# ASSESSMENT OF CORRECTIVE MEASURES CARDINAL SITE – FLY ASH RESERVIOR II BRILLIANT, OHIO

*Prepared for*

**Cardinal Operating Company**
306 County Road 7E
Columbus, Ohio 43213

*Prepared by*


Geosyntec consultants

engineers | scientists | innovators

941 Chatham Lane, Suite 103
Columbus, OH 43221


Project Number CHA6468

July 2019

# TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

## LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ACM | Assessment of Corrective Measures |
| AEP | American Electric Power Service Corporation |
| AMSL | Above Mean Sea Level |
| BAC | Bottom Ash Complex |
| CCR | Coal Combustion Residual |
| CFR | Code of Federal Regulations |
| ESP | Electrostatic Precipitator |
| FAD | Fly Ash Dam |
| FAR | Fly Ash Reservoir |
| FGD | Flue Gas Desulfurization |
| GWPS | Groundwater Protection Standards |
| MNA | Monitored Natural Attenuation |
| MSE | Mechanically Stabilized Earth |
| MW | Megawatts |
| NPDES | National Pollutant Discharge Elimination System |
| PMF | Probable Maximum Flood |
| PTI | Permit to Install |
| RCC | Roller Compacted Concrete |
| RSW | Residual Solid Waste |
| SCR | Selective Catalytic Reduction |
| SSL | Statistically Significant Levels |
| TDS | Total Dissolved Solids |
| USEPA | United States Environmental Protection Agency |

# 1. INTRODUCTION

On behalf of our client, Cardinal Operating Company, Geosyntec has produced this Assessment of Corrective Measures (ACM) report for the Fly Ash Reservoir II (FAR II) at the Cardinal Generating Plant (the Site or Facility). The Site is located one mile south of Brilliant, Ohio in Jefferson County, along the Ohio River. Under the United States Environmental Protection Agency (USEPA) Coal Combustion Residual (CCR) Rule (40 Code of Federal Regulations (CFR) 257 Subpart D), groundwater monitoring is required to assess impacts of CCR activities to groundwater compared to background conditions. In 2018, statistically significant levels (SSL) of lithium and molybdenum above their respective groundwater protection standards (GWPS) were observed at the Site, requiring an ACM under 40 CFR 257.96. This document was developed to identify potential corrective measures that may be appropriate for addressing elevated lithium and molybdenum concentrations in site groundwater and was prepared in accordance with 40 CFR 257.96.

## 1.1 Background

The Facility is located approximately one mile south of Brilliant, Ohio in Jefferson County along the Ohio River (**Figure 1**). The generating station consists of three units with a nominal capacity of 1,830 megawatts (MW). Units 1 and 2 began operation in 1967 and Unit 3 began operation in 1977. All three units are coal powered, with an average annual coal use of 5.2 million tons for the entire plant. As of 2012, all three units were equipped with an electrostatic precipitator (ESP), a selective catalytic reduction (SCR) system, and a flue gas desulfurization (FGD) system. Fly ash generated at the plant was formerly sluiced to the Fly Ash Reservoir I (FAR I), which was impounded by Fly Ash Dam 1 (FAD 1) from 1977 through 1988 when it was filled to capacity. The closure process for FAR I began in 1990 per Permit to Install (PTI) Application No. 17-709 (Buckeye Power, 2019).

The three CCR storage units currently utilized by the Facility, the Bottom Ash Complex (BAC), the FAR I Residual Solid Waste Landfill (FAR I RSW Landfill), and the FAR II reservoir are shown in **Figure 1**. Fly ash is currently sluiced to FAR II, which is impounded by FAD 1 and FAD 2. The construction of FAD 2 and subsequent dam raisings are discussed further in **Section 2.4**. FAR II receives sluiced fly ash from the generating unit's ESPs and collected stormwater and leachate from the FAR I RSW Landfill. FAR II/FAD 2 has a permitted discharge (Outfall 019) through the national pollutant discharge elimination system (NPDES) (Geosyntec, 2017). Monitoring wells within the CCR rule monitoring network and select other locations of interest are shown in **Figure 2**.

## 1.2 ACM Objective

The purpose of this ACM Report is to identify and evaluate potential technologies that may be appropriate for reducing lithium and molybdenum present in site groundwater to acceptable regulatory cleanup levels in accordance with 40 CFR 257.96. The target cleanup levels are the GWPS defined under 40 CFR 257.95(h). The site-specific GWPS for lithium and molybdenum are 140 µg/L and 100 µg/L, respectively. This ACM relies on the Groundwater Characterization Report for the FAR II Unit prepared by Geosyntec in 2019 to focus the evaluation of remedial technologies that will achieve the most efficient and cost-effective method of obtaining concentrations of lithium and molybdenum below the GWPS.

## 1.3 Report Organization

The remainder of this ACM Report is organized as follows:

Section 2: *Summary of Site Conditions* – This section provides a brief description of the site setting, history, and summarizes the investigations performed to support the ACM for the Site, as well as a description of anticipated future conditions at the Site.

Section 3: *Evaluation of Corrective Measure Alternatives* – This section provides evaluation criteria, primary corrective measure technologies, as well as a comprehensive evaluation of the most appropriate groupings of technologies identified to remediate the lithium and molybdenum groundwater impacts at the Site.

Section 4: *Next Steps* – This section presents a summary of follow-on actions pertaining to remedy selection and schedule for implementation and completion.

Section 5: *References* – This section provides a listing of the references cited in this ACM Report

# 2. SUMMARY OF CURRENT CONDITIONS

## 2.1 Site Setting and History

### 2.1.1 Site Geology

The Site is underlain by horizontal sequences of lower Permian and upper Pennsylvanian sedimentary rock. In the vicinity of the Site, the Dunkard Group is the upper most stratigraphic unit of the Washington Formation, and is characterized by non-marine cyclic sequences of sandstone, siltstone, shale, limestone, and coal. Associated rock outcrops appear along the northwest and west ridges of the FAR I/FAD 1 RSW Landfill.

Underlying the Dunkard Group is the Monongahela Group, which is approximately 230 feet thick in the vicinity of the Site. The Monongahela Group consists of sandstone and shale, siltstone, limestone, sandstone, and coal (American Electric Power Service Corporation [AEP], 2006).

Beneath the Monongahela Group, is the Conemaugh Group, which consists of shale, sandstone, limestone, claystone, and coal and is approximately 500 feet thick in Jefferson County (AEP, 2006). This group includes the Morgantown Sandstone underlain by the Elk Lick Limestone, the Skelly Limestone and Shale, the Ames Limestone, the Cow Run Sandstone, and the Buffalo Sandstone. The Morgantown Sandstone is a fractured and jointed conglomeratic sandstone that is approximately 75 to 100 feet thick in the vicinity of the western abutment of FAD 2 (Sanborn Head & Associates, Inc. [Sanborn Head], 2018). In the vicinity of FAD 2, the base of the Morgantown Sandstone slopes south from M-21 to the Jules Verne Seep, and east from M-1003 to the Jules Verne Seep (Sanborn Head, 2018). The Elk Lick Limestone, the Skelly Limestone and Shale and the Ames Limestone vary in a combined thickness of approximately 80 feet. At the bottom of the Conemaugh Group, the Cow Run Sandstone is approximately 20 to 30 feet thick (AEP, 2006).

Prior to the development of the FAR II, overburden in the FAR II valley consisted of 10 to 30 feet of residual soils, mine spoil, landside debris and alluvial deposits (AEP, 1984; AEP, 2006). Along the valley walls, the overburden consisted of clayey colluvium (Amaya et al., 2009). Prior to the construction of FAD 2, a landslide upstream of the western abutment of FAD 2 occurred, exposing the face of the Morgantown Sandstone at approximately 880 feet above mean sea level (AMSL).

