# Assessment of Corrective Measures TVA Shawnee Fossil Plant, Paducah, Kentucky

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This document entitled Assessment of Corrective Measures TVA Shawnee Fossil Plant, Paducah, 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 |
| CWDS | Consolidated Waste Dry Stack |
| DOE | U.S. Department of Energy |
| EIS | Environmental Impact Statement |
| EIST | Enhanced In-Situ Treatment |
| FGD | Flue Gas Desulfurization |
| ft | feet |
| GWPS | Groundwater Protection Standard(s) |
| HSU | Hydro-stratigraphic unit |
| KDOW | Kentucky Division of Water |
| KDWM | Kentucky Department of Waste Management |
| mg/L | Milligrams per liter |
| MNA | Monitored Natural Attenuation |
| NOI | Notice of Intent |
| NPDES | National Pollutant Discharge Elimination System |
| PGDP | Paducah Gaseous Diffusion Plant |
| PRB | Permeable Reactive Barrier |
| PWB | Process Water Basin |
| RGA | Regional Gravel Aquifer |
| ROD | Record of Decision |
| SEIS | Supplemental Environmental Impact Statement |
| SHF | Shawnee Fossil Plant |
| SSL | Statistically Significant Level |
| SSLs | Statistically Significant Levels |
| Tc-99 | Technetium |
| TCE | Trichloroethylene |
| TVA | Tennessee Valley Authority |
| UA | Upper Alluvium |
| UCD | Upper Continental Deposits |
| U.S. EPA | United States Environmental Protection Agency |

# 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 GWPS established under 40 CFR § 257.95(h) for one or more Appendix IV constituents at the in accordance with 40 CFR § 257.95(g) for Ash Pond 2 and the Consolidated Waste Dry Stack (also known as Special Waste Landfill) at the Shawnee Fossil Plant (SHF). During assessment monitoring, one SSL for molybdenum was reported at monitoring well D-74B. As of the date of this report, TVA has not completed a demonstration that a source other than the CCR units associated with well D-74B at SHF caused the SSL, 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 Ash Pond 2 and the Consolidated Waste Dry Stack. These CCR units are monitored by a common, multiunit groundwater monitoring well network at SHF. This ACM Report provides an assessment of the effectiveness of potential corrective measures by addressing the criteria provided in 40 CFR § 257.96(c). The multiunit groundwater monitoring network consists of one upgradient well and four downgradient wells.

Three primary strategies have been evaluated to address groundwater exhibiting concentrations of molybdenum 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). Remedy must be selected as soon as feasible. 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 unit or an error caused the SSL, the owner/operator must initiate an ACM. At the Tennessee Valley Authority (TVA) Shawnee Fossil Plant (SHF), Ash Pond 2 and the Consolidated Waste Dry Stack (also known as the Special Waste Landfill), groundwater assessment monitoring detected an SSL of molybdenum in one monitoring well (D-74B). 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 constituents over GWPS will be defined as a constituent of interest (COI). Ash Pond 2 and the Consolidated Waste Dry Stack (CWDS) will be referred to in this report collectively as the CCR Multiunit.

## 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 §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 Multiunit 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

SHF is located in Paducah, McCracken County, Kentucky. The facility lies on the south bank of the Ohio River at Ohio River Mile 946. **Figure 2-1** shows an overview map of SHF including its facilities and the CCR Multiunit. SHF was constructed between 1951 and 1957 and began operations in the 1960s. The coal combustion process at SHF results in the production of by-products that include fly ash, Flue Gas Desulfurization wastes (FGD), and bottom ash. The plant currently manages these CCR materials in the CCR Multiunit.

## 2.1 CCR UNIT DESCRIPTIONS

The CCR Multiunit at SHF consists of Ash Pond 2 and the CWDS. Ash Pond 2 includes the Main Ash Pond and the Stilling Pond and is located at the northwest corner and northern edge of the plant. It is bordered on the north by the Ohio River and the west by Little Bayou Creek. Ash Pond 2 is formed by the Perimeter Dike along the east, north, and west and by the CWDS to the south. Ash Pond 2 encompasses approximately 100 acres. The unit is considered an active CCR surface impoundment. It is used for storage of bottom ash from coal burning at SHF. It is also used for clarification and treatment of plant waters and stormwater runoff from the plant, CWDS, and Coal Yard Drainage Basin.

The CWDS is located to the west of the powerhouse and is considered an active CCR landfill unit. The original portions of the landfill are covered and consist of approximately 110 acres and rise approximately 100 feet above the surrounding terrain. The landfill currently receives dry fly ash combined with FGD wastes from the plant and dredged bottom ash from Ash Pond 2.

For compliance with the CCR Rule, TVA's engineer certified a single groundwater monitoring well network for both units. This will be referred to as the CCR Multiunit network in this report.

## 2.2 OVERVIEW OF OCTOBER 2016 CLOSURE PLAN

TVA has conducted the necessary environmental reviews regarding potential environmental risks associated with the closure of Ash Pond 2. As a result of the entire EIS process, the decision was made to close in place the CCR Units. Plans for closing the CCR Units were developed in October of 2016 in accordance with 40 CFR § 257.102(b). A brief overview of the environmental review process is described below.

TVA began its evaluation of closure options under U.S EPA 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. Ash Pond 2 was 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, 2016, and the Final Record of Decision (ROD) was published on July 28, 2016. TVA has completed two supplemental EISs to address the potential environmental effects associated with ceasing operations and closing both the Consolidated Waste Dry Stack and Ash Pond 2. In December 2017, TVA issued the *Shawnee Fossil Plant Coal Combustion Residual Management Final Environmental Impact Statement* (Final EIS). On January 16, 2018, TVA issued a ROD regarding other issues studied in the Draft Supplemental EIS (SEIS) but elected to further consider the alternatives regarding the closure of the CCR Units before making a decision. TVA released the SEIS on May 4, 2018, to further analyze the alternatives for closure of the CCR Units, The final SEIS was released on August 24, 2018, and a ROD for closure in place of the CCR Units was published on October 22, 2018.

