Assessment of Corrective Measures Report, Clinch River Pond 1

American Electric Power Service Corporation
Clinch River Power Plant, Cleveland, Russell County, Virginia
Project # 7362192727

Prepared in accordance with 40 CFR §257.96

Prepared for:

American Electric Power Service Corporation
1 Riverside Plaza, Columbus, Ohio 43215

12 December 2019

12 December 2019

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Re: Assessment of Corrective Measures Report, Clinch River Pond 1
In accordance with 40 CFR §257.96
Wood Project No. 7362192727

Dear Mr. Zych:

Wood Environment & Infrastructure, Inc. (Wood) is pleased to provide American Electric Power (AEP) with the Assessment of Corrective Measures prepared for Pond 1 at the Clinch River Power Plant.

We very much appreciate working with AEP on this project. If you require additional information about this report, please feel free to contact Paul Teichert at (865) 218-1028 or Kathleen Regan at (859) 566-3724.

Sincerely,

Wood Environment & Infrastructure Solutions, Inc.

Kathleen D. Regan

W. Paul Teichert
Senior Associate Engineer

Kathleen D. Regan, PE
Senior Associate Engineer

Attachments

/kdr

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1.0 Introduction

The Clinch River Power Plant is a former coal-fired electric generating facility owned and operated by Appalachian Power Company (APCO), a public utility subsidiary of American Electric Power (AEP). Wood Environment & Infrastructure Solutions, Inc. (Wood) has prepared this Assessment of Corrective Measures (ACM) on behalf of AEP to address groundwater impacts identified for Pond 1, which was used for sluicing and settling of coal combustion residuals (CCR) from 1958 until 2015.

Closure of Pond 1 was completed in 2018 in accordance with the Virginia's solid waste regulations for CCR units: Virginia Administrative Code (VAC) Title 9 (Environment), Agency 20 (Virginia Waste Management Board), Chapter 81 (Solid Waste Management Regulations), Section 800, or 9VAC20-81-800. The permit application for the Pond 1 closure was started in October 2015, and the permit (SWP620) was issued by the Virginia Department of Environmental Quality (DEQ) in June 2017. Pond 1 is also subject to the federal CCR rule (40 CFR Part §257) but is considered an inactive impoundment (out of service, but still containing standing water when the rule took effect on 19 October 2015). Pond 1 is currently subject to 40 CFR Part §257, as amended in October 2016 to include Extension of Compliance Deadlines for Certain Inactive Impoundments.

1.1 Regulatory Status

On 15 July 2019, it was determined that Pond 1 would enter assessment monitoring due to statistically significant increases over background for calcium, chloride, sulfate and pH. Because of an accelerated monitoring schedule in the Virginia DEQ program, AEP conducted the statistical evaluation of the Appendix IV constituents at the same time and used this analysis to establish groundwater protection standards (GWPSs) ahead of the federal schedule. For each constituent in Appendix IV, the default GWPS is either the federal maximum contaminant level (MCL) for drinking water (for those constituents with established MCLs), or the US EPA Regional Screening Levels (RSLs) for those constituents without established MCLs. A higher site-specific GWPS can also be established if the statistically-determined background concentration exceeds the default GWPS.

Results of the statistical analysis of Appendix IV data indicated that barium, cobalt, lithium and molybdenum were detected in samples from waste boundary wells at statistically significant levels (SSLs) above their respective GWPS. AEP completed an Alternative Source Demonstration (ASD) for the Appendix IV constituents identified in this analysis, which did not identify a source other than Pond 1. As a result, AEP initiated the ACM, which is required to be completed no later than 11 January 2020. The report documents this process and has been prepared in accordance with §257.96 to evaluate remedial alternatives "to prevent further releases, to remediate any releases and to restore the affected area to original conditions" (§257.96[a]).

1.2 Review of Data Sources

A number of data sources were reviewed to develop an understanding of conditions at the Plant. These sources are discussed in the following sections. In addition, Wood has relied on published technical reports and regulatory guidance that are cited as appropriate in **Section 5**.

Closure Plan CFR §257.102(b), Pond 1, Clinch Power Plant, prepared by Amec Foster Wheeler Environment & Infrastructure, Inc., dated July 2017

This report was prepared by Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler, a predecessor company of Wood) to fulfill the requirements of CFR §257.102(b) for Closure Plans of Existing CCR Surface Impoundments. The Closure Plan specified the Pond would be closed by closure in place, with the existing CCR materials covered with a composite soil and geomembrane cap with vegetative cover, graded to achieve a gently sloping surface to promote surface water runoff.

Pond 1 Groundwater Monitoring Network Evaluation Report, Clinch River Power Plant, prepared by Wood, dated 15 April 2019.

The CCR Rule requires that the proposed groundwater monitoring network for each CCR unit be evaluated, and that a professional engineer certify that the network meets the requirements of 40 CFR Part §257.91. This evaluation and certification was completed by Wood and published in April 2019. This report includes a figure showing the location of existing monitoring wells and other relevant features, boring logs, well completion details, and cross-sections.

Annual Groundwater Monitoring Report, Pond 1, Clinch River Power Plant, prepared by prepared by AEP Service Corporation dated August 2019.

Each year AEP publishes an Annual Groundwater Monitoring Report to document groundwater activities conducted at the Plant. This report includes a figure showing the location of existing monitoring wells and other relevant features, a comprehensive set of all groundwater data collected up through the previous year, and an evaluation of groundwater flow conditions with associated potentiometric maps. The report also provides the following information:

- Assessment of 2017 and 2018 groundwater data to establish background values for Appendix III and Appendix IV parameters;
- Statistical evaluation of groundwater monitoring data based on the background sampling events and the February 2019 detection monitoring event to identify statistically significant increases (SSIs) over background for Appendix III;
- Statistical evaluation of groundwater monitoring data to establish a site-specific Groundwater Protection Standards (GWPSs) for each Appendix IV parameter in accordance with 40 CFR §257.95(h).

2.0 Summary of Site Information

2.1 Location

The Clinch River Power Plant is a 484 megawatt (MW) natural gas fired electric power generating facility located in southwestern Virginia in central Russell County, close to the community of Carbo (**Figure 1**). The Plant site is located on approximately 270 acres along the Clinch River, north of State Route (SR) 665 (**Figures 2).** The facility address is 3464 Power Plant Road, Cleveland, VA 24225, and the plant's geographic coordinates are 36º 55′ 58″ N / 82º 12′ 00″ W in DMS, or 36.932778 N / 82.200000 W in decimal degrees. The power plant itself is situated in a meander of the Clinch River (called Kiser Bend on historical topographic maps), and ancillary waste storage and disposal facilities are located across the river to the northeast, north and west.

2.2 Site Description and History

The facility was constructed between 1955 and 1956 and started operation in 1958. It originally consisted of three coal-powered generating units, each with 235 MW capacity. All power production from coal combustion ceased in September 2015. One of the units was decommissioned, and two of the generating units were converted to natural gas combustion. The facility currently generates power from two 242 MW gas-fired generating units. Water for the plant is supplied primarily from surface water withdrawn from the Clinch River and the plant is equipped with wastewater treatment plants (domestic sewage and industrial) to treat various wastewater streams from the plant processes.

Pond 1 is located near the confluence of Dumps Creek and the Clinch River, northeast of the power generating units and north of the intersection of Route 616 and Route 665 (**Figure 3**). The area immediately surrounding the Pond is undeveloped. The closest residential area is the Town of Carbo, about 3,600 feet (ft) south-southwest of the Pond.

The Virginia Solid Waste Permit 620 Facility Boundary and CCR Unit Boundary of Pond 1 are outlined on the regional topographic map in **Figure 2**. Sluicing of new CCR to Pond 1 ceased in October 2015, as the coal-fired generation units were taken out of service. However, the Pond continued to receive wastewater and sluiced solids (containing small quantities of legacy CCR) during subsequent decommissioning of the coal combustion units. Final closure of Pond 1 (described below) was completed in July 2018.

2.2.1 General Description of Pond 1

Pond 1 was operated by APCO from 1958 (the year the power plant began operation) until late 2018 and has subsequently been closed. The following sections provide additional information on the Pond history before and after closure.

2.2.2 Pre-Closure Construction and Operational History

Pond 1 was constructed between 1955 and 1956, at plant start-up. Based on boring log data, there is a layer of clay under portions of the CCR. However, there is no constructed clay layer or other liner between the CCR in Pond 1 and the underlying alluvium. Pond 1 was used for sluicing and settling of CCR from 1958 until 2015. Settled solids were removed by dredging and landfilled remotely. The pre-closure layout of the Pond is shown in **Figure 4**. The Pond was composed of two cells (Ponds 1A and 1B), that were separated by a splitter dike constructed over placed CCR. Pond 1A was used as the primary settling Pond, and Pond 1B was the clearwater (polishing) Pond. Both Ponds were maintained with shallow serpentine channels on the surface of the CCR to increase the residence time of the sluiced water and aid in the settlement of the CCR. Sluiced ash and water entered at the west end of Pond 1A, excess (decant) water flowed from Pond 1A to Pond 1B, and polished water then discharged through the principal outlet structure located in the eastern end of Pond 1B. The discharged water flowed through the vertical outfall structure to a 36-inch spillway pipe, to a catch basin at the toe of Pond 1B, and from there through an underground 30-inch pipe to the Reclaim Pond at the southern toe of Pond 1A, just above the confluence between Dumps Creek and Clinch River. Water in the Reclaim Pond is pumped across the river to the industrial wastewater treatment plant, referred to as the Advanced Wastewater Treatment Plant (WWTP), located at the power plant (**Figure 3**).

Pond 1 is considered a side-hill impoundment, built adjacent to the bank of Dumps Creek against steep hillsides to the north and west. The main dike runs parallel to the Clinch River on the south-southwest perimeter of Pond 1A, and parallel to Dumps Creek on the southeast of Ponds 1A and 1B. The original engineered earthen embankment rose approximately 35 ft from an original ground surface elevation of approximately 1,505 ft near the confluence of Dumps Creek with the Clinch River, to a crest elevation of

1540 ft. The original embankment was constructed of silty clay soil with shale and sandstone rock fragments. At least two subsequent vertical expansions of the embankment were performed, above and behind the original dike. The first expansion used a mixture of fly ash and bottom ash to raise the crest 10 ft to an elevation of 1550; shale and clay were used to cover the outer face of the CCR material. Shale rock fill was used to raise the embankment again, to a final crest elevation of 1570 ft in 1971. After that, the nominal operating water levels in Ponds 1A and 1B were 1565 and 1558 ft, respectively (AEP, 2010).

During operation, Ponds 1A and 1B had a history of seepage and boils at the toe area on the downstream face of the main dike along the southeast side of Pond 1B. Mitigation measures were installed between the early 1980s and 2009 to control these seeps and boils, remain in place post-closure, and continue to act as designed. Historical mitigation measures, currently still in-place to address potential ongoing seepage through the main embankment, include (AEP, 2010):

- A toe drain consisting of a 10-inch diameter perforated pipe buried in a gravel blanket installed along the toe in the early 1980s; and discharges into the Reclaim Pond,
- A 65-foot deep cutoff wall installed through the crest of the main dike in 1991, consisting of a cement-fly ash and bentonite mix, extending laterally into the abutments and vertically down into the low permeability soils of the original embankment at an elevation of approximately 1495 to 1505 ft; and,
- An inverted filter with a riprap revetment installed in 2009 on the lower half of the downstream slope to control seepage and provide protection against potential piping through the embankment.