FAR II incises the Monongahela Group and partially incises the Conemaugh Group, including the Morgantown Sandstone. Cross sections for the geology at FAD 2 are shown in **Figure 3** and **Figure 4**.

### 2.1.2 Site Hydrogeology

Groundwater at FAR II is present in three aquifers of interest to the ACM: the surficial aquifer, the Morgantown Sandstone, and the Cow Run Sandstone.

The surficial aquifer is contained in the Monongahela group, primarily the Connellsville Sandstone, the Summer Field Limestone, the Bellaire Sandstone, former room and pillar mines, and mine spoils. The groundwater flow in the shallow aquifer tends to follow local topography and generally has high hydraulic conductivity, ranging from $1\times10^{-1}$ to $1\times10^{-4}$ centimeters per second (cm/sec; AEP, 2006). The surficial aquifer and the Morgantown Sandstone are separated by a shale aquitard with a hydraulic conductivity ranging from $1\times10^{-7}$ to $1\times10^{-9}$ cm/s (AEP, 2006).

Regionally, the Morgantown Aquifer flows south-southeast towards the Ohio River in the vicinity of the Site. Groundwater flow in the vicinity of FAR II flows around the eastern and western abutments of the FAD 2 structure (**Figure 5**). Along the western abutment, the Morgantown Sandstone outcrops and groundwater is discharged through the Jules Verne Seep (**Figure 4**)

The Cow Run Sandstone is separated from the Morgantown Sandstone by approximately 50 to 100 feet of low permeability shale and limestone beds. The Cow Run Sandstone Aquifer generally flows south-southeast towards the Ohio River in the vicinity of the Site. Regionally, the Cow Run Aquifer is a saline aquifer, with total dissolved solids (TDS) concentrations at CR-1 and CR-2 frequently reported above 2,000 milligrams per liter (mg/L).

### 2.1.3 Construction of FAD 2

Construction of FAR II began in 1985 under PTI 06-1250 (Buckeye, 2019). The FAR II foundation consists of a claystone and shale, and the abutment consists of the Monongahela Group and a portion of the Conemaugh Group including the Morgantown Sandstone. Prior to the construction of FAR II, permeability testing was conducted on the abutment and foundation rock structures which indicated that the Morgantown Sandstone would be relatively impervious except where the rock face was exposed to the surface of the FAR II unit. The clayey colluvium overburden was left in place along the abutment to provide a naturally impervious barrier (Amaya et.al, 2009). However, prior the construction of FAD 2, a small landslide occurred in the clayey colluvium overburden covering the Morgantown Sandstone just upgradient of the western abutment of FAD 2 at approximately 880 feet AMSL. A cut to rock was made and a grout curtain was installed (AEP, 2016). The abutment was installed such that the clay core contacted the competent rock at 90-degree angles on the upstream side of the abutment to prevent seepage beneath the dam and reduce cracking of the core (AEP 2016). The dam had a final crest height of 925 feet AMSL (AEP, 1997).

The FAD 2 structure has been raised twice since the initial construction. In 1997, the dam elevation was raised to 970 feet AMSL (AEP, 1997). The raising included an earthen embankment with a Roller Compacted Concrete (RCC) zone. The RCC zone was supported on the downstream side of FAD 2 with mine spoils. In 2013, the dam was raised again to a crest height of 983 feet AMSL with a back-to-back mechanically stabilized earth (MSE) wall. The MSE wall consists of a vinyl sheet pile wall that extends from the existing clay core to the Probable Maximum Flood (PMF) level (AEP, 2016). The current maximum operating stage of the FAR II unit is 974 feet AMSL (AEP, 2016).

#### 2.1.4 Summary of ACM Investigations

Additional investigation work was completed in spring 2019 in accordance with 40 CFR 257.95(g)(1). Monitoring well M-2000 was installed in March 2019 to delineate the lithium and molybdenum release and to serve as the additional monitoring well at the facility boundary (FAR II Unit). Additional sampling of the wells in the monitoring network, M-2000, and seeps along the FAD II abutment were sampled in March, April, and May 2019. Concentrations of lithium and molybdenum above the GWPSs were observed at monitoring wells FA-8, M-11, M-2000, and the Jules Verne Seep. These results suggest impacts to the Morgantown Aquifer extend from M-11 to the Jules Verne Seep. These investigation activities and their results were documented in a *Groundwater Characterization Report* (Geosyntec, 2019a).

### 2.2 <u>Characterization of Release</u>

The FAR II unit discharges into the Morgantown Aquifer and impacts from the FAR II unit are limited to monitoring wells FA-8, M-11, M-2000, and the Jules Verne Seep. The Morgantown Aquifer consists of a fractured and jointed conglomeratic sandstone with fractures and joints through which water from the FAR II unit flows around the FAD 2 structure on the western side and ultimately to the Jules Verne Seep. As shown in **Figure 3**, the hydraulic head in the Morgantown Aquifer along the north-south transect of the dam is from north to south (M-11 to M-2000). Along the east-west transect, the hydraulic gradient is from west to east and ultimately discharges through the Jules Verne Seep (M-1003 to Jules Verne Seep; **Figure 4**). Therefore, impacts from FAR II enters the Morgantown Aquifer in the vicinity of M-11 and discharges through the outcrop of the Morgantown Sandstone at Jules Verne Seep. Groundwater discharging from the Jules Verne Seep is collected at the base of FAD 2 and discharged to the Ohio River through NPDES Permitted Outfall 19.

## 2.3 Anticipated Future Conditions

As required under 40 CFR 257.101(a)(1), by October 31, 2020 the facility will cease placing CCR and non-CCR waste streams into the FAR II unit and close the unit in accordance with 40 CFR 257.102. This change in waste disposal practices will be achieved through operational changes to dry ash handling.

Following closure, the facility will comply with the post-closure care and maintenance requirements for a period of 30 years or more, as required by 40 CFR 257.104. These post-closure requirements include maintaining the final cover system, maintaining the leachate collection system, maintaining the groundwater monitoring system, and monitoring groundwater in accordance with 40 CFR 257.90 through 257.98.

# 3. EVALUATION OF CORRECTIVE MEASURES ALTERNATIVES

## 3.1 Evaluation Criteria

The evaluation criteria used to determine the appropriateness of the proposed remedies are outlined in 40 CFR 257.96 and include (1) performance, (2) reliability, (3) ease of implementation, (4) potential impacts, (5) time to begin/complete remedy, and (6) institutional requirements. Each of the evaluation criteria are defined and briefly described in the following paragraphs.

### 3.1.1 Performance

Corrective measure remedies must be protective of human health and the environment. Human health can be protected by preventing exposures through engineering and institutional controls or by reducing concentrations of all chemicals in all media to levels that meet the required corrective measure standards[1].

---

[1] The risk to human health and the environment from exposure to CCR-related constituents in groundwater at the Site was assessed (Geosyntec, 2019b). The risk assessment included an exposure assessment, and a screening-level risk evaluation. The purpose of the exposure assessment was to identify potentially complete exposure pathways by which human or ecological receptors may contact lithium or molybdenum in groundwater, while the purpose of the screening-level risk evaluation was to quantitatively evaluate receptor-exposure scenarios for pathways identified as complete or assumed-to-be compete.

The assessment evaluated current conditions at the Site and assumed that any changes in site conditions, such as FAR II no longer receiving fly ash, likely result in an overestimate of potential exposures and risks. Based on the results of the exposure assessment and screening-level risk evaluation, lithium and molybdenum in FAR II groundwater are unlikely to pose an unacceptable risk to human or ecological receptors in the vicinity of the site under current or near-term future conditions. Anticipated future site conditions are expected to further reduce these risks in the future; however, in the interim, additional actions are not necessary to protect human health and the environment.