## 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 SHF is characterized by four 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 Upper Continental Deposits (UCD), Upper Alluvium (UA), Regional Gravel Aquifer (RGA), and the McNairy Formation. A geologic cross-section is shown on **Figure 2-2.** This cross-section does not depict the Ohio River floodplain and therefore the UA is not shown.

#### 2.3.1.1 Upper Continental Deposits

In the southern part of the SHF on the terrace above the Ohio River flood plain, the UCD are generally present below a blanket of loess. Within the floodplain, the UCD is covered by the UA and pinches out as the depth of the alluvial channel increases to the northeast. The thickness of the UCD ranges from 45 feet upland decreasing to zero where it has been eroded by the incised channel of the Ohio River.

#### 2.3.1.2 Upper Alluvium

The upper alluvium is mainly fine-grained sand and sandy clay that is present within the Ohio River floodplain. Groundwater in the upper alluvium is present under unconfined conditions.

#### 2.3.1.3 Regional Gravel Aquifer

The RGA is bounded by the McNairy Formation below and the UCD and UA above. In the southern part of SHF, the RGA is overlain by the UCD while in the Ohio River floodplain the RGA is overlain by the UA where the UCD has been eroded. Regionally, the RGA has been described as containing poorly sorted sand with lenses of clay and silt (Sexton, 2006). Locally, the RGA consists mainly of cherty well-graded gravel and cobbles with variable amounts of sand and silt with minor amounts of clay. The thickness of the RGA ranges from 30 to 60 feet south of SHF; however, near the Ohio River the thickness is generally less than 10 feet (Hansen 1966; Lindquist et al, 1992). For example, SHF-102G is positioned in a location where the RGA thickness is approximately 40 feet, and well D-74B is positioned in a location where the RGA thickness is less than 5 feet thick. The approximate interpolated thickness of the RGA is presented in **Figure 2-3**. The RGA is considered the uppermost aquifer in the area around the CCR Multiunit.

#### 2.3.1.4 McNairy Formation

The McNairy Formation is located beneath the RGA. Regionally, the McNairy Formation has been described as micaceous clay with silt and interbedded very fine to medium grained sand (Hansen, 1966). Locally, the McNairy Formation is described as laminated clay and silty sand with clay (Kellberg, 1951; Lindquist et al, 1992). The formation is approximately 200 to 300 feet thick (Davis et al,1987 Hansen, 1966; Lindquist et al, 1992).

### 2.3.2 Groundwater Flow Direction

The predominant groundwater flow direction in the RGA is to the northeast. **Figure 2-4** presents a groundwater potentiometric surface contour map for SHF that was developed based on groundwater elevation data in the RGA from a November 11, 2016 sampling event.

### 2.3.3 Potential Receptor Review

Potable use of drinking water in proximity to SHF is prohibited by a U.S. Department of Energy (DOE) water policy. The DOE Paducah Gaseous Diffusion Plant (PGDP) is located south (upgradient) of SHF. Due to the presence of trichloroethylene (TCE) and technetium (Tc-99) impacted groundwater originating from the PGDP facility, the DOE initiated a water policy for an area that encompasses the PGDP groundwater plume. The limits of this Water Policy Boundary are show on **Figure 2-5.** SHF and neighboring properties to the south and southwest are encompassed by this boundary and cannot use groundwater for drinking water purposes.

# 3.0 GROUNDWATER ASSESSMENT MONITORING PROGRAM

Groundwater assessment monitoring has been conducted at SHF in accordance with 40 CFR § 257.95.

## 3.1 GROUNDWATER MONITORING NETWORK

In compliance with 40 CFR § 257.91, one background well (SHF-102G) was established upgradient and four monitoring wells (D-30B, D-74B, SHF-101G, and D-11B) were installed downgradient of the CCR Multiunit. The locations of these monitoring wells are presented on **Figure 2-1**.

## 3.2 GROUNDWATER ASSESSMENT

Groundwater assessment monitoring was conducted during 2018. The following Appendix IV constituent was detected at an SSL above a GWPS:

- An SSL for molybdenum was identified at monitoring well D-74B;
    - The maximum concentration of molybdenum detected in 2018 was 0.232 milligrams per liter (mg/L); and
    - The GWPS for molybdenum is 0.100 mg/L.

## 3.3 GROUNDWATER CHARACTERIZATION

Groundwater data obtained from monitoring wells proximal to monitoring well D-74B were used as the basis to initially characterize the horizontal and vertical extents of molybdenum in groundwater. Data from both CCR and non-CCR monitoring wells were considered in this initial characterization as required by 40 CFR § 257.95(g)(1). The horizontal extent of molybdenum concentrations above the SSL observed at D-74B are defined to the west by SHF-101G and to the east by D-30A/B. The vertical extent of molybdenum was evaluated through analysis of samples from monitoring wells SHF-202 and SHF-203C. These wells are screened in the lower McNairy formation and do not exhibit molybdenum concentrations above the GWPS. The potential treatment zone to address the extent of molybdenum along the perimeter above the GWPS is illustrated on **Figure 3-1**.

Supplemental groundwater characterization will be conducted to further refine the characterization of the nature and extent of molybdenum above the GWPS to support the design and selection of a remedy. Specifically, supplemental characterization may include the following, some of which have already been completed:

- Additional cross-gradient monitoring wells (D-30A/B and SHF-101G) were sampled to refine the extent of Appendix IV constituents greater than the GWPS to the east and west of monitoring well D-74B;

- Additional monitoring wells may be installed to further refine definition the extent of Appendix IV constituents greater than the GWPS as needed to support remedy selection;
- 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;
- Sampling of any wells installed for the 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 SHF for the molybdenum SSL at well D-74B.

# 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 Multiunit indicates that molybdenum was present at an SSL above the GWPS as defined in 40 CFR § 257.95(h) at monitoring well D-74B. As discussed in Section 3.3, additional groundwater characterization will be conducted during the remedy selection process.

