Assessment of Corrective Measures TVA Allen Fossil Plant, Memphis, Tennessee

July 15, 2019

Prepared for:

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This document entitled Assessment of Corrective Measures TVA Allen Fossil Plant, Memphis, Tennessee was prepared by Stantec Consulting Services Inc. (“Stantec”) for the account of Tennessee Valley Authority (TVA; the “Client”).

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Abbreviations

ACM	Assessment of Corrective Measures
ALF	Allen Fossil Plant
CCR	Coal Combustion Residuals
40 CFR	Title 40, Code of Federal Regulations
COI	Constituent of interest
CSM	Conceptual Site Model
EIS	Environmental Impact Statement
EIST	Enhanced In-Situ Treatment
ft	Feet
GWPS	Groundwater Protection Standard(s)
mg/L	Milligrams per liter
MSL	Main Sea Level
MNA	Monitored Natural Attenuation
NEPA	National Environmental Policy Act
NOI	Notice of Intent
NPDES	National Pollutant Discharge Elimination System
RI	Remedial Investigation
ROD	Record of Decision
SSL	Statistically Significant Level
SSLs	Statistically Significant Levels
TDEC	Tennessee Department of Environment and Conservation
TVA	Tennessee Valley Authority
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 in accordance with 40 CFR § 257.95(g) at the East Ash Disposal Area at the Allen Fossil Plant (ALF). During assessment monitoring, SSLs were identified at monitoring wells ALF-202, ALF-203, ALF-204 and ALF-205. The Appendix IV constituents with SSLs above GWPS included arsenic, fluoride, lead and molybdenum. As of the date of this report, TVA has not completed a demonstration that a source other than the CCR unit associated with wells ALF-202, ALF-203, ALF-204 and ALF-205 caused the SSLs at ALF, 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 the East Ash Disposal Area (the CCR Unit) at ALF. 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 CCR Unit is monitored by a CCR groundwater monitoring network consisting of one background well and eight downgradient wells.

Three primary strategies have been evaluated to address groundwater exhibiting concentrations of arsenic, fluoride, lead and 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). 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, Title 40, Code of Federal Regulations 40 CFR § 257.96. During assessment monitoring, if one or more Appendix IV CCR Rule constituent is detected at a statistically significantly level (SSL) above a site-specific groundwater protection standard (GWPS) established pursuant to 40 CFR § 257.95(h), then the owner/operator is given the opportunity to investigate if an alternate source is the cause of the SSL. If a viable alternate source for the SSL cannot be identified, then the owner/operator must initiate an ACM.

At the Tennessee Valley Authority (TVA) Allen Fossil Plant (ALF) East Ash Disposal Area (CCR Unit), groundwater assessment monitoring detected four Appendix IV constituents (i.e., arsenic, fluoride, lead and molybdenum) at SSLs above the GWPS in various wells (i.e., ALF-202, ALF-203, ALF-204 and ALF-205) (Stantec, 2019). 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).

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 Unit 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

ALF is located in Shelby County, in the southwest corner of the City of Memphis, Tennessee. The facility lies on the south bank of McKellar Lake and the eastern bank of the Mississippi River, **Figure 2-1** shows an overview map of ALF's location, facilities, and CCR units. Construction of ALF began in 1956, and all three of its coal-fired units were in operation by 1959. The coal-fired units were retired in March of 2018 (TVA, 2018). The coal combustion process at ALF resulted in the production of by-products that include fly ash and bottom ash. ALF most recently managed these residuals in the CCR Unit.

2.1 CCR UNIT DESCRIPTIONS

The East Ash Disposal Area (CCR Unit) is subject to the CCR Rule. The current area of the CCR Unit is approximately 85 acres inside of the perimeter dikes with a dike height of approximately 237 feet above mean sea level (ft MSL). During plant operations, the CCR Unit received sluiced fly and bottom ash, plant effluent, and stormwater runoff from the Coal Storage Area and Coal Yard Run-off Pond. The last ALF coal-fired generating units were shut down in March 2018. The CCR Unit no longer receives CCR or non-CCR waste streams under the CCR Rule.

2.2 OVERVIEW OF ENVIRONMENTAL REVIEWS OF 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 units. 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 East Ash Disposal Area 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 the East Ash Disposal Area 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, 2016).

TVA is preparing a site specific EIS to address the potential environmental effects associated with the future management of CCR material at ALF. This site specific EIS tiers off the 2016 *Programmatic Ash Closure Final EIS.* TVA published a NOI to prepare an EIS to the Federal Register on November 30, 2018, and accepted comments on the NOI through January 31, 2019 (Stantec, 2019). Additionally, a public information session was held on January 17, 2019 at the Mitchell Community Center in Memphis, TN.

After the scoping period concluded, TVA honed in the proposed alternatives and is evaluating the closure of both the East Ash Disposal Area and West Ash Disposal Area, including closure by removal to an offsite landfill location and closure by removal to a beneficial re-use facility and offsite landfill location.

A Closure Plan, dated April 23, 2019, has been placed in the facility operating record and posted to the CCR website. The Closure Plan states that, subject to the completion of all necessary environmental reviews, TVA intends to close the East Ash Disposal Area by removal of the CCR following the requirements of 40 CFR § 257.102(c).

