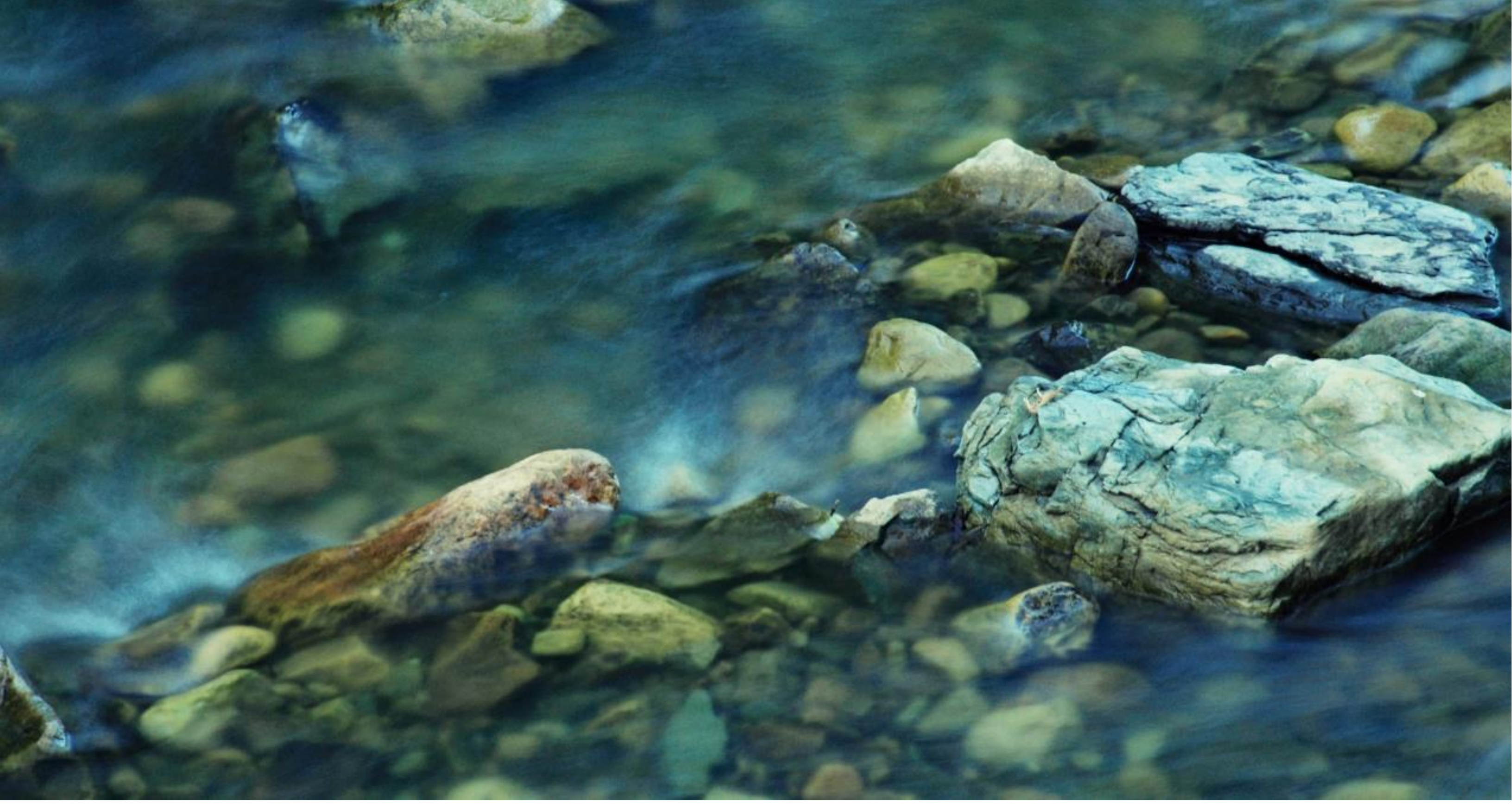


July 2020
Plant Gadsden

Assessment of Corrective Measures Plant Gadsden Ash Pond

Prepared for Alabama Power Company

July 2020
Plant Gadsden

Assessment of Corrective Measures Plant Gadsden Ash Pond

James C. Redwine

James C. Redwine
Senior Reviewer
Date: July 6, 2020

Kristi Mitchell
Originator
Date: July 6, 2020

Prepared for
Alabama Power Company
600 18th Street North
Birmingham, Alabama 35203

Prepared by
Anchor QEA, LLC
600 Vestavia Parkway, Suite 121
Vestavia Hills, Alabama 35216

Project Number: 201114-02.01

TABLE OF CONTENTS

TABLES

FIGURES

ABBREVIATIONS

ACM	Assessment of Corrective Measures
ADEM	Alabama Department of Environmental Management
Admin. Code	Administrative Code
APC	Alabama Power Company
CCR	coal combustion residuals
CFR	Code of Federal Regulations
CMS	corrective measures study
COI	constituent of interest
CSM	conceptual site model
EPRI	Electric Power Research Institute
GWPS	groundwater protection standard
ISS	in situ solidification/stabilization
mg/kg	milligram per kilogram
mg/L	milligram per liter
MNA	monitored natural attenuation
O&M	operation and maintenance
Plant Gadsden	Gadsden Electric Generating Plant
PRB	permeable reactive barrier
RCRA	Resource Conservation and Recovery Act
RCRA FIRST Toolbox	*Resource Conservation and Recovery Act Facilities Investigation Remedy Selection Track: A Toolbox for Corrective Action*
Site	Ash Pond at Plant Gadsden
SSE	selective sequential extraction
SSI	statistically significant increase
SSL	statistically significant level
USEPA	U.S. Environmental Protection Agency
XRD	X-ray diffraction

1 Introduction

This Assessment of Corrective Measures (ACM) has been prepared pursuant to U.S. Environmental Protection Agency (USEPA) coal combustion residuals (CCR) rule (40 Code of Federal Regulations [CFR] Part 257, Subpart D), the Alabama Department of Environmental Management's (ADEM's) Administrative Code (Admin. Code) r. 335-13-15, and an Administrative Order issued by ADEM (19-104-GW) to evaluate potential groundwater corrective measures for the occurrence of arsenic and lithium in groundwater at statistically significant levels (SSLs) at the Ash Pond at Plant Gadsden (Site).

Specifically, this ACM is prepared pursuant to 40 CFR 257.96, ADEM Admin. Code r. 335-13-15-.06(7), and Part D of the Administrative Order. Pursuant to the requirements of Part D of the Administrative Order, this ACM also "include(s) the remedy proposed to ADEM for approval." As required by rule, this ACM was initiated by April 11, 2020 (APC 2020a).

This ACM is the first step in developing a long-term corrective action plan to address exceedances of groundwater protection standards (GWPS) identified at the Site. Based on the results of the ACM, further evaluation will be performed, site-specific studies completed, and a final long-term corrective action plan developed and implemented pursuant to 40 CFR 257.97–98 and ADEM Admin. Code r. 335-13-15-.06(8) and (9).

In addition to the corrective measures discussed in this ACM, the Alabama Power Company (APC) closed the Site by excavating and consolidating the unit's CCR material into a smaller area located within the original footprint of the Site. A final cover system was installed that was designed to minimize infiltration and erosion. A summary of the closure plan was published in April 2018 (APC 2018a). A *Notice of Closure Completion* was published in April 2020 (APC 2020b).

Completing a final long-term corrective action frequently takes several years. Therefore, corrective measures presented herein can be applied as warranted based on site conditions during post-closure monitoring and while implementing a long-term corrective action strategy to meet remedial objectives at the Site.

1.1 Purpose and Approach

The purpose of this ACM is to begin the process of selecting corrective measure(s). This process may be composed of multiple components to analyze the effectiveness of corrective measures and to address the potential prior migration of CCR constituents to groundwater at the Site.

The CCR rule (40 CFR 257, Subpart D), ADEM Admin. Code Ch. 335-13-15, and ADEM AO 19-104-GW provide requirements for an ACM. In addition, the subsequent 2016 USEPA report entitled *Resource Conservation and Recovery Act Facilities Investigation Remedy Selection Track: A Toolbox for Corrective*

Action (RCRA FIRST Toolbox; USEPA 2016) provides general guidance for conducting a Corrective Measures Study (CMS) at Resource Conservation and Recovery Act (RCRA) facilities. Because a CMS is equivalent to an ACM, ACM will be used in this report for consistency with the CCR rule terminology. The RCRA FIRST Toolbox (USEPA 2016) describes three approaches for assessing the need for, or performing, an ACM at RCRA facilities: No ACM, Limited ACM, and Full ACM.

According to the RCRA FIRST Toolbox (USEPA 2016), a full ACM is not required in every case, and determining the appropriate level of study is the first step in an ACM. Because two Appendix IV constituents (arsenic and lithium) were identified at the Site and several technologies are available for addressing the constituents, a full and thorough ACM was performed for the Site.

Per USEPA (2016) guidance, corrective measures that were clearly not viable were not evaluated. Initial steps in the ACM included analyzing existing Site information and developing a conceptual site model (CSM). The anticipated impacts of closure and source control were also considered because those activities are integral to the long-term strategy and will influence groundwater corrective measures performance. Potential groundwater corrective measures were then identified and evaluated against the applicable criteria.

Frequently used technologies that are unlikely to perform satisfactorily or reliably at the Site, or that are technically impractical to implement, were not thoroughly evaluated as part of this ACM. Though several technologies and combinations of these technologies appear viable for the Site, further evaluation of the technologies is needed to identify a remedy (or remedies) that may be implemented as part of a long-term corrective action plan.

1.2 Remedy Evaluation Criteria

Once potential remedies were identified, they were evaluated using the criteria outlined in 40 CFR 257.96 and ADEM Admin. Code r. 335-13-15-.06(7), which state that the ACM should include an analysis of the effectiveness of potential corrective measures that considers the following:

- Performance
- Reliability
- Ease of implementation
- Potential impacts of the remedy (including safety, cross-media impacts, and exposure)
- The time required to begin and complete the remedy
- Any institutional requirements (e.g., permitting or environmental and public health requirements) that could affect implementation of the remedy

These evaluation criteria, discussed in more detail in the following sections, were considered for each potential remedy.

1.2.1 Performance

Factors taken into consideration when determining the performance of a remedy include the degree to which the remedy removes released Appendix IV constituents from the environment and the ability of the remedy to achieve GWPS at compliance boundaries.

1.2.2 Reliability

Reliability includes the type and degree of long-term management (e.g., monitoring, operations, and maintenance) of a remedy, the reliability of the engineering and institutional controls to maintain the effectiveness of the remedy, potential need for replacement, or any other operational reliability issues that may arise for the remedy that will limit its use or effectiveness in meeting the corrective action objectives.

1.2.3 Ease of Implementation

Ease of implementation includes the degree of difficulty associated with installing or constructing a remedy due to site conditions, including the need to obtain necessary approvals and/or permits from other agencies, the availability of necessary equipment and/or specialists to implement the remedy, and the available capacity and location of treatment, storage, or disposal services, if needed.

1.2.4 Potential Impacts of the Remedy

Potential impacts of a remedy include the short-term risks that might be posed to the community or the environment during implementation of the remedy (e.g., due to excavation, transportation, disposal, or containment of CCR material), potential for exposure of humans and environmental receptors to remaining CCR material following implementation of the remedy, and cross-media impacts due to the remedy.

1.2.5 Time Required to Begin and Complete the Remedy

The time required to begin and complete a remedy considers the amount of time needed to completely design and implement (i.e., begin) the remedy as well as the time it will take the implemented remedy to achieve applicable GWPS at compliance points.

1.2.6 Institutional, Environmental, or Public Health Requirements

Institutional requirements can vary from site to site and technology to technology. Any state, local, or site-specific requirements (e.g., permits), or other environmental or public health requirements, that could substantially affect construction or implementation of the remedy are considered.

2 Site Background and Characteristics

2.1 Location and Site History

APC's Gadsden Electric Generating Plant (Plant Gadsden) is located in the northeastern area of the city of Gadsden, in central Etowah County, Alabama. The physical address of the plant is 1000 Goodyear Avenue, Gadsden, Alabama, 35903. Plant Gadsden occupies Sections 2, 3, and 11, Township 12 South, Range 6 East (USGS 1986). The Ash Pond is located northeast of the plant and is separated from the main plant by the Coosa River (Figure 1; SCS 2020a).

Plant Gadsden is an electricity generating facility that included coal-fired units, which have since been converted to natural gas-fired units. The Ash Pond was originally constructed in 1949 by creating an earthen dike around an existing bottom area upslope from the Coosa River. The Ash Pond's original discharge structure was constructed on the Coosa River side of the impoundment and discharged into a channel feeding the river. The Ash Pond was expanded in 1976 and again in 1978 (APC 2018b).

The Ash Pond stopped receiving coal ash in 2015 when Units 1 and 2 were converted to natural gas; however, it continued to receive process water from the plant. The discharge structure continued to function as designed until early 2016 when closure activities began (APC 2018b). The CCR has been graded to its final configuration and covered. The remaining closure activities for the purpose of achieving compliance with regulatory closure requirements were completed in 2020 (APC 2020b).