Preference is generally given to techniques that include source control or reduce the potential for future environmental releases, continuing migration or exposures to human health and the environment by reducing the toxicity, mobility, or volume of source material released.

### 3.1.2 Reliability

This evaluation criterion is used to consider future conditions, which is important for locations where remedial goals and objectives will take several decades or more to be achieved. Corrective measures that incorporate some degree of source removal or control are more effective and reliable in the long-term than technologies that rely on perpetual operation. Alternatives are compared in terms of the risk remaining at the site after the cleanup objectives have been met; the long-term impacts of any adverse consequence of any alternative; operation and maintenance requirements; and the continuity of institutional controls through administrative changes and ownership transactions.

### 3.1.3 Ease of Implementation

This criterion addresses both technical and administrative feasibility of executing a remedial alternative and the availability of various services and materials required during its implementation. The ease of implementation considers:

- Availability of materials and skilled workers to construct, operate, and maintain the system;
- Ease of undertaking or implementing additional remedial actions, off-site storage, or disposal services;
- Consistency of approach with measures that are already operating at the Site;
- Time for full-scale implementation; and
- Time required for beneficial results to be achieved.

Administrative ease of implementation, which involves evaluation of the time and practicability of obtaining needed permits, rights-of-way, or any other administrative approvals, is addressed in the Institutional Requirements evaluation criteria.

### 3.1.4 Potential Impacts

This evaluation criterion considers the potential impacts of the corrective measure implementation. Per 40 CFR 257.96, these impacts include "safety impacts, cross-media impacts and control of exposure to residual contamination." Impacts may be negative such as increased risk of accidents due to trucking, or carbon emissions due to pumping requirements. Some impacts may be unknown due to data gaps, such as potential alteration of the geochemistry resulting in mobilization of other constituents or a reduction of groundwater base flow to adjacent waterbodies.

### 3.1.5 Time Requirements

This evaluation criterion considers the time to begin and complete the remedy to minimize risk in the interim. This evaluation includes the timing of construction, start-up and completion. In this way the assessment may consider the immediate to short-term reduction in exposure risk to receptors. Remedial actions that offer more rapid reduction of COCs in media of concern are favored over remedies that may not reach full effect for years or decades.

### 3.1.6 Institutional Requirements

This evaluation criterion addresses how the specific corrective measure activities will be conducted in compliance with all applicable local, state and federal regulations (e.g., waste handling, closure requirements, land disposal restrictions, discharge permits).

## 3.2 Development of Remedial Technologies

An initial screening was conducted across a range of existing remedial technologies including containment, in-situ treatment, mass removal, ex-situ and integrated approaches. This screening resulted in the identification of five primary corrective measure technologies that could feasibly be implemented within the limitations of the physical setting and geochemistry of the FAR II Unit. The five technologies are (1) Monitored Natural Attenuation (MNA), (2) Vertical Barrier, (3) Cap & Operational Modification, (4) Groundwater Extraction, and (5) Ex-Situ Treatment.

### 3.2.1 MNA

MNA is an in-situ remedial technology that relies on natural processes occurring in aquifers to attenuate dissolved contaminants and thereby reduce their concentrations in groundwater. MNA is effective at sites where the source is controlled, the contaminant plume is stable, and contaminant concentrations are low. Natural attenuation of lithium mainly relies on the dilution process. Dilution is a physical attenuation mechanism that reduces concentrations by distributing constituent concentrations over large volumes of groundwater. Molybdenum is geochemically more reactive and may be attenuated further through precipitation or sorption processes. Precipitation and sorption are chemical mechanisms that reduce concentrations by immobilizing constituents in groundwater.

As concluded in the risk evaluation (Section 1.2), lithium and molybdenum are unlikely to pose unacceptable risks to nearby human or ecological receptors. Additionally, the concentrations of these inorganic constituents in groundwater is low, with concentrations remaining less than one order of magnitude above the GWPS. Due to the low risk to human and ecological receptors and low constituent concentrations, MNA is a viable remedial option.

Advantages:

One of the main advantages of MNA technology is the ability to utilize naturally occurring processes to attenuate concentrations in groundwater. In addition, MNA requires little infrastructure and causes minimal disruption to remediation areas.

Disadvantages:

The MNA remedial option requires that groundwater impacts be stable, otherwise source treatment and control may be required. Another disadvantage for application of MNA for molybdenum is that attenuation of metals does not result in their destruction and the attenuation processes could be reversed under changed subsurface conditions.

### 3.2.2 Vertical Barrier

Vertical barriers are remedial technologies that utilize low-permeability vertical barriers, such as slurry walls or grout curtains, installed around or downgradient of the waste mass to limit the future migration of groundwater impacts. Soil-bentonite slurry walls are commonly used and are installed by either conventional trenching, continuous trenching, or bio-polymer slurry trenching. Grout curtains are typically installed using injection of cement-based grout into underlying bedrock. Slurry walls and/or grout curtains are installed generally with surface caps for more complete containment. Gradient control systems can be used in conjunction with the vertical barrier technology to prevent groundwater mounding behind the barrier. Because this approach does not rely on the geochemical properties of lithium and molybdenum, it is likely to be equally successful for both constituents of interest.

Advantages:

Employment of vertical barriers is a proven technology that is a reliable source control measure for the entire suite of CCR constituents of interest, especially when used in combination with other technologies, such as capping and gradient control systems. Specifically, slurry walls are an effective technology that prevents groundwater migration in the subsurface and grout curtains mitigate groundwater flow through fractured bedrock. Barriers can also be implemented at both active and closed CCR sites.

Disadvantages:

The vertical barrier technology is limited by installation depth and the requirement to find a suitable low permeability layer. In addition, geologic considerations at the site may make it difficult to construct the barrier. For example, variability in fractured bedrock creates difficulty in ensuring the full continuity of the grout curtain. Moreover, dewatering or groundwater extraction may be necessary to relieve backpressure from groundwater flow prior to grouting. Additionally, groundwater extraction may be required after grouting to relieve backpressure as groundwater flow is restricted behind the barrier.

### 3.2.3 Cap & Operational Modification

The capping technology includes a low permeability cover installed over the waste surface to prevent vertical infiltration of stormwater into the CCR unit and reduce impacted groundwater generation. The implementation of a cap system would require operational modification to dry ash handling and subsequent unit closure.

Advantages:

Caps are an effective means for source control by preventing vertical infiltration and generation of impacted groundwater.

Disadvantages:

Although caps are effective at minimizing stormwater infiltration, the effectiveness increases when used with other technologies.

### 3.2.4 Groundwater Extraction

Groundwater extraction technology consists of a network of vertical or horizontal extraction wells to capture and remove contaminated groundwater. Wells can be located both downgradient and within the waste to effectively limit horizontal migration of the groundwater plume and reduce total contaminant mass. Because lithium and molybdenum are not attenuated, they can be readily extracted with groundwater. The extracted groundwater will require ex-situ treatment and permitted discharge.

Advantages:

Groundwater extraction is a proven technology effective at source capture and removal. Groundwater extraction can be used successfully in bedrock aquifers.

Disadvantages:

Groundwater extraction systems will likely require a large quantity of extraction wells to provide adequate hydraulic containment. Complex site geology and anisotropic conditions could challenge the effectiveness of the extraction system. This technology also requires ex-situ water treatment system with additional operation and maintenance considerations.

#### 3.2.5 Ex-Situ Treatment

Ex-situ treatment consists of various technologies that treat extracted groundwater prior to permitted discharge. Such technologies include; precipitation/co-precipitation, adsorption, and membrane filtration.