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

The CCR Unit at ALF was constructed along the south shore of McKellar Lake. The subsurface geology at ALF from youngest to oldest consists of the Alluvial, Upper Claiborne confining unit (Claiborne) and the Memphis aquifer. The uppermost aquifer at ALF is the Alluvial aquifer which ranges from 111 to 245 feet in thickness. The Alluvial aquifer consists of alluvial sand or sand and gravel with an intervening blue clay unit. The CCR Unit directly overlies the Alluvial aquifer. The Claiborne underlies the Alluvial aquifer and consists of 27-69 feet of alluvial clay. The Memphis aquifer underlies the Claiborne and consists of a very coarse-grained sand. A typical cross-section view of the subsurface geology is shown on **Figure 2-2**.

2.3.2 Groundwater Flow Direction

Groundwater flow direction at the CCR Unit is dependent on surface water elevations in McKellar Lake; when McKellar Lake surface water elevations are low, groundwater flow is generally to the north, towards McKellar Lake. However, when surface water elevations in McKellar Lake are high, groundwater flow direction can reverse flow to the south, away from McKellar Lake. **Figure 2-3** presents a groundwater flow direction map for ALF when surface water elevations in McKellar Lake are high.

2.3.3 Potential Receptor Review

The City of Memphis obtains its water supply from multiple well fields that withdraw water from the Memphis aquifer. The Memphis and Fort Pillow aquifers are the primary drinking water sources for the surrounding area, including portions of eastern Arkansas and northern Mississippi. With the exception of the Davis Well Field, Memphis' drinking water well fields are more than 5.5 miles east of ALF. The Davis Well Field is approximately 2 miles south of the CCR Unit.

3.0 GROUNDWATER ASSESSMENT MONITORING PROGRAM

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

3.1 GROUNDWATER MONITORING NETWORK

In compliance with 40 CFR 257.91, one background well (ALF-210) was established and eight monitoring wells (ALF-201, ALF-202, ALF-203, ALF-204, ALF-205, ALF-206, ALF-212, and ALF-213) were installed downgradient of the CCR Unit. The locations of these monitoring wells are presented on **Figure 2-1**.

3.2 GROUNDWATER ASSESSMENT

Groundwater assessment monitoring was conducted in 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:

- An SSL for arsenic was identified at monitoring wells ALF-202, ALF-203 and ALF-204;
    - The maximum concentration of arsenic detected in 2018 was 3.26 milligrams per liter (mg/L) in ALF-203; and
    - The GWPS for arsenic is 0.010 mg/L.
- An SSL for fluoride was identified at monitoring well ALF-203;
    - The maximum concentration of fluoride detected in 2018 was 4.98 mg/L; and
    - The GWPS for fluoride is 4.0 mg/L.
- An SSL for lead was identified at monitoring well ALF-203;
    - The maximum concentration of lead detected in 2018 was 0.056 mg/L; and
    - The GWPS for lead is 0.015 mg/L.
- An SSL for molybdenum was identified at monitoring wells ALF-202, ALF-203 and ALF-205;
    - The maximum concentration of molybdenum detected in 2018 was 0.518 mg/L; and
    - The GWPS for molybdenum is 0.100 mg/L.

3.3 GROUNDWATER CHARACTERIZATION

In June 2017, TVA began a voluntary investigation to delineate constituents of interest in groundwater around the East Ash Disposal Area. In a July 18, 2017 letter, the Tennessee Department of Environment and Conservation (TDEC), requested TVA to develop a Remedial Investigation (RI) Work Plan with respect to the ongoing voluntary investigation. TVA submitted an RI Work Plan to TDEC, and on September 15, 2017, TDEC approved the RI Work Plan. The final RI report was submitted to TDEC on May 31, 2019.

Supplemental site characterization was performed under the 2019 RI and satisfied requirements of 40 CFR § 257.95(g)(1). Specifically, the RI work included the following elements and findings:

- Installation of additional monitoring wells at varying depths into the Alluvial aquifer as needed to define the horizontal and vertical extent of Appendix IV constituents greater than the GWPS;
- Four rounds of groundwater sampling confirmed the highest concentrations of arsenic, fluoride and lead are limited to the north and south areas, primarily above and within the blue clay zone in the upper 40 feet of the shallow Alluvial aquifer. The aquifer is approximately 110-245 feet thick. Groundwater flow in the aquifer is predominately horizontal, although relatively minor vertical gradients also exist.
- The areas of affected groundwater are not impacting the Memphis Aquifer or the public drinking water supply.
- Evaluation of the nature and estimated quantity of material released including concentrations of Appendix IV constituents; and
- Sampling of wells installed for the purpose of evaluating and designing a remedy.
- In December 2018, TVA submitted a Groundwater Monitoring Plan (GWMP) to TDEC specifying quarterly groundwater sampling around the East Ash Disposal Area throughout 2019. TVA will prepare a memorandum following each sampling event, and an Annual Report will be issued. At the end of 2019, the GWMP will be reviewed and modified as required to support the project needs.

Based on the location of CCR monitoring wells with Appendix IV SSLs, available data from existing CCR- and non-CCR monitoring wells, piezometers and geoprobe borings are currently considered for further characterization of COIs.

Arsenic concentrations on the north side of the CCR unit at monitoring wells ALF-203 and ALF-204 are estimated to be delineated horizontally by geoprobe borings GP-2 and GP-9 to the west and monitoring well ALF-205 to the east. Monitoring wells ALF-203A and ALF-204B provide an estimate of vertical delineation of arsenic. Arsenic concentrations on the south side of the CCR unit at monitoring well ALF-202 are estimated to be delineated horizontally by monitoring well ALF-201 to the west and monitoring well ALF-212 to the east. Monitoring well ALF-202B provide an estimate of vertical delineation of arsenic.

