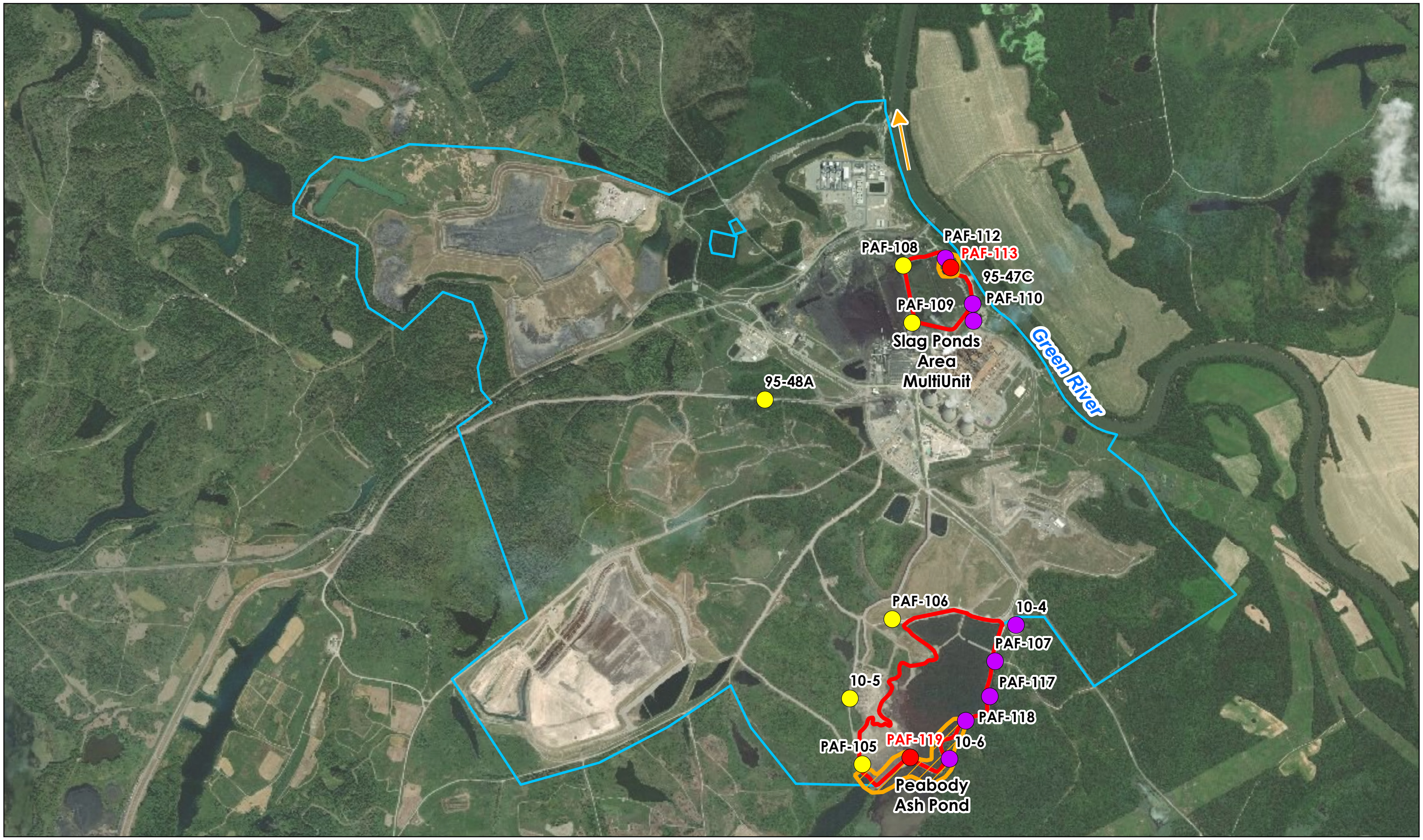
Client/Project
Tennessee Valley Authority
Paradise Fossil Plant
CCR Rule

182603473

Figure No.
Figure 2-5

Title
KY DOW Permitted Withdrawals

U:\TVA-ACM\PAF\gis\mxd\TVA_ACM_PAF_Figure2-5.mxd Revised: 2019-07-11 By: LBlackman



Downgradient Well

Background or Upgradient Well

GWPS Exceedance Well

CCR Unit Subject to CCR Rule Under § 257.96

TVA Property Boundary

Potential Treatment Zones (Arsenic)

N

0 1,500 3,000 Feet

(At original document size of 8.5x11)
1:36,000

Notes

1. Coordinate System: NAD 1983 StatePlane Kentucky South FIPS 1602 Feet

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

TVA

Project Location
Drakesboro
Muhlenberg County, KY

Prepared by LMB on 2019-07-15
Technical Review by EP on 2019-07-15
Independent Review by JB on 2019-07-15

Client/Project
182603473
Tennessee Valley Authority
Paradise Fossil Plant
CCR Rule

Figure No.
Figure 3-1

Title
Monitoring Wells and Limits of COI Impacts

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APPENDIX A

Potential Remedies

1.0 GROUNDWATER CORRECTIVE MEASURES STRATEGIES

Three strategies to address impacted groundwater have been developed to assess corrective measures. Each strategy is detailed in this appendix. For purposes of this report any SSL detections of Appendix IV listed constituents over GWPS will be defined as a constituent of interest (COI).