2.2 Site Geology, Hydrogeology, and Groundwater Flow

Boring logs from monitoring well and piezometer installations provide details on subsurface geologic conditions between ground surface and 30 feet below ground surface. Site geology consists of two distinct geologic units underlying the Site and are described from shallowest to deepest as follows (SCS 2019a):

- Surficial soils are described as Quaternary-age alluvial low terrace deposits and high terrace deposits consisting of varying amounts of sand, silt, clay, and gravel associated with river deposition (Raymond et al. 1988). The thickness of this soil deposit ranges from 20 to 30 feet at the Site. This deposit typically coarsens downward and displays a horizontal coarsening pattern towards the north-northeast. Site groundwater monitoring wells are installed within higher permeability zones near the base of the alluvial deposits and near the interface with underlying rock.
- The Conasauga Formation (Middle and Upper Cambrian) consists of varying amounts of limestone, dolomite, and shale. Chert and siltstone horizons can be present locally. Limited core logs from the Site indicate the Conasauga Formation to be a medium to dark gray mudstone or shale with noticeable calcite veining. In Etowah County, the Conasauga

Formation has been targeted as a potential source for shale gas and is preserved within the Gadsden antiform (Pashin 2008). The Conasauga Formation is not considered to be a water-bearing aquifer at the Site.

Figures 2a and 2b illustrate the above-described geologic stratigraphy beneath the Site.

The uppermost aquifer beneath the Site corresponds to the coarse and more permeable fraction of alluvial overburden soils and weathered/ fractured rock near the soil-rock interface. The uppermost aquifer is typically located at depths between 15 and 50 feet below ground surface. Soils are generally poorly graded sands with layers of clay and well-graded gravels that overlay a mudstone or shale bedrock. Groundwater recharge to the uppermost aquifer is largely accomplished via infiltration of precipitation and subsequent percolation down to the water table. Monitoring wells are typically screened across reddish-brown (iron-coated) coarse sediments and/or weathered Conasauga mudstone/shale (SCS 2019a).

Within overburden soils beneath the Site, groundwater flow occurs via porous (Darcy) flow mechanics with potential for preferential movement along more conductive sand and gravel lenses or channels. Groundwater elevations fluctuate in response to rainfall. Seasonal variations of 3 to 10 feet are typical at the Site with fluctuations typically being greater farther away from the Coosa River, which is consistent with groundwater recharge areas. Slug testing and Shelby tube permeameter testing reveal that sandy fractions generally have a hydraulic conductivity between 0.5 and 7 feet per day (SCS 2019a).

Groundwater level monitoring was initiated with background sampling in December 2017 before Site closure and dewatering were complete. Groundwater elevation contours between December 2017 and December 2018 displayed a radial pattern of groundwater flow away from the Site. Groundwater flow was interpreted to flow to the north, south, east, and west from this mound. Therefore, wells and piezometers around the periphery of the pond are all classified as downgradient. Between December 2018 and February 2019 (5 to 7 months after closure), the radial groundwater flow pattern diminished and became a northeast-to-southwest groundwater flow pattern toward the Coosa River. This is likely the result of groundwater flow restoring to pre-pond conditions as the hydraulic influence of the pond was eliminated by closure and dewatering (SCS 2019a).

Figures 3 depicts groundwater elevations and interpreted flow conditions in April 2020. This map depicts potentiometric surface contours post-closure. Because groundwater flow conditions have changed at the Site, wells previously identified as being downgradient (GSD-AP-MW-1, GSD-AP-MW-2, GSD-AP-MW-3, GSD-AP-MW-4, GSD-AP-MW-5, GSD-AP-PZ-1, GSD-AP-PZ-5, and GSD-AP-PZ-6) now appear hydraulically upgradient of the Site.

2.3 Delineation of Appendix IV Constituents

The groundwater monitoring network is composed of 24 monitoring wells and 1 piezometer installed around the Site (Figure 3 and Table 2). Site monitoring wells consist of: 3 upgradient wells, 16 downgradient wells, 3 horizontal delineation wells, and 2 vertical delineation wells. Monitoring well locations GSD-AP-MW-14, GSD-AP-MW-16, and GSD-AP-MW-17 serve as upgradient locations for the Site. Upgradient wells are located on the opposite side of the Coosa River and are hydraulically disconnected from downgradient flow away from the Site.

Background sampling occurred between December 2017 and February 2019. Groundwater detection monitoring began following completion of background sampling, with the first sampling event occurring in February 2019. Statistically significant increases (SSIs) of Appendix III constituents were noted, as described in the *2018 Annual and 2019 First Semi-Annual Groundwater Monitoring and Corrective Action Report* (SCS 2019b). The Appendix III SSIs triggered assessment sampling for Appendix IV constituents, with the first sampling event occurring in August 2019. Appendix III and IV maximum contaminant level and CCR-rule-specified GWPS values are shown in Table 3. The August 2019 sampling event noted Appendix IV constituents arsenic and lithium at SSLs above GWPS. Recurring SSLs above the GWPS for arsenic (0.01 milligram per liter [mg/L]) and lithium (0.04 mg/L) during assessment monitoring are summarized in the following list. Analytical results from the April 2020 assessment sampling event are summarized in Table 4.

- Arsenic SSLs are above the GWPS at monitoring wells GSD-AP-MW-2 and GSD-AP-MW-4.
- Lithium is reported at an SSL above the GWPS at monitoring well GSD-AP-MW-2.[1]

To further characterize groundwater quality at the Site, additional monitoring wells were installed. In October 2019 and January 2020, delineation wells were installed to define the horizontal extent of arsenic and lithium GWPS exceedances. In addition, existing downgradient piezometers GSD-AP-PZ-1, GSD-AP-PZ-5, and GSD-AP-PZ-6 were also used to further delineate arsenic and lithium GWPS exceedances. Horizontal delineation wells GSD-AP-MW-18H, GSD-AP-MW-19H and GSD-AP-MW-20H were installed in October 2019 north of compliance wells GSD-AP-MW-2 and GSD-AP-MW-4 and in areas historically interpreted as downgradient of the Site. Horizontal delineation wells were installed in coarse fractions of water-bearing alluvial deposits or in shallow, weathered intervals of the Conasauga Formation. Three vertical delineation wells were installed in October 2019 and January 2020 to delineate the vertical extent of GWPS exceedances. These vertical delineation wells were installed adjacent to monitoring wells GSD-AP-MW-2 and GSD-AP-MW-4, where elevated concentrations of constituents have been observed. Vertical delineation wells targeted more permeable/fractured water-bearing zones within Conasauga Formation bedrock in the upper 50 feet of bedrock. Vertical delineation well GSD-AP-MW-2VA was installed because the initial

[1] Lithium was also present at GSD-AP-MW-2VA, but there is an upward vertical groundwater gradient at this location (SCS 2020b).

attempt (GSD-AP-MW-2V) at vertical delineation proximal to GSD-AP-MW-2 did not yield sufficient groundwater for well development. As a result, GSD-AP-MW-2V has been converted to a temporary piezometer (SCS 2020b).

2.4 Soil Characterization

Soil samples were collected from Plant Gadsden and shipped to Anchor QEA's Environmental Geochemistry Laboratory in the fall of 2019. Laboratory work was conducted to help identify alternative sources (whether the natural soils near the Site could be releasing arsenic and lithium to groundwater) and probable attenuating mechanisms and to gain a sense of permanence for the mechanisms.

Samples of the fine fraction of the samples (less than 200 mesh) were analyzed for arsenic, lithium, and elements indicative of attenuating species, specifically iron, manganese, sulfide, total organic carbon, and total inorganic carbon (indicating carbonate minerals).

Lithium, a cation, was expected to be associated with clays. If bulk chemical analysis indicated lithium, then cation exchange tests were performed to help determine if the Site clays could be contributing lithium to groundwater.

The fines fraction was sent to the laboratory at Portland State University for X-ray diffraction (XRD) analysis, which helped identify attenuating minerals and potential natural sources of arsenic and lithium.

To assess potential attenuating mechanisms, and to gain insight into the permanence of the mechanisms, selective sequential extraction (SSE) was performed on select fines samples. Samples were leached with increasingly aggressive solutions according to the SSE protocol. Significant results from the soil characterization include the following:

- Fines from one brown sand-and-gravel sample had elevated arsenic (54 milligrams per kilogram [mg/kg]), 14,400 mg/kg iron, and 2,190 mg/kg manganese. The brown coloration was likely due to iron and manganese oxides, which are probably incorporating arsenic.
- Two samples with elevated lithium (but low arsenic) had high iron and manganese concentrations and appear to be background soil:
  - Sample 1 contained 7 mg/kg arsenic, 42 mg/kg lithium, 53,400 mg/kg iron, and 5,389 mg/kg manganese.
  - Sample 2 contained 7 mg/kg arsenic, 28 mg/kg lithium, 73,500 mg/kg iron, and 2,150 mg/kg manganese.
  - Both samples contained iron oxides, manganese oxide (birnessite), and clay minerals identified by XRD.

- SSE indicated part of the lithium is associated with iron and manganese oxides, suggesting a natural attenuation mechanism.
- A fraction of lithium is exchangeable, easily partitions to water, and could produce concentrations of lithium greater than those observed in well GSD-AP-MW-2, suggesting an alternate source.
- Site-specific results are consistent with lithium reported in naturally occurring manganese oxides in soils in the region (Pierce 1943).

2.5 Pond Closure and Source Control

The Site has been closed by removing some CCR from certain areas and consolidating the CCR to reduce the size of the closure footprint. Site closure appears to have already been effective in controlling the source and reducing infiltration into the underlying aquifer. Prior to closure, a radial groundwater flow pattern away from the Site was observed. Following dewatering and capping, the predominant groundwater flow pattern appears to be returning to equilibrium with flow from the northwest to the southeast and mounding associated with the Site diminishing.

CCR removed from the southwestern portion of the impoundment was used to construct grades to provide drainage on top of the consolidated footprint. The procedure in the closure-by-removal area included removing all visible ash and over-excavating into the subgrade soils. A permanent cover system was placed over the consolidated area, and a stormwater management pond was constructed in the closure-by-removal area (APC 2018a).

The pond was dewatered sufficiently to remove the free liquids, to provide a stable base for the construction of an ash containment structure for the consolidated footprint, to excavate ash outside the consolidated footprint, and to construct the final cover system. In accordance with 40 CFR 257.102(d) and ADEM Admin. Code r. 335-13-15-.07(3)(d), the final cover was constructed to control, minimize, or eliminate, to the maximum extent feasible, post-closure infiltration of liquids into the stacked CCR and potential releases of CCR from the unit. Construction of the final cover provides sufficient grades and slopes to: 1) preclude the future impoundment of water, slurry, or sediment; 2) ensure slope and cover system stability; and 3) minimize the need for further maintenance (APC 2018a).

The final cover system was designed to minimize infiltration and erosion and to meet or exceed the requirements of 40 CFR 257.102(d)(3)(ii) and ADEM Admin. Code r. 335-13-15-.07(3)(d)3.(ii), in that the permeability of the final cover system is less than or equal to the permeability of the natural subsoils present beneath the surface impoundment and not greater than 1×10^{-5} centimeters per second. The final cover consists of an engineered, relatively impermeable cover system utilizing geosynthetic materials. Disruption of the integrity of the final cover system is minimized through a design that accommodates settlement and subsidence, in addition to providing synthetic turf for protection from wind and water erosion (APC 2018a).

CCR grading and consolidation began in June 2016 and was completed in November 2017. Construction activities associated with the project were substantially completed in April 2018. A final certification of physical closure was subsequently prepared. Thereafter, a *Notice of Closure Completion* was finalized and submitted to ADEM in April 2020 (APC 2020b).

3 Groundwater Corrective Measures Alternatives

3.1 Objectives of the Corrective Measures

Pursuant to 40 CFR 257.97(b) and ADEM Admin. Code r. 335-13-15-.06(8)(b), the following summarizes the criteria that must be met by the remedy:

- Protect human health and the environment.
- Attain applicable GWPS.
- Control the source of the release to reduce or eliminate, to the maximum extent feasible, further releases of Appendix IV constituents to the environment.
- Remove from the environment as much of the material released from the CCR unit as is feasible, considering factors such as avoiding inappropriate disturbances of sensitive ecosystems.
- Comply with any relevant standards (i.e., all applicable RCRA requirements) for management of wastes generated by the remedial actions.

All corrective measures selected for evaluation for potential use at the Site are anticipated to satisfy the above performance criteria to varying degrees of effectiveness.

3.2 Potential Groundwater Corrective Measures

The following presents a summary of potential groundwater corrective measures evaluated as part of this ACM. Based on site-specific information and knowledge of corrective alternatives, the following remedies—or combination of remedies—are being considered using the evaluation criteria specified in 40 CFR 257.96(c) and ADEM Admin. Code r. 335-13-15-.06(7)(c):

- Monitored natural attenuation (MNA)
- Hydraulic containment
  - Pump-and-treat
  - Tree wells
- Permeable reactive barrier (PRB) walls
- Vertical barrier walls
- Geochemical manipulation (in situ injection)
- Permeation grouting
- In situ solidification/stabilization (ISS)

3.2.1 Monitored Natural Attenuation

MNA has been a component of corrective action at RCRA and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) sites since the 1990s. MNA describes a range of physical and biological processes in the environment that reduce the concentration, toxicity, or mobility of constituents in groundwater. For inorganic constituents, the mechanisms of natural attenuation include biostabilization, sorption, dispersion, and precipitation (USEPA 1999, 2007a, 2007b). MNA as a remedial alternative depends on a good understanding of localized hydrogeologic conditions and may require considerable information and monitoring over an extended period of time. MNA is not an approach that will lead to rapid closure of a site and is frequently used in combination with other remedies at a site.

Where site conditions are conducive to MNA, it has the potential to provide a more sustainable, lower-cost alternative to aggressive remediation technologies such as pump-and-treat. The Electric Power Research Institute (EPRI) has prepared a document describing implementation of MNA for 24 inorganic constituents (EPRI 2015a).