Exhibit 2-1 summarizes the basic pre-closure characteristics of Pond 1.

Table 1. Pond 1 Pre-Closure Dimensions

Characteristic	Dimension
Embankment Height (feet)	65
Embankment Crest Width (feet)	35
Embankment Length (feet)	3,150
Nominal Crest Elevation (feet)	1,570
Final Operating Pool Elevation in 1A/1B (feet)	1,566.6 / 1,557.2
Maximum Pool Surface Area (Acre)	21.0
Closure Area (acres)	26
Volume of CCR (million cubic yards)	2.44 (includes area permitted by SWP 620)

Source: AEP (2013); VA DEQ SWP 620 (June 2017).

2.2.3 Closure and Post-Closure

The post-closure layout and cover over Pond 1 is shown on the aerial photograph in **Figure 5**.

In anticipation of Pond closure, construction of a diversion channel to the northwest and west side of Pond 1 (the Pond 1A Diversion Ditch) began in 2014. The diversion channel, separated from the CCR in the Pond by a diversion berm, captures clean surface water runoff from drainage areas to the north and west and diverts it to the Clinch River downstream of the Pond (at Outfall VPDES 503), preventing contact with the CCR in the Pond.

In 2016, the principal Pond outfall located at the eastern end of Pond 1B was removed from service. The 42-inch weir inlet structure was removed, and the 30-inch outlet pipe was abandoned in-place with grout. Once the principal spillway was abandoned, excess water that accumulated in Pond 1 was pumped to the Reclaim Pond and from there to the Advanced WWTP across the river at the power plant. Draining of the remaining free water in the Pond was initiated in July 2017. The wastewater generated was first treated in a temporary pre-treatment facility set up on-site and adjacent to the Reclaim Pond, primarily for selenium removal. Effluent from the temporary pre-treatment facility was pumped into the Reclaim Pond. The treated effluent was then pumped to the Advanced WWTP for additional treatment before being discharged. Operation of the temporary treatment system ceased in November 2017 when Pond 1 was drained of free water, and the CCR at the surface was dry enough to be graded.

A second stormwater diversion ditch (Pond 1B Diversion Channel) was cut and lined with riprap, along the north side of Pond 1B, draining to an inlet structure (catch basin) at the northeast corner of the Pond. The Pond 1B catch basin drains southwest through a 48-inch pipe to an existing pipe pit. The pit feeds into an existing tunnel that drains under the road (SR 665) and railroad into Dumps Creek at Outfall VPDES 504.

Final grades on the Pond 1 cover system were designed to drain to the diversion channels. The surface of the western cell (former Pond 1A) drains to a center channel (grass-lined), and then southwest to the 1A diversion channel. The surface of the eastern cell (former Pond 1B) drains uniformly to the northeast, to the 1B diversion channel. The engineered, multi-layer geosynthetic cover system constructed over the graded Pond surface consists primarily of: a 30-millimeter flexible PVC geosynthetic membrane (FML), under a double-sided geocomposite drainage net, capped with 24 inches of vegetated soil cover.

During construction it was also necessary to construct an interceptor drain to capture seepage into the 2-ft soil cover from the double sided geocomposite and transfer it to the Reclaim Pond for treatment prior to discharge. The interceptor drain piping is permanently routed beneath the Pond 1B Diversion Channel, is a 6-inch diameter perforated PVC pipe, resides approximately 3 ft below the diversion channel bottom, connects to the 10-inch toe drain at the end of the Pond 1B Diversion Channel, and flows to the Reclaim Pond. Closure of Pond 1 was completed in July 2018. **Figure 5** shows the configuration of Pond 1 after closure, including the principal features affecting surface water flows in the immediate vicinity of the Pond. It also includes the locations of the 12 monitoring wells that were installed in 2017 to make up the long-term groundwater monitoring network for the closed CCR unit.

2.3 Conceptual Site Model

In order to support the ACM, a Conceptual Site Model (CSM) has been developed for the Clinch River Pond 1 impoundment. The CSM identifies the sources of specific Constituents of Concern (COCs) in the environment, describes how they migrate in the subsurface from the source along potential transport pathways, and identifies the human and ecologic receptors that may be exposed to the COCs as they migrate through the environment. The following sections provide information on the hydrogeologic setting of the AEP Clinch River Pond 1 impoundment, including climate, physiography and drainage, geology, hydraulic properties of the principal groundwater flow zone, surface water and interactions between surface water and groundwater. A more detailed presentation of the CSM will be included in the NES Report, anticipated to be completed by early 2020.

2.3.1 Climate

Virginia's Southwestern Mountain Region is considered a humid, subtropical area with 30 year daily average air temperatures ranging from 34.7 degrees Fahrenheit (°F) in the winter to 70.5 °F in the summer. The 30-year (1981-2010) average annual precipitation is approximately 42.9 inches per year, with an average of 2.4 inches in October and an average of 4.6 inches in June for data from the closest National Oceanic and Atmospheric Administration (NOAA) precipitation network station at Lebanon, Virginia within Russell County (NOAA, 2018).

There are no long-term climate stations in Russell County; the nearest stations are in Grundy (Buchanan County) and Abingdon (Washington County). Based on the records for these stations between 1971 and 2000, the average annual total precipitation over Russell County ranges from approximately 44 inches in lowest valley areas to slightly over 50 inches at highest elevations. The average seasonal snowfall is somewhat dependent on elevation, with about 12 inches common in the lowest valleys, and more than 24 inches at higher elevations (USDA, 2007).

2.3.2 Surface Water Hydrology

The area of Pond 1 is drained by the Clinch River and its tributary Dumps Creek. The Clinch River rises near Tazewell, Virginia, and flows southwest for more than 300 miles, before joining the Tennessee River in Kingston, Tennessee.

The closest stream gauge maintained by the USGS (Station 03524000) is located approximately 4 miles upstream of the Clinch River Plant on the Clinch Ri in Cleveland (Russell County, Virginia). According to data provided on the USGS website for the station (USGS, 2019), the average annual flow in the Clinch River at Cleveland from 1921 to 2017 ranged from 300 to 1,252 cubic ft per second (cfs), and averaged 710 cfs; in million gallons per day (MGD), the average annual flow ranged from 194 to 809, and averaged 459 MGD. Based on 101 peak flow events between 1862 and 2017, peak flows ranged from 2,430 to 34,500 cfs (1,571 to 22,299 MGD). The median daily flow in the Clinch River at Cleveland (based on 98 years of data) ranges from approximately 100 cfs (65 MGD) in October to 1,000 cfs (650 cfs) in March. The river stage at Cleveland ranges from a low elevation close to 1,500 ft, up to a peak elevation of approximately 1,526 ft NAVD88, and 1,514 ft is considered flood stage.

Discharges from the Clinch River Plant are permitted under a Virginia Pollutant Discharge Elimination System (VPDES) permit, Permit VA0001015 (June 2016). According to the Fact Sheet attached to the permit, both the Clinch River and Dumps Creek are in Section 2 of the Clinch subbasin of the Tennessee – Big Sandy basin. Based on information in the Fact Sheet, the normal pool elevation of the Clinch River near the confluence with Dumps Creek is estimated to be 1490 ft and the low water pool elevation is 1,484 ft. According to information provided separately by AEP, the 100-year flood elevation is approximately 1,515 ft.

2.3.3 Site Overburden Materials

Based on boring logs recorded during drilling and monitoring well installation in 2009 and 2017, as well as other historical borings, natural and manmade soils (unconsolidated materials) above bedrock, in and adjacent to Pond 1, have been characterized into the following general categories: waste fill, soil fill, alluvium and residuum overlying bedrock.

The waste fill in Pond 1 consists primarily of CCR, including fly ash and bottom ash. Historical borings in Pond 1 performed for geotechnical evaluations have shown that the bottom of the CCR in Pond 1 is relatively flat, occurring between elevations of 1,495 and 1,505 ft. Assuming an average graded CCR surface elevation of 1,668 ft after closure, this corresponds to a thickness of approximately 70 ft, and the in-place volume of CCR is estimated to be 2.1 million cubic yards (cy). The characteristics of the CCR were found to be locally variable; however, in the 2013 investigations as in previous investigations, the permeability of the CCR was found to be on the order of 0.07 ft per hour (ft/hr), corresponding to 1.7 ft per day (ft/day), or 6 x 10^{-4} centimeters per second (cm/sec).

Natural soil covering over bedrock in upland areas was found to be thin (less than 5 ft). In the valleys, natural soil cover (including alluvium and residuum) ranged from 10 to 15 ft thick. In the borings along the Pond 1 embankment, between 14 and 36 ft of fill soils were found overlying natural soils. Based on borings completed through the CCR inside Pond 1, the CCR in Pond 1 is on the order of 70 ft thick and overlies 10 to 15 ft of alluvium and weathered rock.

2.3.4 Geologic Setting

The site is situated within the Valley and Ridge physiographic province, which is characterized by a northeast-southwest trending series of parallel ridges and valleys composed of folded and faulted Paleozoic sedimentary rock. The primary geomorphological features are mainly the result of differential weathering of various rock types, which include limestone, dolomite, shale, sandstone, and siltstone. Larger valleys may have a comparatively thin mantle of alluvial soils ranging in size from clay to coarse sand to boulders, and deeply weathered alluvium deposited near streams and rivers may be found both in low-lying areas and on hills, reflecting the dynamic geologic nature of the province.

The bedrock geology in the region of the site (including the USGS St. Paul and Carbo quadrangles) is mapped and described in DMME Publication 106 (Evans and Troensegaard, 1991). The structural setting of the area is reflective of episodes of uplift and mountain building to the east-southeast, resulting in a series of imbricate (shingle-stacked), repeating stratigraphic sequences that have been moved northwestward via relatively low angle thrust faults. The site is near the Alleghanian structural front that marks the northwest edge of the Valley and Ridge province. Along this front, older Cambrian and Ordovician-age rock formations have been thrust along low-angle faults from the southeast over younger rocks of Silurian to Pennsylvanian age to the northwest.