1.1 MONITORED NATURAL ATTENUATION

Monitored Natural Attenuation (MNA) is a remedial strategy that involves establishing a program to monitor the physical, chemical, or biological processes that currently exist at a site. These processes can often work to reduce the toxicity, concentration, and mobility of site COIs in a time frame that is acceptable and that at times can be comparable to other technologies MNA is increasingly employed at sites where COI concentrations are near threshold levels, do not have an immediate pathway to sensitive receptors, and are not resultant from an on-going source.

MNA implementation would consist of establishing a monitoring and assessment program to determine if the COI concentrations present in the groundwater were being reduced as a result of closure of the CCR Unit and CCR Multiunit. Existing and potentially new monitoring wells at the facility would be used to characterize reduction in COI concentrations over time.

At wells PAF-113 and PAF-119 of the CCR Unit and CCR Multiunit at PAF, there is a statistically significant level (SSL) above the groundwater protection standard (GWPS) for arsenic. Closure of the CCR Unit and CCR Multiunit will commence once CCR discharges cease. The following conditions at PAF make MNA a viable strategy:

- Limited impacts to groundwater: Currently, an SSL above GWPS established under 40 CFR § 257.95(h) for arsenic is observed along isolated portions of the CCR Unit and CCR Multiunit. There are no drinking water supply wells on site, including between the CCR units and the adjacent surface water. A limited extent of impact and no drinking water receptors increase the likelihood that natural systems can attenuate arsenic in an acceptable time frame.
- Naturally-occurring reactions in native soils: Arsenic susceptible to a variety of filtering and oxidation/reduction (redox) reactions that can separate or precipitate dissolved concentrations to remove them from aqueous solution. Arsenic can be present in multiple valance states and their chemical reactivity is affected by groundwater pH, redox potential, the presence of iron and sulfur, and other subsurface variations. The effectiveness of geochemical processes can be evaluated by collecting native soil and groundwater samples and conducting bench-scale testing to evaluate the effectiveness of MNA.

Continued monitoring, in accordance with the groundwater monitoring program, would be necessary to validate that the arsenic concentrations continue to decrease at an acceptable rate.

Reliance on existing systems rather than active treatment may require institutional controls to restrict access to impacted zones. MNA relies upon naturally occurring processes to reduce impact levels and, by itself, does not provide a means to affect change in the subsurface environment. This strategy can be effective, especially when used in combination with unit closure and source control.

1.2 HYDRAULIC CONTAINMENT AND GROUNDWATER TREATMENT

Hydraulic containment is a technology that has been employed for decades to control impacted groundwater. Containment is typically achieved through the use of low-permeability barriers, high-permeability collection galleries, submersible pumps, or a combination of these features. The applicability and orientation of a hydraulic containment system is largely based on site-specific conditions including aquifer dimensions and conductivity, presence of confining layers, depth, gradient, characteristics of the arsenic, and presence of receiving water bodies or wells.

Hydraulic containment systems can be very effective at controlling the migration of constituents in groundwater, particularly when there are sensitive systems nearby or a continuing source of contamination.

Hydraulic containment systems include physical barriers and pumping systems as summarized below:

- Physical Barriers:
    - Slurry Walls: Soil/bentonite slurries placed inside a 3-foot wide trench keyed into an impermeable soil layer (clay) serves as a physical barrier that prohibits the movement of groundwater and contains arsenic migration.
    - Sheet Pile Walls: Steel panels driven through the soil column to key into an impermeable zone serves as a physical barrier that prohibits movement of groundwater and contains arsenic migration.
    - Soil/Bentonite Walls: Dry soil/bentonite mixtures placed inside a 3-foot wide trench keyed into an impermeable soil layer (clay) serves as a physical barrier that prohibits the movement of groundwater and contains arsenic migration.
- Pumping Systems:
    - Vertical Wells: The use of vertical wells is a proven technology that can be used in unconsolidated soils and bedrock. The number of wells, spacing between wells and well depths are a function of aquifer characteristics.
    - Horizontal Wells: The use of horizontal wells potentially allows for the installation of more well screen along a zone of arsenic impacts, in comparison with vertical wells, thus improving the overall efficiency of the extraction system. The use of horizontal wells is not recommended for aquifers where there is large differential between high and low groundwater elevations as it may be difficult to pinpoint the arsenic recovery zone. Deep horizontal wells may not be as practical as vertical wells due to Site-specific conditions.
    - Trenching Systems: Trenches function in a manner similar to horizontal wells but are installed with conventional excavation techniques. The use of trenches is cost-effective when arsenic is present at shallow depths and high groundwater flow rates.

- Phytoremediation: This technique is feasible when arsenic is present at concentrations less than those levels that are toxic to plant life. Trees with deep root zones can extract groundwater containing arsenic above GWPS and assimilate the arsenic within their cell structure. This removes arsenic from the groundwater and can result in obtaining the GWPS in an accelerated time frame. For closed in-place CCR Units, it is important to promote vertical growth of the tree root structure as opposed to lateral growth. Lateral growth of the plant roots can damage the liner system covering the CCR. Damages to the liner system would allow rainwater to come into contact with the CCR which could extend the time required to achieve GWPS.

The basis of design for a hydraulic containment system is typically generated by developing a detailed hydrogeologic CSM and a numerical groundwater model. The CSM serves as the basis for developing a numerical groundwater flow and solute transport model that is calibrated and verified against actual site conditions. The calibrated groundwater model is then used to evaluate a variety of approaches (e.g., vertical wells, horizontal wells, physical barriers) and to estimate the groundwater extraction rates necessary to contain the target zone. Understanding extraction rate requirements is important to developing an effective means of treating extracted groundwater.