Fluoride and lead concentrations on the north side of the CCR unit at monitoring well ALF-203 are estimated to be delineated horizontally by geoprobe borings GP-2 and GP-9 to the west and geoprobe borings GP-8 and GP-24 to the east with partial delineation to the north by boring GP-4. Monitoring well ALF-203A provides an estimate of vertical delineation of fluoride and lead.

Molybdenum concentrations on the north side of the CCR unit at monitoring wells ALF-203 and ALF-205 are estimated to be delineated horizontally by piezometers ALF-P-4 and ALF-P-4S to the west and monitoring well ALF-206 to the east. Monitoring wells ALF-203A and ALF-205B provide an estimate of vertical delineation of molybdenum. Molybdenum concentrations on the south side of the CCR unit at monitoring well ALF-202 are estimated to be delineated horizontally by monitoring well ALF-214 to the west and monitoring well ALF-212 to the east. Monitoring well ALF-202A provides an estimate of vertical delineation of molybdenum.

The potential treatment zones to address the extent of arsenic, fluoride, lead and molybdenum along the unit perimeter above the GWPS is illustrated on **Figure 3-1**

As part of the interim response activities resulting from the RI work, TVA has initiated interim measures to control and begin treating impacted groundwater, and to remove free water and ash pore water from the East Ash Disposal Area through a dewatering process. In March 2019, TVA released the ALF Ash Impoundment Closure Environmental Impact Statement (EIS) Scoping Document. Through the National Environmental Policy Act (NEPA) process, TVA considered multiple options for ash impoundment closure and determined that closure-in-place should be eliminated from further consideration. The NEPA process will continue to address the alternatives of closure by removal of the CCR Unit to an offsite landfill and/or to a beneficial reuse facility in accordance with applicable state and federal laws.

Additionally, TVA is currently conducting an environmental investigation of the CCR disposal sites at ALF under the oversight of the Tennessee Department of Environment and Conservation (TDEC) through the TDEC Commissioner's Order, OGC 15-0177 (TDEC Order), issued on August 6, 2015. The CCR Unit is included in the TDEC Order process. Once the environmental investigations are complete, TVA must submit environmental assessment reports (EAR) that provide an analysis of the extent of CCR contamination, including groundwater contamination, at each site to TDEC for approval. Then, as part of the TDEC Order process, TVA must submit a Corrective Action/Risk Assessment (CARA) Plan that specifies all actions that TVA plans to take at a site, including corrective measures for groundwater remediation. TDEC must approve the CARA Plan, including the selected remedy(s) and corrective measures for groundwater remediation, before TVA may commence implementation. The work being performed under the TDEC Order process will further inform the evaluation and selection of the groundwater remedy(s) under 40 CFR § 257.97 of the CCR Rule.

3.4 SUMMARY OF ALTERNATE SOURCE DEMONSTRATION

At this time, TVA has not completed an alternate source demonstration at ALF for the SSL exceedances over the GWPS for the CCR Unit.

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 has determined that arsenic, fluoride, lead and molybdenum were present at an SSL above the GWPS as defined in 40 CFR § 257.95(h) at monitoring wells ALF -202, ALF-203, ALF-204 and ALF-205. As discussed in Section 3.3, additional groundwater characterization will be conducted as a component of the remedy selection process.

This section of the report provides an ACM to address groundwater exhibiting arsenic, fluoride, lead and molybdenum concentrations 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 UNIT

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 convert from wet to dry handling of CCR and to comply with regulatory requirements and timeframes under the CCR Rule, TVA has removed the CCR Unit from service and has initiated closure. Subject to the necessary environmental review, the preferred alternative for closure of the East Ash Disposal Area is closure by removal accordance with 40 CFR § 257.102. Removing the CCR Unit from service will limit the potential for COI releases due to the ceasing of placement of additional CCR materials. Closure of the CCR Unit will further reduce releases since rainwater will not come into contact with the CCR.

Annual reports will be generated pursuant to 40 CFR § 257.90(e) to summarize the results of the groundwater assessment monitoring, and semi-annual progress 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 COIs from the CCR Unit.

4.3 POTENTIAL REMEDIAL TECHNOLOGIES

This ACM provides an evaluation of potential remedial technologies to address the SSLs observed at monitoring wells ALF-202, ALF-203, ALF-204 and ALF-205. As discussed in Section 4.2, subject to environmental review, the preferred alternative for the East Ash Disposal Area is closure by removal. Closure of the CCR Unit 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 measures both require treatment of groundwater (either in-situ or ex-situ). **Table 1** presents a summary of technologies evaluated to treat arsenic, fluoride, lead and 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 Unit 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 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, fluoride, lead and molybdenum concentrations above 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 the 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 arsenic, fluoride, lead and 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 arsenic, fluoride, lead and molybdenum at ALF. Bench-scale treatability studies may be conducted on representative groundwater samples collected from ALF monitoring wells 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

Stantec. (2019). *Annual Groundwater Monitoring and Corrective Action Report, Allen Fossil Plant, East Ash Disposal Area CCR Unit.* January 31.

TVA. (2016). Final Ash Impoundment Closure Environmental Impact Statement Part 1 – Programmatic NEPA Review. June.

TVA. (2018). *Allen Natural Gas Plant Goes Commercial.* Tennessee Valley Authority. May 1.