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

## 4.1 ANALYSIS OF CORRECTIVE MEASURES

The objective of the ACM is defined in 40 CFR § 257.96(a) and consists of 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 MULTIUNIT

The objectives of corrective measures under 40 CFR § 257.96(a) are to “prevent further releases [from the CCR Multiunit], 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 control 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. TVA has already implemented operational changes such as lowering the water surface elevation in Ash Pond 2 to reduce the pressure head and reduce the rate of potential process water infiltration. To achieve TVA’s commitment to convert from wet to dry handling of CCR and to comply with regulatory requirements and timeframes under the CCR Rule, TVA will close the CCR Multiunit at SHF in the future. Closure, regardless of the method selected, will control the source. Stopping flows to Ash Pond 2 and dewatering the pond will lead to further control of the source and prevention of releases. This is planned to occur by October 2020, to comply with the CCR Rule (40 CFR § 257.101(a)(1)).The CWDS, which is a landfill, can continue to operate under the CCR Rule so long as the owner/operator continues to comply with the groundwater monitoring and corrective action requirements.

TVA is currently in the process of constructing a new lined CCR landfill and a process water basin (PWB) to enable closure of the CCR Multiunit at SHF. A PWB is being constructed to handle non-CCR process flows and stormwater. Before the CWDS is closed, a new lined CCR landfill must be constructed.

Closure of the CCR Multiunit will be 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. Closure of the CCR Multiunit is expected to support decreasing trends of Appendix IV constituents in the groundwater. Ground surface of the CCR Multiunit will be restored with a vegetative cover after closure.

Since closure of the 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 molybdenum at concentrations above the GWPS. Groundwater assessment monitoring as required by 40 CFR § 257.96(b) will continue until a groundwater remedy is selected. 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 drinking water receptors could be impacted by the release of molybdenum from the CCR Multiunit.

## 4.3 POTENTIAL REMEDIAL TECHNOLOGIES

This ACM provides an evaluation of potential remedial technologies to address the SSL observed at monitoring well D-74B. As discussed in Section 4.2, closure of the CCR Multiunit 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 (limited by groundwater use restriction due to contaminant releases from an upgradient U.S. governmental facility); 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 measures both require treatment of groundwater (either in-situ or ex-situ). **Table 1** presents a summary of technologies evaluated to treat molybdenum in groundwater.

## 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 Multiunit are presented in **Appendix B** and **Table B-1**.

# 5.0 SELECTION OF GROUNDWATER REMEDY

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 is expected to be obtained and reviewed prior to selection of a groundwater remedy.

## 5.1 DATA REQUIREMENTS FOR DESIGN OF GROUNDWATER REMEDY

The groundwater remedy selection process will include the collection of supplemental data to fill data gaps. In addition, groundwater modeling, as appropriate, will 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 molybdenum 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 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 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 COIs 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 molybdenum 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 molybdenum at SHF. 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 - SHAWNEE FOSSIL PLANT CCR MULTIUNIT**

| Water Treatment Technology | COI* |
|---|---|
| | Molybdenum |
| Advanced Filtration | X |
| Chemical Precipitation | X |
| Co-Precipitation | X |
| Redox Manipulation | X |
| Absorption (Chemical Fixation) | X |
| Ion Exchange | X |

*Constituent of Interest

# Figures



**Legend**

- Background Well
- Downgradient Well
- Investigation Well
- CCR Unit Subject to CCR Rule
- SHF Site Boundary

N

0 750 1,500 Feet

(At original document size of 8.5x11)
1:18,000

***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*
West Paducah
McCracken 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

182603475

*Client/Project*
Tennessee Valley Authority
Shawnee Fossil Plant
CCR Rule

*Figure No.*
**Figure 2-1**

*Title*
**CCR Multiunit With Background and Downgradient Wells**

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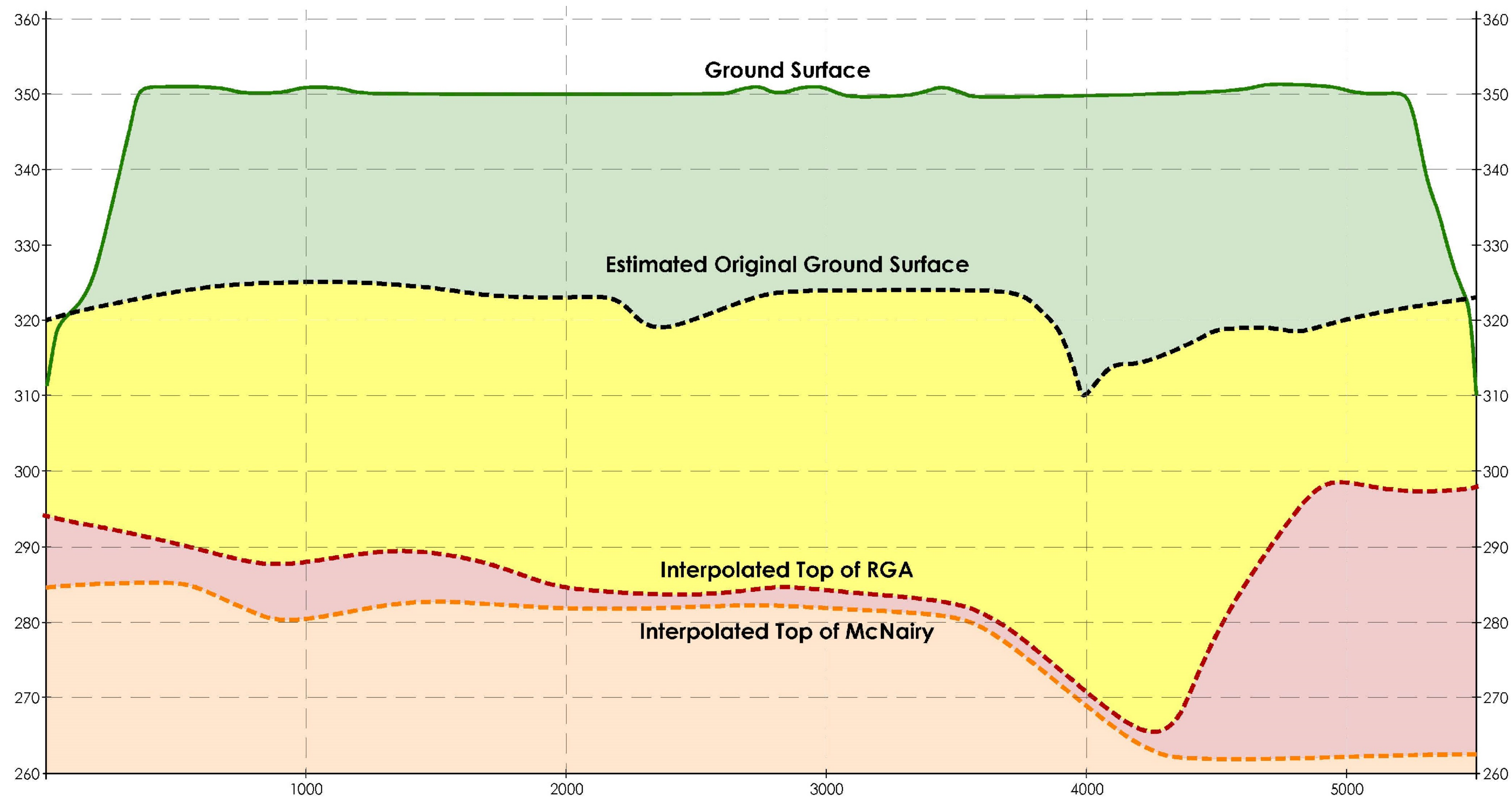