Extracted groundwater often requires treatment to remove or reduce the concentration of arsenic prior to discharge to a receiving water body, publicly owned treatment works, land application, or re-injection through a well system.

Treatment of the impacted groundwater can be completed on or off-site using one of the following treatment methodologies:

- pH Adjustment: In cases where low pH is the primary COI, the groundwater can be treated by simple pH adjustment. Increasing the pH of the groundwater is accomplished by the addition of caustic solution (e.g., sodium hydroxide) at a rate that can be determined through bench-scale testing. Similarly, high pH groundwater can be treated through the addition of an acidic solution at a rate that can be determined through bench-scale testing. Other treatment methods discussed below may also require some pH adjustment to facilitate treatment.

- Chemical Precipitation: Arsenic can be removed from groundwater by raising the pH, using sodium hydroxide, calcium carbonate, or sulfides to convert the soluble arsenic to an insoluble form that precipitates out from the water stream. Bench-scale testing can be used to determine the addition rates of chemical precipitates and the percent arsenic removal that can be achieved through this process.

- Adsorption: Arsenic can be removed from groundwater by passing groundwater through an adsorption media such as bentonite, activated alumina, granular activated carbon, or iron-impregnated silica sands. Arsenic is adsorbed onto the surface of the media and removed from the groundwater. The adsorption material has a limited service life due to the amount of available treatment surfaces on the media. This adsorption material must be periodically replaced when the available surfaces are consumed with arsenic. Bench-scale testing can be used to define the groundwater/media contact time for arsenic removal and estimate the active life of the adsorption media before it requires replacement.

- Ion Exchange: In this process an ion on the surface of the treatment media is exchanged with the ion that is removed from the impacted groundwater. Ion exchange is a proven technology with different media performing better for different COIs. This technology can be expensive depending on the cost of the ion exchange media. Advances in the beneficial reuse of high calcium content biomaterials has made the use of this technology attractive for some COIs. Bench-scale testing may be completed to determine if ion exchange is a viable technology for consideration. Bench-scale testing can also determine the necessary contact time between the impacted groundwater and ion exchange media, and the service life of the ion exchange media.

- Hydraulic containment and groundwater treatment are applicable remedial alternatives due to several conditions at PAF, including:

  - *Precludes migration to potential receptors*: Operation of a hydraulic containment system would demonstrably capture arsenic-containing groundwater and prevent migration;

  - *Localized area of impacts*: Arsenic has been detected above GWPS within one assessment monitoring well around the perimeter of the CCR Unit and the CCR Multiunit. The arsenic impacts are estimated to have a localized extent of impacts and could be managed with a limited number of extraction points; and

  - *Established treatment technologies*: Treatment of arsenic in industrial wastewaters is accomplished through multiple proven technologies. Potential treatment alternatives include advanced filtration, chemical precipitation, redox manipulation, adsorption and ion exchange. The most effective alternative(s) would be selected based on the geochemistry of the groundwater and potential bench-scale treatability testing.

A hydrogeologic model would be required to design the hydraulic containment system orientation and bench-scale testing could assist in selecting the preferred treatment technology.

A groundwater monitoring program is typically an integral part of any hydraulic containment system. It is anticipated that after selection of the remedy, a corrective action groundwater monitoring program will be implemented in accordance with 40 CFR § 257.98(a)(1). This monitoring program will track changes in arsenic concentrations and the extent and effectiveness of the containment system.

The time frame to achieve GWPS with a hydraulic containment system is strongly dependent on the site’s hydrogeologic conditions, the degree and extent of COI impact, and the chemical behavior of COIs in the subsurface. These inherent site conditions often function as rate limiting characteristics and should be considered when considering the schedule for achieving GWPS.

1.3 Enhanced In-Situ Treatment (EIST)

In-situ treatment of groundwater using EIST is an established technology for a variety of site conditions and contaminants. This alternative includes measures implemented in-situ to immobilize or reduce the concentration of arsenic. In-situ technologies can be deployed in a variety of configurations depending on the extent of arsenic impacts and its proximity to potential receptors. Examples of EIST approaches include:

- Infiltration galleries: Regularly spaced injection wells would be installed in the target area to allow for delivery of a reagent to stabilize or transform arsenic in-place. An injection gallery allows for repeated treatments as needed to meet remedy goals.
- Direct injection: Regularly spaced injection points can be advanced into the target area to allow for one-time delivery of a reagent to stabilize or transform arsenic in-place.
- Permeable reactive barrier: Excavation of a trench perpendicular to groundwater flow direction can be backfilled with a permeable treatment media that allows groundwater to flow through it while reducing concentrations of arsenic through chemical, physical, and/or biological processes.

Evaluation of these technologies will require development of a detailed hydrogeologic CSM and a groundwater model. The CSM serves as the basis for developing a numerical groundwater flow and solute transport model that is calibrated and verified against actual site conditions. The hydrogeologic model can then be used to determine the basis of design for deploying an EIST remedy and evaluating contact time and groundwater flow requirements.

Bench-scale testing can be used to evaluate potential reagents to be used in-situ. The bench-scale testing can be designed to develop an understanding of the geochemistry and assess the effectiveness of prospective reagents. Bench-scale testing can also be used to determine the scope and necessity of field-scale pilot testing.