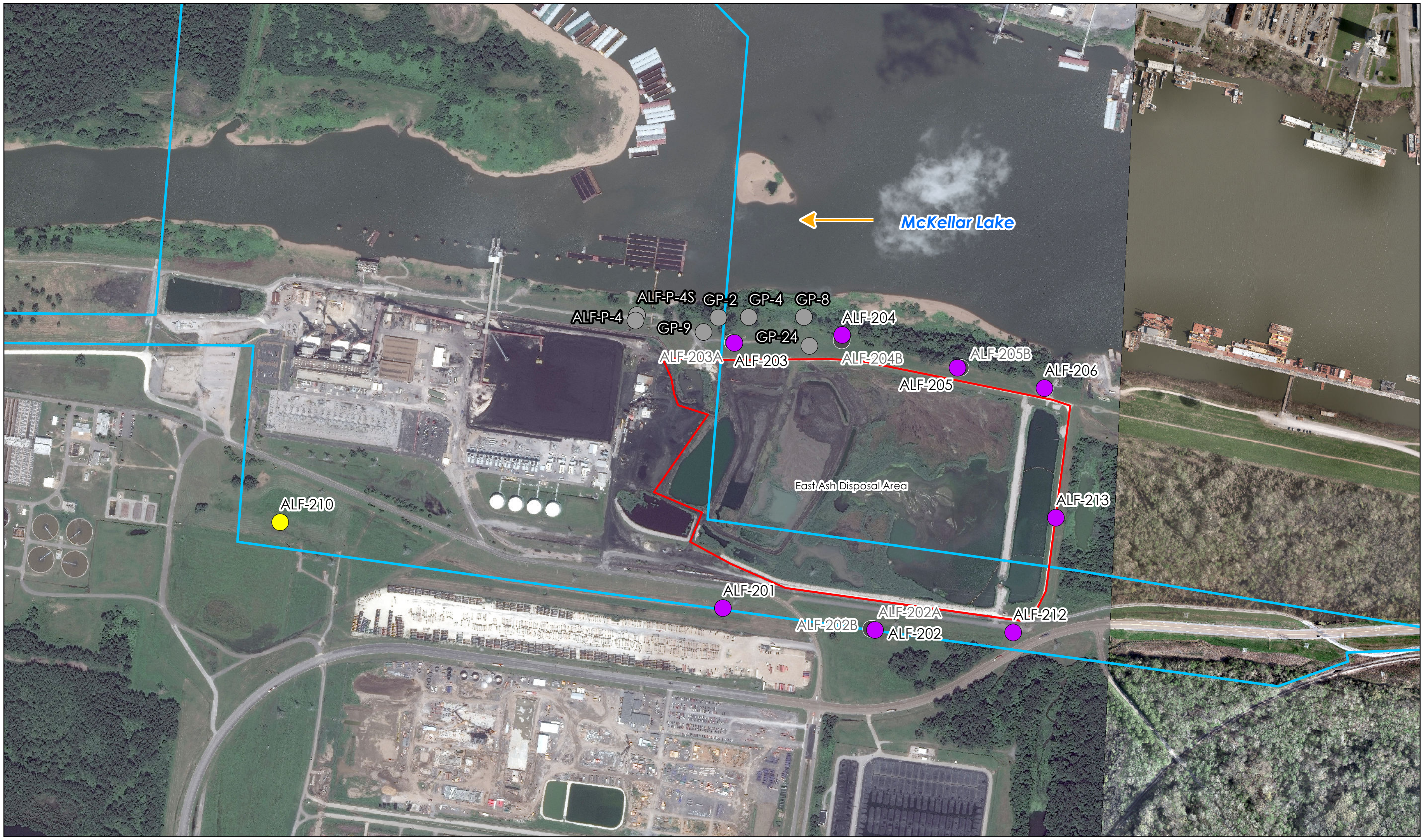
TABLES

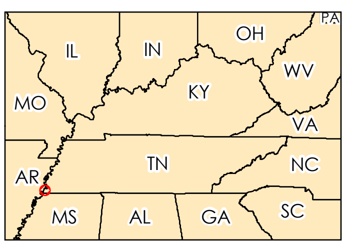
TABLE 1.
WATER TREATMENT TECHNOLOGIES FOR CONSTITUENTS
TENNESSEE VALLEY AUTHORITY - ALLEN FOSSIL PLANT
CCR UNIT

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

*Constituent of Interest

Figures





Legend

- Piezometers or Geoprobe Borings
- Investigation Well
- Background Well
- Downgradient Well
- CCR Unit Subject to CCR Rule
- TVA Property Boundary

N

0 500 1,000 Feet

(At original document size of 8.5x11)
1:12,000

Notes
1. Coordinate System: NAD 1983 StatePlane Tennessee FIPS 4100 Feet
2. Background: TVA Imagery 2015/2016

Project Location
City of Memphis
Shelby County, TN

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
182603470
Tennessee Valley Authority
Allen Fossil Plant
CCR Rule