The local geology as mapped by Evans and Troensegaard (1991) is shown on the map in **Figure 6**. The bedrock underlying Pond 1 is locally influenced by the Dumps Fault, a component of the regionally extensive Clinchport fault system, which includes the Honaker fault to the southeast (Adkins, 2017). Along the Dumps Fault, dolomite and limestone of the Cambrian-age Rome Formation overlie younger clastic rock (shale, siltstone and sandstone) of Devonian and Mississippian ages. The younger rock to the northwest of the fault has been folded into an arched structure (the Sinkhole Valley Syncline), which includes the Mississippian Greenbrier Limestone along the centerline of the syncline, bracketed both to the northwest and southeast by the Mississippian Maccrady and Price Formations (undivided) the Devonian Chattanooga Shale. The formations that occur in the vicinity of Pond 1 are described by Evans and Troensegaard (1991) as follows:

- Greenbrier Limestone (Lower Mississippian): limestone, light- to medium-gray, thin-bedded to massive, micritic, locally abundant fossils; grayish-red, shaley limestone and calcareous shale are present in the upper part of the section.
- Maccrady and Price Formations, undivided (Lower Mississippian): siltstone, grayish-red to greenish-gray, very thin- to medium-bedded, interbedded with shale, grayish-red, laminated to very-thin-bedded (Maccrady); and siltstone, light-olive-gray, thing to medium-bedded, sandstone, medium gray, fine-grained, medium-to thick-bedded, and shale, greenish-gray, laminated to thin bedded, interbedded with sandstone and siltstone (Price).
- Chattanooga Shale (Devonian): shale, medium-gray to black, very fine-grained, laminated to thin-bedded, interbedded in upper section with siltstone, medium gray to grayish-yellow, thin-bedded.
- Rome Formation (Cambrian): shale and siltstone, greenish-gray or grayish red, thinly laminated to very-thin-bedded), sandstone (greenish-gray, fine-to-medium-grained, thin-bedded), dolomite (dark-

gray, fine- to medium-grained, massive) and limestone (light-gray, weathering to rusty-orange, argillaceous-ribbon-banded). The dolomite and limestone occur in zones up to 50 ft thick and constitute less than 30 percent of the section. As with the other formations, the Rome exhibits complex faulting and folding within the mapped area.

The Dumps Fault runs southwest to northeast regionally. To the northwest of Pond 1, it curves to the southeast, then east and back to the northeast beneath the footprint of Pond 1A, as shown in **Figure 6**. A branched section is joined just northwest of Pond 1 by a right-lateral fault, aligned north-northwest, that is associated with the St. Paul Fault to the northwest. Under Pond 1, the Dumps Fault is mapped as a single fault. The interpreted location of the Dumps fault, based on the available data and findings of the 2017 borings, is shown on the map in **Figure 7, 8** and **9** are cross-sections illustrating the bedrock geology underlying Pond 1 and the surrounding area.

2.3.5 Groundwater Occurrence and Hydrostratigraphic Units

Pond 1 was constructed on a riverbank terrace adjacent to Dumps Creek, just above its confluence with the Clinch River. The original ground surface appears to have been relatively flat, sloping up from a low point near the confluence with an elevation of about 1495 to 1,505 ft, gently across the terrace and then steeply to highlands on the north and west. A relatively wide valley enters from the west, while shorter, steep and narrow valleys enter from the highlands on the north. The underlying bedrock surface would be expected to have a similar slope. Based on the monitoring well borings completed in 2017, the top of bedrock ranges in elevation from approximately 1,485 to 1,491 ft along Dumps Creek, and the bedrock surface was encountered at similar elevations in historical borings through the CCR. At the closest upgradient well locations outside the Pond to the north (MW-1601 and MW-1602), the top of bedrock was encountered almost 100 ft higher, at elevations of 1,574 and 1,583 ft, respectively, and even higher at the well locations to the west (MW-1608, MW-1609, and MW-1611). These bedrock elevations reflect the very steep relief of the highlands adjacent to Pond 1 on the north and west.

Above the bedrock surface, natural soil overburden materials including residuum and alluvium are relatively thin, ranging in thickness from less than 5 ft in upland areas to 10-15 ft in valleys. Because these materials are thin, locally discontinuous, and inconsistently saturated, they are not distinguishable from the overlying manmade materials. Therefore, they do not represent a significant hydrostratigraphic unit that can be monitored as a separate unit from the manmade materials in the overburden. By contrast to the natural soils, the overlying manmade materials, and specifically the CCR contained within the Pond 1 embankment, have significant saturated thickness (on the order of 40 ft). Water in the saturated section of the CCR (and the thin underlying layer of natural soils) flows primarily toward the adjacent streams as seepage at the toe of the embankment. The water that discharges above an elevation of approximately 1,510 ft is collected by the embankment toe drain system for transfer into the plant’s onsite industrial wastewater treatment system. Potential secondary pathways for migration of the underground water that collects in the CCR of Pond 1 would be laterally below the level of the toe drain system into the surface streams, and/or downward into shallow bedrock.

Bedrock is typically most permeable near the contact with the overlying unconsolidated materials, where both primary porosity and secondary openings (from fracturing, including stress relief fracturing as well as fracturing associated with faulting, and solutioning) have been enlarged from the effects of weathering and subsurface water circulation. Therefore, in steep terrains with thin soil cover, shallow bedrock is generally the predominant groundwater flow zone. Groundwater flow in these terrains generally follows the topographic gradient, although locally flow is highly influenced by patterns of openings (faults, fractures, and solution openings) in the rock. Groundwater flowing through bedrock discharges to perennial streams, with the depth of circulation between recharge and discharge zones being dependent on the degree of topographic relief as well as the permeability of the rock.

Based on the flow conditions described above, two hydrostratigraphic units can be identified in the vicinity of Pond 1:

1. The overburden flow zone, consisting of manmade fill (CCR and embankment material), and thin, discontinuous natural soils consisting of alluvium and residuum. The majority of the discharge from this zone is collected by the toe drain system at the foot of the embankment, and water underflowing the toe drain (if any) would be expected to discharge as seepage into the adjacent surface streams. Although this zone contains and transmits subsurface water, it is not considered an aquifer, because it has limited extent and is made up of a significant portion of waste material.
2. The bedrock flow zone, consisting of the shallow bedrock that occurs near the surface, just below the soil-bedrock interface. This zone is considered the uppermost aquifer in the area. Groundwater flow in this zone would be expected to circulate laterally, or downward and then upward, into adjacent surface streams, following localized pathways associated with openings in the rock.

In summary, groundwater in the vicinity of Pond 1 occurs in a complicated system of fractured and faulted shale and limestone bedrock overlain with relatively thin unconsolidated fill and alluvial sediment that discharges to the Clinch River. A summary of the key points of Pond 1 hydrogeology is presented below.

- Unconsolidated overburden materials, including fill, residuum and alluvium, are relatively thin, locally discontinuous, and inconsistently saturated, and do not represent a significant hydrostratigraphic unit.
- The uppermost aquifer underlying Pond 1 is the shallow fractured bedrock that varies in lithology depending on location but generally consists of groundwater in two formations:
    - Chattanooga Shale interbedded with siltstone
    - Rome Formation limestone and dolomite
- The yield of the uppermost aquifer (both Rome Formation and Chattanooga Shale) is low, and six of the wells have yields that may be too low to support low-flow sampling.

2.3.6 Monitoring Well Network

Twelve wells were installed in 2017 as the principal component of the long-term post-closure groundwater monitoring network for Pond 1. These wells (MW-1601 through MW-1612) were installed in shallow bedrock to collect piezometric (water level) data and water quality samples from the uppermost aquifer. The drilling, construction and development of the 2017 monitoring wells are fully documented in the *Pond 1 Groundwater Monitoring Network Evaluation Report* (Wood, 2019). All of the wells are constructed of 2-inch inner diameter flush-threaded PVC, with 10 ft of screen. The screens are set in bedrock and sand-packed, with the annulus above the sand pack being sealed to the ground surface. The wells are finished at the surface with a concrete pad and a steel protective casing. The monitoring well network at Clinch River Pond 1 meets the requirements of 9 VAC 20-81-250.A 3.

Figure 10 shows the locations of the monitoring wells in the long-term network, which were located to yield representative samples of the dominant rock types, on both sides of, and across, the Dumps Creek fault. The seven downgradient wells are located at the CCR waste boundary, along the Pond embankment. These wells were placed so that the surface pad and casing would be above the Clinch River 100-year flood level of 1,515 ft. Bedrock in the downgradient wells was encountered at 25 to 40 ft below ground surface (bgs), and the top of the screen in these wells is 6 to 18 ft below the top of bedrock. The downgradient wells include four wells finished in shale (MW-1603, MW-1604, MW-1612 and MW-1605), one well screened across the apparent fault zone (MW-1610), and two wells finished in limestone above the fault (MW-1606 and MW-1607). The screened intervals in most of these wells are set at or close to elevations 1,470 to 1,480 ft, below the river normal pool level of 1,494 ft.

The five upgradient/background wells are located north and west of the Pond, with ground surface elevations 40 to 100 ft higher than the downgradient well locations, and with bedrock close to the surface. The screens in these wells were set deeper into bedrock, in order to intersect similar elevations in bedrock as the downgradient wells. The three upgradient/background wells on the north and northwest (MW-1601, MW-1602 and MW-1608) were installed in shale, with screens installed in vertical positions close to the screened intervals of the downgradient wells. One well on the far west (MW-1609) was intended to be screened across the fault, but shale was not encountered down to an elevation of 1475 ft; therefore, the screen was installed in limestone, in a position where sufficient apparent water yield was present, but significantly higher than the downgradient wells. Well MW-1611 was advanced to the deepest elevation (1,410 ft) and appeared to penetrate a complex fault zone associated with the Dumps Creek fault; the screen in this well was finished across a limestone-shale interface at an elevation lower than the screens in the downgradient wells. A summary of well types by geologic formation is presented below.

Table 2. Monitoring Wells by Geologic Formation

	Geologic Formation		
Well Type	**Chattanooga Shale**	**Rome Formation**	**Dumps Fault System**
Background	MW-1601 MW-1602 MW-1608	MW-1609	MW-1611
Waste Boundary	MW-1603 MW-1604 MW-1605 MW-1612	MW-1606 MW-1607	MW-1610

A diagram of well construction and geologic formations is presented on **Figure 11**.

2.3.7 Groundwater Monitoring Results

In accordance with federal groundwater monitoring requirements, eight sampling events were conducted between October 2017 and December 2018 to collect samples from the CCR compliance wells. Monitoring well MW-1612 was not installed in time for the first event and was therefore only sampled in seven baseline events. The baseline events included Appendix III, Appendix IV and state-only parameters specified in the state solid waste permit for Pond 1. Following baseline monitoring, a Phase II monitoring event was completed on 12 February 2019, with a resampling event completed in 10 April 2019. Potentiometric surface maps of the overburden and bedrock wells are presented on **Figures 12 and 13**, respectively.

Results were pooled from all background wells by geologic formation (Chattanooga Shale, Rome Formation and Dumps Fault) and results were statistically analyzed using interwell statistics in accordance with the Statistical Analysis Plan prepared by Geosyntec Consultants in collaboration with Sanitas Technologies, Inc. and MacStat Consulting, Ltd. (Geosyntec, 2019). Background concentrations were established for each constituent, by formation. Upper prediction limits (UPLs) were calculated for each parameter to represent background values, and the GWPS was established for each constituent by geologic formation. The GWPS determined to be the higher of the default GWPS (MCL or RSL) or the background concentration. The only parameter which had a higher background concentration than the default GWPS was arsenic, in the Chattanooga Shale and the Dumps Fault System. All other constituents in each of the three formations use the default GWPSs.