## GENERALIZED CROSS-SECTION

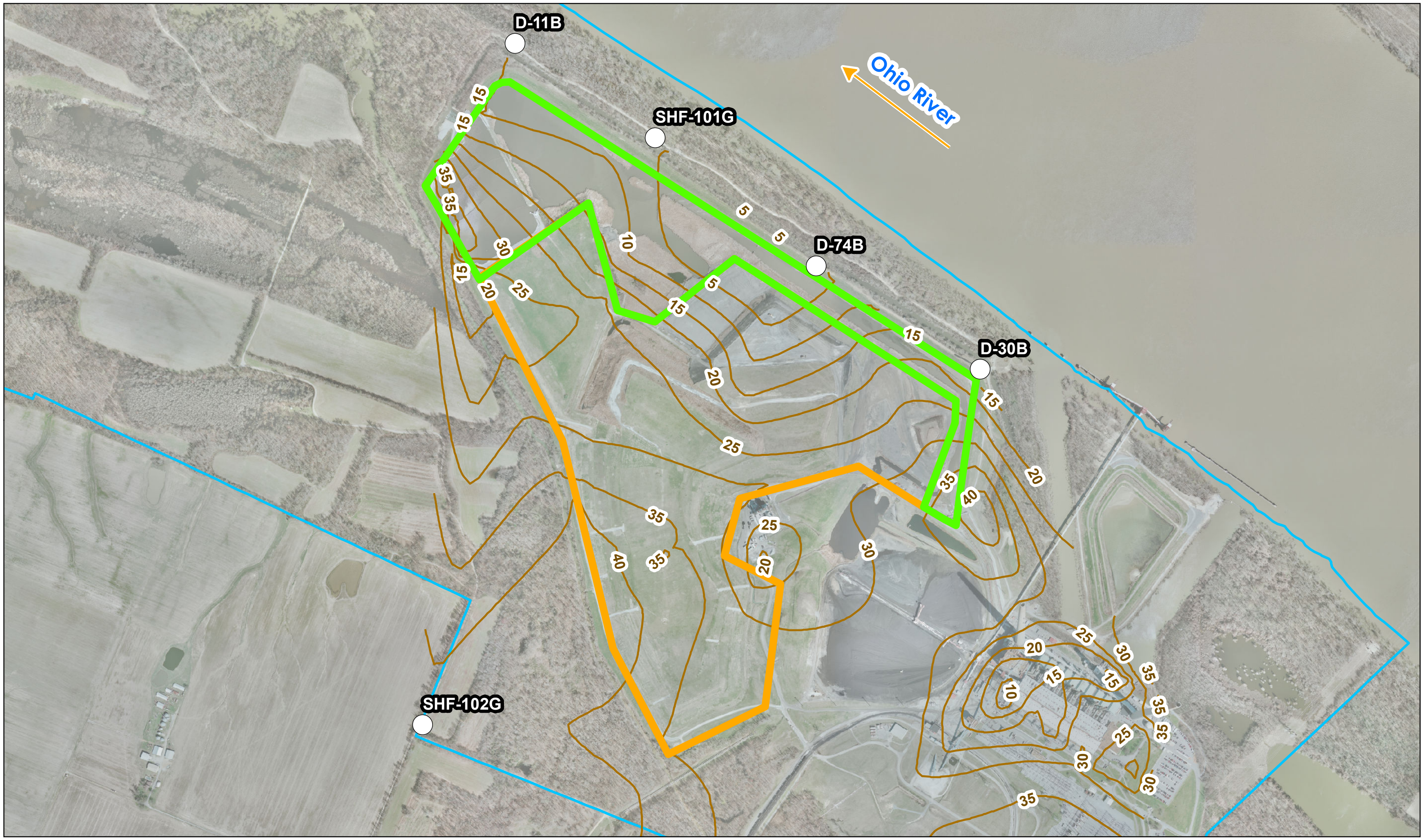

*Project Location*
West Paducah
McCracken County, KY

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*
182603475
Tennessee Valley Authority
Shawnee Fossil Plant
CCR Rule

*Figure No.*
**Figure 2-2**

*Title*
**Geologic Cross-Section**





Legend

- CCR Monitoring Well
- CCR Ash Pond 2 (Main Ash Pond/Stilling Pond)
- Consolidated Waste Dry Stack CCR Landfill
- SHF Site Boundary
- Thickness of RGA (C.I. = 5 ft.)