EIST is an applicable remedial alternative based on several conditions at sites, including:

- Localized area of impacts: Arsenic has been detected above GWPS within a limited number of wells around the perimeters of the CCR Unit and CCR Multiunit. This indicates that in-situ stabilization or an EIST barrier would be limited to only a portion of the perimeter. Additional investigations would be conducted to define the area of treatment or required length of the barrier.
- Metals treatment technologies: Removal of arsenic with multiple treatment technologies have been demonstrated in industrial wastewater applications. Potential treatment alternatives include advanced filtration, co-precipitation, redox manipulation, adsorption, and ion exchange. The most effective alternative(s) would be selected based on the geochemistry of the groundwater and potential bench-scale treatability testing. Bench-scale testing can help determine the preferred treatment media, groundwater/treatment media contact time, and effectiveness of an EIST barrier application in achieving GWPS.

A groundwater monitoring program is typically an integral part of any EIST system. It is anticipated that after selection of the remedy, a corrective action groundwater monitoring program will be implemented in accordance with 40 CFR § 257.98(a)(1). This monitoring program will track changes in arsenic concentrations and the extent and effectiveness of the EIST system.

Several critical site-specific conditions need to be considered when evaluating the applicability of an EIST barrier, including:

- Site Access: EIST barriers can require access for heavy equipment and a working platform to excavate the trench. Uneven or wooded terrain would complicate site preparation activities and may make installation infeasible.
- Dike Stability: The installation of an EIST could require the use of trenches. The location of the trenches in relationship to the dikes of the CCR Unit and CCR Multiunit require careful evaluation to make sure that stability of the dike structures is maintained.
- Depth: Installation of EIST barriers can be limited by the design depth and soil types present. Depending on depth and soil characteristics, specialized installation techniques may be required. For example, single-pass trenching machines can install EIST barriers in sandy materials without obstructions but are limited to a maximum depth of approximately 50 feet below ground surface. Slurry trenching techniques can be used to reach deeper impacts, but additional site infrastructure is required to support the installation.
- Geochemistry: The valence state of arsenic, pH and redox potential of groundwater, and chemical makeup of the subsurface must be evaluated to determine the applicability of an EIST barrier.

APPENDIX B

ASSESSMENT OF POTENTIAL REMEDIES

1.0 INTRODUCTION

The evaluation of appropriate remedies to meet the requirements of 40 CFR § 257.96(c) is provided in the subsections below and is presented in **Table B-1**. The qualitative assessments in **Table B-1** (low, medium, high) are based on experience, professional judgement, and known Site conditions. This document provides evaluation in compliance with 40 CFR § 257.96(c).

Five remedial alternatives for treatment of arsenic in groundwater classified under three technology types, hydraulic containment, monitored natural attenuation, and in-situ treatment, will be evaluated as groundwater corrective measures:

- Hydraulic Containment:
    - Conventional Vertical Well System;
    - Horizontal/ Angular Well System; and
    - Trenching System.
- Monitored Natural Attenuation; and
- Enhanced In-Situ Treatment.

2.0 PERFORMANCE

The performance criteria described in the following section focuses on the specified technology's goal of corrective measures to prevent further releases, remediate any current releases, and restore the affected area to original conditions.

2.1 SOURCE CONTROL TECHNOLOGIES

Source control will be achieved by ceasing discharge of CCR and/or flows to the CCR Unit and CCR Multiunit and initiating dewatering operations to remove water above the CCR. The CCR Unit and CCR Multiunit will then be closed in accordance with 40 CFR § 257.102. Source control technologies are not further evaluated in this report since this assessment of corrective measures focuses only on groundwater corrective actions.

2.2 GROUNDWATER CORRECTIVE MEASURES

The groundwater corrective measures for arsenic removal evaluated include:

- Monitored Natural Attenuation (MNA);
- Hydraulic Containment; and
- Enhanced In-Situ Treatment.

This section describes these technologies in more detail.

2.2.1 Monitored Natural Attenuation

Additional groundwater assessment monitoring is conducted once source control has been implemented for the CCR Unit and CCR Multiunit to determine if the arsenic concentrations are stable or decreasing. Once the source is controlled, natural groundwater flux should result in reduced concentrations of arsenic after a period of time. The groundwater assessment monitoring will determine if the source control measures are reducing or stabilizing arsenic concentrations in the groundwater to levels necessary to achieve the GWPS. Trend analyses will be completed to predict the time that it will take for the groundwater to reach GWPS. MNA is a proven technology that has been effectively used at groundwater remediation sites. MNA is considered a **high** performing alternative based on project experience on similar sites and professional judgement.

2.2.2 Hydraulic Containment

If source control technologies do not reduce arsenic concentrations to below the GWPS, then additional groundwater remediation corrective measures may be required.

Several site-specific conditions contribute to the effective performance of the hydraulic containment system. These site-specific conditions include:

- Depth to impacted groundwater at PAF;

- Length of impacts along the perimeters of the CCR Unit and CCR Multiunit;
- Thickness of Alluvium at PAF;
- Groundwater capture zones within the Alluvium; and
- Arsenic to be removed from the groundwater.

Hydraulic containment systems can be designed based upon data obtained through additional site characterization assessments, groundwater modeling, and potential bench-scale treatability testing. These additional studies are focused on the arsenic present at the CCR Unit and CCR Multiunit that exceed GWPS. Data from these studies will help develop a basis of design for the hydraulic containment system which includes:

- Number and depth of the extraction wells installed within the Alluvium;
- Groundwater extraction rate from the Alluvium;
- Optimum above ground groundwater treatment approach for arsenic;
- Treated groundwater discharge location; and
- Estimated time frame to achieve GWPS.