Figure No.
Figure 2-1

Title
CCR Unit with Background and Downgradient Wells

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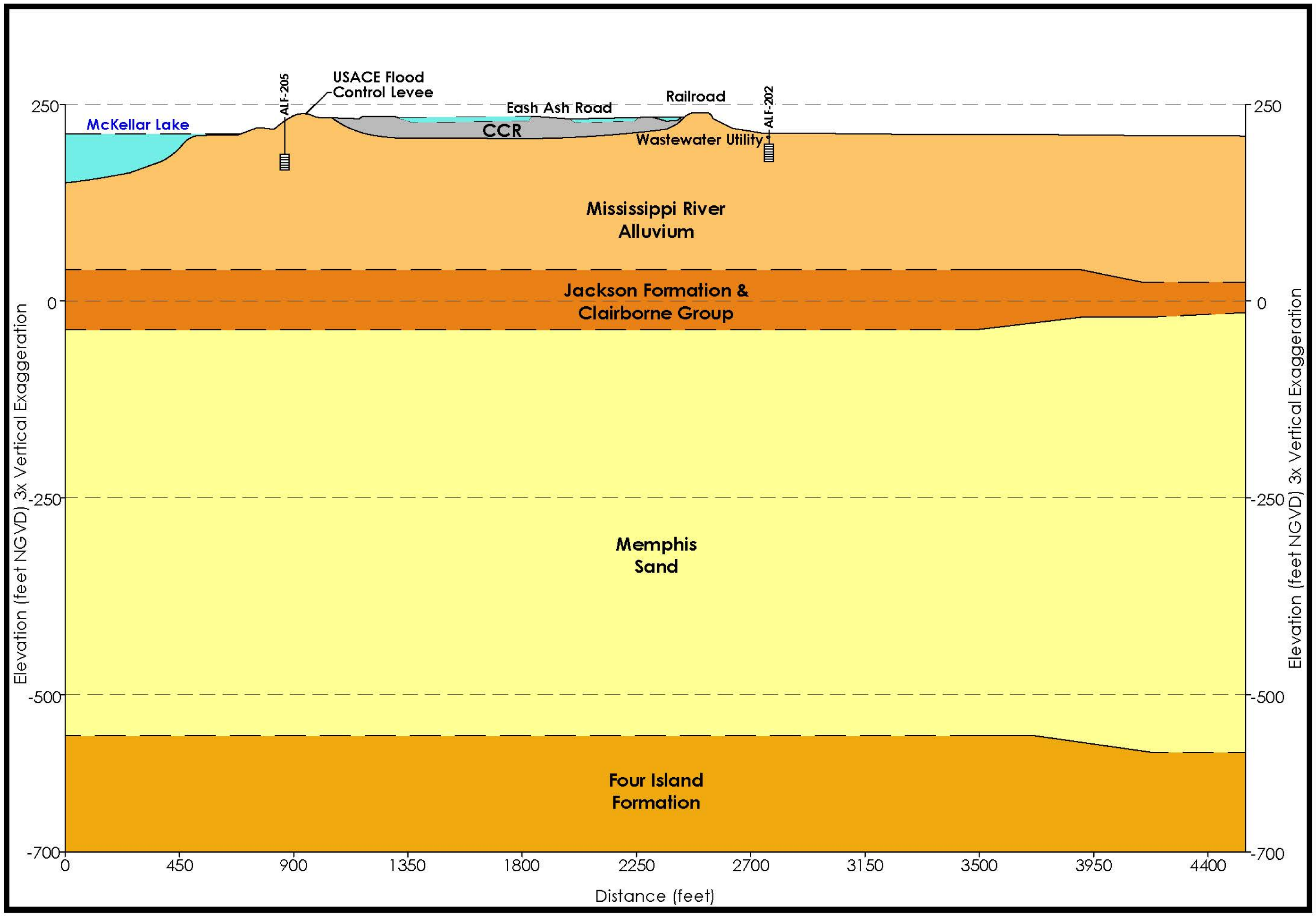
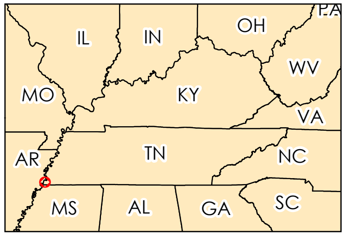




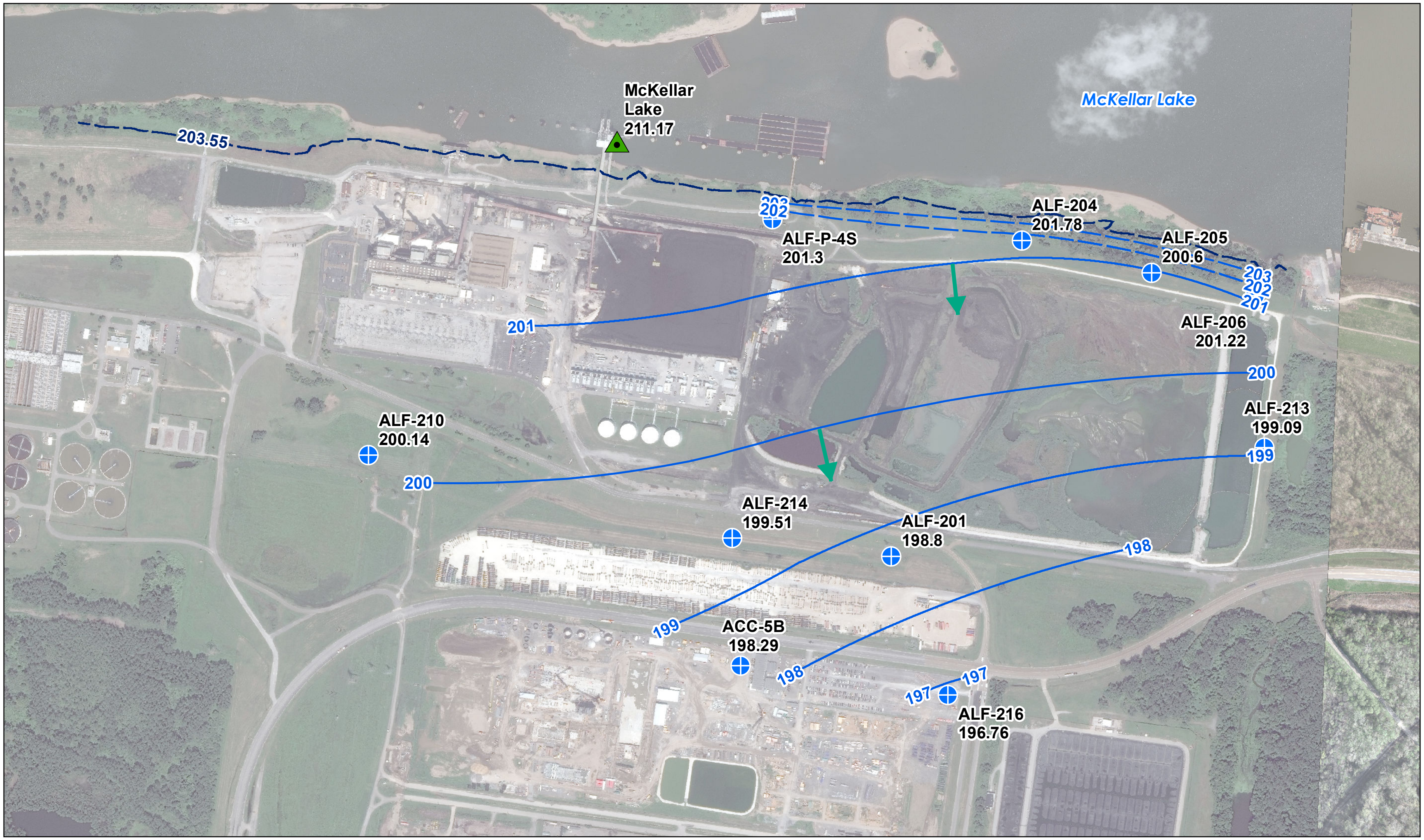
Project Location
City of Memphis
Shelby County, TN