N

0 800 1,600 Feet

(At original document size of 8.5x11)
1:16,000

**Notes**
1. Coordinate System: NAD 1983 StatePlane Kentucky South FIPS 1602 Feet
2. Background: TVA 2016 Imagery

TVA

*Project Location*
West Paducah
McCracken County, KY

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*Figure No.*
**Figure 2-3**

*Title*
**RGA Thickness**

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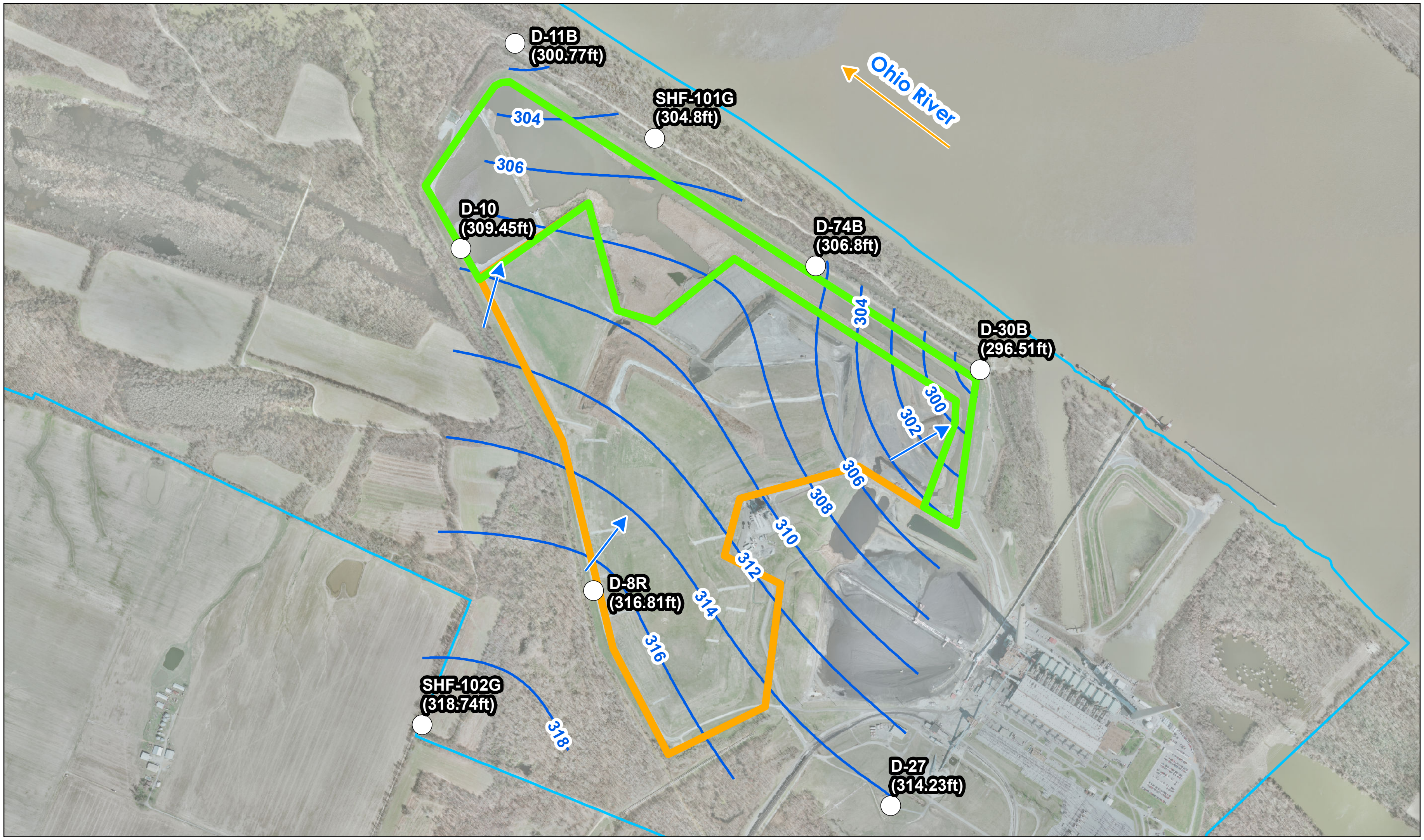



Legend

- Monitoring Well
- CCR Ash Pond 2 (Main Ash Pond/Stilling Pond)
- Consolidated Waste Dry Stack CCR Landfill
- SHF Site Boundary
- Groundwater Elevation Contours (CI = 2 Feet)
- Groundwater Flow Direction