Groundwater extraction and treatment is a feasible technology at PAF with a **high** or **medium-rated** performance depending on site-specific issues such as groundwater use restrictions.

2.2.3 Enhanced In-Situ Technologies

Several site-specific conditions contribute to the effective performance of the enhanced in-situ technologies (EISTs). These site-specific conditions include:

- Depth to impacted groundwater within the Alluvium;
- Length of arsenic impacts along the perimeters of the CCR Unit and CCR Multiunit;
- Groundwater flow rate within the Alluvium; and
- Arsenic to be removed from the groundwater;

EISTs can be designed based upon data obtained through additional Site characterization assessments, groundwater and potential bench-scale treatability test. These additional studies are focused on the arsenic present at the CCR Unit and CCR Multiunit that exceed GWPS. Data from these studies will help develop a basis of design for the EIST which includes:

- Location and depth of the EIST to intercept arsenic present in the Alluvium;
- Optimum EIST media for arsenic treatment of arsenic;

- EIST detention times for effective treatment;
- Service life for the EIST media;
- Provisions for media replacement; and
- EIST quantities.

EISTs would generally be considered **high to medium** performing alternatives based on project experience on similar sites and professional judgement. Bench-scale testing of multiple reagents or modelled site conditions cab be evaluated to determine retention times, reaction rates, media selection, quantities and delivery methods for treatment using EIST.

3.0 RELIABILITY

The reliability criterion is based on the degree of certainty that the technology will consistently work toward and attain the specified goal(s) of corrective measures over time.

3.1 GROUNDWATER CORRECTIVE MEASURES

The reliability of the following groundwater corrective measures for arsenic removal will be evaluated in this section:

- MNA;
- Hydraulic Containment; and
- EIST.

3.1.1 Monitored Natural Attenuation

MNA is a commonly applied corrective measure that can, under appropriate conditions, reliably reduce arsenic concentrations after source control measures are completed. The process of determining the effectiveness and reliability of MNA involves regular monitoring and analysis of groundwater data following closure. This monitoring process and the related data analysis is central to determining whether appropriate conditions exist to support MNA and will serve as the primary means of determining and confirming reliability. MNA may not result in the arsenic levels in the groundwater to return to levels below the GWPS. Arsenic concentration reduction is achieved through a variety of geochemical and hydrogeologic processes that affect the solubility, sorption, and concentration of the constituents. Therefore, the reliability of MNA is considered to be **high to medium** depending on site conditions.

3.1.2 Hydraulic Containment

Hydraulic containment alternatives are generally considered to be **highly** reliable for containing the arsenic contamination and preventing migration. This technology may not be as reliable when considering the reduction of arsenic concentrations within the aquifer. Reduction of arsenic concentrations is highly dependent on the success of source control steps and the ability of the arsenic to be adsorbed within the soil column. Conventional vertical wells are installed within the Alluvium in a line or series with overlapping radii of influence to effectively capture groundwater. Modifications can be made during startup and as site conditions change to optimize the system's performance. If needed, extraction well systems can be expanded with additional wells, after the initial installation. Horizontal well reliability and extraction trench reliability is generally comparable to that of vertical wells, although the application is less common. Site-specific issues could restrict the extraction of groundwater and as a result could lower the reliability of this approach to **medium**.

3.1.3 Enhanced In-Situ Technologies

EIST is a commonly applied corrective measure that can, under appropriate conditions, reliably reduce arsenic concentrations after source control measures are completed. The EIST processes can include one or more of the following treatment mechanisms:

- Advanced Filtration;
- Chemical Precipitation; and
- Adsorption.

The process of determining the effectiveness and reliability of EIST involves regular monitoring and analysis of groundwater data following closure. Groundwater monitoring will be conducted to determine the effectiveness of EIST and to determine the time frame required to achieve GWPS for arsenic. Bench testing allows for the development of a site-specific approach to treat arsenic to achieve GWPS.

The reliability of EIST is considered to be **high to medium** depending on the COI being treated and site-specific considerations.

4.0 EASE OF IMPLEMENTATION

This criterion requires evaluation of the alternatives based on the ease of implementation for each of the technologies at the site.

4.1 GROUNDWATER CORRECTIVE MEASURES

The ease of implementation criterion is based on the degree of certainty that the technology can be installed and reduce the concentrations of arsenic over time to achieve the GWPs.

4.1.1 Monitored Natural Attenuation

MNA can be readily implemented and existing monitoring wells (potentially supplemented with additional wells) could be used for groundwater monitoring purposes. MNA does not require significant infrastructure and instead relies on natural processes to attenuate arsenic concentrations over time. Standard techniques for obtaining and analyzing groundwater data for arsenic is readily available. Therefore, an MNA corrective measure is evaluated as **highly** implementable.

4.1.2 Hydraulic Containment

Hydraulic containment systems are widely implemented and are a proven technology for capture of arsenic contamination. The ease of implementation varies across the range of available hydraulic containment systems from **medium to high**. Implementation issues associated with each of these techniques is discussed below:

Vertical Wells:

- The number of extraction wells and their spacing distance is dependent upon the horizontal and vertical extent of arsenic impacts within the Alluvium the hydrogeologic characteristics of the Alluvium, the groundwater extraction rate from the Alluvium and the groundwater capture zone within the Alluvium;
- Specialized drilling equipment may be required to install the wells within the Alluvium depending on the depth of arsenic impacts; and
- Limited space may be available on the top of the dikes adjacent to wells PAF-113 and PAF-119 to install the hydraulic containment system.