USEPA defines MNA as follows (USEPA 1999, 2015):

> The reliance on natural attenuation processes (within the context of a carefully controlled and monitored site cleanup approach) to achieve site-specific remediation objectives within a timeframe that is reasonable compared to that offered by other more active methods. The "natural remediation processes" that are at work in such a remediation approach include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater.

When properly implemented, MNA removes constituents from groundwater and immobilizes them onto aquifer solids. Decisions to utilize MNA as a remedy or remedy component should be thoroughly supported by site-specific data and analysis (USEPA 1999, 2015).

According to USEPA guidance (USEPA 2015), a four-phase approach should be used to establish whether MNA can be successfully implemented at a given site. The phases (also referred to as "steps" or "tiers") include the following (USEPA 1999, 2007a):

1. Demonstrate that the extent of groundwater impacts is stable.
2. Determine the mechanisms and rates of attenuation.
3. Determine if the capacity of the aquifer is sufficient to attenuate the mass of constituents in groundwater and that the immobilized constituents are stable and will not remobilize.
4. Design a performance monitoring program based on the mechanisms of attenuation and establish contingency remedies (tailored to site-specific conditions) should MNA not perform adequately.

Based on MNA case histories for inorganic constituents, MNA timeframes range from a few years to decades (EPRI 2015a).

Attenuation mechanisms can be placed in two broad categories: physical and chemical. Physical mechanisms include dilution, dispersion, flushing, and related processes. All constituents are subject to physical attenuation mechanisms, so physical processes should be considered in MNA evaluations. In its most recent guidance, USEPA discourages using dilution and dispersion as primary MNA mechanisms, as these mechanisms disperse contaminant mass rather than immobilize it (USEPA 2015). Further, USEPA advises that dilution and dispersion may be appropriate as a polishing step (e.g., at the boundaries of a plume, when source control is complete, an active remedy is being used at the site, and appropriate land use and groundwater controls are in place).

Common chemical mechanisms of attenuation for inorganic constituents include adsorption to, or coprecipitation with, oxides and hydrous oxides (oxyhydroxides) of iron and manganese; coprecipitation with, and adsorption to, iron sulfides such as pyrite (FeS_2); and precipitation as carbonates, sulfides, sulfates, and/or phosphates (USEPA 2007b).

Arsenic and lithium are subject to physical attenuation mechanisms. Arsenic is frequently reported to be readily chemically attenuated (EPRI 2015a), e.g., by sorption to naturally occurring oxyhydroxides of iron and other metals and by coprecipitating with common minerals such as iron sulfides. Though lithium is reported to be poorly chemically attenuated (EPRI 2015a), site-specific geochemical work suggests that lithium may be attenuated by manganese minerals (e.g., birnessite) and by clay minerals at the Site. Therefore, MNA is a potentially viable corrective measure for groundwater at the Site.

3.2.2 Hydraulic Containment

Hydraulic containment utilizes pumping wells (and sometimes injection wells, trenches, galleries, and/or trees) to contain and prevent the expansion of impacted groundwater. Effective hydraulic containment uses pumping wells or other subsurface hydraulic mechanisms to create a horizontal and vertical capture zone or a hydraulic barrier. If pumped, the water may be reused in beneficial applications or treated, discharged, or reinjected. Hydraulic containment is one of the most mature corrective action technologies, and it is described in *Pump-and-Treat Ground-Water Remediation: A Guide for Decision Makers and Practitioners* (USEPA 1996) and *Groundwater Contamination, Optimal Capture and Containment* (Gorelick et al. 1993).

Due to the hydraulic characteristics of the more permeable sand-and-gravel zone, as determined during slug and Shelby tube permeameter testing, hydraulic containment could be implemented within the surficial soils. Hydraulic containment could be achieved by pumping wells or possibly by trees that would transpire (pump) water from the surficial aquifer. Arsenic is readily treatable by commonly used water treatment technologies, and though less common, lithium water treatment technologies are available. Therefore, pump-and-treat is a potentially viable corrective measure for groundwater at the Site.

3.2.3 Permeable Reactive Barrier Walls

A PRB wall is the emplacement of chemically reactive materials in the subsurface to intercept impacted groundwater, provide a flow path through the reactive media, and capture or transform the constituents in groundwater to achieve GWPS downgradient of the PRB (Powell et al. 1998).

EPRI (2006) provides an overview of PRBs and possible PRB reactive media for constituents from CCR. In addition, development and testing of new reactive media for CCR constituents, including arsenic and lithium, has been performed in the last few years. The PRB is an in situ technology that allows impacted water to flow through the media and provides a barrier to constituents rather than to groundwater flow. PRBs can be used to treat groundwater impacted with metals and metalloids, chlorinated volatile organic compounds, petroleum hydrocarbons, and radionuclides. The main processes by which a PRB is used to remediate groundwater are transformation and immobilization. Transformation, or conversion, involves transforming a constituent to a less toxic form such as chemical reduction of chromium (VI) to chromium (III). Immobilization is of the most interest with respect to inorganic constituents such as those from CCR sites. Immobilization of constituents takes place through precipitation from the dissolved state or through sorption to reactive media in the PRB (Powell et al. 2002; EPRI 2006).

There are two design configurations for PRB walls (ITRC 2005; EPRI 2006):

- Continuous PRBs are ones in which the reactive media extend across the entire path of the plume. These should have minimal impact on groundwater flow and do not necessarily have to be tied to a low hydraulic conductivity unit, although that would be dependent on the depth of impacts and would safeguard against constituents flowing under the PRB if permeability of the reactive media was reduced.
- Funnel-and-gate systems incorporate barrier walls to control and direct flow to the reactive gate. The funnels can be constructed of sheetpiles, bentonite, or other barrier wall material. Similar to barrier walls used for containment, funnels must be tied into a confining bed or low hydraulic conductivity unit to avoid having impacted water flow under the wall. Funnels can also be placed in zones of greatest contaminant mass flux through the aquifer, to maximize efficiency of treatment. The use of a funnel can cause a significant increase in groundwater flow velocity, which must be considered in designing the reactive portion of the wall for residence time. The funnel must be designed to extend beyond the extent of the plume to avoid end-around flow.

Groundwater residence time through the gate needs to be sufficient to allow capture of the constituents as groundwater moves through the reactive media.

Site characterization is especially important with PRBs to allow proper design where groundwater flows naturally through the reactive media. An understanding of the following site and constituent characteristics is required for the success of the system (Powell et al. 1998; EPRI 2006):

- The permeability of the reactive zone, which must be kept greater than or equal to the aquifer to avoid diverting flow away from the PRB
- An understanding of the groundwater impact area boundaries and flow paths
  - The reactive media and funnel system, if used, must be properly designed and placed such that the groundwater will not bypass or be diverted around or under the system.
  - Excessive depth and fractured rock are difficult for placement of media.
- The geochemistry of the constituents and how they will interact with the reactive media
- Determination of how quickly groundwater will move through the reactive media to calculate residence time of the impacted groundwater
- The ability of the reactive media to remove constituents from groundwater yet remain reactive for an extended period

Major considerations in selecting reactive media for PRBs include the following (Gavaskar et al. 1998; EPRI 2006):

- Reactivity: The media should have adequate reactivity to immobilize a constituent within the residence time of the design.
- Hydraulic performance: The media should facilitate adequate flow through the PRB, which usually means it has a greater particle size than the surrounding aquifer media. Alternatively, gravel may be placed upgradient of PRBs to direct flow through them.
- Stability: The media should remain reactive for an amount of time that makes its use economically viable compared to other technologies.
- Environmentally compatible by-products: The media should not release by-products that are not environmentally acceptable in the aquifer environment. For example, media should not produce excess alkalinity (or acidity) such that pH is raised (or lowered) to unacceptable levels.
- Availability and price: The media should be easy to obtain in large quantities at a price that makes the PRB economically feasible.

Inorganic constituents have been shown to be amenable to remediation using PRB technology when using the appropriate reactive media. These include arsenic, chromium, sulfate, selenium, nickel, lead, lithium, uranium, technetium, iron, manganese, copper, cobalt, cadmium, zinc, molybdenum, nitrate, and phosphate (McGregor et al. 2002; EPRI 2006; EPRI 2015a; Dugan 2017).

A PRB can be installed through trenching, or soil excavation, in a similar manner as a slurry wall. A biopolymer slurry is used to stabilize the trench walls during excavation. The biopolymer is usually guar gum-based to allow microbial breakdown of residual slurry after placement of the reactive media. The reactive media is placed through the slurry by tremie. The depths are limited to about 90 feet or the depth a trench can be kept open (ITRC 2005).

Due to the hydraulic characteristics of the surficial (alluvial) soils, the presence of a laterally extensive underlying rock unit (Conasauga Formation), and the availability of reactive media for arsenic and lithium, the PRB wall is a potentially viable corrective measure for groundwater at the Site. However, due to reversal of the groundwater gradient (and resultant flow) at the north side of the Site, the geometry may not be conducive for PRB placement. In other words, the PRB may be upgradient of impacts rather than downgradient.

3.2.4 Vertical Barrier Walls

Vertical barrier walls are used to stop the flow of groundwater and any constituents that groundwater contains. Though effective, vertical barrier walls may serve as groundwater dams, so hydraulic containment to address mounding of groundwater behind barrier walls or flow of groundwater around the ends of barrier walls should be considered.

Bentonite slurry walls have been used for decades to control the flow of groundwater in both environmental applications as well as general foundation construction. Soil-bentonite walls are constructed by excavating a narrow vertical trench and injecting bentonite slurry to support the trench walls. The bentonite slurry used to support the trench walls is generally a mixture of pulverized bentonite in water. Water from the slurry bleeds into the trench wall, leaving behind a mat of particles known as filter cake, which along with the hydrostatic force of the slurry, holds the trench open. Once the trench reaches final grade, the trench is backfilled with a mixture of soil from the excavation, slurry, and soil from other sources, as necessary, to achieve the desired properties of strength and hydraulic conductivity. The backfill is generally placed with a tremie, clamshell, and/or a bulldozer, displacing the trench support slurry. The filter cake remains in place and, along with the gradation of the backfill used in the wall, is a function of the hydraulic conductivity of the final wall. Installation of soil-bentonite barrier walls can require significant amounts of space for mixing backfill (Bliss 2014). At CCR facilities, berms may be constructed to provide the working space for barrier wall emplacement.

Cement-bentonite barrier walls are similar to soil-bentonite walls except that the stabilizing fluid used during excavation is a cement-bentonite water mix. The slurry remains in place to form the wall, so a separate operation to mix the backfill and displace the slurry is not necessary. Because the excavated material is not used in the backfill mix, significant amounts of spoil are generated with this type of barrier wall. Also, due to the method of excavation with the slurry, there can be a significant amount of slurry waste (up to 40% of the total trench/panel volume) during excavation (EPRI 2015b).

Barrier walls used alone at the Site could produce groundwater mounding, with possible rise of groundwater to the surface, and could produce groundwater flow around the end of the barrier walls. However, barrier walls could be used to improve the subsurface hydraulic (flow) conditions for PRB walls and pump-and-treat. For example, barrier walls could form the impermeable portions of a funnel-and-gate PRB wall to direct groundwater to the treatment gates containing reactive media and could be used in a similar way to direct groundwater toward pumping wells in a pump-and-treat system. Because they could be part of PRB or hydraulic containment (pump-and-treat) systems, barriers walls are potentially viable corrective measures at the Site. Note that to be effective for environmental applications, barrier walls should be tied into a continuous, relatively impermeable layer such as the Conasauga Formation at the Site.

3.2.5 Geochemical Manipulation (In Situ Injection)

Geochemical manipulation, usually via subsurface injections, is an emerging remediation technology for inorganic constituents in groundwater. Geochemical manipulation for inorganic constituents may be applied in three modes: redox manipulation; adsorption to iron or other metal oxyhydroxides under oxidizing groundwater conditions; and adsorption to, or coprecipitation with, iron or other metal sulfides under reducing conditions (sequestration in sulfides).

Redox manipulation has been applied to metals such as chromium since the 1990s, where reducing compounds are injected to chemically reduce chromium (VI) to the more benign chromium (III) (USEPA 2000; Ludwig et al. 2007). Geochemical processes such as sorption and coprecipitation are applicable to arsenic, and coprecipitation and ion exchange are applicable to lithium. Though proprietary at the present time, EPRI has performed successful geochemical manipulation studies for lithium in the laboratory and plans to test the technology in field pilot studies.

Arsenic may be attenuated by sorption onto hydrous metal oxides (e.g., ferrihydrite) under oxidizing conditions, and precipitation and coprecipitation with metal sulfides (e.g., pyrite and/or realgar) and sorption onto the sulfide mineral surfaces under reducing conditions. In sorption under oxidizing conditions, an iron source (such as ferrous sulfate) is injected into the subsurface and oxidizes to iron oxyhydroxide (ferrihydrite) to which arsenic sorbs (Pugh et al. 2012; Redwine et al. 2004).

In the sequestration-in-sulfides technology, soluble sources of organic carbon, ferrous iron, and sulfate are injected into the subsurface to optimize conditions for sulfate-reducing bacteria growth (Saunders 1998). Sulfate-reducing bacteria produce sulfide minerals as a by-product of their metabolism, and arsenic is removed from groundwater and immobilized by the sulfide minerals. Arsenic sulfide phases such as realgar may precipitate directly, and/or arsenic may substitute for other elements in the iron sulfide (pyrite) mineral structure. In addition, arsenic may sorb to sulfide mineral surfaces. In recent successful applications for arsenic, a treatment solution containing molasses, ferrous sulfate heptahydrate, and small amounts of commercial fertilizer dissolved in unchlorinated water were injected to significantly decrease arsenic concentrations in groundwater.