Table 3. Summary of Site-Specific Groundwater Protection Standards by Geologic Formation

Appendix IV Constituent	MCL or RSL	Groundwater Protection Standards		
		Chattanooga Shale	Rome Formation	Dumps Fault System
Antimony, Total (µg/L)	6	6	6	6
Arsenic, Total (µg/L)	10	26	10	52
Barium, Total (µg/L)	2,000	2,000	2,000	2,000
Beryllium, Total (µg/L)	4	4	4	4
Cadmium, Total (µg/L)	5	5	5	5
Chromium, Total (µg/L)	100	100	100	100
Cobalt, Total (µg/L)	*6*	6	6	6
Combined Radium, Total (pCi/L)	5	5	5	5
Fluoride, Total (µg/L)	4,000	4,000	4,000	4,000
Lead, Total (µg/L)	*15*	15	15	15
Lithium, Total (µg/L)	*40*	160	40	190
Mercury, Total (µg/L)	2	2	2	2
Molybdenum, Total (µg/L)	*100*	100	100	100
Selenium, Total (µg/L)	50	50	50	50
Thallium, Total (µg/L)	2	2	2	2

In order to identify SSLs in samples from waste boundary wells, a confidence interval was constructed for each constituent with a possible exceedance at the applicable downgradient wells. An SSL was concluded if the lower confidence limit (LCL) exceeded the GWPS (i.e., if the entire confidence interval exceeded the GWPS). A summary of these data for potential exceedances are presented below.

Table 4. Summary of SSLs by Monitoring Well

Monitoring Well	Constituent µg/L	GWPS µg/L	LCL µg/L
MW-1604 (Chattanooga Shale)	Barium	2000	3010
MW-1605 (Chattanooga Shale)	Lithium	160	190
MW-1606 (Rome Formation)	Cobalt	6	5.3
	Lithium	40	78
	Molybdenum	100	70
MW-1607 (Rome Formation)	Cobalt	6	8.4
	Lithium	40	120
	Molybdenum	100	130
MW-1610 (Dumps Fault)	Cobalt	6	8.5
	Molybdenum	100	138

GWPS = Groundwater Protection Standard
LCL = Lower Confidence Limit

An alternative source demonstration (ASD) evaluation was completed by Geosyntec and submitted to the AEP on 29 August 2019. The evaluation was conducted in accordance with the requirements specified in §257.95(h)(3)(ii) in an attempt to determine if a source other than Pond 1 was responsible for the observed SSIs. The ASD was primarily a desktop geochemical investigation augmented by the collection of one surface water sample from the Reclaim Pond. Geosyntec concluded that the data evaluation was insufficient to demonstrate a source other than Pond 1.

3.0 Initial Screening of Remedial Technologies

This section describes the initial screening of applicable remedial technologies and process options for groundwater corrective action at Pond 1 at the Clinch River plant. The purpose of this section is to establish Corrective Action Objectives (CAOs) and perform an initial screening of broad classes of remedial technologies for suitability to the site-specific conditions present at Pond 1. Technologies which are capable of meeting the CAOs at the Pond 1 site are combined into Corrective Action Alternatives which are evaluated in detail in **Section 5**.

3.1 Corrective Action Objectives

The objective of corrective action under the CCR Rule is to "attain the groundwater protection standard as specified pursuant to §257.95(h)" and "to remediate any releases and to restore affected area to original conditions" (40 CFR § 257.96(a)). Evaluation criteria specified in §257.96 include:

- The performance, reliability, ease of implementation, and potential impacts of appropriate potential remedies, including safety impacts, cross-media impacts, and control of exposure to any residual contamination;
- The time required to begin and complete the remedy; and
- The institutional requirements, such as state or local permit requirements or other environmental or public health requirements that may substantially affect implementation of the remedy(s).

The cleanup criteria used for corrective action is the site-specific GWPS, calculated for each Appendix IV COC. Four COCs exceed their respective site-specific GWPSs: barium, cobalt, lithium and molybdenum. A summary of these GWPSs are presented below on **Table 5**. The cleanup criteria used for corrective action is the site-specific GWPS, calculated for each COC by geologic formation.

Table 5. Corrective Action Objectives (Groundwater Protection Standards)

Constituent	Default GWPS (MCL/ RSL)	Background Limits by Geologic Formation			Groundwater Protection Standards		
		Chattanooga Shale	Rome Formation	Dumps Fault System	Chattanooga Shale	Rome Formation	Dumps Fault System
Barium, Total (µg/L)	2,000	310	580	100	2,000	2,000	2,000
Cobalt, Total (µg/L)	6	0.54	1.9	0.17	6	6	6
Lithium, Total (µg/L)	40	160	30	190	160	40	190
Molybdenum, Total (µg/L)	100	22	3.2	6.8	100	100	100

Based on previous evaluations conducted at Pond 1, an alternative source of groundwater impacts has not been identified and an assessment of corrective measures is required.

3.2 Screening and Evaluation of Remedial Technologies

Certain common remediation technologies are not well suited to certain CCR constituents because of their unique physical and chemical characteristics. For example, many organic COCs can be degraded over time into harmless byproducts through biological or chemical processes. Some organics can be volatilized and removed from the groundwater by transferring them into the air phase (air sparging), and or by heating the aquifer matrix to more aggressively volatilize the compounds (steam stripping or electrical resistance heating). These types of technologies were not evaluated because all Appendix IV constituents are naturally occurring metals or metalloids. These constituents are elements and cannot be transformed or degraded into harmless byproducts through chemical or biological treatment techniques used for organics. These metals are in a relatively soluble form and generally less volatile than water which prohibits phase transfer.

At best, CCR constituents can be made immobile through stabilization within the soil matrix, either through adsorption or conversion into less soluble forms, or removed from the environment through extraction of impacted groundwater. General response actions or general technology categories potentially applicable at the site may include:

- Removal of Source Materials in conjunction with monitored natural attenuation (MNA) for residual groundwater impacts
- In-Situ Technologies
- Containment (Groundwater Extraction), with and without a physical barrier; ex-situ treatment and discharge

Each of the general technology types and process options evaluated was screened for applicability at the site and either retained or not retained for further evaluation with regard to effectiveness, implementability, and cost. **Table 6** at the end of this report presents the screening matrix for each of these technologies, including a description of each technology, and the rationale for selecting or rejecting each from further consideration.

3.2.1 Removal of Source Material

In general, the removal technology option assumes that all CCR materials are excavated from Pond 1A and 1B and disposed of in an appropriately permitted solid waste landfill. Prior to removal of the residuals, the technology category of removal also requires removal of sufficient pore water (dewatering) so that the ash surface is stable enough to support construction equipment and construction of soil bridges. Ash removal requires heavy equipment to cross the ash surface during excavation and a depth of 10 to 15 ft of unsaturated ash above the saturated ash layer is required to support the weight of equipment typically used to excavate ash or construct the cap. As ash is removed in successive lifts, dewatering must also continue during the process. Removed pore water will require treatment for a variety of constituents and the nature of those constituents may change during the removal activity. Following ash removal, the backfill materials must be placed in a stable manner and blended into the natural topography, and a soil cover must be installed to minimize erosion.

Removal of source material is an effective technology for mitigating groundwater impacts. Following removal of the source material, natural attenuation will generally reduce concentrations of COCs to levels below the GWPS over time. The length of time needed for natural attenuation to achieve GWPS in the downgradient aquifer is a function of both advective flow and the geochemical conditions in the aquifer.

Removal of the source material was retained for further evaluation as a corrective action option for the Pond 1 site.

3.2.2 In-Situ Treatment

Certain traditional in-situ remediation technologies are not well suited to Appendix IV COCs because of the unique physical and chemical characteristics. Many organic COCs can be degraded over time into harmless byproducts through biological or chemical processes. Some organics can be volatilized and removed from the groundwater by transferring them into the air phase (air sparging), and or by heating the aquifer matrix to more aggressively volatilize the compounds (steam stripping or electrical resistance heating). These types of technologies were not evaluated, since all Appendix IV constituents are naturally occurring metals or metalloids. These constituents are elements and cannot be transformed degraded into harmless byproducts through chemical or biological treatment techniques used for organics and the vapor pressures of these metals are too low for removal by heating or phase transfer techniques.

The four COCs that exceed their federal rule respective site-specific GWPS are barium, cobalt, lithium and molybdenum. At best, these Appendix IV COCs can be made immobile through stabilization within the soil matrix, either through redox manipulation, adsorption or conversion into less soluble forms. Iron coprecipitation, through redox manipulation or injection of zero valent iron may be applied to remove cobalt and molybdenum. Barium is generally removed from water using either carbonate or sulfate-based precipitation techniques.

As indicated in **Figure 8**, the waste management unit boundary wells (and the impacted groundwater) is in the bedrock aquifer. Injection of ZVI or similar amendments into fractured media is difficult and can be impractical depending on fracture apertures. Although soluble amendments can be injected into fractured shale or limestone, there is considerable difficulty in attaining adequate delivery to ensure treatment throughout the impaired zone. Injection of certain amendments for in-situ precipitation can also result in matrix dissolution. Conversely, in-situ precipitation of metals in fractured media may occlude fractures and limit the potential success of such approaches.

Lithium cannot be removed from groundwater by utilizing redox manipulation techniques since it is a monovalent cation. Lithium does not form insoluble species and removal techniques usually involve adsorption, reverse osmosis or ion exchange. Although developmental work is currently ongoing to develop lithium specific adsorbents for its extraction from sea brines, wastewater and various other media, there are currently not any commercially available absorbents for lithium. Some laboratory bench testing has been performed for adsorption of lithium using mixed metal oxide amendments, but the viability of such an adsorbent as an injected amendment has not been investigated.

In situ treatment approaches were not retained for further evaluation due to the uncertainty concerning delivery of the amendments into the fractured aquifer matrix and potential consequences on the matrix that could result from certain amendments.

3.2.3 Containment

A groundwater plume may be contained by physical means, by hydraulic control, or a combination of the two methods. Containment systems are placed on the periphery of the plume or around or over the boundaries of the source area and plume so that the encompassed area is effectively isolated from the surrounding environment. Containment measures for contaminated groundwater typically include caps or similar barriers to vertical migration, physical barriers to lateral migration such as slurry walls or grout curtains, and hydraulic gradient controls.

3.2.3.1 Physical Barriers

Slurry walls are the most common form of subsurface barrier used for horizontal hydraulic control. Slurry walls offer a relatively inexpensive means of vastly reducing groundwater flow in unconsolidated media. The term "slurry wall" applies to barriers that are constructed in a vertical trench excavated under a slurry. The slurry is usually a mixture of bentonite and water that hydraulically shores the trench walls during construction. The wall is typically constructed using a bentonite slurry and soil mixture or cement that displaces the hydraulic slurry and that subsequently forms a low permeability layer to horizontal groundwater flow. Slurry walls can be placed upgradient or completely surrounding the contaminated area.

Construction of an upgradient slurry wall was considered in the technology screening as a potential remedial approach for the site. In order to evaluate this approach, a slurry wall was simulated using the groundwater numerical software package MODFLOW-NWT to model the potential effectiveness of the wall to divert groundwater flow away from the CCR in Pond 1. The hypothetical slurry wall in the model was installed approximately 15 to 20 ft into the bedrock to an elevation of 1490 ft (ft) above mean sea level (MSL) and was assigned a conductivity of 10^{-7}cm/s. The simulated slurry wall was placed along the entire upgradient length of Pond 1A and 1B and extended along the Pond western edge to essentially encircle the unit.