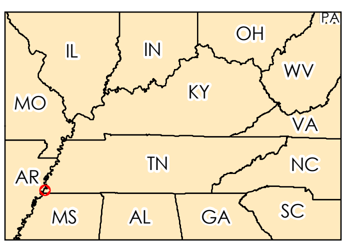
Prepared by LMB on 2019-07-15
Technical Review by EP on 2019-07-15
Independent Review by JB on 2019-07-15

Client/Project
182603470
Tennessee Valley Authority
Allen Fossil Plant
CCR Rule

Figure No.
Figure 2-2

Title
Geologic Cross-Section





Pressure Transducer Location (Sandy Zone Shallow Wells - 12/26/18)

McKellar Lake Gauging Station

Inferred Groundwater Elevation Surface (C.I. = 1 ft)

Dashed Where Estimated Between Wells and Lake McKellar

Estimated McKellar Lake Shoreline (203.55)

Generalized Flow Direction

N

0 425 850 Feet

(At original document size of 8.5x11)
1:10,200

Notes
1. Coordinate System: NAD 1983 StatePlane Tennessee FIPS 4100 Feet
2. Background: TVA Imagery 2015/2016

Project Location
City of Memphis
Shelby County, TN

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
Allen Fossil Plant
CCR Rule

182603470

Figure No.
Figure 2-3

Title
Groundwater Flow Direction (Alluvial Aquifer)

TVA

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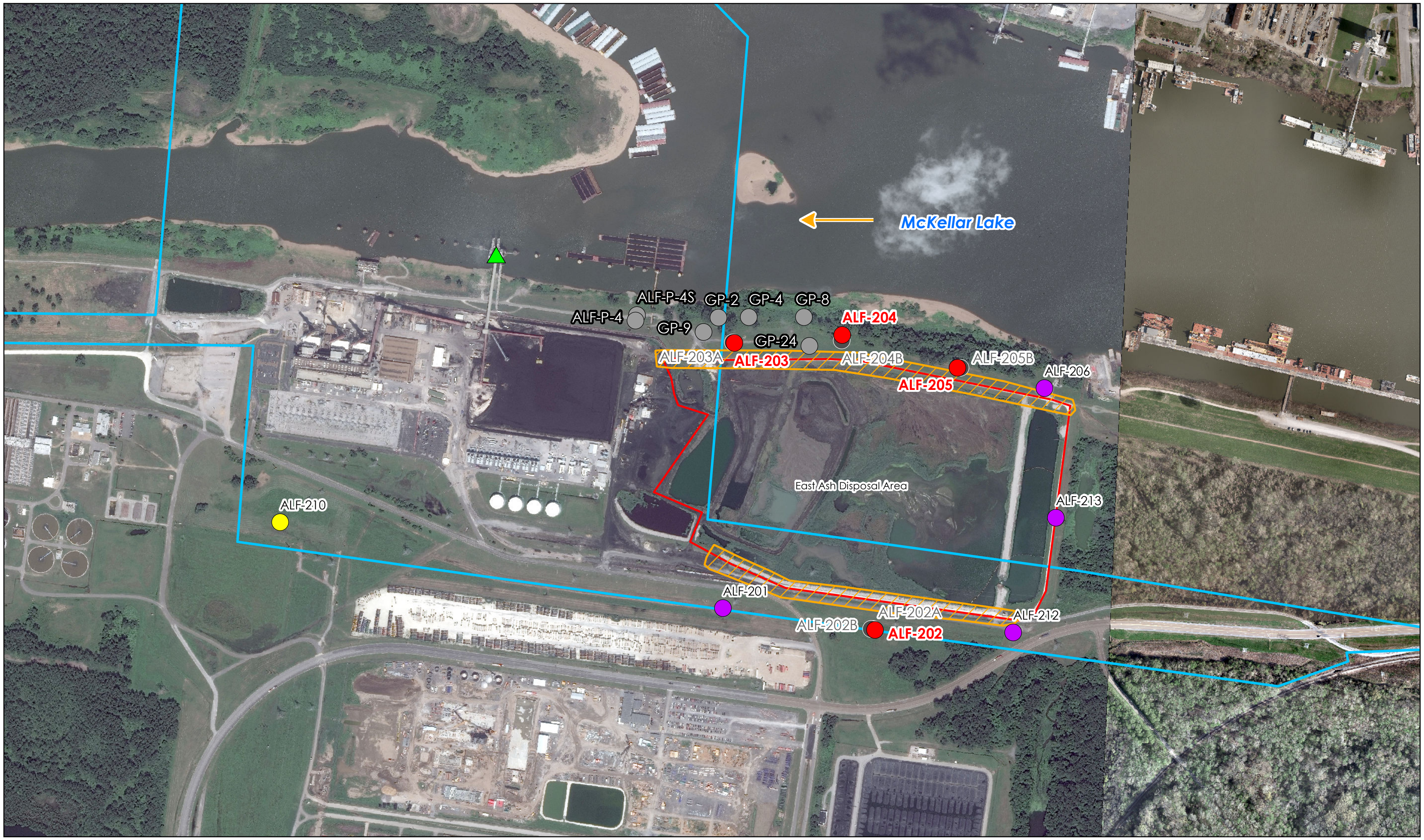