Site-specific geochemical analysis, treatability, and/or pilot studies would need to be performed to determine the specific treatment solution for geochemical manipulation. Mixed metal oxides containing both iron and manganese may be capable of treating both arsenic and lithium. Because the technology has not yet been demonstrated for large areas, its optimum application may be treatment of isolated areas (e.g., in the vicinity of a few impacted wells, such as GSD-AP-MW-2 and GSD-AP-MW-4 at the Site).

3.2.6 Permeation Grouting

Grouting is another way to construct a barrier to groundwater flow. Though there are several types of grouting, permeation grouting is likely the most applicable to groundwater corrective action at CCR settings. Permeation grouting is a method of impregnating the void space within a soil or rock mass, thereby displacing water and air from the voids and replacing it with grout, without displacing the soil particles or widening existing fractures in rock (Wani 2015).

Permeation grouting utilizes low pressure injection to reduce the permeability and improve the strength of granular soils or fractured or solutioned (karst) rock (Keller Ground Engineering 2017). In groundwater corrective action applications, permeability (hydraulic conductivity) reduction and impeding the flow of impacted groundwater are the primary objectives. Permeation grouting can be effective in unconsolidated alluvial soils (Pearlman 1999), such as those often found at CCR settings, and in rock. In classic grouting theory for porous material such as sand and gravel, overlapping columns are constructed by grouting to create a wall. In rock, the void space to be grouted is more irregular than that in porous media, though the wall concept still applies. Grout mixtures may be particulate, chemical, or a combination of both. Particulate mixtures contain a slurry of cement and bentonite and/or other additives combined with water. Chemical grout mixtures contain a chemical base (such as sodium silicate, acrylate, and urethane), a catalyst, and solvent (typically water). Particulate grouts are generally more viscous and better suited for larger pore spaces, while chemical grouts are usually preferred for smaller voids (Pearlman 1999; USEPA 2014).

Grout barriers can be used either as stand-alone barriers to contain or control groundwater flow, or they may be used in conjunction with another type of technology. Grout may be injected at the bottom of geomembrane or PRB walls to address fracturing that may have occurred when these barriers were keyed into underlying bedrock. Grout barriers may also be installed at any angle, including horizontally, which may be beneficial at sites where there is no accessible underlying aquitard to tie into. However, maintaining continuity of the grout installation is typically more difficult for angled drilling and grouting (USEPA 1998; Pearlman 1999).

3.2.7 In Situ Solidification/Stabilization

ISS is a method for solidifying soil or waste material, immobilizing the constituents of interest (COIs) in the solid matrix, and preventing the mobility of the COI in groundwater due to permeability reduction (solidification) and chemical reactions (stabilization). Common additives include Portland cement, bentonite, and/or additives that are specific for the COI. Iron compounds such as zero-valent iron or ferrous sulfate may be added for arsenic, and manganese compounds may be added for lithium. ISS may be implemented by mixing with a bucket, auger, or rotary methods.

ISS has been used for decades and has widespread regulatory acceptance and a track record for success. Many case histories exist for the treatment of arsenic using ISS, and at least one exists for lithium (Bates and Hills 2015). Due to the unconsolidated alluvial soils, relatively shallow depths, and anticipated relatively small area of treatment, ISS is a viable groundwater corrective action at the Site.

3.3 Potential Remedy Evaluation

3.3.1 Introduction

The following remedies are considered potentially viable for corrective measures for groundwater at the Site:

- MNA
- Hydraulic containment
    - Pump-and-treat
    - Tree wells
- PRB walls
- Vertical barrier walls as components of other corrective measures
- Geochemical manipulation (injections)
- Permeation grouting
- ISS

Although these technologies are potentially feasible remedies, further data collection and evaluation are required to: 1) verify the feasibility of each; and 2) provide sufficient information to design a corrective action system that meets the criteria specified in 40 CFR 257.97(b) and ADEM Admin. Code r. 335-13-15-.06(8)(b). Table 5 provides a summary of these technologies compared to the evaluation criteria discussed in Section 1 as applied to Site conditions. Table 6 discusses the advantages and disadvantages of each technology that should be considered.

3.3.2 Monitored Natural Attenuation

MNA is compatible with the other groundwater corrective actions that are potentially viable for the Site. At a minimum, MNA can serve as a polishing step (USEPA 2015), which may be all that is needed at the Site due to source control and the relatively small area of impacts.

The performance of MNA requires further investigation, especially related to the identification of attenuating mechanisms, aquifer capacity for attenuation, and time to achieve GWPS. Because of the sand and gravel in the surficial soils, the capacity for attenuation may not be as high as in an aquifer that contains more fines (silt and clay) or organic material. Therefore, MNA performance is considered medium in the absence of additional data. Dewatering, consolidation, and capping of the Site, however, will likely reduce the source contribution to groundwater such that the attenuation capacity of the aquifer may be sufficient to achieve GWPS in a reasonable timeframe.

Implementation of MNA at the Site will be relatively easy. Most of the wells for MNA are already in place, though a few additional wells may need to be installed to monitor progress in critical areas. Solid (e.g., aquifer) samples and precipitates forming in wells (if present) will need to be collected and analyzed to identify attenuating mechanisms, test capacity and permanence, and help determine the time required to achieve GWPS.

Reliability of MNA will be relatively high because MNA requires almost no operation and maintenance (O&M). Potential impacts of the remedy will be negligible because MNA is non-intrusive and produces no effluents or emissions.

Implementation of MNA would require some geochemical studies and possibly the installation of some new wells. Because MNA does not require design and construction of infrastructure other than new monitoring wells, it can be initiated within 6 months to a year. At least 1 year of groundwater monitoring data is recommended before implementation of MNA is considered complete. The additional data would be needed for statistical analysis and to determine if additional monitoring wells need to be installed. Therefore, complete implementation of MNA would take about 18 to 24 months.

Time for MNA to achieve GWPS is currently unknown and would require additional studies. Published and unpublished case histories for arsenic, and by inference lithium, suggest that MNA would take more than a decade to achieve GWPS. However, the timeframe at the Site may be less because of the source control measures (dewatering, consolidation, and capping) and the relatively small area of impacts.

3.3.3 Hydraulic Containment

Hydraulic containment may be achieved by two methods at the Site: pump-and-treat and tree wells, where the trees function as small pumps during the growing season.

Hydraulic containment via pump-and-treat has been used for groundwater corrective action for decades. When the pump-and-treat system is online, the performance is considered high: arsenic and lithium are readily treated, and if the system subsurface hydraulics are designed properly, the area of impact will stabilize or shrink. Because these systems require substantial O&M, the reliability is considered not quite as high as some other technologies. In other words, pumps, piping, and the water treatment system must be maintained and will be offline occasionally for various reasons.

Similarly, pump-and-treat is not as easy to implement as some other technologies (e.g., MNA or geochemical manipulation), due to design, and installation of wells, pumps, and piping. An on-site water treatment plant would be required to accommodate both the quantity and constituents in the pumped groundwater. Because the quantity of water requiring treatment cannot be determined without further study, the design parameters of the treatment system would also need to be verified through additional investigations.

Pump-and-treat could probably be designed and installed within 1 to 2 years. Based on published and unpublished case histories, time to achieve GWPS could take more than a decade due to the slow desorption kinetics of arsenic from the aquifer and through both the completed closure and source control; MNA should accelerate this process.

Regulatory requirements and institutional controls may be greater for pump-and-treat than some of the other technologies. For example, permits may be required for the withdrawal and re-injection (if used) of water, and the chemistry of the effluent after treatment would need to be compatible with the Site's National Pollutant Discharge Elimination System permit.

Trees have been used to extract water and some organic contaminants from the ground in phytoremediation applications (ITRC 2009). Trees can affect hydraulic gradients and groundwater flow by removal of water and thus can be used to create a partial barrier to groundwater flow. This process may be enhanced by planting the tree in a column of more permeable material (i.e., a tree well), such that flow of water increases to the tree and it acts more like a pumping well (Treemediation.com 2017).

To fully evaluate hydraulic containment using trees, the following investigations should be performed: 1) determine the amount of water transpired (pumped) by each tree during the growing season; 2) determine the number and placement of trees; and 3) determine if hydraulic containment could be achieved with the tree array. Both performance and reliability of trees are considered medium because the trees will not transpire (pump) during winter (3 to 4 months of the year). Implementation of hydraulic containment using trees at the Site will be relatively easy, primarily consisting of constructing the tree wells and planting the trees. Tree wells are compatible with both MNA and geochemical manipulation, should any advantage be gained by implementing two or three of these technologies simultaneously.

Active technologies such as pump-and-treat may offer few or no advantages over MNA. For example, pump-and-treat for arsenic, lithium, and other inorganic constituents may reach a point of diminishing returns relatively quickly (few months to a few years), as the concentration decreases and the subsequent reduction in concentration changes very little through time (EPRI 2018). The diminishing rate of concentration reduction is likely due to the slow desorption kinetics of constituents from aquifer solids (Bethke and Brady 2000; USEPA 2000). Due to the slow desorption kinetics, hydraulic containment (by either pump-and-treat or tree wells) may take a decade or more to achieve GWPS, such that it offers no time advantage over MNA (EPRI 2018).

3.3.4 Permeable Reactive Barrier Walls

PRB walls may be installed with continuous reactive media or with impermeable sections punctuated by reactive treatment gates (funnel-and-gate configuration). The funnel-and-gate configuration directs flow through the reactive gates, thereby improving treatment efficiency. Because of the small areas to be treated, the continuous reactive media configuration is envisioned for the Site. However, due to reversal of the groundwater gradient (and resultant flow) at the north side of the Site, the geometry may not be conducive for PRB placement. In other words, the PRB may be upgradient of impacts rather than downgradient.

When working effectively in suitable conditions, PRB walls can reduce constituents to GWPS downgradient of the walls. However, because of site-specific uncertainties associated with the reactive media and subsurface hydraulics, performance is considered medium to high. Similarly, because the reactive media is expended, may clog through time, and will need to be replaced at some point, reliability is considered to be medium. Further technology-specific evaluation is required to more definitively determine the feasibility of implementing a PRB at the Site.

Because it involves trenching, ease of implementation is considered medium. Alteration of subsurface hydraulics (flow) may be a potential impact of this remedy. Because of required laboratory treatability studies on the reactive media, analysis of the subsurface hydraulics, and relatively small area of emplacement, time to implement the remedy is estimated to be 1 to 2 years. Time to achieve GWPS is estimated to be at least a decade or more.

3.3.5 Vertical Barrier Walls

Vertical barrier walls, such as slurry walls, would not be applied alone at the Site due to the potential for groundwater rise to the surface and flow of impacted groundwater around the ends of walls. Impermeable barrier walls could be used to enhance the subsurface hydraulics for other treatments, for example, as impermeable sections between pumping zones or beneath a PRB wall to tie the wall into the Conasauga Formation (rock) and prevent escape of arsenic and lithium beneath the wall.

Subsurface vertical barrier walls are a widely used and accepted technology, with relatively high performance and reliability. Ease of implementation at the Site is considered medium, due to trenching or other emplacement methods. Potential impacts of the remedy include alteration of subsurface hydraulics (flow).

Time to implement the remedy (design and construct the wall) could be 1 to 2 years, and time to achieve GWPS would be the same length of time as the companion technology (i.e., hydraulic containment or PRB wall).

3.3.6 Geochemical Manipulation (In Situ Injection)

Geochemical manipulation (injection) is an emerging technology for inorganic constituents. Due to its short history of application, the permanence of geochemical manipulation beyond 3 years has not yet been demonstrated; therefore, performance is considered medium at present. Similarly, reliability is considered medium because Site geochemical conditions should not change beyond the tolerance of the treatment. The most effective use of this technology is probably for smaller isolated areas (which are present at the Site), where performance can be readily monitored and retreatment applied if needed.

Geochemical manipulation is relatively easy to implement, particularly in small areas. The main infrastructure required are injection wells, though the treatment solution may be injected through direct-push drill rigs. Even though infrastructure requirements are minimal, some laboratory and/or field pilot test work will need to be done, and a state underground injection control permit may be required, so geochemical manipulation is estimated to require 1 to 2 years to implement at the Site. Because the longevity of this technology has not yet been demonstrated and multiple injections may be required, 5 to 10 years may be needed to achieve GWPS in relatively small, localized areas.

3.3.7 Permeation Grouting

Analogous to ISS, permeating grouting would fill pore spaces with grout and reduce permeability in the areas of impact in the vicinity of wells GSD-AP-MW-2 and GSD-AP-MW-4. Performance and reliability of permeation grouting is considered medium at the present time, without additional Site data. Though grouting is a conventional and proven technology, grouting in alluvial soils is less common such that grout may not be able to penetrate sufficient pore spaces due to formation grain size (performance), and some areas may be missed (reliability). Ease of implementation is considered medium because optimum grout mixes would need to be developed through laboratory and field pilot testing, and mixes and pressures would need to be controlled in the field to achieve optimal coverage and permeability reduction of the alluvial soils. As with impermeable barrier walls, grouting will change groundwater flow (subsurface hydraulics), and the changes should be considered when evaluating this option. Grouting (including pre-design testing and design) is estimated to take 1 to 2 years at the Site, based on grouting programs in similar terrain. Length and depth of the grout curtain (wall), spacings of grout holes (borings), and volume and composition of the mixture would need to be established through a test grouting program. Time to achieve GWPS is estimated to be 1 to 5 years, provided the grouting program is effective.

3.3.8 In Situ Solidification/Stabilization

ISS would be applied in the vicinity of wells GSD-AP-MW-2 and GSD-AP-MW-4 or possibly in a relatively narrow strip between those wells along the northern side of the Site. ISS has been used for source control and groundwater corrective action for decades, so a large body of remedial effectiveness data exist. Therefore, performance and reliability are considered high.