N

0 800 1,600 Feet

(At original document size of 8.5x11)
1:16,000

**Notes**

1. Coordinate System: NAD 1983 StatePlane Kentucky South FIPS 1602 Feet
2. Background: TVA 2016 Imagery

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*Figure No.*
**Figure 2-4**

*Title*
**Groundwater Flow Direction**

TVA

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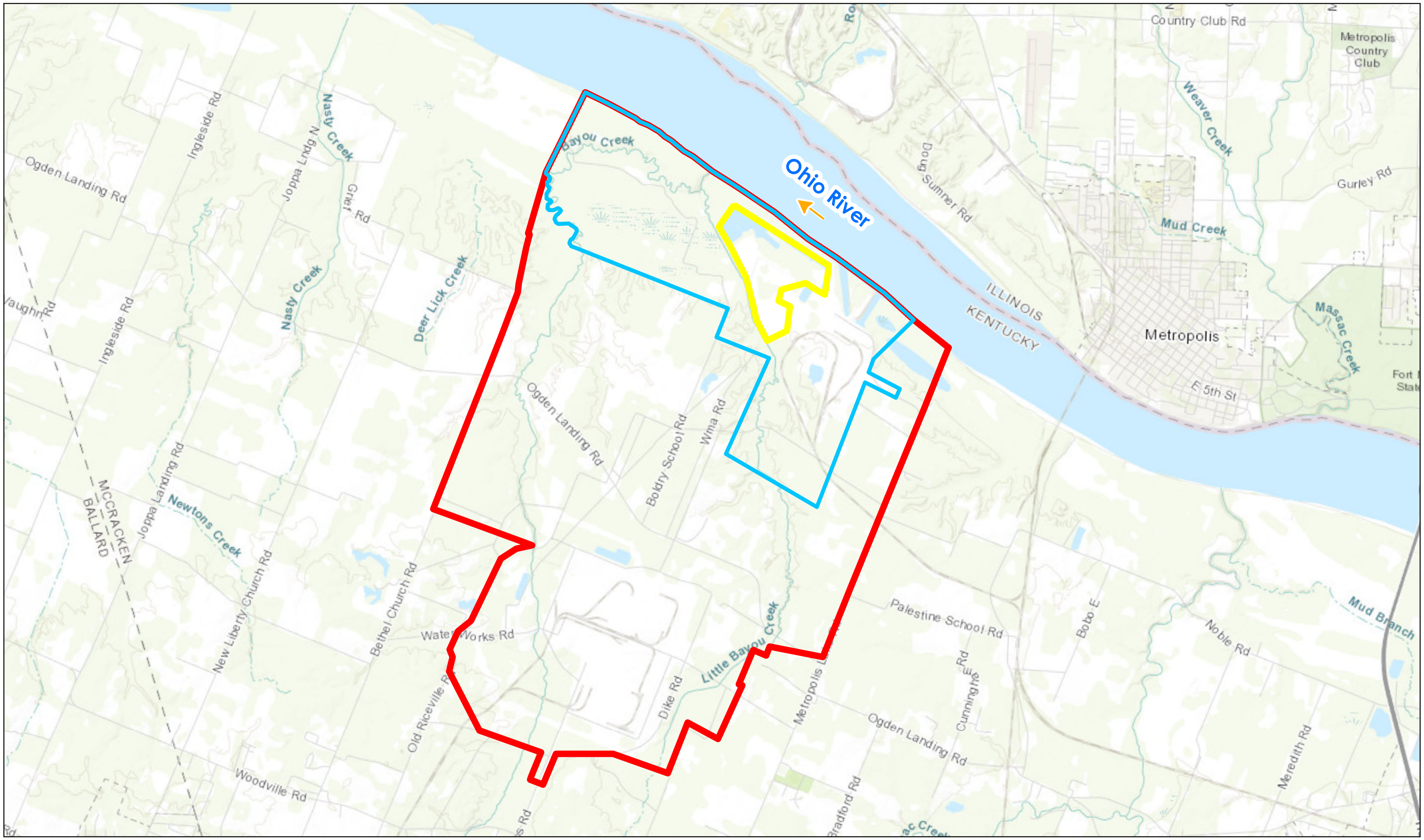



**Legend**

- CCR Multiunit
- SHF Site Boundary
- DOE Water Policy

N

0 5,000 10,000 Feet

(At original document size of 8.5x11)
1:80,000

**Notes**

1. Coordinate System: NAD 1983 StatePlane Kentucky South FIPS 1602 Feet
2. Background: TVA 2016 ImagerySources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors,

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182603475

*Client/Project*
Tennessee Valley Authority
Shawnee Fossil Plant
CCR Rule

*Figure No.*
**Figure 2-5**

*Title*
**DOE Water Policy Boundary**

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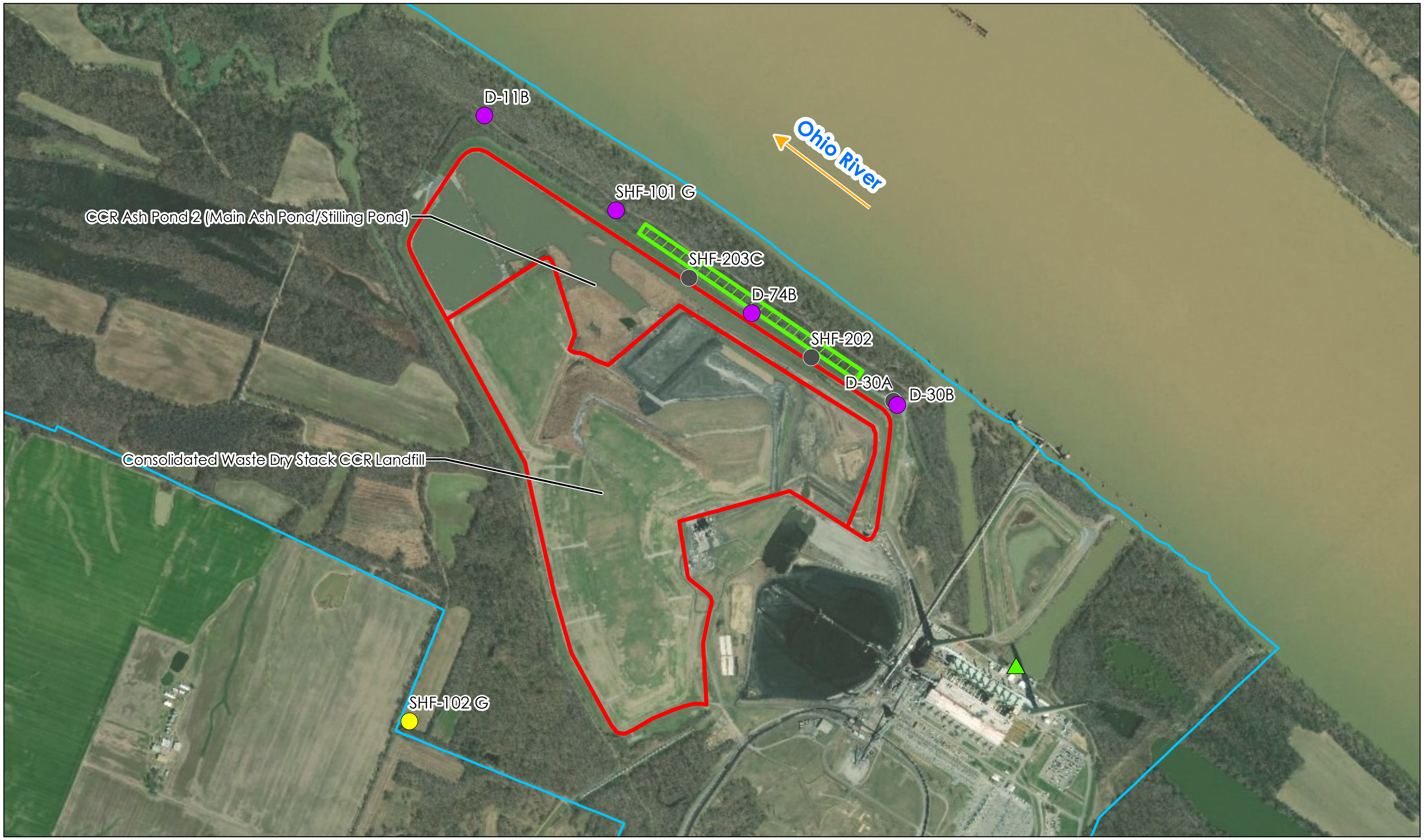



**Legend**

- Staff Gauge
- Investigation Well
- Background Well
- Downgradient Well
- Potential Molybdenum Treatment Zone
- CCR Unit Subject to CCR Rule
- SHF Site Boundary

N

0 750 1,500 Feet

(At original document size of 8.5x11)
1:18,000

***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

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182603475

*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 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 Multiunit. Existing and potentially new monitoring wells at the facility would be used to characterize reduction in COI concentrations over time.