Horizontal Wells:

- The length of horizontal wells and their installation depth is dependent upon the horizontal and vertical extent of arsenic impacts, the hydrogeologic characteristics of the Alluvium, the groundwater extraction rate from the Alluvium and the groundwater capture zone within the Alluvium;
- Specialized drilling equipment will be required to install the horizontal wells in the Alluvium; and

- It may be difficult to place the horizontal wells at the desired depths due to surface constraints associated with the CCR Unit and CCR Multiunit.

Trenches:

- Specialized drilling equipment will be required to install the trenches within the Alluvium;
- Trench stabilization techniques (sheet pile, bio-degradable slurry) are required to prevent collapse of the sidewalls during installation; and
- It may be difficult to place the arsenic treatment media at depth in narrow trenches.

The number of wells required for effective capture is based upon the horizontal and vertical extent of the arsenic impacts within the Alluvium and groundwater flow characteristics in the Alluvium. Vertical extraction wells could be executed relatively easily with existing site conditions and result in a **high** ease of implementation. Horizontal extraction wells suggest a **medium** ease of implementation due to additional clearances necessary to install wells. Trenching systems suggest a **medium** ease of implementation due to trench stability concerns and potential impacts on sensitive ecosystems.

4.1.3 Enhanced in-situ treatment

EIST would require design time, infrastructure, additional design and up-front monitoring for implementation. EISTs could be permeable reactive barriers (PRBs), infiltration galleries or through direct injections specifically designed for arsenic removal from groundwater. Implementation issues associated with each of these techniques is discussed below:

PRBs:

- Construction of a PRB for arsenic removal may require specialized equipment and construction techniques that could impact the ease of implementation; and
- Following installation, a PRB typically requires minimal maintenance and periodic monitoring.

Infiltration Galleries:

- Injection galleries can be installed for arsenic treatment with standard drilling equipment;
- Access can be limited, so the location of slopes, existing infrastructure, and other obstructions must be factored into the design; and
- Injection galleries are subject to fouling that can inhibit the injection of reagents particularly if multiple injection events are required.

Direct Injection:

- Direct injection for arsenic treatment can be accomplished with standard drilling equipment;

- Access can be limited, so the location of slopes, existing infrastructure, and other obstructions must be factored into the design; and
- Multiple direct injection events may be required to achieve the GWPS for arsenic.

Once the EIST barriers are installed the remedial alternative is passive and would require only periodic monitoring and maintenance. The overall ease of implementation for an EIST alternative would be **high** to **medium** depending on the depth of installation. At PAF the installation depth would be greater than 50 feet so the scoring of this alternative would be **medium**

5.0 POTENTIAL SAFETY IMPACTS

This criterion evaluates the alternatives based on potential safety impacts that may occur as a result from the implementation of the technologies on site.

5.1 GROUNDWATER CORRECTIVE MEASURES

Safety impacts that may occur as a result from the implementation of groundwater corrective measures for arsenic is discussed in this section.

5.1.1 Monitored Natural Attenuation

MNA safety impacts are minimal due to the inherent passive nature of the system. The primary safety concerns would be associated with the installation of any additional wells to monitor arsenic trends in the groundwater should they be required to supplement the existing well network. Additional opportunities for safety impacts would be during groundwater monitoring activities. These impacts are common to any technology that may be deployed, because groundwater monitoring will be required regardless of which remedial technology is implemented. For these reasons, MNA has a **low risk** of safety concerns.

5.1.2 Hydraulic Containment

Groundwater extraction well construction or trenching activities for capturing arsenic impacted groundwater would require construction activities and consequently pose a **medium risk** of safety impacts. Construction equipment involved in the installation of extraction wells, drilling, electrical work and piping would be a main area for safety impact concern. Operations and maintenance, repair, and replacement activities may also present safety hazards, but are generally lower risk than construction-related safety impacts.

5.1.3 Enhanced In-Situ Technologies

EISTs for arsenic treatment would require a more detailed construction plan and therefore a **medium risk** for safety impacts. Construction equipment would be the main concern because construction projects are inherently more dangerous than other site work due to the presence of heavy machinery. Once installed, EISTs are passive and would result in minimal safety impact potential. EISTs implementation has a **medium risk** for safety concerns.

6.0 POTENTIAL CROSS-MEDIA IMPACTS

This criterion evaluates the alternatives based on potential cross-media impacts that may occur as a result from the implementation of the technologies on site.

6.1 GROUNDWATER CORRECTIVE MEASURES

Potential cross-media impacts that may occur as a result from the implementation of groundwater corrective measures for arsenic treatment is discussed in this section.

6.1.1 Monitored Natural Attenuation

Monitored natural attenuation poses minimal risk of cross-media impacts as the systems, when installed are passive and primarily interact with existing groundwater flow. MNA is considered **low risk** for cross-media impacts.

6.1.2 Hydraulic Containment

Extracted groundwater containing arsenic is transported from the recovery well to the treatment system using enclosed piping. The main potential for cross-media impacts would occur if the piping failed and untreated extracted groundwater is released to the environment. This risk is mitigated through periodic monitoring of the secondary containment. Hydraulic containment technologies are considered to have a **medium** risk.