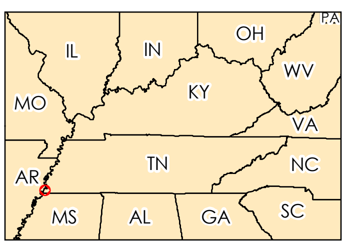

Legend

- Piezometers or Geoprobe Borings
- Investigation Well
- Staff Gauge
- Background Well
- Downgradient Well
- GWPS Exceedance Well
- CCR Unit Subject to CCR Rule
- TVA Property Boundary
- Potential Treatment Zones (Arsenic, Lead, Molybdenum, Fluoride)

N

0 500 1,000 Feet

(At original document size of 8.5x11)
1:12,000

Notes
1. Coordinate System: NAD 1983 StatePlane Tennessee FIPS 4100 Feet
2. Background: TVA Imagery 2015/2016

Project Location
City of Memphis
Shelby County, TN

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
182603470
Tennessee Valley Authority
Allen Fossil Plant
CCR Rule

Figure No.
Figure 3-1

Title
Monitoring Wells and Limits of COI Impacts

TVA

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

At wells ALF-202, ALF-203, ALF-204 and ALF-205 of the CCR Unit at ALF, there is a statistically significant level (SSL) above the groundwater protection standard (GWPS) for arsenic, fluoride, lead and molybdenum. Closure of the CCR Unit has been initiated since the CCR Unit is no longer receiving waste streams. The following conditions at ALF make MNA a viable strategy:

- Limited impacts to groundwater: Currently, an SSL above GWPS established under 40 CFR § 257.95(h) for arsenic, fluoride, lead and molybdenum is observed along an isolated portion of the CCR Unit. There are no drinking water supply wells on site, including between the CCR Unit and the adjacent surface water. 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: COIs are 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 Assessment 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 to 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 ALF, 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 Unit. 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 potential 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 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 Unit. 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, 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 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 Unit 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 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 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

Discharge of CCR to the CCR Unit ceased in 2017. Only stormwater and water from steam generation enters the CCR Unit. Elimination of the CCR discharge reduces the source of COIs released to the groundwater.

2.2 GROUNDWATER CORRECTIVE MEASURES

The groundwater corrective measures evaluated for arsenic, fluoride, lead and molybdenum 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 to determine if the arsenic, fluoride, lead and molybdenum concentrations are stable or decreasing. Once the source is controlled, natural groundwater flux should result in reduced concentrations of these COIs after a period of time. The groundwater assessment monitoring will determine if the source control measures are reducing or stabilizing arsenic, fluoride, lead and 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 ALF;
- Length of impacts along the perimeter of the CCR Unit;

- Thickness of Alluvium at ALF;
- Groundwater capture zones; and
- Arsenic, fluoride, lead 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 tests. These additional studies are focused on the arsenic, fluoride, lead and molybdenum present at the CCR Unit 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, fluoride, lead and molybdenum;
- Treated groundwater discharge location; and
- Estimated time frame to achieve GWPS.

Groundwater extraction and treatment is a feasible technology at ALF 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, fluoride, lead and molybdenum impacts along the perimeter of the CCR Unit;
- Groundwater flow rate within the Alluvium; and,
- Arsenic, fluoride, lead 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 arsenic, fluoride, lead and molybdenum present at the CCR Unit 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, fluoride, lead and molybdenum present in the Alluvium;
- Optimum EIST media for arsenic, fluoride, lead and molybdenum treatment;

- 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 used to evaluate 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, fluoride, lead and molybdenum 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, fluoride, lead and 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 of arsenic, fluoride, lead and molybdenum levels in the groundwater returning to levels below the GWPS. In these instances, arsenic, fluoride, lead and 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 arsenic, fluoride, lead and molybdenum contamination and preventing migration. This technology may not be as reliable when considering the reduction of arsenic, fluoride, lead and molybdenum concentrations within the aquifer. Reduction of arsenic, fluoride, lead and molybdenum concentrations is highly dependent on the success of source control steps and the ability of arsenic, fluoride, lead and molybdenum 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 for arsenic, fluoride, lead and molybdenum treatment that can, under appropriate conditions, reliably reduce arsenic, fluoride, lead and 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 arsenic, fluoride, lead and molybdenum. Bench testing allows for the development of a site-specific approach to treat arsenic, fluoride, lead and 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 arsenic, fluoride, lead and 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 arsenic, fluoride, lead and molybdenum concentrations over time. Standard techniques for obtaining and analyzing groundwater data for arsenic, fluoride, lead and 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 arsenic, fluoride, lead and molybdenum contamination and are applicable for groundwater treatment at ALF. 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, fluoride, lead and molybdenum 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, fluoride, lead and molybdenum impacts; and
- Limited space may be available on the top of the dikes adjacent to ALF-202, ALF-203, ALF-204 and ALF-205 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, fluoride, lead and molybdenum 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.