As previously shown in Figure 8, the water table elevation within the unit ranges from approximately 1550 ft MSL on the upgradient side to 1520 ft MSL at the southern embankment. Groundwater contours within the Pond under current conditions, generated by the model, are provided in **Figure 15**.

The location and configuration of the simulated slurry wall are shown in **Figure 16**. The groundwater contours that are predicted with the installed slurry wall are also shown in **Figure 16**. Although groundwater elevations are depressed by the slurry wall, the modeling indicated that groundwater would flow beneath the wall and upward into the ash. As shown in Figure 16, groundwater elevations within the unit would remain between 1510 ft MSL to 1535 ft MSL following installation of a slurry wall.

The evaluation of a slurry wall option was extended by introducing a drain on the upgradient side of the slurry wall in an attempt to further depress the water table. This drain was located along the entire length of the upgradient side of the slurry wall. In order to appreciably depress the groundwater table further the drain must be located as close as practical to the bottom of the Pond which is generally considered to be 1500 to 1505 ft MSL. This concept design also simulated practical construction, so the drain was placed at an elevation corresponding to a depth accessible by a continuous trencher (50 to 60 ft bgs). This approach placed the drain at approximately 1505-1510 ft MSL. These considerations place the wall approximately 20-30 ft south of the Pond upgradient boundary with the drain located in the unconsolidated overburden material. **Figure 17** provides a cross section of this slurry wall and drain concept design.

Figure 18 presents a plan view for the slurry wall and drain concept design and the results of the groundwater modeling of that approach. Incorporation of the drain further depresses the water table to approximately 1505 ft MSL to 1515 ft MSL. Although this approach further depresses the water table, approximately 5-10 ft or 20%of the residuals remain in a saturated condition.

The modeling simulations suggested that an upgradient slurry wall would not sufficiently prevent groundwater contact with the ash to achieve meeting the GWPS and therefore these approaches were not retained for further consideration as stand-alone options. However, these approaches were retained for further consideration in conjunction with hydraulic containment options.

3.2.3.2 Hydraulic Containment

Groundwater extraction and treatment is one of a very limited set of technologies available to control highly soluble metal COCs that are recalcitrant to the types of redox manipulation used in in-situ treatment. This technology is effective at preventing further migration of COCs; however, it removes COCs from the groundwater flow system at a relatively slow rate, requiring large volumes of water to be extracted to remove a small mass of contaminants in dilute plumes.

Groundwater in the vicinity of Pond 1 occurs in a complicated system of fractured and faulted shale and limestone bedrock overlain with relatively thin unconsolidated fill and alluvial sediment. Bedrock yields can be quite low unless a productive fracture system is intercepted by the extraction well network, and the presence of a large fault system under the Pond adds further uncertainty to this option. However, based on preliminary modeling groundwater extraction and treatment has the potential to be effectively employed at the site and this technology was retained for further consideration.

3.3 Development of Corrective Measures Alternatives

Corrective action measures assessed for Pond 1 at the Clinch River plant have been developed based on site-specific conditions at the Plant in conjunction with remedial actions that are technically implementable and effective for the identified COCs. Corrective Measure Alternatives were developed that combined effects of source control on groundwater quality, followed by other combinations of technologies for retained for additional evaluation.

Two broad classes of alternatives have been identified which are capable of meeting the objectives of corrected action. In general, these are described below:

- Alternative 1: Removal of CCR Material from Pond 1, in conjunction with monitored natural attenuation (MNA) to reduce residual concentrations remaining in the groundwater.
- Alternative 2: Extraction of groundwater to limit the amount of flow through the fill material, and to remove impacted groundwater from the bedrock flow system. Three variations were considered to implement this alternative.
  - 2A: Groundwater Extraction and Treatment at the Downgradient Edge of the Unit
  - 2B: Groundwater Extraction and Treatment at the Downgradient Edge of the Unit with an Upgradient Barrier
  - 2C: Groundwater Extraction and Treatment at the Upgradient Unit Boundary.

Section 4 contains a detailed evaluation of each alternative, compared to correction action objectives specified in **Section 3.1**.

4.0 Detailed Evaluation of Corrective Measure Alternatives

The following sections contain a site-specific evaluation of various Corrective Measure Alternatives. These alternatives have been selected in consideration of the physical setting of the Pond, and the geochemical characteristics of the COCs. Following a description of each alternative, we have included an evaluation against the specific criteria outlined in the §257.96(c).

4.1 Alternative 1: Source Removal with Monitored Natural Attenuation

4.1.1 Description

The removal alternative assumes that all CCR materials are excavated from the permitted boundary of Pond 1 and are disposed of in an appropriately permitted offsite solid waste landfill. Following removal, groundwater quality will be monitored for at least two years to assess the effects of removal on groundwater quality and the ability of natural attenuation processes to achieve the COAs. Removal of the CCR material will be conducted in lifts, followed by placement of backfill material to achieve the final grade, and providing a soil cover to minimize erosion along the relatively steep slopes. Several key assumptions have been made in performing this analysis:

- There is insufficient capacity in the facility's onsite Possum Hollow Landfill to dispose of the fill material removed from the Pond 1 unit. While AEP continues to evaluate multiple disposal options, this evaluation assumes that excavated fill material must be disposed of offsite in the nearest commercial landfill permitted to accept the waste.
- The removal alternative was evaluated assuming that fill material would be transported by truck to the offsite landfill. AEP is also working to identify options that would permit the CCR fill to be transported offsite by rail. Rail transport would reduce the cost of the removal option and mitigate some of the negative aspects associated with truck transportation, but this option is not currently available.

Excavation activities will include:

1. Soil cover would be excavated and placed in a staging area of the site.
2. The CCR fill would be excavated and, to the extent possible, loaded directly into haul trucks. Dewatering would be conducted to maintain a stable working surface as fill material is removed.
3. Portions of the existing embankment will have to be removed and stored or hauled offsite due to upstream construction with ash used for interior slopes. The crest will also be lowered to maintain stability and haulage.
4. Approximately 20 tons of CCR fill material per truckload would be hauled to an offsite landfill.
5. Staged soil cover and other onsite materials will be backfilled in the area of excavation to approximately the original grade of the area prior to installation of the Pond.

Removal is significantly complicated by the presence of saturated ash within the Pond 1 fill. Preliminary data indicates that as much as 40 ft of pore water may be present beginning 20 to 30 ft below the cap. Piezometric data has not indicated a significant drop in water elevation within the fill since closure of the Pond was completed in 2018. Removal of the material will require significant dewatering once construction has removed the initial layer of unsaturated material from the top of the closed unit. Typically, a depth of 10 to 15 ft of unsaturated ash above the saturated ash layer is required to support the weight of equipment typically used for excavation.

Additionally appropriate management of water generated during this process presents important challenges for this alternative. While the Clinch River plant operates an AWWTP which treats leachate from the Pond, a temporary treatment system with its own VPDES permit likely will be required due to the increased flow rate generated during dewatering. Data on pore water quality within the Pond is being collected as part of the NES and these results, in conjunction with design data from the AWWTP, will be used to refine this concept further and identify any specific constituents that may require additional treatment.

Since closure by removal would remove the ash source, transfer of COCs into the groundwater plume would be assumed to cease. Long-term groundwater monitoring will be conducted following removal to assess the ability of natural attenuation processes to achieve the GWPSs. Natural attenuation processes involved in the MNA approach include physical, chemical, and/or biological processes that occur without human intervention to reduce mass, toxicity, volume, mobility, or concentration of contaminants. COCs at the Pond 1 site would naturally attenuate through redox reactions (such as precipitation and coprecipitation) based on groundwater flow system geochemistry, adsorption, dispersion and/or advection. In conjunction with removal of new COCs transferring into the groundwater flow system, MNA can be effective in reducing COC constituents below their respective GWPSs.

4.1.2 Evaluation

4.1.2.1 Remedy Performance

Removal of source material has been demonstrated successfully to restore groundwater quality to below GWPSs in many environments. Pond 1 is a hillside fill unit that was closed with waste in place in 2018. Since the unit has been closed, groundwater has continued to pass through the waste fill, entering the fill via the face of the hillside on the upgradient side of the waste. If the fill material were removed, the transfer of CCR constituents into the groundwater system would cease, and groundwater quality would be restored through a process of natural attenuation. This option is well suited to the setting of Pond 1, in that the groundwater plume is believed to extend laterally only to the surface water bodies (Dumps Creek and Clinch River),and is not believed to extend deep into the bedrock flow system. These assumptions will be evaluated as part of the NES. In addition, the CCR fill materials, once transported to an offsite landfill, will be managed in a facility with improved environmental controls (that is, improved isolation from the environment with a lined bottom and sides, and improved leachate management).

4.1.2.2 Remedy Reliability

Removal conclusively eliminates source material from the environment and the corresponding transfer of CCR constituents into the groundwater. Restoration of groundwater quality through MNA following removal is anticipated to be highly effective given the relatively small area of impact.

4.1.2.3 Ease of Implementation

Removal is difficult to implement compared to other alternatives which leave the waste in place. The presence of constant groundwater flow during excavation will make water management critical Ongoing dewatering activities can be challenging due to variable permeabilities within the fill and methods by which Pond 1 (parts A and B) were constructed during their operating life.

4.1.2.4 Potential Impacts During Implementation

Potential exposure pathways for CCR materials during this alternative include direct contact with, inhalation of particulates from, and incidental ingestion of fill materials during excavation, transport, and offsite disposal. These individuals would also be exposed to the normal health and safety considerations associated with heavy construction and on-road truck transportation. Secondary exposure may be associated with contact with groundwater during dewatering operations. These potential exposure routes will be addressed by engineering controls (including dust control as appropriate) and personal protective equipment where appropriate. Dust control is anticipated to be sufficient to address incidental exposure to members of the public driving near Pond 1 and workers at the power plant.

The potential for ecological exposure includes erosion of CCR materials during excavation which could potentially enter the surface water system. These impacts would be controlled by an erosion and sediment control plan to be implemented during construction. An additional ecological exposure exists for the discharge of treated pore water into the Clinch River. This risk will be mitigated by a permit, and the proper frequency of effluent testing to demonstrate compliance with the permit.

4.1.2.5 Ability of the Remedy to Control Exposure to Groundwater Contaminants

Removal eliminates the transfer of CCR constituents into the groundwater, and groundwater quality is restored through natural attenuation of residual contamination. Exposures associated with Pond 1 groundwater contamination are well controlled.

4.1.2.6 Remedy Start-Up Time

Start-up of source removal involves a timeline controlled primarily by water management. Prior to startup, the temporary dewatering treatment system must be designed, permitted and placed at the site. It is estimated this may take as long as 12 months following initiation of remedy implementation. Site mobilization and initial excavation activities would be coordinated with the installation and start-up of the dewatering treatment system. Once excavation is underway, it is anticipated that the removal action would take 13 years to complete, including backfill and final grading.

4.1.2.7 Time Required to Complete Groundwater Remedy

It is anticipated that groundwater quality will achieve compliance with the GWPS over time, as the fill material is removed. Given the long period of time required to remove the fill, it is anticipated that groundwater quality will achieve compliance with the GWPS one to two years of fill removal.

4.1.2.8 Institutional Requirements

This alternative will require a VPDES discharge permit for the temporary wastewater treatment system used during dewatering. In addition, a VPDES stormwater permit for construction activities will be required for excavation of the fill materials. These are the only permits anticipated for this alternative.