6.1.3 Enhanced In-Situ Technologies

There is a potential for the accidental release of diesel fuel during the installation of subsurface barrier walls for arsenic treatment. In addition, if the barrier wall is installed within CCR materials there is the potential that CCR materials can be exposed and then released to the environment. Also, injected treatment reagents for arsenic treatment would have the potential for being released to the environment. The potential for these types of releases are mitigated through the development of spill prevention control and countermeasure plans. Due to the minimal potential for spills of fuel or treatment reagents during construction activities, EIST is considered a **medium risk**.

7.0 CONTROL OF EXPOSURE TO RESIDUAL CONTAMINATION

This criterion evaluates the alternatives based on exposure to residual arsenic contamination to receptors such as humans and the environment that may occur as a result from the implementation of the technologies on site.

7.1 GROUNDWATER CORRECTIVE MEASURES

Each groundwater corrective measure discussed in this report has a **low risk** of residual contamination. This is the result of arsenic being present in the groundwater at concentrations general less than a part per million. In addition, the groundwater impacts are present below the ground surface, and when groundwater is brought above the ground surface, it is transported through double walled piping to the treatment system. Therefore, the risk of exposure to residual contamination is **low**.

8.0 TIME REQUIRED TO BEGIN REMEDY

This criterion evaluates the alternatives based on time required for completion of design, planning, bench-scale testing, permitting, installation and startup of the remedial technologies.

8.1 GROUNDWATER CORRECTIVE ACTION

Due to the fact that MNA does not involve the introduction of an additional chemical or physical remedial tools, the process would likely require one to one and one-half years prior to implementation of the alternative to obtain groundwater trending data for arsenic. This lead time would be necessary to complete required additional monitoring, determine if additional monitoring wells are required and construct wells, if needed.

Hydraulic containment systems or EISTs would be expected to require between three to five years after selection of a groundwater corrective measure to implement due to the following reasons;

- Design, bench- and pilot-scale testing, reporting and state approval is anticipated to require multiple years.
- State, local, or other environmental permit requirements are anticipated to affect implementation of hydraulic containment or EISTs.
- Closure of the CCR Multiunit will take two to twenty years to complete depending on the remedy deployed;
- Interim measures for groundwater remediation for molybdenum, if instituted prior to CCR Multiunit closure, will take one to three years to complete;
- Groundwater assessment monitoring will determine the need for additional groundwater corrective measures beyond MNA and interim measures; and
- Obtaining enough groundwater data to evaluate the performance of the CCR Multiunit closure method requires time.

9.0 TIME REQUIRED TO COMPLETE REMEDY

This criterion evaluates the alternatives based on time required to achieve the necessary goals of the corrective measures and restore groundwater in the affected area to achieve GWPS.

9.1 GROUNDWATER CORRECTIVE MEASURES

Since MNA does not introduce a reagent or barrier, the time to reach the GWPS for arsenic is unknown. The duration is directly dependent on the concentrations of arsenic present in the groundwater and the effectiveness of the engineered cap to prevent further releases. It is possible that several decades of monitoring may be required before necessary groundwater conditions are achieved. Fate and transport modeling can be used to predict remediation time frames once enough post-closure monitoring data is obtained.

The time frame to achieve GWPS for arsenic with hydraulic containment remedies are also subject to concentrations of arsenic in the groundwater. Fate and transport modeling will be used to predict remediation time frames once enough post-closure monitoring data is obtained. The alternatives of vertical or horizontal extraction wells would remove arsenic mass from the subsurface, thereby reducing the volume still present in the subsurface. Therefore, the extraction alternatives may restore groundwater in a shorter time frame if source control efforts are effective.

The time frame to achieve GWPS with a EIST system is strongly dependent on the site's hydrogeologic conditions within the Alluvium, the degree and extent of arsenic impact within the Alluvium, and the chemical behavior of arsenic in the subsurface, These inherent site conditions often function as rate limiting characteristics and should be considered when considering the schedule for achieving GWPS for arsenic. Groundwater fate and transport modeling can be used to provide an estimated range of time frames to achieve GWPS

10.0 INSTITUTIONAL REQUIREMENTS: STATE, LOCAL OR OTHER ENVIRONMENTAL PERMIT REQUIREMENTS THAT MAY SUBSTANTIALLY AFFECT IMPLEMENTATION

This criterion evaluates the alternatives based on state, local or other permitting requirements that may substantially affect the implementation of the technologies on site.

10.1 GROUNDWATER CORRECTIVE MEASURES

A groundwater assessment monitoring program will be developed to monitoring the effectiveness of the CCR unit closure method and groundwater in-situ treatment or groundwater extraction and treatment technologies for arsenic. State and local approvals may be necessary to execute the construction work plan for additional groundwater corrective measures. The following permits would likely be required:

- Stormwater Permit for Construction Activities – applies for all corrective measures (Hydraulic Containment and EIST) where greater than one acre of land is disturbed as a result of construction activities; and
- Kentucky NPDES Permit Modification – modifications to the existing NPDES permit may be required for the hydraulic containment options since an additional source of impacted water is routed to the on-site treatment plant that discharges through the permitted outfall.