Though the granular alluvial soils and relatively shallow depths are optimum for ISS, it involves subsurface work with heavy equipment, so ease of implementation is considered medium. ISS could probably be designed and implemented in 1 to 2 years. Laboratory treatability studies would be necessary to select and design the treatment mixes and determine their effectiveness. In the treatability studies, different additives (Portland cement, bentonite, and possibly others) proven effective for arsenic and lithium would be mixed in various proportions. Permeability and leachability tests would be performed on the solidified blocks from the treatability studies to determine the optimum treatment mix.

One disadvantage of ISS is that typically an increase in COI is observed in groundwater during implementation due to subsurface disruption. This increase dissipates with time. One advantage of ISS in the anticipated treatment area at the Site is that time to achieve groundwater protection standards would be relatively short (i.e., as soon as the construction groundwater increase dissipates, which is estimated at 1 to 5 years).

4 Remedy Selection

Pursuant to 40 CFR 257.97 and ADEM Admin. Code r. 335-13-15-.06(8), after completing this ACM, the Site must select a remedy as soon as feasible. In contrast, Part D of the Administrative Order states that this ACM must include the remedy proposed to ADEM for approval.

To meet the requirement of Part D, the Site remedy is proposed to consist of the following:

1. Source control by dewatering the Site, consolidating the CCR material, and capping it with a low-permeability cover system to prevent infiltration (completed)
2. MNA with routine evaluation of system performance to ensure that remediation goals are being met
3. Adaptive site management and remediation system enhancement or modification to ensure that remediation performance goals are met

40 CFR 257.97(b) and ADEM Admin. Code r. 335-13-15-.06(8)(b) specify the following criteria that must be met by the remedy:

- Protect human health and the environment
- Attain applicable GWPS
- Control the source of the release so as to reduce or eliminate, to the maximum extent feasible, further releases of Appendix IV constituents to the environment
- Remove from the environment as much of the material released from the CCR unit as is feasible, considering factors such as avoiding inappropriate disturbances of sensitive ecosystems
- Comply with any relevant standards (i.e., all applicable RCRA requirements) for management of wastes generated by the remedial actions

Combined closure/source control and MNA are anticipated to meet the requirements of 40 CFR 257.97(b) and ADEM Admin. Code r. 335-13-15-.06(8)(b). Geochemical manipulation and ISS are alternative corrective measures, should MNA not perform as expected. Source control has been completed and appears to be effective in reducing contributions to groundwater. In an adaptive site management process, system performance is monitored, and one or more technologies identified in this ACM will be used to supplement the remedy as soon as feasible if the system is not performing as intended or corrective action goals are not met.

Using adaptive site management, a remedial approach will be implemented, conditions monitored, and results interpreted. Based on monitoring data, adjustments will be made to the corrective measures as necessary, leading to continuous improvements in Site knowledge and corrective measures performance. Moreover, Site conditions may require the implementation of more than one corrective measure technology to meet remediation goals over the life of the project.

At the Site, pond closure is complete. As soon as practical, MNA will be implemented to address the SSLs based on the current Site conditions. Using an adaptive site management approach, a remediation approach will be used whereby: 1) the corrective measures system will be implemented to address current conditions; 2) the performance of the system will be monitored and evaluated semi-annually; 3) the CSM will be updated as more data are collected; and 4) adjustment and augmentation will be made to the corrective action system to ensure that performance criteria are met.

4.1 Additional Data Needs and Planned Activities

Additional data and analysis will be required to perform a thorough site-specific evaluation and supplemental design of groundwater corrective actions for the Site. The following provides a summary of typical additional data needed to evaluate and select a remedy system:

- Geochemical studies of groundwater and aquifer media and simple geochemical modeling
- Subsurface hydraulic calculations or models
- Laboratory treatability studies on groundwater, aquifer media (soils), reactive media, and potential treatment solutions for injection
- Field pilot studies based on results of laboratory treatability studies

Both MNA and geochemical manipulation are geochemically based, such that geochemical investigations to support MNA will also support geochemical manipulation. Specific, short-term activities to support MNA and geochemical manipulation include the following:

- Evaluating groundwater analytical data (primarily graphing) to look for evidence of natural attenuation occurring spatially and temporally
- Collecting groundwater samples from unimpacted and impacted wells and performing a complete chemical analysis on the samples to enable groundwater geochemical modeling and the development of a geochemical CSM
- Performing geochemical modeling using the U.S. Geological Survey computer program PHREEQC with the WATEQ4F thermodynamic database
- Collecting solid precipitate samples (if present) from the bottom of monitoring wells
- Analyzing precipitate samples to help identify attenuating mechanisms and their stability; solids analysis include:
  - Chemical analysis by X-ray fluorescence
  - Mineralogical analysis by XRD
  - Scanning electron microscopy to directly observe attenuating mineral phases
  - SSE to determine the association of arsenic and lithium with attenuating phases and the relative strength of attenuation and to provide a sense of permanence
  - Cation exchange capacity to assess ion exchange as an attenuation mechanism

- Other potential remedies identified in the ACM will continue to be evaluated with respect to technical feasibility, ability to attain target standards, and ease of implementation. Based on the site-specific evaluation, additional studies may be implemented.

Once these geochemical investigations are complete, a plan will be developed to evaluate MNA following USEPA's recommended four phase approach:

1. Demonstrate that the extent of groundwater impacts is stable[2].
2. Determine the mechanisms and rates of attenuation.
3. Determine if the capacity of the aquifer is sufficient to attenuate the mass of constituents in groundwater and that the immobilized constituents are stable and will not remobilize.
4. Design a performance monitoring program based on the mechanisms of attenuation and establish contingency remedies (tailored to site-specific conditions) should MNA not perform adequately.

In addition, should the geochemical data indicate that the Site is amenable to geochemical manipulation (injections), a bench-scale and pilot test plan will be considered for the Site.

Using available information, we anticipate developing a conceptual corrective action strategy plan for the Site. The conceptual corrective action strategy will serve as the basis for developing a final remedy plan and include a description of the conceptual corrective action strategy, identified points of compliance, performance standards, potential data gaps, monitoring approaches, and adaptive triggers. The conceptual corrective action strategy will serve as the basis for developing a final remedy and remedy selection report for the Site.

4.2 Schedule

Table 7 provides a generalized conceptual schedule for advancing the selected remedy and for continued evaluation of other remedies to potentially supplement the proposed corrective action if needed.

[2] Based on monitoring data to date, impacts appear to be stable and limited in extent.

5 References

APC (Alabama Power Company), 2018a. *Closure Plan for Existing CCR Surface Impoundment.* Gadsden Steam Plant Ash Pond. April 2018.

APC, 2018b. *History of Construction for Existing CCR Surface Impoundment.* Gadsden Ash Pond. April 17, 2018.

APC, 2020a. *Notice of Assessment of Corrective Measures.* Plant Gadsden Ash Pond. May 11, 2020.

APC, 2020b. *Notice of Closure Completion.* Plant Gadsden Ash Pond. April 2020.

Bates, E., and C. Hills, 2015. *Stabilization and Solidification of Contaminated Soil and Waste: A Manual of Practice*. Hygge Media.

Bethke, C.M., and P.V. Brady, 2000. *How the K_d Approach Undermines Ground Water Cleanup.* Groundwater 38(3):435–443.

Bliss, M., 2014. *Chapter 16: "Cutoff Walls." Design Standard No. 13 Embankment Dams. DS-13(16)-14: Phase 4 Final.* Prepared for the U.S. Department of the Interior, Bureau of Reclamation. July 2014.

Dugan, P.J., 2017. *What's Really in the Water? New Treatment Options for Coal Combustion Residuals (CCRs) and Mining-Influenced Water*. Paper presented at the 34th Annual Pittsburgh Coal Conference 2017 (Pittsburgh, Pennsylvania); September 2017.

EPRI (Electric Power Research Institute), 2006. *Groundwater Remediation of Inorganic Constituents at Coal Combustion Product Management Sites: Overview of Technologies, Focusing on Permeable Reactive Barriers*. EPRI, Palo Alto, California: 2006. 1012584.

EPRI, 2015a. *Monitored Natural Attenuation for Inorganic Constituents in Coal Combustion Residuals.* EPRI, Palo Alto, California: December 2015. 3002006285.

EPRI, 2015b. *Corrective Action for Closed and Closing Ash Ponds*. Final Report. EPRI, Palo Alto, California: December 2015. 3002006292.

EPRI, 2018. *Groundwater Remediation Planning, Applications, Limitations, Cost Model.* EPRI, Palo Alto, California: 2018. 3002012313.

Gavaskar, A., B. Sass, N. Gupta, J. Hicks, S. Yoon, T. Fox, and J. Sminchak, 1998. *Performance Evaluation of a Pilot-Scale Permeable Reactive Barrier at Former Naval Air Station Moffett Field, Mountain View, California.* Prepared for the Naval Facilities Engineering Service Center, Port Hueneme, California.

Gorelick, S.M, R.A. Freeze, D. Donohue, and J.F. Keely, 1993. *Groundwater Contamination Optimal Capture and Containment.* Boca Raton, Florida: Lewis Publishers.

ITRC (Interstate Technology and Regulatory Council), 2005. *Permeable Reactive Barriers: Lessons Learned/New Directions*. Interstate Technology and Regulatory Council, Permeable Reactive Barriers Team, PRB-4, Washington, D.C.

ITRC, 2009. *Phytotechnology Technical and Regulatory Guidance and Decision Trees, Revised*. February 2009.

Keller Ground Engineering, 2017. "Permeation Grouting." Accessed September 29, 2017. Available at: http://www.kellerge.com.au/techniques/permeation-grouting/.

Ludwig, R.D., C. Su, T.R. Lee, R.T. Wilkin, S.D. Acree, R.R. Ross, and A. Keeley, 2007. "In Situ Chemical Reduction of Cr(VI) in Groundwater Using a Combination of Ferrous Sulfate and Sodium Dithionite: A Field Investigation." *Environmental Science and Technology* 41(15):5299-5305.

McGregor, R.G., S. Hansler, D.W. Blowes, and E. Laratta, 2002. "The Use of a PRB to Treat Groundwater Impacted by Coal-Combustion By-Products." In *Proceedings, Third International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, Calif.* Paper 2A-02. Columbus, Ohio: Battelle Press.

Pashin, J.C., 2008. *Gas Shale Potential of Alabama.* International Coalbed & Shale Gas Symposium. Tuscaloosa, Alabama. May 2008.

Pearlman, L., 1999. *Subsurface Containment and Monitoring Systems: Barriers and Beyond – Overview Report.* Prepared for the U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response Technology Innovation Office. March 1999.

Powell, R.M., P.D. Powell (Powell & Associates Science Services), and R.W. Puls (Subsurface Protection and Remediation Division National Risk Management Research Laboratory), 2002. *Economic Analysis of the Implementation of Permeable Reactive Barriers for Remediation of Contaminated Ground Water*. EPA/600/R-02/034. June 2002.

Powell, R.M., R.W. Puls, D.W. Blowes, J.L. Vogan, R.W. Gillham, P.D. Powell, D. Schultz, R. Landis, and T. Sivavec, 1998. *Permeable Reactive Barrier Technologies for Contaminant Remediation*. EPA/600/R-98/125. September 1998.

Pierce, W.G., 1943. "Cobalt-Bearing Manganese Deposits of Alabama, Georgia, and Tennessee." *Strategic Minerals Investigations.* 265-285.

Pugh, J.D., D.W. Morris, and J.C. Redwine, 2012. U.S. Patent 8,157,476: In situ Systems and Methods for the Immobilization of Contaminants. Original Assignee: Southern Company Services, Inc. April 2012.

Raymond, D.E., W.E. Osbourne, C.W. Copeland, and T.L. Neathery, 1988. "Alabama Stratigraphy." *Geological Survey of Alabama.* Circular 140. July 26, 1988.

Redwine, J.C., J.R. Howell, R.J. Donahoe, and L. Yang, 2004. "In situ Chemical Fixation of Arsenic in Soil: Laboratory and Field Results." In: *Proceedings, Air and Waste Management Association* 97th *Annual Conference and Exhibition, Indianapolis, Indiana*.

Saunders, J.A., 1998. *Situ Bioremediation of Contaminated Groundwater*. United States: US 5,833,855.

SCS (Southern Company Services), 2019a. *Facility Plan for Groundwater Investigation.* Plant Gadsden Ash Pond. Prepared for Alabama Power Company. September 2019.

SCS, 2019b. *2018 Annual & 2019 First Semi-Annual Groundwater Monitoring and Corrective Action Report.* Plant Gadsden Ash Pond. Prepared for Alabama Power Company. August 1, 2019.

SCS, 2020a. *2019 Semi-Annual Groundwater Monitoring and Corrective Action Report.* Plant Gadsden Ash Pond. Prepared for Alabama Power Company. February 1, 2020.

SCS, 2020b. *Groundwater Investigation Report.* Plant Gadsden Ash Pond. Prepared for Alabama Power Company. May 22, 2020.

Treemediation.com, 2017. TreeWell® Treatment System. Accessed September 29, 2017. Available at: www.treemediation.com/Technical/treewell.htm.

USGS (U.S. Geological Survey), 1986, Gadsden West and Gadsden East Alabama Quadrangles, 7.5 Minutes Series Topographic Map.

USEPA (U.S. Environmental Protection Agency), 1996. *Pump-and-Treat Groundwater Remediation: A Guide for Decision Makers and Practitioners*. EPA 625/R-95/005. July 1996.