Insufficient capacity exists onsite to properly dispose of the material within the Clinch River Plant boundaries. Therefore, offsite transportation will be required. Source control is included as part of this alternative, either through source removal or composite capping. Either option significantly reduces the migration of COCs into the groundwater. Natural attenuation processes reduce the mass of COCs in the groundwater through adsorption and concentrations would decrease through dilution and dispersion. Institutional controls to prevent groundwater use will be required for this alternative, and additional controls will be required to maintain the cap for the life of the alternative.

Ongoing groundwater monitoring to assess improvements to groundwater quality will involve the collection of purge water from monitoring wells which will be collected and treated in the plant's onsite AWWTP as is currently done now.

4.1.2.9 Addresses Community Concerns

Source removal from unlined ponds is effective in control migration of CCR constituents into the environment, and initial community acceptance of the concept is high. However, the activities as described can be disruptive to the community during implementation. In the case of Pond 1, approximately 2.9 million cubic yards of material are anticipated to be transported offsite due to the lack of permitted storage space on the Clinch River Plant property. It is estimated at least 194,000 truckloads of waste will be transported from the site, introducing additional air pollution from diesel engines and traffic congestion along the small and winding roads between the site and interstate I-81. Rail transportation would minimize these disruptions if an alternative could be identified. However, the disruption to traffic in the immediate vicinity of Pond 1 during excavation will be unavoidable. The downgradient berm of Pond 1 is located directly adjacent to State Route 616, and construction at the edge of the pond will require road closures during at least part of the activities.

4.2 Alternative 2: Groundwater Extraction, Treatment and Surface Water Discharge

4.2.1 Description

This alternative consists of groundwater extraction from the fill material and bedrock flow system, followed by wastewater treatment prior to direct discharge to the Clinch River under a VPDES permit. Three variations of this alternative were evaluated for this ACM, each of which rely heavily on hydraulic control of the groundwater plume:

- 2A: Groundwater Extraction and Treatment at the Downgradient Edge of the Unit
- 2B: Groundwater Extraction and Treatment at the Downgradient Edge of the Unit with an Upgradient Barrier
- 2C: Groundwater Extraction and Treatment at the Upgradient Unit Boundary.

In general, the three alternatives are anticipated to meet the corrective action objectives for the site, but additional data collection will be required to complete the evaluations of three groundwater extraction variations. Specifically, the descriptions of each alternative below are based in large measure on groundwater modeling which will be refined after additional data is collected during the NES.

4.2.1.1 2A: Groundwater Extraction and Treatment at the Downgradient Edge of the Unit

This alternative consists of groundwater extraction at the downgradient edge of the waste management unit boundary followed by wastewater treatment prior to direct discharge to the Clinch River.

For this pumping scenario, 14 extraction wells were placed along the downgradient edge of the unit boundary as shown in **Figure 19.** These wells are installed to approximately 70 to 80 ft bgs (1440 to 1450 ft MSL) and extend into either the Chattanooga Shale, Dumps Fault or Rome dolomite formations. The concentrations of the potential constituents in the groundwater at the individual points of extraction will differ depending on whether a given well has been installed within the Chattanooga, Rome, or Dumps Fault formations. However, the combined influent will have characteristics that are related to the proportion of flow from each of the respective units. As shown in **Figure 19,** the extraction system was estimated to place seven individual wells in the Chattanooga Shale, one well within Dumps Fault, and seven extraction wells in the Rome formation. Each extraction well was assumed to remove groundwater at the same rate. In order to estimate the influent characteristics, the mean and maximum constituent concentrations from the waste management unit boundary wells in each formation were proportioned based on the ratio of the number of wells within a formation to the total number of extraction wells. **Table 8** summarizes the mean and maximum constituent concentrations estimated for the extracted groundwater.

Table 7. Estimated Influent Concentrations and Discharge Criteria, Alternative 2A

	Estimated Mean Influent Concentration	Estimated Maximum Influent Concentration	Human Health Criterion	Aquatic Life Ambient Water Quality Criteria
Constituent	**µg/L**	**µg/L**	**µg/L**	**µg/L**
Antimony	0.0544	0.1898	5.6	190 [3]
Arsenic	3.55	8.916	10	150
Barium	687.7	1625.3	2000	220 [3]
Beryllium	0.024	0.028	4.0	11 [3]
Boron		434.7	4000[1]	3900 [3]
Cadmium	0.073	0.1287	5.0	0.26 to 2.38 [4]
Chromium	0.205	0.327	100	11 [5]
Cobalt	4.516	7.26	6.0[1]	24 [3]
Copper	0.19	1.08	1300	2.85 to 30.49 [4]
Iron		9.78	300[2]	
Lead	0.85	1.512	15	2.31 to 78.8 [4]
Lithium	113	171.7	40 [1]	431 [6]
Manganese		57	430 [2]	
Mercury	0.051	0.069	2.0	0.77
Molybdenum		58.9	100 [1]	20,000 [3]
Nickel	12.4	17.9	390	6.29 to 65.07 [4]
Selenium	0.09	0.173	170	5
Silver	0.014	0.88	94	3.4 (0.37 to 44) [4]
Thallium	0.058	0.059	0.24	17 [3]
Tin	0.71	15.07	12000	180 [3]
Vanadium	0.68	4.25	86 [1]	44 [3]
Zinc	4.9	12.54	6000 [1]	37 to 387.8[4]

[1] MCL or human health water quality criteria are not promulgated under 9VAC25-260-140 for this constituent. Value is Regional Screening Level for tapwater from USEPA RSL tables. Tapwater RSL is a risk screening value that is appropriate for end of pipe use and not applicable in stream

[2] Secondary water quality criteria for aesthetic purposes

[3] Aquatic Life water quality criterion have not been promulgated under 9VAC25-260-140. For comparative purposes, a search was conducted among states that have promulgated criteria. AWQC are from state of Ohio OEPA WQC (35 OAC3745 to 1)

[4] Ambient water quality criteria based on hardness. Under 9VAC25-260-140 Range of hardness allowed is 25 mg/L to 400 mg/L. Values are for the allowed range of hardness in the rule

[5] AWQC is for chromium in hexavalent state

Extracted groundwater will be discharged to surface water following limited treatment. Therefore, probable discharge limits were based on maximum contaminant levels or human health based ambient water quality criteria. Where MCLs are not promulgated for a constituent, tapwater Regional Screening Levels (RSLs) were used. However, RSLs are risk screening values for end of pipe or direct consumption and are not applicable as in stream criteria. **Table 8** also includes water quality criteria for aquatic life promulgated under 9VAC25-260-140. However, VDEQ has not promulgated water quality criteria for all of the constituents that will be present in the combined influent. In order to estimate probable discharge limits, a search was conducted among states that have promulgated criteria. Ohio has promulgated AWQC for most of the potential constituents likely to be in the combined influent and those values have been included in **Table 8** as a potential benchmark for discharge criteria.

The aquatic life criteria in **Table 8** are generally based on chronic values because those values are more stringent and must be attained outside of the mixing zone allowed under 9VAC25 to 260 to 20B. The aquatic life criteria for a number of metals are based on in stream hardness with a range of hardness values from 25 mg/L to 400 mg/L allowed under the rule. For those metals, **Table 8** presents the chronic water quality criteria corresponding to the allowed hardness range.

Virginia has not promulgated AWQC for lithium. The state of Michigan has promulgated a final chronic value for lithium for aquatic life of 440 µg/L and an aquatic life maximum of 910 µg/L. In order to further estimate a potential discharge limit for lithium, toxicity studies with various aquatic organisms were reviewed. A Tier 2 WQC was estimated using the methodology outlined in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" (USEPA, 2010). These guidelines outline a multi-step process for the calculation of water quality criteria based on existing published toxicity studies. The toxicity study data provided an estimated final chronic value for lithium of 431 µg/L.

Based on the mean and maximum concentrations at the waste management unit boundary wells proportioned relative to placement of the extraction wells, the metals that may require treatment in the extracted groundwater are barium, cobalt, lithium, nickel and silver. The projected influent concentrations of both cobalt and lithium were below Tier 2 values or chronic water quality criteria published from Ohio and only exceed a tapwater RSL. The tapwater RSL is a risk screening value considered appropriate at the end of pipe and is not applicable as an in-stream concentration. Therefore, treatment for those metals is not anticipated to be necessary. The maximum projected influent concentration for silver exceeds the lower bound hardness adjusted acute water quality criteria for aquatic life. Data from the upstream monitoring station provided in AEPs VPDES permit indicated an upstream value of 147 mg/L. The corresponding acute AWQC for silver for protection of aquatic life for that hardness value is 7.87 µg/L. The projected influent concentrations are below that threshold and therefore treatment for silver is not considered necessary. As a conservative basis, treatment was considered for removal of barium and nickel.

Fourteen extraction wells will be installed across the site as shown in **Figure 19.** The extraction wells be installed by sonic drilling techniques to a depth of 80 ft bgs and will be constructed of 4 in PVC well casing and screen. The recovery wells will have a 20 to 30 ft screened interval.

Groundwater modeling of the necessary extraction rate for capture indicated that each of the 14 wells would need to pump at 5 to 6 gpm yielding a total influent flow rate of 70 to 80 gpm. It is assumed that adequate 230 V or 460V, 3 phase electrical power is readily available at the site. Stainless steel turbine pumps powered by 1.0 horsepower, 230 V 3 phase motors will be installed in each extraction well. Each of the submersible pumps will be capable of providing 130 to 200 ft of total discharge head (TDH) at 11 to 13 gpm. The extraction wells will also be provided level transducers and level controls to provide automated operation of the pumps based on water elevations.

Extracted groundwater will be treated to reduce TDS, barium, and nickel concentrations removal using conventional precipitation, coagulation and direct filtration techniques. Conventional techniques for barium removal include lime-soda softening, calcium sulfate-based precipitation, ion exchange and reverse osmosis. Lime-soda softening, and calcium sulfate precipitation are capable of removing 90 to 95% of barium to concentrations of 200 to 500 µg/L. The general method for calculation of an allowable discharge concentration is based on proportion of the in-stream concentration, 7Q10 low stream flow and the discharge flow from the following formula:

$$C_A=[(Q_U+Q_W)*C_S-Q_U(C_U)]/Q_W$$

Where: C_A=allowable discharge concentration

C_S =in stream standard

Q_U=upstream 7day, 10 year low flow

Q_W=discharge flow

C_U = upstream constituent concentration

The 7-day 10-year (7Q10) low flow for the Clinch River above the site is 56 cfs (25,132 gpm). Based on the ratio of the discharge rate and stream flow, reduction of barium concentrations to 200 to 500 µg/L will be adequate to meet any likely discharge limit. Nickel is readily removed to 1 to 5 µg/L by hydroxide precipitation at a pH of approximately 10.5. Therefore, the treatment process was based on lime soda softening at a pH of 10 to 10.5.