Precipitation/co-precipitation uses chemicals to transform dissolved contaminants into an insoluble solid. The precipitation/co-precipitated solid is then removed from the liquid phase by clarification or filtration. Adsorption is accomplished by passing contaminated groundwater through a column where the contaminants are adsorbed into the column media. The column must be regenerated or replaced when the media becomes full. Lastly, membrane filtration separated contaminants from water by passing it through a semi-permeable barrier or membrane.

Advantages:

Ex-situ treatment can be combined with other technologies to facilitate their application.

Disadvantages:

This approach has limited applicability for lithium lithium precipitation is limited and dependent on pH and other variables.  Likewise, lithium adsorption is rarely favorable. Both lithium and molybdenum require additional removal steps and produce large volumes of residuals. Additionally, the potential for high concentrations of competing contaminants and the fouling of the adsorption media due to the presence of other suspended or dissolved matter could inhibit its efficiency

### 3.3 Description and Assessment of Corrective Measure Options

The five identified technologies discussed in **Section 3.2** were then assembled into four corrective measure options:

(1) *MNA* – includes MNA only

(2) *Closure and Monitor* – FAR II unit closure and capping with long-term monitoring

(3) *Bedrock Grouting* –bedrock grouting of west FAD 2 abutment, with groundwater extraction to control hydraulic gradients and ex-situ treatment if needed

(4) *Hydraulic Gradient Control* – Groundwater extraction upgradient of west FAD 2 abutment with ex-situ treatment

Each of the four corrective measure options is described and evaluated based on the evaluation criteria presented in Section 3.1. The findings of this section are summarized in **Table 1**.

### 3.3.1 Option #1 – Monitored Natural Attenuation

MNA relies on natural attenuation processes to achieve site-specific GWPS within a reasonable time frame. It requires demonstration of attenuation mechanisms and aquifer attenuation capacity over the long term. While there are few potential impacts and a high ease of implementation, the time to complete the remedy cannot be determined at this time as it relies on performance and this technology performs best when paired with source control.

### 3.3.2 Option #2 – Closure of FAR II unit with Long-Term Monitoring

Anticipated operational changes to dry ash handling allows for unit closure and capping. As part of closure, the unit will be dewatered and the proposed cap will prevent infiltration of precipitation in to the groundwater system. Closure will be completed in accordance with 40 CFR 257.100 through 257.104. This plan will incorporate long-term monitoring and will address any potential long-term impacts, including any groundwater issues associated with future Site conditions.

### 3.3.3 Option #3 – Bedrock Grouting or Cutoff Wall

This option will include bedrock grouting of the FAD 2 western abutment to cut off flow of impacted groundwater from the vicinity of M-11 to Jules Verne seep. Groundwater extraction will be required to minimize hydraulic head such that the grouting can be implemented. Data gaps associated with complex fractured bedrock geology limit evaluation of the performance of this option. Long-term groundwater extraction may be required to control groundwater flow following implementation of bedrock grouting if it changes groundwater direction or hydrostatic pressure behind the dam. If long-term extraction is required, the time to complete remedy could be infeasible. Extracted groundwater may require treatment prior to discharge.

### 3.3.4 Option #4 – Hydraulic Gradient Control

Extraction wells are used to capture impacted groundwater and hydraulically contain impacts. Captured groundwater may subsequently require ex-situ treatment and discharge to a permitted outfall. Reliability and performance may be limited due to the complex, fractured bedrock geology. Additionally, the time to complete this remedy could be infeasible.

## 4. NEXT STEPS

According to the 40 CFR 257.96, the owner or operator must discuss the results of this ACM in a public meeting with interested and affected parties at least 30 days prior to the selection of the remedy. Remedy selection will occur as soon as feasible based on the need to fill data gaps prior to remedy selection. The remedy selection will include a schedule for implementation and completion. The unit will cease receiving waste no later than October 31, 2020, which will initiate the closure and post-closure care process.

## 5. REFERENCES

Amaya, Pedro J., Massey-Norton, John T., and Stark, Timothy D., 1999. Evaluation of Seepage from an Embankment Dame Retaining Fly Ash. Journal of Performance of Constructed Facilities. American Society of Civil Engineers. November-December 2009.

American Electric Power Service Corporation (AEP), 1984. Design Report Proposed Dam for Flyash Retention Pound II. December 1984

AEP, 1997. Final Design Report for Proposed Earth Fill-Roller Compacted Concrete Raising of Dam.

AEP, 2004. Seepage Analysis, FAR DAM II, Cardinal Plant, Brilliant, Ohio. October.

AEP and Geosyntec Consultants, Inc., May 2006. Hydrogeological Investigation Report. May 2006.

AEP. 2014. Fall 2014 Groundwater Monitoring Data and Statistical Analyses for Cardinal Operating Company's Cardinal Waste Management Units. December.

AEP, 2016. History of Construction, Fly Ash Reservoir I, Cardinal Plant, Brilliant, Ohio. August.

(https://www.aep.com/Assets/docs/requiredpostings/ccr/2016/HistoryofDesignandConstruction/CD-FAR2-History-101616.pdf)

Buckeye Power, 2019. Fall 2018 Groundwater Monitoring Data and Statistical Analyses for Cardinal Operating Company's Cardinal Waste Management Units. January 2019.

Geosyntec Consultants, Inc. (Geosyntec), 2019a. Groundwater Characterization Report – Cardinal Site – Fly Ash Reservoir II. July.

Geosyntec, 2019b. Exposure Assessment and Screening-Level Risk Evaluation. Cardinal Plant – Fly Ash Reservoir (FAR) II. June.

Sanborn, Head & Associates, Inc., 2018. Conceptual Site Model Summary Report. March.

# TABLES

**TABLE 1 - DEVELOPMENT AND EVALUATION OF POSSIBLE CORRECTIVE MEASURE OPTIONS SUMMARY**

Assessment of Potential Corrective Measures for Groundwater CCR Unit - Fly Ash Reservoir II