USEPA, 1998. *Evaluation of Subsurface Engineered Barriers at Waste Sites*. EPA 542-R-98-005. August 1998.

USEPA, 1999. *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites.* EPA/OSWER No. 9200.4-17P, Office of Solid Waste and Emergency Response, Washington D.C.

USEPA, 2000. *In Situ Treatment of Soil and Groundwater Contaminated with Chromium*. Technical Resource Guide. EPA-625/R-00/005. October 2000.

USEPA, 2007a. *Monitored Natural Attenuation of Inorganic Contaminants in Ground Water. Volume 1–Technical Basis for Assessment*. EPA/600/R-07/139. October 2007.

USEPA, 2007b. *Monitored Natural Attenuation of Inorganic Contaminants in Ground Water. Volume 2. Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium*. EPA/600/R-07/140. October 2007.

USEPA, 2014. "Dense Nonaqueous Phase Liquids (DNAPLS) Treatment Technologies: Containment." Updated: September 8, 2017. Accessed September 29, 2017. Available at: http://www.cluin.org/contaminantfocus/default.focus/sec/dense_nonaqueous_phase_liquids_(dnapls)/cat/Treatment_Technologies/p/2.

USEPA, 2015. *Use of Monitored Natural Attenuation for Inorganic Contaminants in Groundwater at Superfund Sites.* U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response Directive 9283.1-36. August 2015.

USEPA, 2016. *Resource Conservation and Recovery Act Facilities Investigation Remedy Selection Track: A Toolbox for Corrective Action*. May 20, 2016.

Wani, S.B., 2015. Presentation on Grouting in Soils. January 18. Available at: https://www.slideshare.net/shoaibwani/grouting-in-soils.

Tables

Table 1
Historical Groundwater Elevations Summary

Well ID	Average GW Elevation (feet MSL)	Highest GW Elevation (feet MSL)	Lowest GW Elevation (feet MSL)	GW Elevation Variation (feet)
GSD-AP-MW-1	513.92	519.26	511.57	7.69
GSD-AP-MW-2	513.76	518.15	511.73	6.42
GSD-AP-MW-3	513.67	517.38	511.90	5.48
GSD-AP-MW-4	513.65	517.13	511.89	5.24
GSD-AP-MW-5	510.69	513.01	508.88	4.13
GSD-AP-MW-6	509.76	511.64	508.21	3.43
GSD-AP-MW-7	508.22	513.85	506.97	6.88
GSD-AP-MW-8	507.84	511.45	506.60	4.85
GSD-AP-MW-9	507.85	511.42	506.60	4.82
GSD-AP-MW-10	509.47	511.87	508.97	2.90
GSD-AP-MW-11	508.15	511.67	507.53	4.14
GSD-AP-MW-12	511.35	515.43	509.64	5.79
GSD-AP-MW-14	500.27	501.78	499.17	2.61
GSD-AP-PZ-1	512.82	519.05	509.86	9.19
GSD-AP-PZ-2	508.07	511.33	507.39	3.94
GSD-AP-PZ-5	512.62	519.28	509.93	9.35
GSD-AP-PZ-6	512.59	518.72	509.93	8.79
GSD-AP-MW-16	530.68	531.98	529.67	2.31
GSD-AP-MW-17	532.09	534.03	530.77	3.26

Notes:

Source: Southern Company Services, 2019. *2018 Annual & 2019 First Semi-Annual Groundwater Monitoring and Corrective Action Report.* Plant Gadsden. Prepared for Alabama Power Company. August 1, 2019.

GW: groundwater

MSL: mean sea level

Table 2
Groundwater Monitoring Network Details

Well Name	Installation Date	Northing[1]	Easting[1]	Ground Elevation[2]	Top of Casing Elevation[2]	Top of Screen Elevation[2,4]	Bottom of Screen Elevation[2,4]	Purpose
GSD-AP-MW-1	8/8/2017	1279914.40	615079.93	523.48	526.37	509.08	499.08	Downgradient
GSD-AP-MW-2	8/10/2017	1280352.80	614599.21	523.04	526.16	508.49	498.49	Downgradient
GSD-AP-MW-3	8/11/2017	1280742.72	614102.00	523.68	526.80	509.85	499.85	Downgradient
GSD-AP-MW-4	7/15/2013	1281001.39	613884.36	517.27	520.60	504.83	494.83	Downgradient
GSD-AP-MW-5	8/15/2017	1281367.84	613584.86	513.26	516.27	499.89	489.89	Downgradient
GSD-AP-MW-6	8/3/2017	1281745.78	612969.64	512.09	515.23	499.48	489.48	Downgradient
GSD-AP-MW-7	7/16/2013	1281131.20	612627.76	517.05	519.86	500.06	490.06	Downgradient
GSD-AP-MW-8	8/2/2017	1280261.79	612527.24	516.02	519.22	497.04	487.04	Downgradient
GSD-AP-MW-9	7/16/2013	1279916.88	613123.38	517.41	520.36	495.67	485.67	Downgradient
GSD-AP-MW-10	8/3/2017	1279709.35	613729.63	527.70	530.91	492.99	482.99	Downgradient
GSD-AP-MW-11	7/17/2013	1279209.03	614235.25	514.18	517.01	492.51	482.51	Downgradient
GSD-AP-MW-12	7/17/2013	1279381.38	614989.08	518.73	521.82	500.57	490.57	Downgradient
GSD-AP-MW-14	3/27/2018	1277336.39	615233.22	545.49	548.34	525.50	516.00	Upgradient
GSD-AP-MW-16	9/20/2018	1277286.36	615079.67	553.08	555.83	530.10	520.10	Upgradient
GSD-AP-MW-17	9/24/2018	1277101.94	615157.25	546.88	550.11	497.83	487.83	Upgradient
GSD-AP-PZ-1[3]	8/14/2017	1281425.06	614048.07	518.80	521.64	504.67	494.67	Downgradient
GSD-AP-PZ-2[3]	8/16/2017	1281957.82	612944.02	513.46	516.49	503.05	493.05	Downgradient
GSD-AP-PZ-5[3]	3/28/2018	1280939.08	614998.03	521.36	524.26	503.99	493.99	Downgradient
GSD-AP-PZ-6[3]	3/28/2018	1280911.35	614555.89	516.69	519.60	507.75	497.75	Downgradient
GSD-AP-MW-2V[5]	10/24/2019	1280364.25	614608.05	522.90	525.31	472.90	462.90	Piezometer
GSD-AP-MW-2VA	1/30/2020	1280385.77	614620.77	521.54	524.94	456.39	446.39	Vertical Delineation
GSD-AP-MW-4V	10/22/2019	1280986.06	613900.64	517.56	520.33	485.58	475.58	Vertical Delineation
GSD-AP-MW-18H	10/24/2019	1280350.60	615161.03	522.28	524.45	506.85	496.85	Horizontal Delineation
GSD-AP-MW-19H	10/24/2019	1280656.67	614589.91	513.95	517.32	505.24	495.24	Horizontal Delineation
GSD-AP-MW-20H	10/24/2019	1281024.09	613927.12	514.28	516.68	506.39	496.39	Horizontal Delineation

Notes:
Source: Southern Company Services, 2020. *Groundwater Investigation Report.* Plant Gadsden Ash Pond. Prepared for Alabama Power Company. May 22, 2020.
1. Northing and easting are in feet relative to the State Plane Alabama West North American Datum of 1983.
2. Elevations are in feet relative to the North American Vertical Datum of 1988.
3. Piezometers have been converted to downgradient compliance wells.
4. Top of screen and bottom of screen elevations are calculated relative to top of casing elevation and less the well sump length of 0.4'.
5. Location GSD-AP-MW-2V was orginially intended for vertical delineation but has been converted to a temporary piezometer due to low groundwater recharge. This location will be abandoned in the future.

Table 3
Groundwater Protection Standards

Constituent	Units	Background	Federal GWPS	State GWPS
Antimony	mg/L	0.003	0.006	0.006
Arsenic	mg/L	0.005	0.01	0.01
Barium	mg/L	0.259	2	2
Beryllium	mg/L	0.003	0.004	0.004
Cadmium	mg/L	0.00101	0.005	0.005
Chromium	mg/L	0.01	0.1	0.1
Cobalt	mg/L	0.0538	0.006	0.0538
Combined Radium 226+228	pCi/L	1.213	5	5
Fluoride	mg/L	0.23	4	4
Lead	mg/L	0.005	0.015	0.015
Lithium	mg/L	0.02	0.04	0.04
Mercury	mg/L	0.000664	0.002	0.002
Molybdenum	mg/L	0.01	0.1	0.1
Selenium	mg/L	0.01	0.05	0.05
Thallium	mg/L	0.001	0.002	0.002

Notes:
Source: Southern Company Services, 2020. *2019 Semi-Annual Groundwater Monitoring and Corrective Action Report.* Plant Gadsden. Prepared for Alabama Power Company. February 1, 2020.
GWPS: groundwater protection standard
mg/L: milligrams per liter
pCi/L: picocuries per liter

Table 4
April 2020 Assessment Sampling Results

Well ID	Purpose	Sample Date	Arsenic[1] (mg/L)	Lithium[2] (mg/L)
GSD-AP-MW-1	Downgradient	4/15/2020	0.00309 (J)	ND
GSD-AP-MW-2	Downgradient	4/15/2020	0.709	0.0406
GSD-AP-MW-2VA	Vertical Delineation	4/15/2020	ND	0.0783
GSD-AP-MW-3	Downgradient	4/13/2020	ND	ND
GSD-AP-MW-4V	Vertical Delineation	4/15/2020	ND	0.0219
GSD-AP-MW-4	Downgradient	4/15/2020	0.0121	ND
GSD-AP-MW-5	Downgradient	4/13/2020	ND	ND
GSD-AP-MW-6	Downgradient	4/13/2020	ND	ND
GSD-AP-MW-7	Downgradient	4/15/2020	ND	ND
GSD-AP-MW-8	Downgradient	4/14/2020	0.00295 (J)	ND
GSD-AP-MW-9	Downgradient	4/14/2020	0.00118 (J)	ND
GSD-AP-MW-10	Downgradient	4/15/2020	0.00236 (J)	ND
GSD-AP-MW-11	Downgradient	4/14/2020	0.00286 (J)	ND
GSD-AP-MW-12	Downgradient	4/14/2020	ND	ND
GSD-AP-MW-14	Upgradient	4/16/2020	0.00483 (J)	ND
GSD-AP-MW-16	Upgradient	4/15/2020	0.0034 (J)	ND
GSD-AP-MW-17	Upgradient	4/16/2020	ND	0.0127 (J)
GSD-AP-MW-18H	Horizontal Delineation	4/15/2020	ND	ND
GSD-AP-MW-19H	Horizontal Delineation	4/14/2020	ND	ND
GSD-AP-MW-20H	Horizontal Delineation	4/14/2020	0.00287 (J)	ND
GSD-AP-PZ-1	Downgradient	4/13/2020	ND	ND
GSD-AP-PZ-2	Downgradient	4/13/2020	ND	ND
GSD-AP-PZ-5	Downgradient	4/15/2020	ND	ND
GSD-AP-PZ-6	Downgradient	4/15/2020	ND	ND

Notes:
1. Groundwater protection standard for arsenic is 0.01 mg/L.
2. Groundwater protection standard for lithium is 0.04 mg/L.
J: Estimated value; value may not be accurate. Spike recovery or relative percent difference outside of criteria.
mg/L: milligrams per liter
ND: non-detect; indicates that the concentration was not detected above the laboratory method detection limit

Table 5
Groundwater Corrective Action Evaluation Summary

Technology	Evaluation Criteria						
	Performance	Reliability	Ease or Difficulty of Implementation	Potential Impacts of Remedy	Time to Implement Remedy (Influenced by Regulatory Approval Process)	Time to Achieve Groundwater Protection Standard at the Waste Boundary	Institutional Requirements
Monitored Natural Attenuation[1]	Medium due to the sand and gravel in the surficial soils	Relatively high due to little O&M and other potential repair needs	Relatively easy due to minimal infrastructure (e.g., monitoring wells) needed to implement remedy	None	18 to 24 months	Estimated > 10 years[2]	None identified
Hydraulic Containment (pump-and-treat)	High; reduces constituents to compliance levels when online	Medium to high; system offline at times for maintenance	Medium due to design and installation of pump-and-treat system	Pumped water will need to be treated	12 to 24 months	Estimated > 10 years[2]	Needs to be compatible with Site NPDES permit; State Underground Injection Control permit may be required
Hydraulic Containment (tree wells)	Medium; the trees will not transpire (pump) during winter	Medium; the trees will not transpire (pump) during winter	Relatively easy	None	6 to 9 months	Estimated > 10 years[2]	None identified
Permeable Reactive Barriers	Medium to high; reduces constituents to compliance levels downgradient of reactive barrier	Medium; reactive media will need to be replaced periodically	Medium due to trenching	May alter groundwater flow hydraulics beneath and adjacent to the Site, could be evaluated with groundwater model	12 to 24 months	Estimated > 10 years	None identified
Vertical Barrier Walls (in conjunction with hydraulic containment or PRB walls)	Relatively high; many successful case histories over decades	Relatively high due to minimal need for O&M or replacement	Medium due to trenching or other emplacement methods	Will alter groundwater flow hydraulics beneath and adjacent to the Site, could be evaluated with groundwater model	12 to 24 months	Contingent on companion technology, i.e. > 10 years for PRB walls and hydraulic containment	None identified
Geochemical Manipulation (in situ injection, spot treatment)	Medium	Medium; site geochemical conditions need to be maintained to prevent rebound	Relatively easy due to minimal infrastructure (e.g., injection wells or direct push)	Constituents may be mobilized initially upon injection before ultimate immobilization	12 to 24 months	Estimated 5 to 10 years (for small, localized areas)	State Underground Injection Control permit may be required
Permeation Grouting	Medium; grout may not be able to penetrate sufficient pore spaces in the areas of impact	Medium	Medium	Will alter groundwater flow hydraulics beneath and adjacent to the Site	12 to 24 months	Estimated 1 to 5 years after implementation	None identified
In Situ Solidification/ Stabilization	High; many successful case histories over decades	High; little O&M after initial implementation	Medium; requires subsurface work with heavy equipment	Initial increase in COI concentrations due to subsurface disruption; concentrations expected to decrease in a relatively short time period	12 to 24 months	Estimated 1 to 5 years after implementation	None identified