The pump discharge will be conveyed approximately 2000 ft to a wastewater treatment system housed in a building located to the west of the Pond 1 western diversion ditch. The influent will initially be directed to a 2'x2'x3' height rapid mix tank designed for a retention time of approximately 45 to 60 seconds. Agitation in the rapid mix tank will be provided using a 0.5 HP propeller mixer. Calcium oxide solution or limewater will be added from four 12000 gallon make up tanks containing a 1.5 g/L solution of lime. The lime water will be metered to the rapid mix tank with a 1 HP metering pump to attain an instream dose of 348 mg/L. A sodium carbonate solution at a concentration of 100 g/L will be stored in a 7000 gal make up tank. A 1.0 HP metering pump will provide for addition of the sodium carbonate solution to the rapid mix tank at an in-stream concentration of 202 mg/L.

Ferric sulfate coagulant purchased as a 10% solution will be stored in a 4,000 to gallon reagent storage tank as a stock reagent at 1.0%. The ferric sulfate coagulant will be dosed at approximately 42 LPH to achieve 40 to 50 mg/L of coagulant concentration in the wastewater stream. Process control to maintain pH at 10 to 10.5 units will consist of pH probes interlocked with the metering pumps.

The wastewater stream from the rapid mix tanks will be conveyed to a single circular axial mix flocculation tank using a 230 V, 2 HP recessed open impeller centrifugal pumps operated at 1,750 rpm. The axial mix flocculation tank will provide a retention time of approximately 40 to 60 minutes and have approximate dimensions of 11 to 13 ft in height and 4.5 to 5.5 ft in diameter.

Following flocculation, the process stream will be conveyed to primary clarification using a 230 V, 3 phase, 11 HP progressive cavity pump to minimize shear. Primary filtration will be provided by a 5 ft diameter by 6 ft high multimedia filter designed for operational loading at 3 to 4 gpm per ft^2. The multimedia filter will be are loaded with progressive layers of gravel, garnet and sand to remove particles down to the range of 5 to 10 microns. A parallel set of two additional multimedia filters will be incorporated to allow continuous flow during the 10- to 15-minute backwash cycles which would occur at approximate 8 hour intervals.

The multimedia filters will be backwashed at a frequency of approximately every 8 hours for approximately 10 to 15 minutes at 300 gpm. It is assumed that the potable water supply for backwash can be available from an on-site potable supply well or by retaining from the makeup water system of the generating station. Each backwash cycle will generate approximately 4000 gallons of backwash that will be conveyed to a set of three 5000 gallon backwash holding tanks. The backwash is estimated to contain approximately 1900 mg/L of TSS which will be maintained in suspension by recirculation. The backwash stream will subsequently be processed through an inclined plate settler with approximately 200 square ft of plate area with the overflow directed to a polishing bag filtration train. The polishing filter preliminarily sized as a 20-bag vessel using number 2 bags at 10 microns. The underflow from the plate settler will be directed to either filter press or drying bed for removal of water. It is estimated that wastewater treatment will generate approximately 18 pounds per day of sludge at 30% solids content and an arsenic concentration of mg/kg.

4.2.1.2 2B: Groundwater Extraction and Treatment at the Downgradient Edge of the Unit with Upgradient Barrier

Evaluation of the groundwater extraction system located along the downgradient edge of the Pond (Alternative 2A), indicated that the 14 wells would provide capture at a rate of approximately 5 to 6 gpm per well. While this extraction system is sufficient to hydraulically contain the plume, it is estimated to only reduce the saturated thickness by about 10 ft. Therefore, this variation combines physical containment in conjunction with the downgradient extraction system described for Alternative 2A. The use of an upgradient barrier wall and subsurface drain were evaluated to assess whether physical containment could improve the dewatering which occurs with downgradient pumping. The purpose of the wall and drain would be to divert the flow of groundwater around the Pond fill, allowing the downgradient pumping wells to more successfully reduce the amount of pore water held in the ash. While it has been assumed that both the diverted upgradient groundwater and the extracted ground water from the downgradient system will require treatment, it is assumed that this approach would reduce the overall mass loading to the groundwater treatment system since less water will be flowing through the ash prior to collection. The downgradient pumping system used in this alternative is a modified version of the system described for Alternative 2A. The upgradient barrier wall, gravity drain and downgradient pumping system are described below.

Slurry Wall

The upgradient slurry wall will be installed by slurry trench methods. Slurry trench is a generic term referring to a specific trenching technique used to install vertical structures and walls. Walls installed using the slurry trench method are among the most common type of vertical barrier walls and can be considered a baseline technology for comparison to other barrier installation techniques. Since the 1940s, these walls have been used in the construction industry to contain and direct water, and as a result, the requirements and practices for designing and installing a wall in a slurry trench are well established.

The wall at Pond 1 will be installed along the entire upgradient length of Pond 1A and 1B. The new wall will extend along the western edge of the Pond and connect to the existing downgradient barrier thereby nearly encircling the unit. The north perimeter of the vertical barrier will be approximately 1,800 linear ft and will extend around the western side of the Pond for a length of approximately 700 ft for a total length of 2500 ft as shown in **Figure 20**. The design conductivity of the wall material will be 10 to ^{7} centimeters per second (cm/s). Since the fill was placed directly against the hillside, the slurry trench is proposed to be located within the CCR fill material (fly ash). Fly ash has been successfully used as an additive in Portland cement concrete, and a portion of the excavated CCR material could be used to construct the wall.

In order to provide an adequate key in and cut off groundwater flow the wall must be installed beneath the bottom of the Pond into the bedrock. The slurry wall will be installed approximately 15 to 20 ft into the bedrock. It has been assumed that the slurry wall will be installed by DeWind One Pass Trenching and will be 27 inches wide. DeWind One Pass Trenching uses an in-situ mixing technology that homogenizes the soils with bentonite from top to bottom in a continuous linear wall. Fifty ft is the maximum practical installation depth using one pass continuous trenching and therefore a 30 ft bench would need to be excavated along the length of the slurry walls to achieve an overall depth of 80 ft below surface. This technique will result in a wall with a maximum permeability of 10^{-7} centimeters/second.

Gravity Drain

A gravity drain will be installed upgradient of the wall to further divert the groundwater intercepting the wall, thereby further lowering the level of pore water in the pond and to depress the water table. The drain on the upgradient side of the slurry wall may be installed in a second pass with the DeWind One Pass Trencher. This drain will be located along the entire length of the upgradient side of the wall. In order to appreciably depress the groundwater table, the drain must be located as close as practical to the bottom of the Pond which is generally considered to be 1500 to 1505 ft MSL which will require a second bench on the ash surface of approximately 15 ft. Both the slurry wall and drain will be installed approximately 20 to 30 ft south of the Pond's upgradient boundary with the drain located in the unconsolidated overburden material.

Downgradient Extraction System

For this extraction scenario, modeling indicates that 13 extraction wells will be needed along the downgradient edge of the unit boundary as shown in **Figure 20.** These wells will be installed using sonic drilling techniques to approximately 70 to 80 ft bgs (1440 to 1450 ft MSL) and extend into either the Chattanooga Shale, Dumps Fault or Rome dolomite formations. The extraction wells will be constructed of 4 in schedule 40 PVC well casing and screen. The recovery wells will have 20 to 30 ft screened intervals.

Groundwater modeling indicated that each of the 13 wells would need to pump at 3 to 3.5 gpm to provide hydraulic control of the impacted groundwater, yielding a total flow rate from the wells of 40 to 45 gpm. Modeling further indicates that the gravity drain would provide a flow of approximately 35 gpm, for a total collection rate of 75 to 80 gpm, nearly identical to that predicted for Alternative 2A.

It is assumed that adequate 230 V or 460V, 3 phase electrical power is readily available at the site. Stainless steel turbine pumps powered by 1.0 horsepower, 230 V 3 phase motors will be installed in each extraction well. Each of the submersible pumps will be capable of providing 130 to 200 ft of total discharge head (TDH) at 11 to 13 gpm.

The pump discharge will be conveyed approximately 2000 ft to a wastewater treatment system housed in a building located to the west of the Pond 1 western diversion ditch as previously described. The influent characteristics will be very similar to those described for Alternative 2A. Therefore, the extracted groundwater will be treated to reduce TDS, barium, and nickel concentrations removal using conventional precipitation, coagulation and direct filtration techniques based on lime soda softening at a pH of 10 to 10.5. The unit operations for that treatment were previously described in **Section 4.2.1.1**.

4.2.1.3 2C: Groundwater Extraction and Treatment at the Upgradient Unit Boundary.

Alternative 2C is a hydraulic containment option that depresses the groundwater table upgradient of the Pond 1 to maximize dewatering of the fill. This alternative consists of groundwater extraction at the upgradient edge of the Pond and along most of its western boundary followed by wastewater treatment prior to direct discharge to the Clinch River.

For this pumping scenario, 30 extraction wells will be installed along the upgradient edge of the unit boundary as shown in **Figure 21.** These wells will be installed on a 20-degree angle from vertical by sonic drilling techniques to approximately 100 ft bgs (1470 ft MSL) and extend into either the Chattanooga Shale, Dumps Fault or Rome dolomite formations. The concentrations of the potential constituents in the groundwater at the individual points of extraction will differ depending on whether a given well has been installed within the Chattanooga, Rome, or Dumps Fault formations. However, the combined influent will have characteristics that are related to the proportion of flow from each of the respective units. The extraction system was estimated to place twenty individual wells in the Chattanooga Shale, two wells in Dumps Fault, and eight extraction wells in the Rome formation. Each extraction well was assumed to remove groundwater at the same rate. In order to estimate the influent characteristics, the mean and maximum constituent concentrations from the waste management unit boundary wells in each formation were proportioned based on the ratio of the number of wells within a formation to the total number of extraction wells. **Table 9** summarizes the mean and maximum constituent concentrations estimated for the extracted groundwater.