Cardinal Plant, Brilliant, Ohio

| Possible Corrective Measures Technologies / Evaluation Criteria Considered | | Corrective Measures Options | | | |
|---|---|---|---|---|---|
| | | CMO #1: MNA | CMO #2: Closure and Monitoring | CMO #3: Bedrock Grouting | CMO #4: Hydraulic Gradient Control |
| Primary Corrective Measure Technologies | Monitored Natural Attenuation | ● | ● | | |
| | Vertical Barrier | | | ● | |
| | Cap & Oper. Modification | | ● | | |
| | Groundwater Extraction | | | ● | ● |
| | Ex-Situ Treatment | | | ○ | ● |
| Summary | Description of CMO | MNA of CCR related metals and other inorganic species relies on physical and chemical processes to achieve site-specific groundwater protection standards (GWPS) within a reasonable time frame. This approach requires demonstration of attenuation mechanisms and aquifer capacity over the performance period. The primary constituents of interest at FAR II are molybdenum and lithium. The primary attenuation process for these metals is dilution. | The 'closure and monitor' corrective measure requires operational changes to dry ash handing allowing for unit closure, dewatering and capping. Capping acts as source control to prevent influx of precipitation and production of leachate. As with CMO #1, MNA relies on natural attenuation processes to achieve site-specific GWPS within a reasonable time frame and to monitor impacts within the aquifer. | The bedrock grouting corrective measure involves grouting fractured bedrock along the western abutment of Fly Ash Dam II in order to limit the migration of impacted groundwater. Groundwater extraction will be required to reduce hydraulic head prior to grouting. Additional measures, including groundwater extraction and treatment may be necessary to address groundwater migration through fractured bedrock. | Installation of extraction wells would be required in the vicinity of the western abutment upgradient of the existing groundwater seeps. Groundwater extraction wells are used to capture and hydraulically contain impacted groundwater. Extracted groundwater would subsequently require on site ex-situ treatment and discharge to a permitted outfall. |
| Assessment Criteria (40 CFR §257.96) | Performance | MNA can be an effective option to achieve GWPS within a reasonable time frame. Currently, dilution is the primary attenuation process that reduces exposure pathways. Additional data is needed to further evaluate the attenuation capacity of the site and determine the future performance of the MNA corrective measure because the FAR II is incised into the Morgantown sandstone and upgradient groundwater will continue to migrate through the fly ash within the unit. Additionally, precipitation may infiltrate the fly ash and mobilize lithium and molybdenum. However, performance of MNA is enhanced when it is used in combination with source control technologies. | Closing in conjunction with MNA has proven to effectively achieve GWPS. Currently, dilution is the primary attenuation process that eliminates exposure risks. After dewatering and closure, it is expected that the hydrostatic head within the impoundment should approximately equal historic groundwater elevations in the Morgantown sandstone at the west abutment. Additional data will be collected after the closure of the unit to address any post-closure concerns. | Bedrock grouting has been used effectively to prevent groundwater seepage and limit groundwater flow in fractured bedrock aquifers. However, the complex bedrock geology increases the difficulty of barrier construction and the heterogeneity of the bedrock could limit performance. Additional data from pump tests, flow modeling, capture zone analysis, and subsurface geologic investigations will need to be collected to adequately evaluate performance. | Groundwater extraction can be effectively used to limit infiltration, control hydraulic gradient, and reduce hydraulic head behind the dam. Additional data from pump tests, flow modeling, and capture zone analysis will need to be collected to adequately evaluate performance. |
| | Reliability | An evaluation will be needed to gather additional data necessary to evaluate the reliability of the MNA option. It is important to plan a tiered approach, where each subsequent change in hydraulic conditions is assessed for impacts on the transport of Li and Mo. If favorable aquifer conditions and adequate attenuation capacity exist it is possible that MNA will be reliable when coupled with source control. | Capping is effective at preventing infiltration of precipitation into the groundwater system and thus achieving source control. Given that no current exposure risks were identified, MNA is a sufficient method to monitor downgradient concentrations. | Depending on the extent of bedrock fractures, bedrock grouting ranges from moderately uncertain to moderately reliable as a source control measure to prevent migration of impacted groundwater. Pairing with groundwater extraction will improve the reliability of the approach. . | Hydraulic gradient control is a reliable measure for source control. However, given the fractured geology, complete capture of groundwater using the system is not guaranteed. |

**TABLE 1 - DEVELOPMENT AND EVALUATION OF POSSIBLE CORRECTIVE MEASURE OPTIONS SUMMARY**

Assessment of Potential Corrective Measures for Groundwater CCR Unit - Fly Ash Reservoir II

Cardinal Plant, Brilliant, Ohio

| **Possible Corrective Measures Technologies / Evaluation Criteria Considered** | | **Corrective Measures Options** | | | |
|---|---|---|---|---|---|
| | | CMO #1: MNA | CMO #2: Closure and Monitoring | CMO #3: Bedrock Grouting | CMO #4: Hydraulic Gradient Control |
| Primary Corrective Measure Technologies | Monitored Natural Attenuation | ● | ● | | |
| | Vertical Barrier | | | ● | |
| | Cap & Oper.Modification | | ● | | |
| | Groundwater Extraction | | | ● | ● |
| | Ex-Situ Treatment | | | o | ● |
| Assessment Criteria (40 CFR 257.96) | Ease of Implementation | The ease of implementation would be relatively straightforward with respect to the installation of infrastructure. The current groundwater monitoring well network should continue to provide adequate monitoring capability for mass flux calculations needed as part of MNA. | The ease of implementation is moderate with respect to infrastructure as capping of the unit is a significant effort. A sufficient groundwater monitoring well network currently exists. Additional groundwater sampling which will be required as part of the post-closure plan will also assist in monitoring progress in attenuation. | The ease of implementation is moderate with respect to construction. Additional data is required to aid in design of both the groundwater extraction system and the bedrock grouting approach. If utilized, the groundwater extraction and water treatment systems will have additional operation and maintenance requirements. | The ease of implementation is moderate, as the groundwater extraction and water treatment systems will have additional operation and maintenance requirements. |
| | Potential Impacts | The potential impacts of MNA are minimal. MNA relies on processes that are naturally occurring in the aquifer; therefore, surface and subsurface impacts that are adverse to treatment are unlikely. Although exceedances have been demonstrated in Site wells and seeps, there are currently no receptors at risk of exposure. | Short term impacts are expected during construction and include land disturbance, trucking and equipment activity, and carbon emissions. Any long-term impacts will be evaluated under the post-closure monitoring program. | Intermediate impacts include changes to groundwater flow/rerouting and increase in hydrostatic pressure behind the dam. While unlikely, dam weakening is a potential impact. Additional data will need to be collected to determine the potential impacts from changed groundwater conditions. | Short term impacts are expected during installation. Long-term impacts include disposal of spent media from the ex-situ treatment process. |
| | Time to Begin/Complete Remedy | With the groundwater monitoring network already established, the time to implement the MNA option is very short. However, it will take some additional time to collect the data necessary to establish groundwater flow characteristics and attenuation capacity. The time to complete the remedy cannot be determined at this time, as it relies on MNA performance. | Time to implement capping and monitoring will be moderate. It will take time to complete dewatering operations, cap design, cap construction. Upon completion, monitoring can begin immediately since the groundwater monitoring network is already established. The time to complete the remedy cannot be determined at this time, as it relies on MNA performance. | The time to implement the corrective measure is moderate. It will take time to complete the design, groundwater extraction system installation, ex-situ water treatment system installation (if needed), and bedrock grouting operations. The groundwater extraction and treatment systems must be maintained long term; therefore, the time to complete is indefinite | The time to implement the corrective measure is moderate. It will take time to complete the design, groundwater extraction system installation, and ex-situ treatment installation. The groundwater extraction and treatment systems must be maintained long term; therefore, the time to complete is indefinite. |
| | Institutional Requirements | Groundwater is currently captured and discharged under the existing NPDES permit. There are no anticipated changes to present operations and water will continue to be discharged under the existing NPDES permit. Given that receptors are currently not at risk of exposure, no additional changes are required to minimize risk. | Groundwater and seepage are currently captured and discharged under the NPDES permit after mixing with other discharge streams. | If ex-situ treatment is required, discharge permitting may be needed. | A permit would be required for discharge of extracted groundwater. |