Notes:
1. MNA is often used in combination with other remedial technologies.
2. Timeframes shown are estimated based on case histories of MNA and hydraulic containment (respectively) of arsenic-impacted sites. Detailed estimate of time requires further investigation.
COI: constituent of interest
MNA: monitored natural attenuation
NPDES: National Pollutant Discharge Elimination System
O&M: operation and maintenance
PRB: permeable reactive barrier

Table 6
Technology Advantages and Disadvantages

Technology	Advantages	Disadvantages
MNA	• Minimal site disruption • Sustainable • Applicable in congested, sensitive or less accessible areas where other technologies may not be feasible • Minimal O&M	• Other treatment technologies may be required
Hydraulic Containment (pump-and-treat)	• Pump-and-treat systems are very effective at hydraulically containing impacted groundwater • Systems can be installed as deep as typical well drilling technology allows • Systems can be modified over time to increase or decrease extraction rates and/or to adapt to changing site conditions	• More labor, O&M required than other technologies • Constituent levels can rebound if treatment is halted • System may reach a point of diminishing returns where concentrations stabilize above regulatory standards for inorganic constituents
Hydraulic Containment (tree wells)	• Minimal site disruption • Sustainable • Easy to implement • Minimal O&M	• Trees may not transpire (pump) sufficient water to facilitate hydraulic containment • More trees may be required than space available • Trees do not transpire (pump) in winter
Permeable Reactive Barriers	• Low labor, O&M requirements until media needs to be replaced • No need to manage extracted groundwater • Reduced need to dispose treatment by-products until media needs to be replaced	• Reactive media will need to be replaced at some point • Used media will need to be assessed for hazardous characteristics • Hydraulic conductivity of the media may diminish with time • Due to reversal of groundwater gradient at the north side of the Site, geometry may not be conducive for PRB placement, i.e., PRB may be upgradient of impacts rather than downgradient
Vertical Barrier Walls (in conjunction with hydraulic containment or PRB walls)	• Reliable and widely accepted technology	• Mounding, end-around, or under-flow could occur if hydraulics not evaluated properly
Geochemical Manipulation (in situ injection, spot treatment)	• Ability to treat small, localized areas • Minimal site disruption • Applicable in congested, sensitive or less accessible areas where other technologies may not be feasible	• Emerging technology, permanence for inorganic constituents not demonstrated for greater than 3 years
Permeation Grouting	• Reliable and widely accepted technology • Applicable to fractured rock • Relatively short time anticipated to achieve GWPS at the Site (1 to 5 years after implementation)	• Heterogeneity of the subsurface can impact the ability to emplace the grout curtain (wall) • Too many fine particles in alluvial material can impede grout travel
In Situ Solidification/Stabilization	• Reliable and widely accepted technology • Extensive remedial effectiveness data for arsenic and some data for lithium • Relatively short time anticipated to achieve GWPS at the Site (1 to 5 years after implementation)	• Based on implementation at other sites, an initial increase in COI concentrations may occur in groundwater during implementation, due to subsurface disruption; increase is expected to dissipate in a short period of time (1 to 5 years)

Notes:
Sources: 1) Electric Power Research Institute, 2015. *Corrective Action for Closed and Closing Ash Ponds*. 3002006292. December 8, 2015. 2) Anchor QEA project experience
COI: constituent of interest
GWPS: groundwater protection standard
MNA: monitored natural attenuation
O&M: operation and maintenance
PRB: permeable reactive barrier

Table 7
Schedule

Estimated Completion Date	Task
July 2020 - September 2020	Evaluate existing groundwater analytical data for MNA (graphing)
	Collect groundwater samples and precipitates
September 2020 - February 2021	Perform XRD, XRF, SSE, SEM, and CEC work on precipitates and initial geochemical modeling
	Integrate the XRD, XRF, SEM, SSE, CEC, and geochemical modeling results into a geochemical CSM; perform additional geochemical modeling if needed
February 2021 - December 2021	Perform a conceptual-level feasibility study of potentially viable corrective actions
	Develop a conceptual corrective action strategy plan
	Develop plans for laboratory treatability and field pilot tests as needed
2022	Collect additional data to fill identified data gaps
	Perform laboratory treatability studies and implement field pilot tests
2023	Develop a detailed groundwater remedy plan

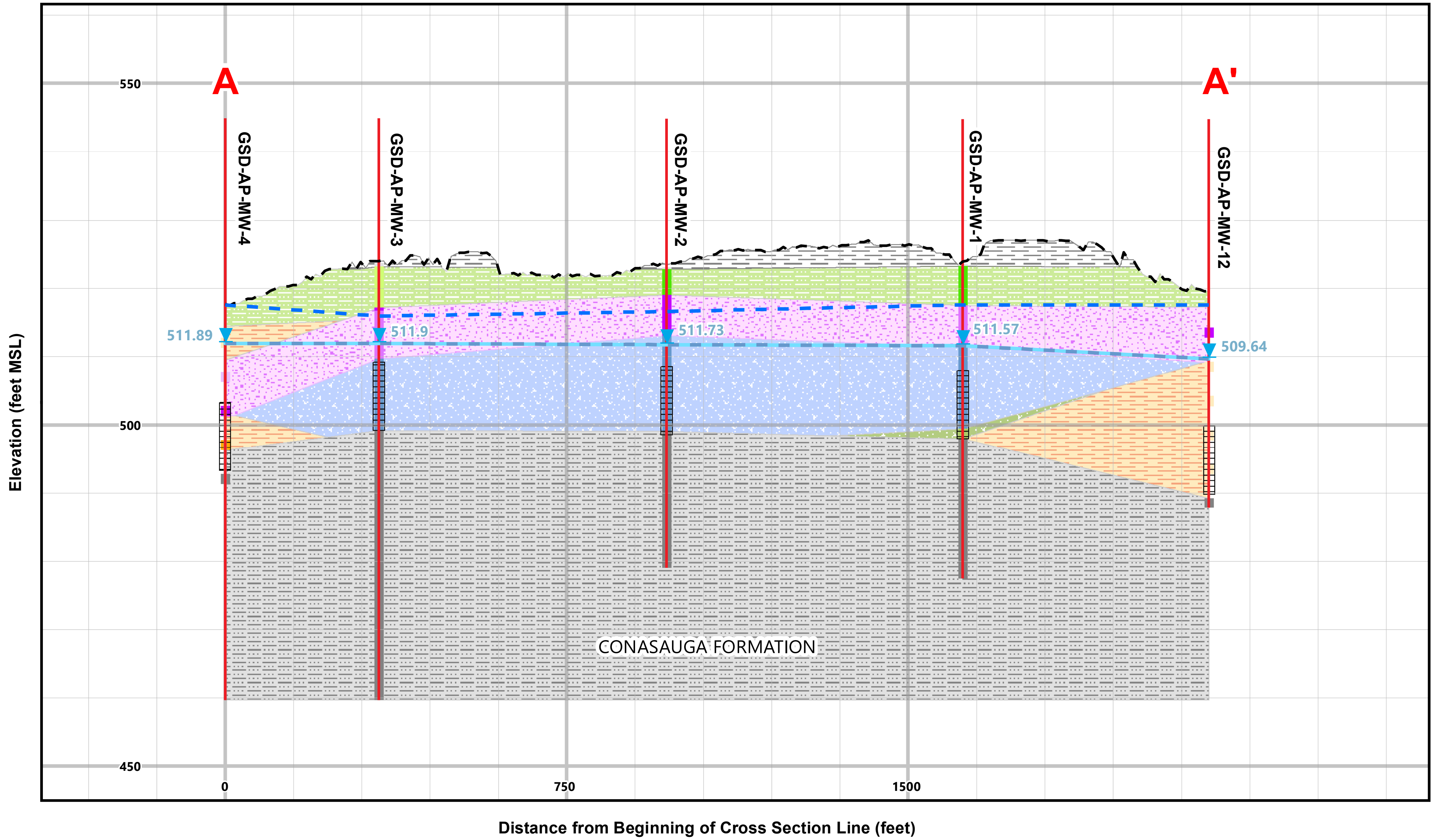
Notes:
CEC: cation exchange capacity
CSM: conceptual site model
SEM: scanning electron microscopy
SSE: selective sequential extraction
XRD: X-ray diffraction
XRF: X-ray fluorescence

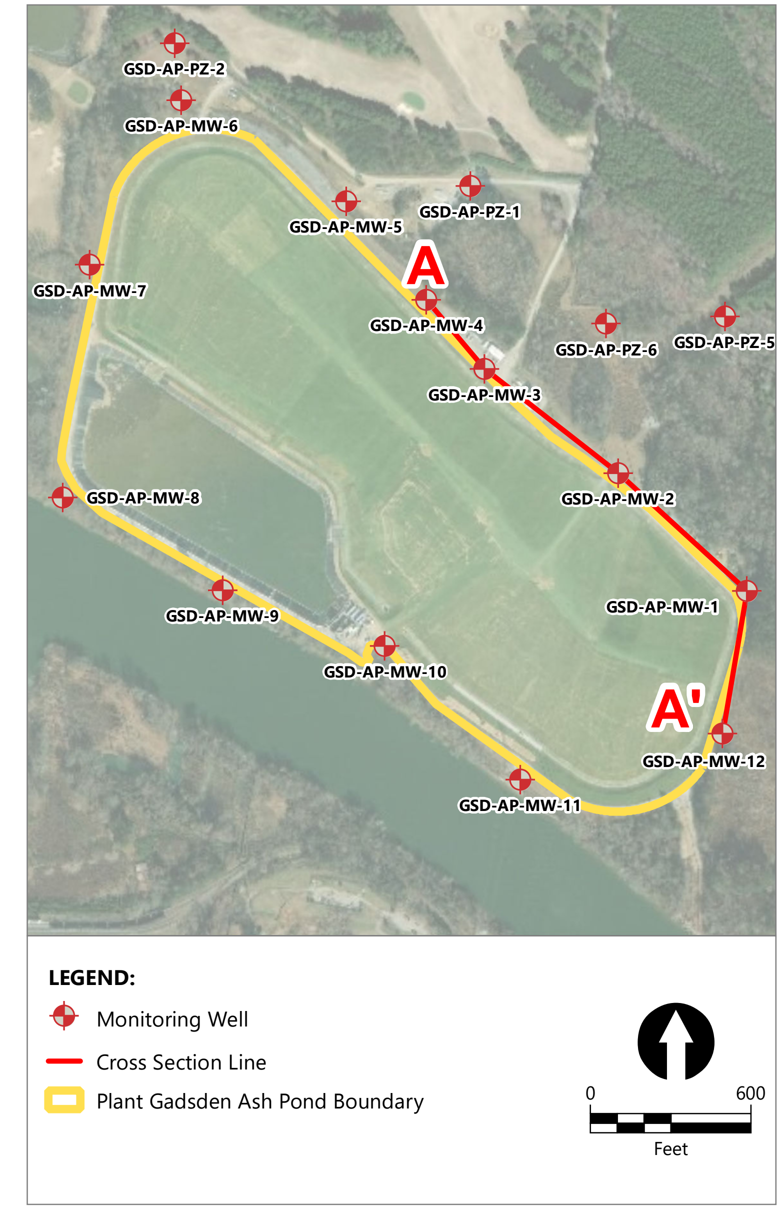
Figures

Publish Date: 2020/06/30, 4:32 PM | User: jquinley
Filepath: \\orcas\GIS\Jobs\SouthernCompany_1114\GadsdenSteamPlant\Maps\2020_ACM\AQ_PlantGadsdenACM_Figure01_SiteLocation.mxd

ANCHOR QEA

Figure 1
Site Location Map
Assessment of Corrective Measures
Plant Gadsden





LEGEND:

- Approximate Groundwater Elevation (10/22/2018)
- Approximate Groundwater Elevation (10/22/2018)
- Maximum Groundwater Elevation
- Minimum Groundwater Elevation
- Ground Surface Elevation
- Monitoring Well Location
- Screen Interval
- Topsoil/Fill
- Lean and Sandy Lean Clay
- Silty Clay
- Silt
- Sandy Silt
- Silty Sand
- Well-graded Sand
- Poorly-graded Sands
- Clay, Sand, and Gravel Mix
- Well-graded Gravel
- Mudstone/Shale
- Dike Fill
- Clays
- Silts
- Sands
- Gravel
- Undifferentiated Clay, Sand, and Gravel
- Mudstone/Shale

NOTES:

1. Stratagraphic layers were correlated using boring data.
2. Approximate Groundwater Elevation data are reported using Mean Sea Level (MSL).
3. Approximate groundwater elevation was collected from monitoring network wells on October 22, 2018.
4. Maximum and minimum groundwater elevation data were derived from the highest and lowest groundwater elevation values recorded during events spanning August 15, 2013 to October 22, 2018.