TABLES

TABLE B-1
CORRECTIVE MEASURES QUALITATIVE EVALUATION - 257.96(c) Analysis Criteria
PAF CCR Units

	Groundwater Restoration Action		*Groundwater Restoration Actions*		
	Monitored Natural Attenuation	**Enhanced In-Situ Treatment**	**Conventional Vertical Well System**	**Horizontal/ Angular Well System**	**Trenching System**
257.96(c)(1)					
Performance	**High** Soil column will filter particulate that contains arsenic/dissolved arsenic. Loading will be reduced by source control approaches.	**High** Enhanced in-situ treatment technologies are evaluated based upon bench-scale testing of impacted groundwater.	**High** Technology is feasible and will be further evaluated in accordance with 257.97, prior to remedy selection.	**High** Technology is feasible and will be further evaluated in accordance with 257.97, prior to remedy selection.	**High** Technology is feasible and will be further evaluated in accordance with 257.97, prior to remedy selection.
Reliability	**High** Soil column will filter particulate that contains arsenic/dissolved arsenic. Loading will be reduced by source control approaches.	**High** Enhanced in-situ treatment technologies are evaluated based upon bench-scale testing of impacted groundwater.	**High** Technology is feasible due to narrow GW extraction window and ability to capture arsenic present in groundwater	**High** Technology is feasible due to narrow GW extraction window and ability to capture arsenic present in groundwater	**High** Technology is feasible due to narrow GW extraction window and ability to capture arsenic present in groundwater.
Ease of implementation	**High** Corrective Action Groundwater Monitoring will be conducted in accordance with 257.98 (a) (1).	**Medium** The enhanced in-situ treatment technologies are would be more difficult to install due to the depth of arsenic groundwater impacts..	**High** Proven technology can be executed from top of berm/small hydraulic containment zone. This limits the number of extraction wells required to recover arsenic	**Medium** Proven technology can be executed from top of berm but requires greater clearance zone/small hydraulic containment zone. This limits the length of horizontal wells.	**Medium** Proven technology can be executed from top of berm but requires greater clearance zone/small hydraulic containment zone. This limits the length of recovery trenches.
Potential impacts of appropriate potential remedies: safety impacts	**Low Risk** All work activities are conducted in accordance with a site-specific health and safety plan for safe execution of groundwater monitoring activities	**Medium Risk** More advanced worker training is required to operate specialized equipment.	**Medium Risk** More advanced worker training is required to operate specialized equipment.	**Medium Risk** More advanced worker training is required to operate specialized equipment.	**Medium Risk** More advanced worker training is required to operate specialized equipment.
Potential impacts of appropriate potential remedies: cross-media impacts	**Low Risk** All work activities occur in-situ.	**Medium Risk** All work activities occur in-situ with some potential to release COC's to the environment through spills.	**Medium Risk** All work activities bring soils and groundwater to ground surface with some potential to release COC's to the environment through spills.	**Medium Risk** All work activities bring soils and groundwater to ground surface with some potential to release COC's to the environment through spills.	**Medium Risk** All work activities bring soils and groundwater to ground surface with some potential to release COC's to the environment through spills.
Potential impacts of appropriate potential remedies: control of exposure to residual COIs	**Low Risk** All work activities occur in-situ/groundwater impacts previously identified.	**Low Risk** All work activities occur in-situ with some potential to release COC's to the environment through spills.	**Low Risk** All work activities bring soils to ground surface with some potential to release COC's to the environment through spills.	**Low Risk** All work activities bring soils to ground surface with some potential to release COC's to the environment through spills.	**Low Risk** All work activities bring soils to ground surface with some potential to release COC's to the environment through spills.
257.96(c)(2)					
Time required to begin remedy	1 to 1.5 years	3 to 5 years after a corrective measure is selected	3 to 5 years after a corrective measure is selected	3 to 5 years after a corrective measure is selected	3 to 5 years after a corrective measure is selected
Time required to complete remedy	Varies dependent on groundwater fate, transport modeling and concentrations of arsenic in CCR pore water.	Varies dependent on groundwater fate, transport modeling and concentrations of arsenic in CCR pore water.	Varies dependent on groundwater fate, transport modeling and concentrations of arsenic in CCR pore water.	Varies dependent on groundwater fate, transport modeling and concentrations of arsenic in CCR pore water.	Varies dependent on groundwater fate, transport modeling and concentrations of arsenic in CCR pore water.
257.96(c)(3)					
State, local or other environmental permit requirements that may substantially affect implementation	KYDEP input required on Groundwater Corrective Action Monitoring Program.	KYDEP input required on Groundwater Corrective Action Monitoring Program.	KYDEP input required on Groundwater Corrective Action Monitoring Program. A Kentucky NPDES permit is required.	KYDEP input required on Groundwater Corrective Action Monitoring Program. A Kentucky NPDES permit is required.	KYDEP input required on Groundwater Corrective Action Monitoring Program. A Kentucky NPDES permit is required.
Comments	No timeframe specified to comply with 257.98 (c). Long term groundwater monitoring may be required.	No timeframe specified to comply with 257.98 (c). Corrective Action Groundwater Monitoring terminates if 3 years of data below the GWPS is obtained.	No timeframe specified to comply with 257.98 (c). Corrective Action Groundwater Monitoring terminates if 3 years of data below the GWPS is obtained.	No timeframe specified to comply with 257.98 (c). Corrective Action Groundwater Monitoring terminates if 3 years of data below the GWPS is obtained.	No timeframe specified to comply with 257.98 (c). Corrective Action Groundwater Monitoring terminates if 3 years of data below the GWPS is obtained.