*Notes:*

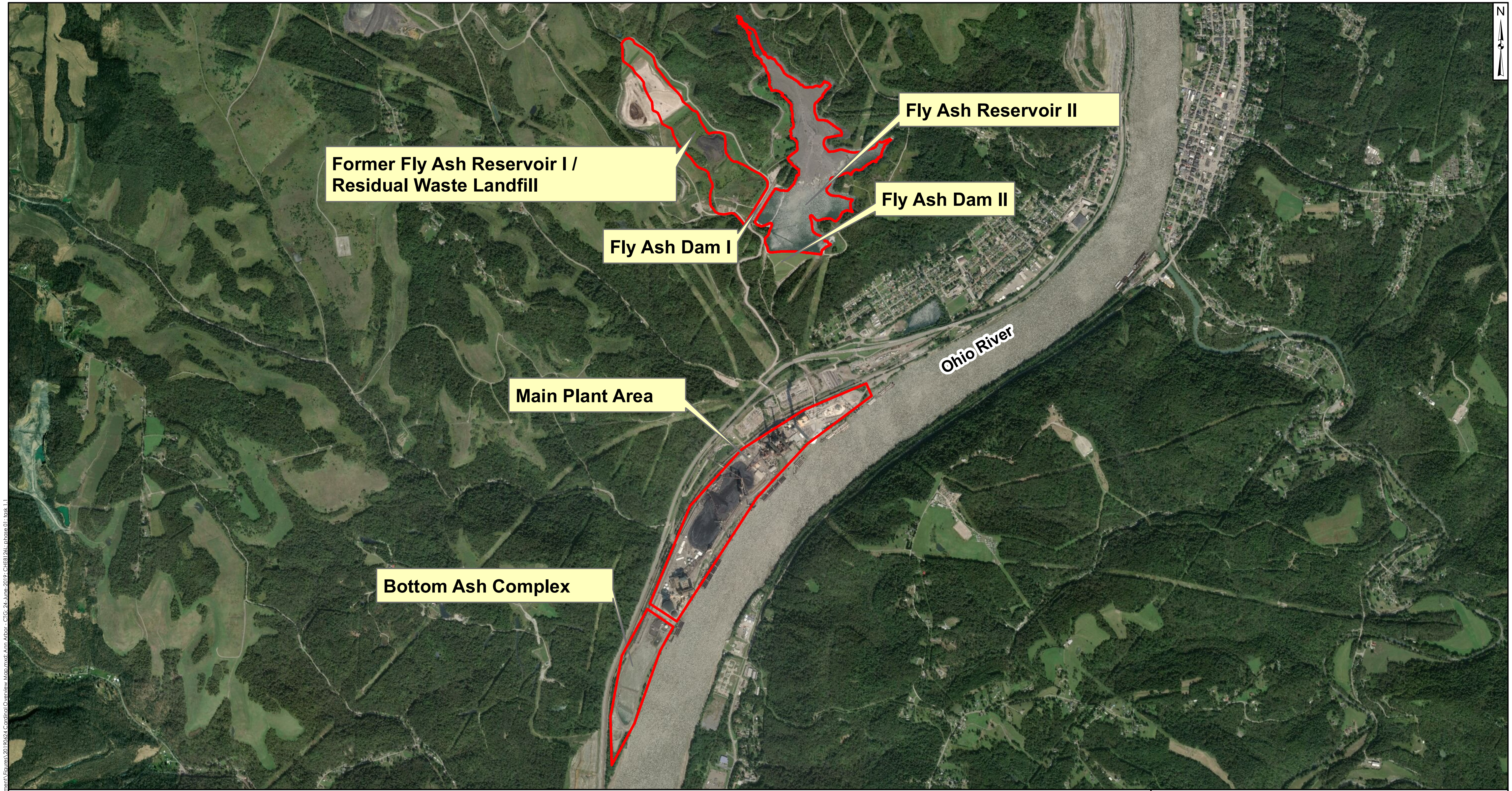
CMO - corrective measures option

MCL - federal drinking water maximum contaminant level

● = technology is part of CMO

o = technology may be required for success of CMO

# FIGURES




**Legend**

Site Boundary

**Notes**
- Aerial imagery courtesy of ESRI.
- All boundaries are approximate.
- CCR = Coal Combustion Residual

2,000 1,000 0 2,000 Feet

**Plant and CCR Unit Location Map**
**Fly Ash Reservoir II**

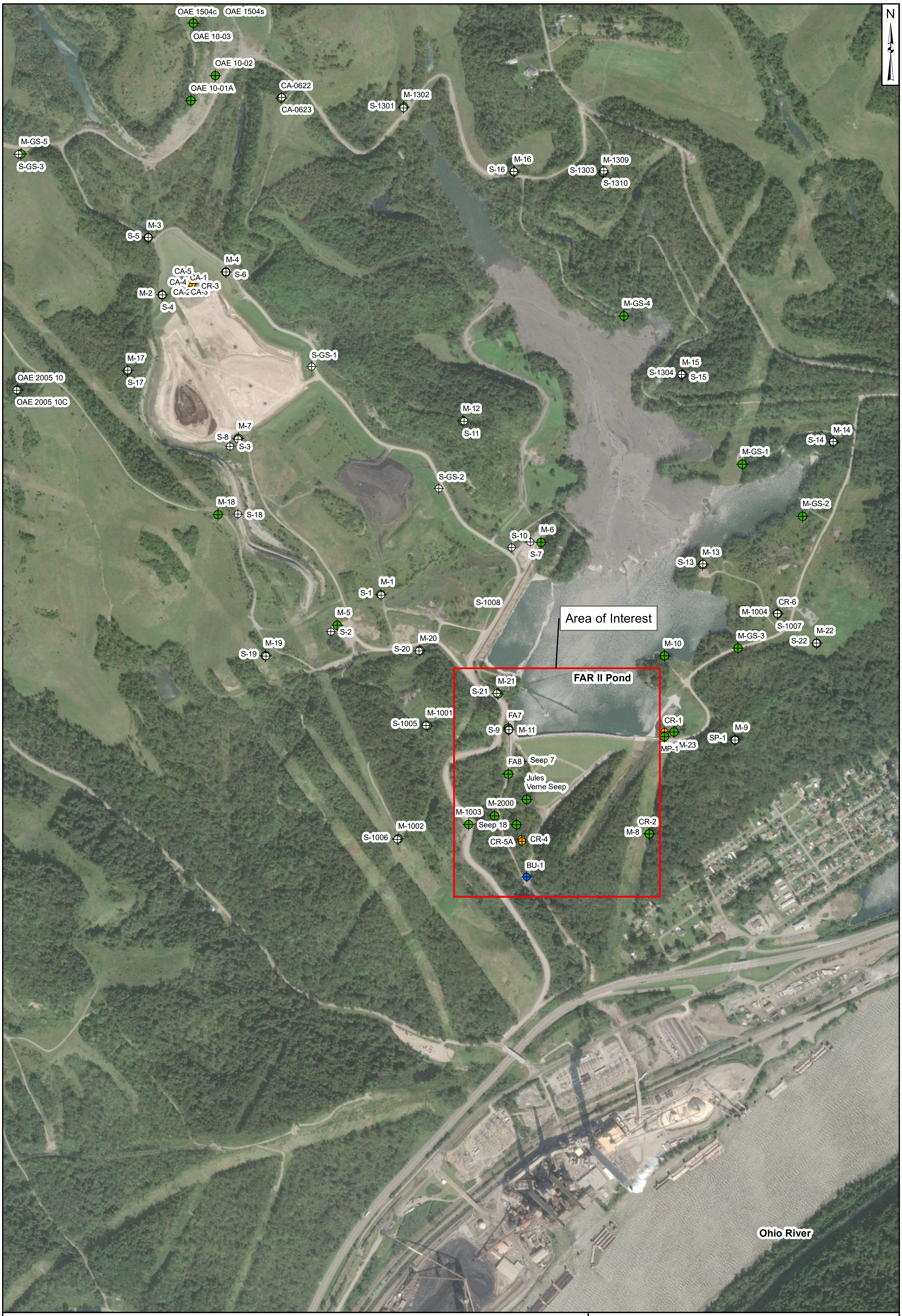
Buckeye Power Cardinal GeneratingPlant
Brilliant, Ohio

Geosyntec consultants

Figure
1

Ann Arbor, Michigan

06/24/2019




**Monitoring Wells**

- Buffalo
- Cow Run
- Morgantown
- Shallow

**Notes**

- Monitoring well coordinates and water level data (collected on August 21, 2018) provided by AEP.

-Site features based on information available in Groundwater Monitoring Network Evaluation - Cardinal Site - Fly Ash Reservoir II (Geosyntec, 2017) provided by AEP.