SOURCES:

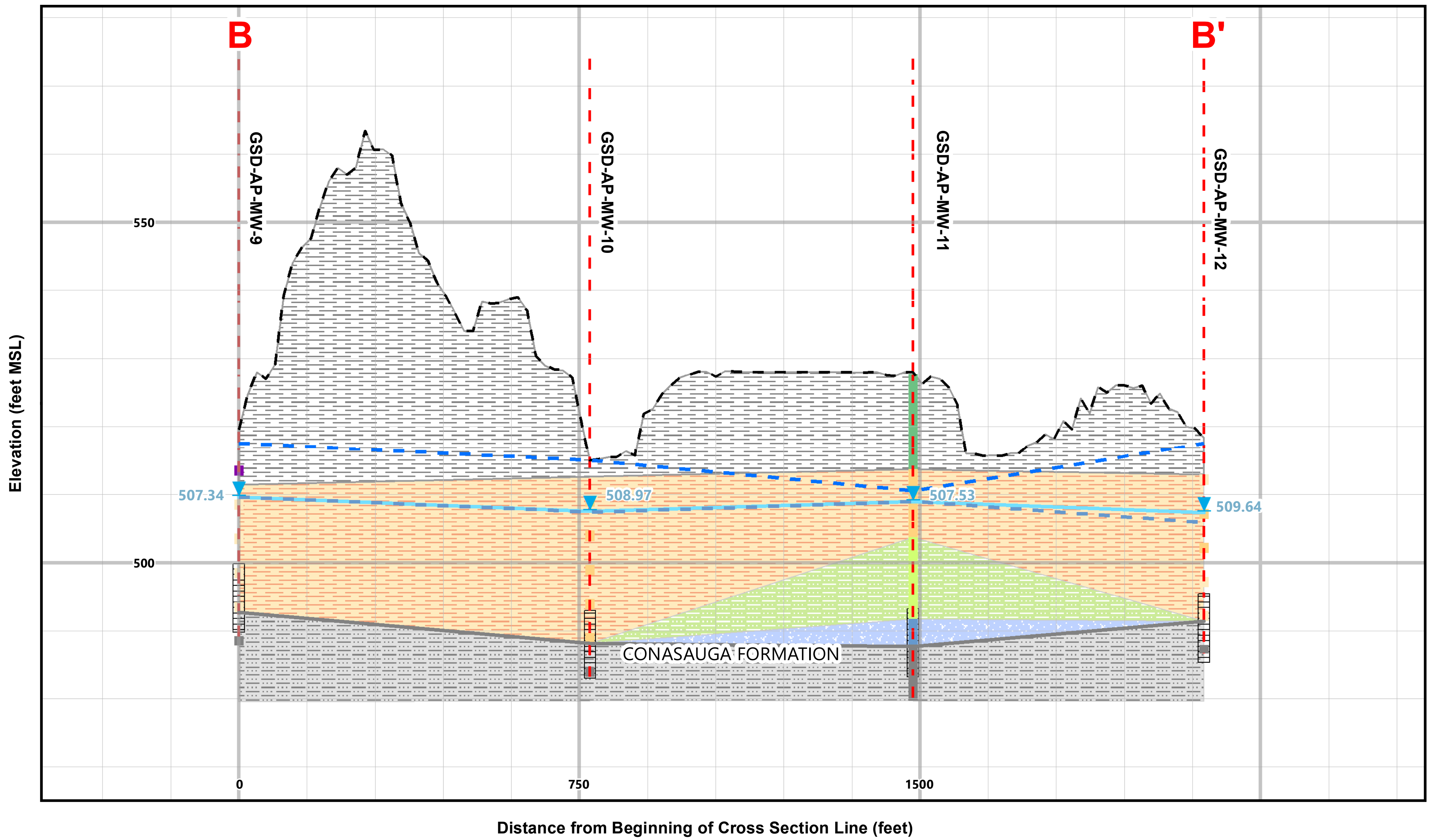
SCS, 2020. *2019 Semi-Annual Groundwater Monitoring and Corrective Action Report*. Plant Gadsden Ash Pond. Prepared for Alabama Power Company. Februrary, 2020.

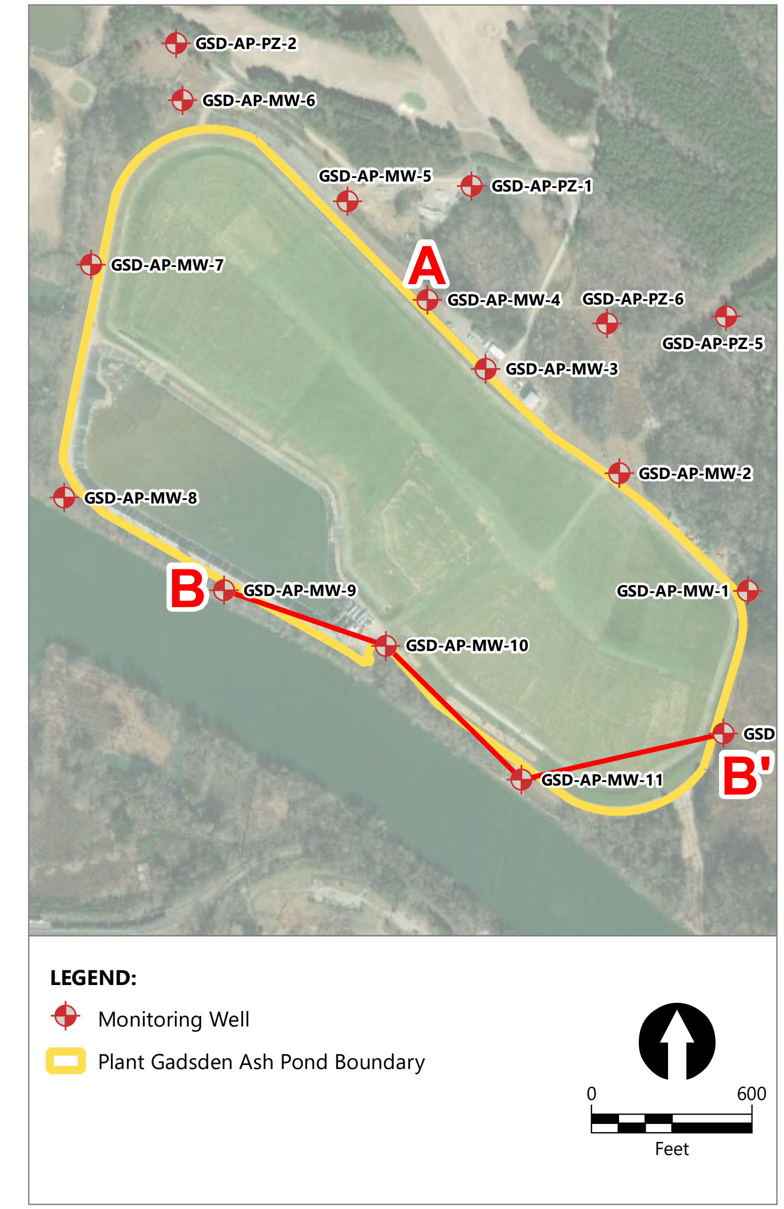
Aerial Imagery from Esri Basemaps.

Publish Date: 2020/06/30, 4:16 PM | User: jquinley
Filepath: \\orcas\GIS\Jobs\SouthernCompany_1114\GadsdenSteamPlant\Maps\2020_ACM\AQ_PlantGadsdenACM_Figure02a_xSectionA.mxd

ANCHOR QEA

Figure 2a
Geologic Cross Section: A-A'
Assessment of Corrective Measures
Plant Gadsden





LEGEND:

- Approximate Groundwater Elevation (10/22/18)
- Approximate Groundwater Elevation (10/22/18)
- Maximum Groundwater Elevation
- Minimum Groundwater Elevation
- Monitoring Well Location
- Screen Interval
- Clay, Silt, and Gravel Fill
- Lean Clays
- Fat and Silty Clays
- Silt
- Poorly-graded Gravelly Sand
- Well-graded Gravel
- Shale/Siltstone
- Topsoil/Fill
- Clays
- Silts
- Gravel
- Siltstone/Shale

NOTES:

1. Stratagraphic layers were correlated using boring data.
2. Approximate Groundwater Elevation data are reported using Mean Sea Level (MSL).
3. Approximate groundwater elevation was collected from monitoring network wells on October 22, 2018.
4. Maximum and minimum groundwater elevation data were derived from the highest and lowest groundwater elevation values recorded during events spanning August 15, 2013 to October 22, 2018.

SOURCES:

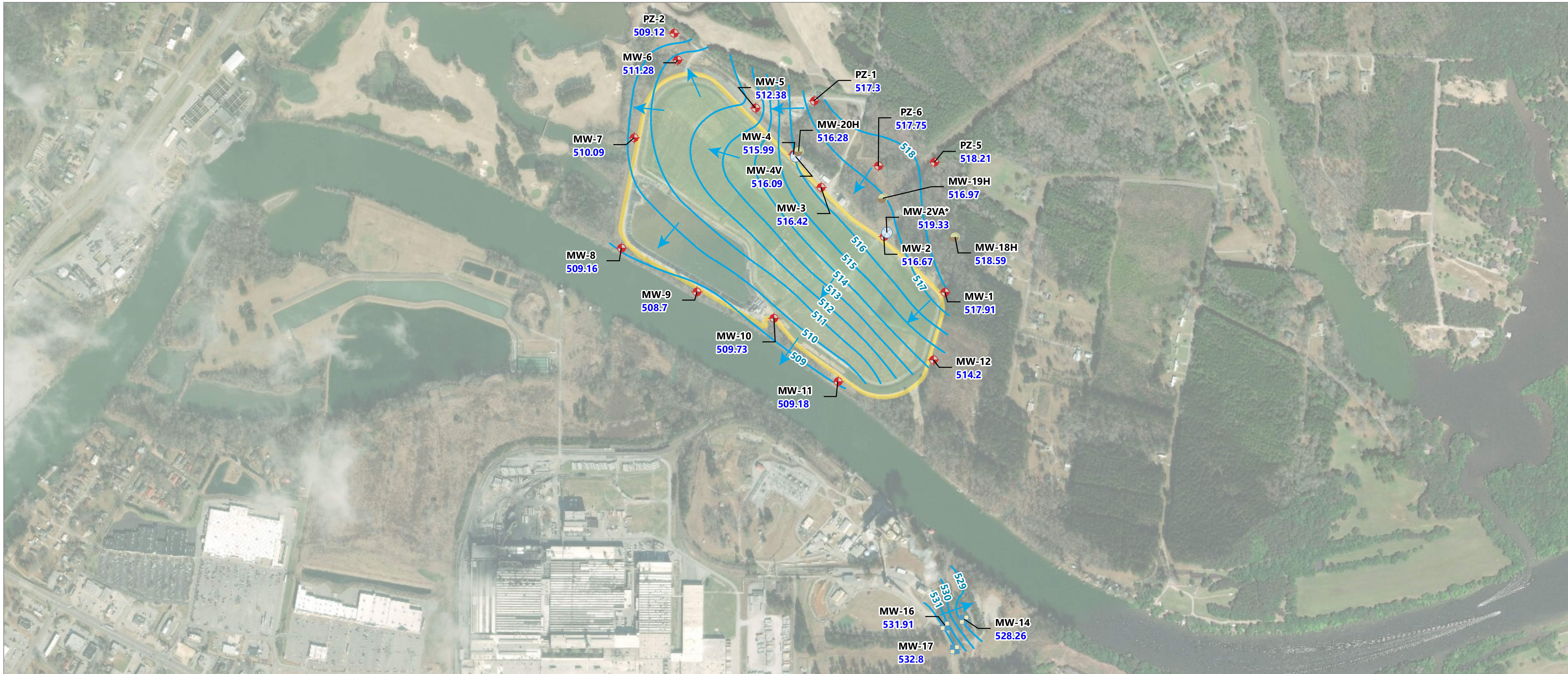
SCS, 2020. *2019 Semi-Annual Groundwater Monitoring and Corrective Action Report.* Plant Gadsden Ash Pond. Prepared for Alabama Power Company. Februrary, 2020.

Aerial Imagery from Esri Basemaps.

Publish Date: 2020/06/30, 4:15 PM | User: jquinley
Filepath: \\orcas\GIS\Jobs\SouthernCompany_1114\GadsdenSteamPlant\Maps\2020_ACM\AQ_PlantGadsdenACM_Figure02b_xSectionB.mxd

ANCHOR QEA

Figure 2b
Geologic Cross Section: B-B'
Assessment of Corrective Measures
Plant Gadsden



LEGEND:

Plant Gadsden Ash Pond Boundary

Downgradient Monitoring Well

Upgradient Monitoring Well

Horizontal Delineation Well

Vertical Delineation Well

Piezometer

Potentiometric Surface Contour (ft NAVD88)

Approximate Groundwater Flow Direction

GSD-AP-MW-1 Well ID

519.26 Groundwater Elevation

NOTES:

1. Depth to water was measured on April 13, 2020
2. NAVD88: North American Vertical Datum of 1988
3. *: Vertical delineation well MW-2VA was exceluded from potentiometric surface calculation because it appears to be screened in a seperate hydrogeologic unit.

SOURCES:

Groundwater elevation data provided by Southern Company Services, Inc.

Aerial Imagery from Esri Basemaps

0 1,000

Feet

Publish Date: 2020/06/30, 4:10 PM | User: jquinley

Filepath: \\orcas\GIS\Jobs\SouthernCompany_1114\GadsdenSteamPlant\Maps\2020_ACM\AQ_PlantGadsdenACM_Figure03_PotentiometricSurface.mxd

ANCHOR QEA

Figure 3

Potentiometric Surface Map

Assessment of Corrective Measures

Plant Gadsden

ANCHOR QEA

anchorqea.com