At well D-74B of the CCR Multiunit at SHF, there is a statistically significant level (SSL) above the groundwater protection standard (GWPS) for molybdenum. Closure of the CCR Multiunit will commence once CCR discharges cease. The following conditions at SHF make MNA a viable strategy:

- Limited impacts to groundwater: Currently, an SSL above GWPS established under § 257.95(h) for molybdenum is observed along an isolated portion of the CCR Multiunit. There are no drinking water supply wells on site, including between the CCR Multiunit and the adjacent surface water. A Water Policy Boundary established by the Department of Energy (DOE) prevents the groundwater at SHF and in the vicinity from being used as a drinking water source. This is due to a groundwater plume, with primary constituents including trichloroethylene and technetium-99, from the DOE facility. A limited extent of impact and no drinking water receptors increase the likelihood that natural systems can attenuate COIs in an acceptable time frame.

- Naturally-occurring reactions in native soils: Molybdenum is susceptible to a variety of filtering and oxidation/reduction (redox) reactions that can separate or precipitate dissolved concentrations to remove them from aqueous solution. COIs 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 COI 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 COIs, 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 COI 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 COI 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 COI 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 COI 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 COI 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 COIs are present at shallow depths and high groundwater flow rates.
- Phytoremediation: This technique is feasible when COIs are present at concentrations less than those levels that are toxic to plant life. Trees with deep root zones can extract groundwater containing COIs above GWPS and assimilate the COIs within their cell structure. This removes the COI 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 for developing an effective means of treating extracted groundwater.

Extracted groundwater often requires treatment to remove or reduce the concentration of the COIs 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: COIs can be removed from groundwater by raising the pH, using sodium hydroxide, calcium carbonate, or sulfides to convert the soluble COI 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 COI removal that can be achieved through this process.
- Adsorption: COIs 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. COIs are 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 the COI. Bench-scale testing can be used to define the groundwater/media contact time for COI 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 SHF, including:

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

  - *Localized area of impacts*: COIs have been detected above GWPS within one assessment monitoring well around the perimeter of the CCR Multiunit. The COI 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 COIs 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 257.98(a)(1). This monitoring program will track changes in COI 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 COIs. In-situ technologies can be deployed in a variety of configurations depending on the extent of COIs and their 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 COIs 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 COIs 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 COIs 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: COIs have been detected above GWPS within a limited number of wells around the perimeter of the 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; and
- Metals treatment technologies: Removal of COIs 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 257.98(a)(1). This monitoring program will track changes in COI 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 Multiunit requires 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 COIs, 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 40CFR §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 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 Multiunit and initiating dewatering operations to remove water above the CCR. The CCR Multiunit will then be closed in accordance with 40 CFR § 257.102. The water elevation in Ash Pond 2 has been lowered to reduce the pressure head and rate of potential process water infiltration. Source control technologies are not further evaluated in this report since this assessment of corrective measures focuses on groundwater corrective actions.

## 2.2 GROUNDWATER CORRECTIVE MEASURES

The groundwater corrective measures 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 Multiunit to determine if the molybdenum concentrations are stable or decreasing. Once the source is controlled, natural groundwater flux should result in reduced concentrations of molybdenum after a period of time. The groundwater assessment monitoring will determine if the source control measures are reducing or stabilizing molybdenum 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 COI 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 SHF;
- Length of impacts along the perimeter of the CCR Multiunit;
- Thickness of RGA at SHF;
- Groundwater capture zones; and
- Molybdenum 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 molybdenum present at the 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 RGA;
- Groundwater extraction rate from the RGA;
- Optimum above ground groundwater treatment approach for molybdenum;
- Treated groundwater discharge location; and
- Estimated time frame to achieve GWPS.

Groundwater extraction and treatment is a feasible technology at SHF with a **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 RGA;
- Length of molybdenum impacts along the perimeter of the CCR Multiunit;
- Groundwater flow rate within the RGA; and,
- Molybdenum to be removed from the groundwater.

EISTs 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 molybdenum present at the 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 molybdenum present in the RGA;

- Optimum EIST media for molybdenum treatment of molybdenum;
- 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 can 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 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 molybdenum 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 molybdenum levels in the groundwater returning to levels below the GWPS. In these instances, Molybdenum 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 molybdenum contamination and preventing migration. This technology may not be as reliable when considering the reduction of molybdenum concentrations within the aquifer. Reduction of molybdenum concentrations is highly dependent on the success of source control steps and the ability of the molybdenum to be adsorbed within the soil column. Conventional vertical wells are installed within the RGA 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 molybdenum 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 molybdenum. Bench testing allows for the development of a site-specific approach to treat molybdenum 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 COIs over time to achieve the GWPS for molybdenum.