0 250 500 1,000 Feet

**Monitoring Well Network**
**Fly Ash Reservoir II**

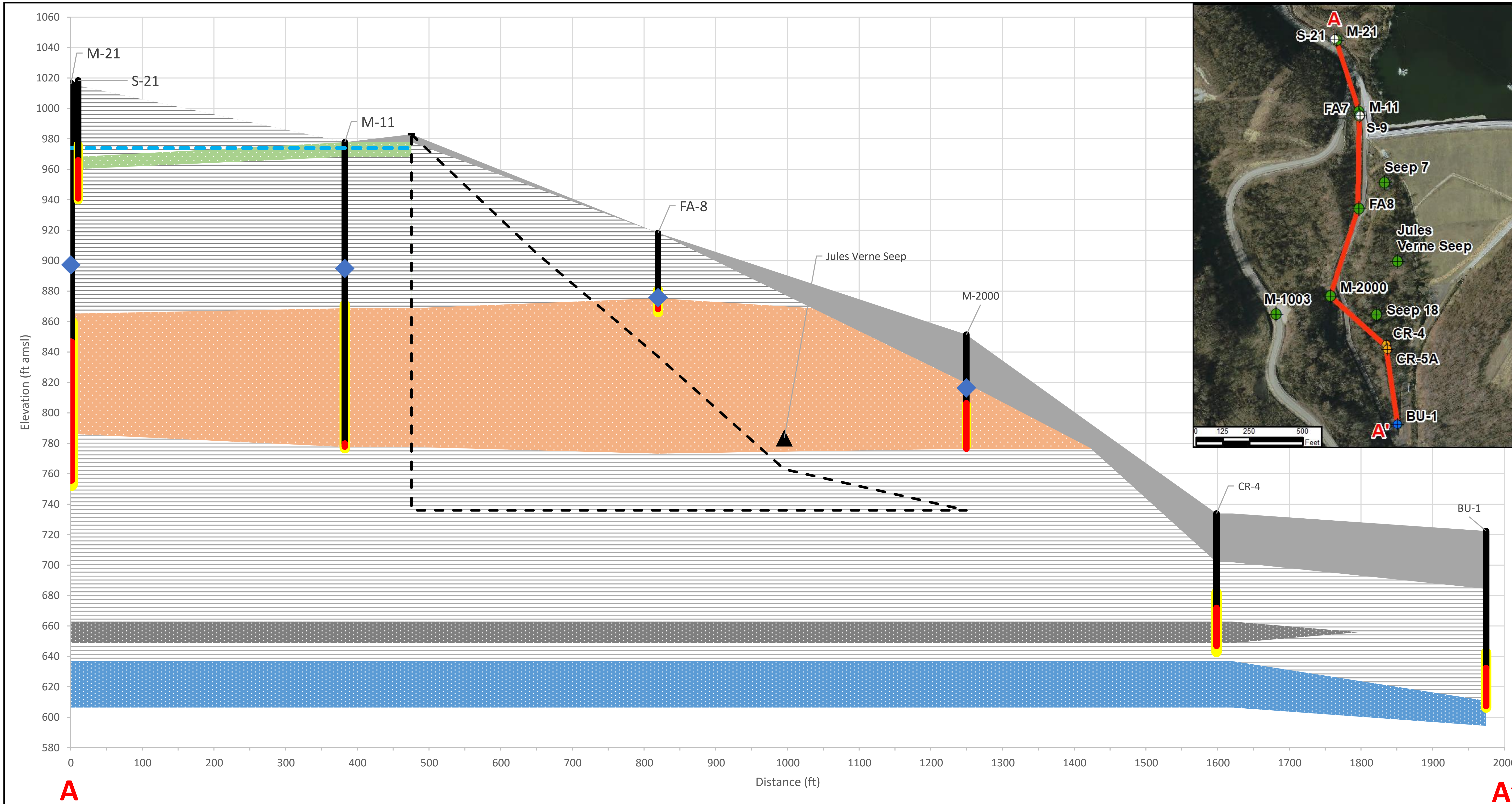
Buckeye Power Cardinal Generating Plant
Brilliant, Ohio

Geosyntec consultants

Figure **2**

Columbus, Ohio | 2019/06/21

C:\Users\eolree\Documents\ArcGIS\Buckeye-Cardinal_FAR_II_CMS_SiteOverview_2019-06.mxd. EOlree. 6/21/2019. CHA8423/01/08.




**Legend**

- Overburden
- Shales, Limestones, Minor Sandstones
- Connellsville Sandstone
- Morgantown Sandstone
- Cow Run Sandstone
- Buffalo Sandstone
- Well Casing
- Well Screen
- Well Sand Pack
- FAD II Outline
- FAR II Max Stage
- March 2019 Water Level in Morgantown Sandstone Well

Notes:

1. FAD – Fly Ash Dam
2. FAR – Fly Ash Reservoir
3. Elevations are approximate and were developed and interpolated from boring logs, existing cross sections, available LiDAR data, and well construction information.
4. The FAD II Outline and Jules Verne Seep locations represent an estimated projection against the cross-section plane from available LiDAR data.
5. LiDAR data for topography projections and inset aerial imagery from the Ohio Statewide Imagery Program (OSIP)
6. Inset map in Ohio State Plane North projection.

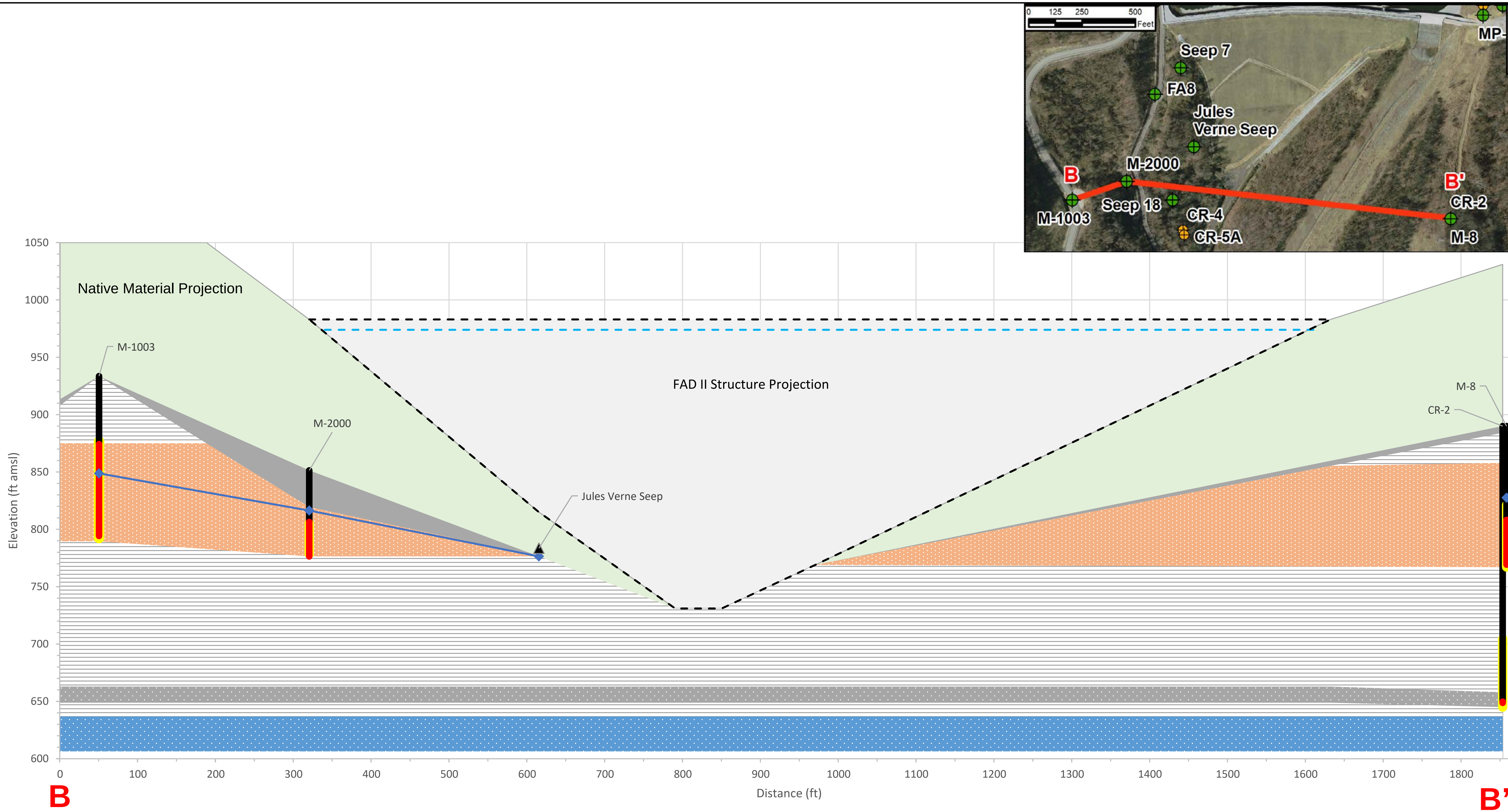
**Cross Section A-A'**
**Fly Ash Reservoir II**