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, fluoride, lead and 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 arsenic, fluoride, lead and molybdenum 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 extensive 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, fluoride, lead and molybdenum removal from groundwater. Implementation issues associated with each of these techniques is discussed below:

PRBs:

- Construction of a PRB for arsenic, fluoride, lead and 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 arsenic, fluoride, lead and molybdenum treatment with standard drilling equipment;

- Access can be limited at ALF, 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, fluoride, lead and molybdenum treatment can be accomplished with standard drilling equipment;
- Access can be limited at ALF, 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, fluoride, lead and 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 to treat arsenic, fluoride, lead and molybdenum in groundwater.

5.1 GROUNDWATER CORRECTIVE MEASURES

Safety impacts that may occur as a result from the implementation of groundwater corrective measures for arsenic, fluoride, lead and molybdenum 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, fluoride, lead and 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 arsenic, fluoride, lead and 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 arsenic, fluoride, lead and molybdenum treatment would require a more complex construction plan due to the depth of barrier wall construction 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, fluoride, lead and 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 arsenic, fluoride, lead and 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 arsenic, fluoride, lead and 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 arsenic, fluoride, lead and 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 arsenic, fluoride, lead and 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 arsenic, fluoride, lead and 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 arsenic, fluoride, lead and 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 corrective measure selection 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 Unit will take eight to ten years to complete using a closure by removal approach;
- Interim measures for groundwater remediation for arsenic, fluoride, lead and molybdenum, if instituted prior to CCR Unit 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 Unit 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, fluoride, lead and molybdenum is unknown. The duration is directly dependent on the concentrations of arsenic, fluoride, lead and 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. Groundwater 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, fluoride, lead and molybdenum with hydraulic containment remedies are also subject to concentrations of COIs in the groundwater. Groundwater 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 arsenic, fluoride, lead and arsenic, fluoride, lead and 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 Alluvium, the degree and extent of arsenic, fluoride, lead and molybdenum impact within the Alluvium, and the chemical behavior of arsenic, fluoride, lead and 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 arsenic, fluoride, lead and 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 monitoring the effectiveness of the CCR Unit closure method and groundwater in-situ treatment or groundwater extraction and treatment technologies for arsenic, fluoride, lead and 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

- Tennessee 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
ALF CCR Unit

	Groundwater Corrective Action		*Groundwater Corrective Action*		
	Monitored Natural Attenuation	**Enhanced In-Situ Treatment**	**Conventional Vertical Well System**	**Horizontal/ Angular Well System**	**Trenching System**
257.96(c)(1)					
Performance	**High** Source control approaches will reduce loading of COIs to the groundwater. COI concentrations reduced resulting from adsorption and co-precipitation as COIs migrate through the soil column.	**High** Enhanced in-situ treatment technologies can be 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, adsorb or co-precipitate GW that contains COIs. Loading of COIs will be reduced by source control approaches improving the reliability of MNA.	**High** Enhanced in-situ treatment technologies can be evaluated based upon bench-scale testing of impacted groundwater.	**High** Technology is reliable due to defined GW extraction window and the downward vertical flow component of groundwater.	**High** Technology is reliable due to defined GW extraction window and the downward vertical flow component of groundwater.	**High** Technology is reliable due to defined GW extraction window and the downward vertical flow component of groundwater.
Ease of implementation	**High** Corrective Action Groundwater Monitoring Conducted in Accordance with 257.98 (a) (1)	**Medium** The treatment zone has a narrow window. Installation of technology may require specialized construction equipment.	**High** Proven Technology Can Be Executed from Top of Berm. Small Hydraulic Containment Zone Limits the Number of Extraction Wells Required	**Medium** Proven Technology Can Be Executed from Top of Berm But Requires More Clearance Zone. Small Hydraulic Containment Zone Limits the Length of Horizontal Wells	**Medium** Proven Technology Can Be Executed from Top of Berm But Requires More Clearance Zone. Small Hydraulic Containment Zone Limits the Length of Recovery Trenches
Potential impacts of appropriate potential remedies: safety impacts	**Low Risk** All work activities are conducted in accordance with TVA's Safe Work Practices.	**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 COIs in CCR pore water.	Varies dependent on groundwater fate, transport modeling and concentrations of COIs in CCR pore water.	Varies dependent on groundwater fate, transport modeling and concentrations of COIs in CCR pore water.	Varies dependent on groundwater fate, transport modeling and concentrations of COIs in CCR pore water.	Varies dependent on groundwater fate, transport modeling and concentrations of COIs in CCR pore water.
257.96(c)(3)					
State, local or other environmental permit requirements that may substantially affect implementation	TDEC input required on Groundwater Corrective Action Monitoring Program and remedy selection.	TDEC input required on Groundwater Corrective Action Monitoring Program and remedy selection.	TDEC input required on Groundwater Corrective Action Monitoring Program and remedy selection. A TNDES permit modification may be required.	TDEC input required on Groundwater Corrective Action Monitoring Program and remedy selection. A TNDES permit modification may be required.	TDEC input required on Groundwater Corrective Action Monitoring Program and remedy selection. A TNDES permit may be 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.