### 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 molybdenum concentrations over time. Standard techniques for obtaining and analyzing groundwater data for molybdenum are 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 molybdenum 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 molybdenum impacts within the RGA, the hydrogeologic characteristics of the RGA, the groundwater extraction rate from the RGA and the groundwater capture zone within the RGA;
- Specialized drilling equipment may be required to install the wells within the RGA depending on the depth of molybdenum impacts; and
- Limited space may be available on the top of the dikes adjacent to D-74B 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 molybdenum impacts, the hydrogeologic characteristics of the RGA, the groundwater extraction rate from the RGA and the groundwater capture zone within the RGA;
- Specialized drilling equipment will be required to install the horizontal wells in the RGA; and

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

Trenches:

- Specialized drilling equipment will be required to install the trenches within the RGA;
- 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 molybdenum 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 molybdenum impacts within the RGA and groundwater flow characteristics in the RGA. 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 for molybdenum treatment would require additional design, up-front monitoring and shallow wall installation for implementation. This technology is more difficult at SHF due to the depth of wall installation that is required to treat groundwater. EISTs could be permeable reactive barriers (PRBs), infiltration galleries or through direct injections specifically designed for molybdenum removal from groundwater. Implementation issues associated with each of these techniques is discussed below:

PRBs:

- Construction of a PRB for molybdenum 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 molybdenum 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 molybdenum 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 molybdenum.
- 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 **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 molybdenum are 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 molybdenum 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 molybdenum 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 molybdenum 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 molybdenum 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 molybdenum 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 molybdenum 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 molybdenum 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 molybdenum 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 molybdenum being present in the groundwater at concentrations generally 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 molybdenum. 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 molybdenum is currently unknown. The duration is directly dependent on the concentrations of molybdenum 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 molybdenum with hydraulic containment remedies are also subject to concentrations of COIs in the groundwater. Fate and transport modeling can 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 molybdenum 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 RGA, the degree and extent of molybdenum impact within the RGA, and the chemical behavior of molybdenum 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 molybdenum.  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 monitor the effectiveness of the CCR Multiunit closure method and groundwater in-situ treatment or groundwater extraction and treatment technologies for molybdenum. 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 Kentucky 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**

**SHF CCR Multiunit**

| | *Groundwater Restoration Action* | | *Groundwater Restoration Action* | | |
|---|---|---|---|---|---|
| | **Monitored Natural Attenuation** | **Enhanced In-Situ Treatment** | **Conventional Vertical Well System** | **Horizontal/ Angular Well System** | **Trenching System** |
| **257.96(c)(1)** | | | | | |
| **Performance** | **High**<br>Soil column will filter particulate that contains molybdenum/dissolved molybdenum. Loading will be reduced by source control approaches. | **High**<br>Enhanced in-situ treatment technologies are evaluated based upon bench-scale testing of impacted groundwater. | **Medium**<br>Technology is feasible due to narrow GW extraction window and groundwater pumping restrictions. Due to DOE's contamination of groundwater, restricted use of technology may occur. | **Medium**<br>Technology is feasible due to narrow GW extraction window and groundwater pumping restrictions. Due to DOE's contamination of groundwater, restricted use of technology may occur. | **Medium**<br>Technology is feasible due to narrow GW extraction window and groundwater pumping restrictions. Due to DOE's contamination of groundwater, restricted use of technology may occur. |
| **Reliability** | **High**<br>Soil column will filter particulate that contains molybdenum/dissolved molybdenum. Loading will be reduced by source control approaches. | **High**<br>Enhanced in-situ treatment technologies are evaluated based upon bench-scale testing of impacted groundwater. | **High**<br>Technology is reliable due to narrow GW extraction window and the downward vertical flow component of groundwater. Extraction of groundwater could be impacted or restricted by the DOE contamination plume. | **High**<br>Technology is reliable due to narrow GW extraction window and the downward vertical flow component of groundwater. Extraction of groundwater could be impacted or restricted by the DOE contamination plume. Application less common than vertical wells. | **High**<br>Technology is reliable due to narrow GW extraction window and the downward vertical flow component of groundwater. Extraction of groundwater could be impacted or restricted by the DOE contamination plume. Application less common than vertical wells. |
| **Ease of implementation** | **High**<br>Corrective Action Groundwater Monitoring will be conducted in accordance with 257.98 (a) (1). | **Medium**<br>The treatment zone has a narrow window. Installation of technology may require specialized construction equipment. Depth of installation makes use of technology more difficult. | **High**<br>Proven technology can be executed from top of berm/small hydraulic containment zone. This limits the number of extraction wells. | **Medium**<br>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. Surface constraints may limit ability for placement. | **Medium**<br>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 stability concerns during installation. |
| **Potential impacts of appropriate potential remedies: safety impacts** | **Low Risk**<br>All work activities are conducted in accordance with a site-specific health and safety plan for safe execution of groundwater monitoring activities. | **Medium Risk**<br>More advanced worker training is required to operate specialized equipment. | **Medium Risk**<br>More advanced worker training is required to operate specialized equipment. | **Medium Risk**<br>More advanced worker training is required to operate specialized equipment. | **Medium Risk**<br>More advanced worker training is required to operate specialized equipment. |
| **Potential impacts of appropriate potential remedies: cross-media impacts** | **Low Risk**<br>All work activities occur in-situ. | **Medium Risk**<br>All work activities occur in-situ with some potential to release treatment reagents to the environment through spills. | **Medium Risk**<br>All work activities bring soils and groundwater to ground surface with some potential to release COC's to the environment through spills. | **Medium Risk**<br>All work activities bring soils and groundwater to ground surface with some potential to release COC's to the environment through spills. | **Medium Risk**<br>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**<br>All work activities occur in-situ/groundwater impacts previously identified. | **Low Risk**<br>All work activities occur in-situ with some potential to release COC's to the environment through spills. | **Low Risk**<br>All work activities bring soils to ground surface with some potential to release COC's to the environment through spills. | **Low Risk**<br>All work activities bring soils to ground surface with some potential to release COC's to the environment through spills. | **Low Risk**<br>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 molybdenum in groundwater. | Varies dependent on groundwater fate, transport modeling and concentrations of molybdenum in groundwater. | Varies dependent on groundwater fate, transport modeling and concentrations of molybdenum in groundwater. | Varies dependent on groundwater fate, transport modeling and concentrations of molybdenum in groundwater. | Varies dependent on groundwater fate, transport modeling and concentrations of molybdenum in groundwater. |
| **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. May require KYDES permit modification. | KYDEP input required on Groundwater Corrective Action Monitoring Program. May require a KYDES permit modification. | KYDEP input required on Groundwater Corrective Action Monitoring Program. May require a KYDES permit modification. |
| **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. |