Buckeye Power Cardinal Generating Plant
Brilliant, OH

Geosyntec consultants

| CHA8468 | June 2019 | Figure 3 |
|---|---|---|

\\annarbor-01\data\Projects\Buckeye Power\Corrective Measures Assessment\Cross Sections




**Legend**

- Overburden
- Shales, Limestones, Minor Sandstones
- Connellsville Sandstone
- Morgantown Sandstone
- Cow Run Sandstone
- Buffalo Sandstone
- Well Casing
- Well Screen
- Well Sand Pack
- FAD II Outline
- FAR II Max Stage
- March 2019 Water Level in Morgantown Sandstone Well

Notes:

1. FAD – Fly Ash Dam
2. FAR – Fly Ash Reservoir
3. Elevations are approximate and were developed and interpolated from boring logs, existing cross sections, available LiDAR data, and well construction information.
4. The FAD II Outline and Jules Verne Seep locations represent an estimated projection against the cross-section plane from available LiDAR data.
5. LiDAR data for topography projections and inset aerial imagery from the Ohio Statewide Imagery Program (OSIP)
6. Inset map in Ohio State Plane North projection.

**Cross Section B-B'**
**Fly Ash Reservoir II**

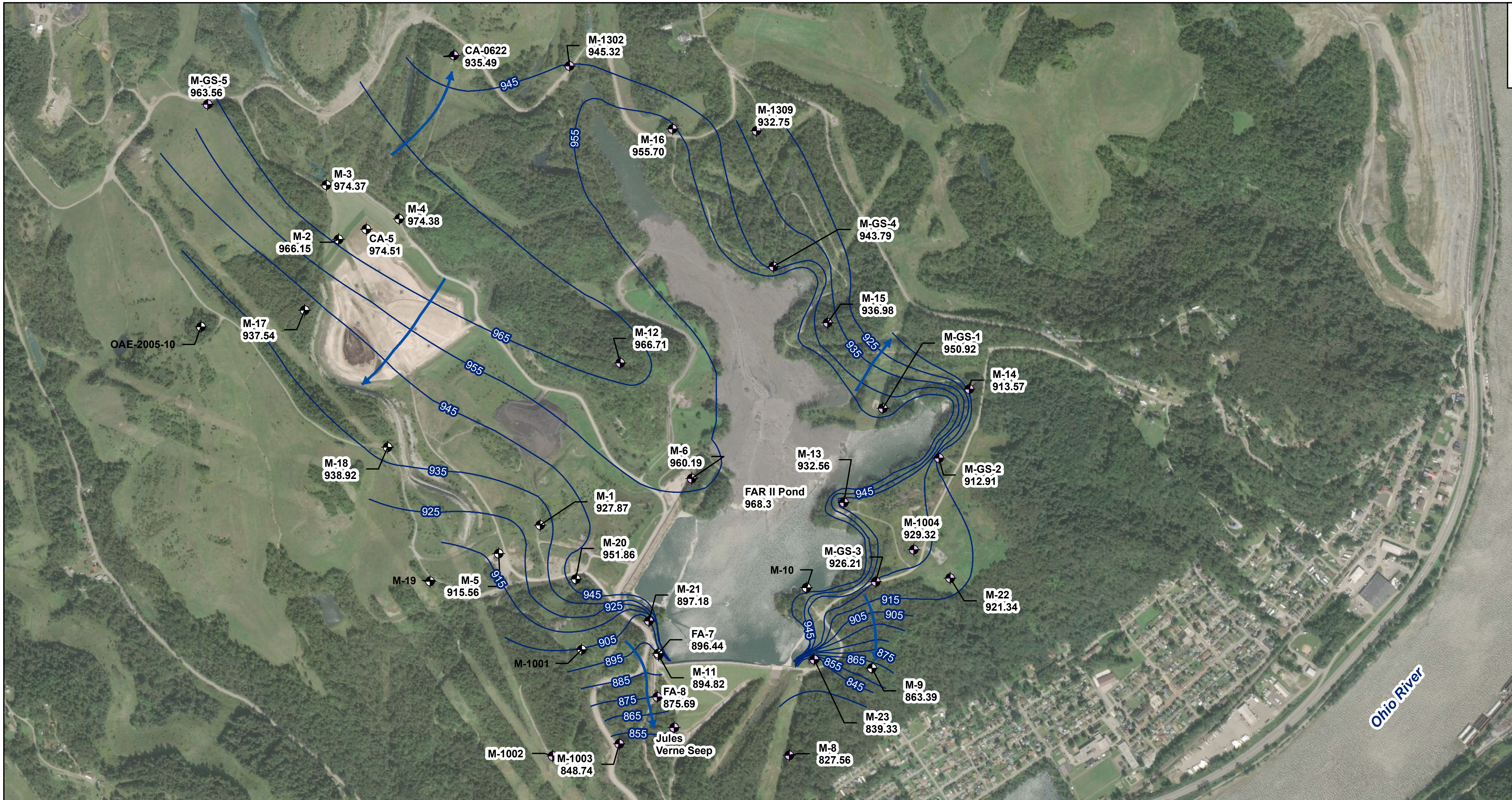
Buckeye Power Cardinal Generating Plant
Brilliant, OH

Geosyntec consultants

CHA8468 | June 2019

**Figure 4**

\\annarbor-01\data\Projects\Buckeye Power\Corrective Measures Assessment\Cross Sections




**Legend**

- FAR II Network Monitoring Well
- State/Other Program Monitoring Well
- Groundwater Elevation Contour
- Approximate Groundwater Flow Direction

**Notes**

- Monitoring well coordinates and water level data (collected on March 21, 2019) provided by Buckeye Power.
- Site features based on information available in Groundwater Monitoring Network Evaluation - Cardinal Site - Fly Ash Reservoir II (Geosyntec, 2017) provided by AEP.
- Groundwater discharge observed from Jules Verne Seep location.
- OAE-2005-10, M-10, M-19, and M-1001 were not gauged in March 2019.
- Groundwater elevation units are feet above mean sea level.

1,000 500 0 1,000 Feet

**Potentiometric Surface Map - Morgantown Aquifer**
**Fly Ash Reservoir II**
**March 2019**

Buckeye Power Cardinal Generating Plant
Brilliant, Ohio

Geosyntec consultants

Figure **5**

Columbus, Ohio | 2019/06/24

P:\Projects\Buckeye Power\GIS\MXDs\Buckeye-Cardinal_FAR_II_GW_2019-03.mxd. ARevezzo. 6/24/2019. CHA8423/01/08.