Table 8. Estimated Influent Concentrations and Discharge Criteria, Alternative 2B

Constituent	Estimated Mean Influent Concentration µg/L	Estimated Maximum Influent Concentration µg/L	Human Health Criterion µg/L	Aquatic Life Ambient Water Quality Criteria µg/L
Antimony	0.198	0.299	5.6	190[3]
Arsenic	8.82	26.67	10	150
Barium	173.93	326.5	2000	220[3]
Beryllium	0.0104	0.0156	4.0	11[3]
Boron	495.24	650.0	4000[1]	3900[3]
Cadmium	0.019	0.0313	5.0	0.26 to 2.38[4]
Chromium	0.352	0.689	100	11[5]
Cobalt	0.1359	0.463	6.0[1]	24[3]
Copper	0.306	1.611	1300	2.85 to 30.49[4]
Iron	71.23	297.9	300[2]	
Lead	0.1659	0.437	15	2.31 to 78.8[4]
Lithium	62.55	119.2	40[1]	431[6]
Manganese	110.54	479.1	430[2]	
Mercury	0.086	0.1	2.0	0.77
Molybdenum	5.647	26.86	100[1]	20,000[3]

Table 8. Estimated Influent Concentrations and Discharge Criteria, Alternative 2B

Constituent	Estimated Mean Influent Concentration µg/L	Estimated Maximum Influent Concentration µg/L	Human Health Criterion µg/L	Aquatic Life Ambient Water Quality Criteria µg/L
Nickel	0.713	1.32	390	6.29 to 65.07 [4]
Selenium	0.066	0.217	170	5
Silver	0.286	1.02	94	3.4 (0.37 to 44) [4]
Thallium	0.026	0.055	0.24	17 [3]
Tin	1.282	2.32	12000	180 [3]
Vanadium	1.225	2.23	86 [1]	44 [3]
Zinc	4.466	26.62	6000 [1]	37 to 387.8[4]

[1] MCL or human health water quality criteria are not promulgated under 9VAC25-260-140 for this constituent. Value is Regional Screening Level for tapwater from USEPA RSL tables. Tapwater RSL is a risk screening value that is appropriate for end of pipe use and not applicable in stream

[2] Secondary water quality criteria for aesthetic purposes

[3] Aquatic Life water quality criterion have not been promulgated under 9VAC25-260-140. For comparative purposes, a search was conducted among states that have promulgated criteria. AWQC are from state of Ohio OEPA WQC (35 OAC3745 to 1)

[4] Ambient water quality criteria based on hardness. Under 9VAC25-260-140 Range of hardness allowed is 25 mg/L to 400 mg/L. Values are for the allowed range of hardness in the rule

[5] AWQC is for chromium in hexavalent state

Extracted groundwater will be discharged to surface water following limited treatment. Therefore, probable discharge limits were based on maximum contaminant levels or human health based ambient water quality criteria. Where MCLs are not promulgated for a constituent, tapwater Regional Screening Levels (RSLs) were used. However, RSLs are risk screening values for end of pipe or direct consumption and are not applicable as in stream criteria. **Table 9** also includes water quality criteria for aquatic life promulgated under 9VAC25-260-140. However, VDEQ has not promulgated water quality criteria for all the constituents that will be present in the combined influent. Ohio has promulgated AWQC for most of the potential constituents likely to be in the combined influent and those values have been included in **Table 9** as a potential benchmark for discharge criteria. Where AWQC for protection of aquatic life are dependent on hardness in the receiving stream, **Table 9** presents the chronic water quality criteria corresponding to the allowed hardness range.

Virginia has not promulgated AWQC for lithium. The basis for the values for protection of aquatic life for lithium were previously described and derive from state of Michigan and derivation of a Tier 2 value from toxicity study data.

Based on the mean and maximum concentrations from the upgradient extraction wells proportioned relative to placement of the extraction wells, the metals that may require treatment in the extracted groundwater are arsenic, barium, lithium, and silver. The projected influent concentration of lithium is below Tier 2 values or chronic water quality criteria published from Michigan and only exceed a tapwater RSL. The tapwater RSL is a risk screening value considered appropriate at the end of pipe and is not applicable as an in-stream concentration. Therefore, treatment for lithium is not anticipated to be necessary.

The maximum projected influent concentration for silver very slightly exceeded the lower bound hardness adjusted acute water quality criteria for aquatic life. Data from the upstream monitoring station provided in AEPs VPDES permit indicated an upstream value of 147 mg/L. The corresponding acute AWQC for silver for protection of aquatic life for that hardness value is 7.87 µg/L. The projected influent concentration of silver is below that threshold and therefore treatment for silver is not considered necessary.

The maximum projected combined influent concentration for arsenic was above the MCL and the projected barium concentration was above the AWQC for protection of aquatic life. As a conservative basis, treatment was considered for removal of arsenic and barium.

Thirty extraction wells will be installed across the upgradient boundary of the site as shown in **Figure 21.** The extraction wells be installed by sonic drilling techniques to a depth of 100 ft bgs and will be constructed of 4 in PVC well casing and screen. The recovery wells will have 20 to 30 ft screened interval

Groundwater modeling of the necessary extraction rate for capture indicated that each of the 30 wells would need to pump at 2 to 2.5 gpm yielding a total influent flow rate of 60 to 75 gpm. It is assumed that adequate 230 V or 460V, 3 phase electrical power is readily available at the site. Stainless steel turbine pumps powered by 1.0 horsepower, 230 V 3 phase motors will be installed in each extraction well. Each of the submersible pumps will be capable of providing 130 to 200 ft of total discharge head (TDH) at 11 to 13 gpm. The extraction wells will also be provided level transducers and level controls to provide automated operation of the pumps based on water elevations.

Extracted groundwater will be treated to reduce TDS, arsenic and barium concentrations removal using conventional precipitation, coagulation and direct filtration techniques. Coagulation using iron salts is widely used for arsenic removal for drinking water treatment and is capable of reducing arsenic concentrations to 2 to 5 µg/L. Aeration as a pretreatment step will oxidize arsenic enhancing its removal. Conventional techniques for barium removal include lime-soda softening, calcium sulfate-based precipitation, ion exchange and reverse osmosis. Lime-soda softening and calcium sulfate precipitation are capable of removing 90 to 95% of barium to concentrations of 200 to 500 µg/L. As previously discussed, lime soda softening is expected to provide adequate removal of barium to meet anticipated discharge limits calculated from proportion of the in-stream concentration, 7Q10 low stream flow and the discharge flow.

The discharge from the individual pumps will be conveyed up to approximately 2,500 ft to a wastewater treatment system housed in a building located to the west of the Pond 1 western diversion ditch.

The initial unit operation will be oxidation in a 750 to 1000-gallon aeration tank sized to provide 10 to 15 minutes of retention time. Aeration will be provided by a 230 V, 0.5 HP regenerative blower providing approximately 10 to 20 cfm of air flow. The influent will subsequently be put into a rapid mix tank designed for a retention time of approximately 45 to 60 seconds. Calcium oxide solution or limewater will be added from four 12,000 gallon make up tanks containing a 1.5 g/L solution of lime. The lime water will be metered to the rapid mix tank with a 1 HP metering pump to attain an instream dose of 480 mg/L. A sodium carbonate solution at a concentration of 100 g/L will be stored in a 7,000 gal make up tank. A 1.0 HP metering pump will provide for addition of the sodium carbonate solution to the rapid mix tank at an in-stream concentration of 540 mg/L.

Ferric sulfate coagulant purchased as a 10% solution will be stored in a 4,000 to gallon reagent storage tank as a stock reagent at 1.0%. The ferric sulfate coagulant will be dosed at approximately 42 LPH to achieve 40 to 50 mg/L of coagulant concentration in the wastewater stream. Process control to maintain pH at 10 to 10.5 units will consist of pH probes interlocked with the metering pumps.

The remaining unit operations will be similar to those previously described for the downgradient extraction and treatment system. Some adjustment of pump sizing and power requirements will be needed, and an additional multimedia filter may be required. Overall daily sludge generation will be similar to that previously estimated.

4.2.2 Evaluation

This section presents the evaluation of the three variations of Alternative 2 using the criteria specified in §257.96(c). In general, each of the three variations are very similar in their ability to address the specified criteria. All three variations involve treatment of extracted groundwater. Where differences exist, the alternatives are discussed individually.

4.2.2.1 Remedy Performance

Groundwater extraction is one of the earliest groundwater remediation techniques. In "Remediation Case Studies: Groundwater Pump and Treat {Nonchlorinated Contaminants)" the Federal Remediation Technologies Roundtable (1998), presents 14 case studies, some of which were implemented as far back as 1985. These case studies show the performance of the remedy is highly dependent on the types of contaminants involved, and on site-specific factors which control the effectiveness of extraction in capturing the COCs. Extraction alone can take many years to reduce groundwater constituents below the GWPSs.

However, as described in **Section 4,** several CCR constituents including lithium are highly soluble and are not removed by current in-situ technologies. Therefore, impacted groundwater must be removed from the subsurface and treated above-ground prior to discharge in order to prevent migration of these constituents from the unit boundary.

In addition to preventing migration, groundwater extraction is anticipated to improve groundwater quality directly under Pond 1 by reducing the amount of water stored in the fill, and thereby limiting the mass transfer of constituents into the groundwater. System performance depends upon the ability to effectively capture groundwater as it migrates from the unit boundary. Hydraulic characteristics of the fill and bedrock flow systems are under evaluation as part of the NES, and the extraction system design will be refined based on those findings.

Currently, there is not any data concerning the concentrations of the COCs in the ash and modeling cannot be conducted to evaluate the time required for source depletion. Recently several vibrating wire piezometers were installed along the ponds cover and during their installation corings of the ash were obtained. Once this data is available source depletion modeling can be conducted. It is currently assumed that the extraction wells and treatment system will need to operate as long as the waste is in place.

Alternative 2A : Figure 19 presented the locations of the extraction wells along the downgradient edge of the unit boundary for Alternative 2A. Comparison of the groundwater contours predicted for only downgradient extraction with the current groundwater contours **(Figure 15)** indicates that downgradient extraction alone will only depress the water table by approximately 10 ft in the upgradient and central portion of the Pond. Along the downgradient edge, the extent of dewatering is greater with depression of the water table of 15 to 20 ft. However, Alternative 2A will leave a significant mass of ash saturated.

Alternative 2B : Figure 20 presents the modeled groundwater contours for Alternative 2B which augments the downgradient extraction system with an upgradient slurry wall and gravity drain. With upgradient extraction by the drain system, the water table along the north side of the Pond is depressed to 1510 to 1515 ft MSL. In the central portion of the Pond, augmentation with the drain system reduces the water table to approximately 1505 ft MSL. Therefore, addition of the upgradient slurry wall and drain provide a substantial improvement in dewatering of the ash. However, the lower 10 ft of approximately 8 acres of ash will continue to remain saturated. Addition of the upgradient slurry wall and drain to the downgradient extraction system will dewater approximately 90% of the ash volume,

Alternative 2C : Figure 21 presents the modeled groundwater contours for Alternative 2C which depresses the water table by upgradient groundwater extraction. With upgradient pumping, the water table is depressed below 1500 MSL (the bottom of the Pond) across almost the entire Pond area. Only a limited area of approximately 30 to 40 ft width along most of the northern unit boundary remains with water in the lower 3 to 5 ft of ash. This area widens to approximately 100 ft along the eastern edge of the unit. Therefore, the upgradient pumping provides a substantial improvement in dewatering of the ash relative to downgradient pumping without augmentation by the upgradient drain. Furthermore, upgradient pumping provided additional dewatering beyond Alternative 2B with approximately 98% of the ash volume above the water table.

4.2.2.2 Remedy Reliability

Groundwater extraction is conducted through a mechanical system of pumps and piping, which require routine maintenance throughout the operating period to ensure reliable operation. Replacement of pumps, valves and other fittings are required over a long operating life.

Groundwater extraction is a proven and reliable technology for groundwater remediation. However, groundwater extraction requires very long time frames to reach remedial goals as constituent concentrations in the extracted water decline with time toward asymptotic values due to adsorption on the saturated matrix.

Groundwater pump and treat approaches at the site are complicated because extraction occurs in fractured media and a fault zone. Full scale design will require fracture and lineament analyses from data obtained during downhole logging to develop fracture pattern mapping to refine extraction well placement. Test borings will also be needed along the predicted fracture lineaments.

4.2.2.3 Ease of Implementation

Implementation of a groundwater extraction and treatment system is relatively easy, given that the equipment is easily available, the installation is routinely undertaken and the technologies to be used at the Clinch River Plant have been employed for many similar groundwater corrective actions. Installation of the upgradient barrier wall and drain are also executed using common construction techniques, but the depth of the barrier wall and its tie-in to the underlying bedrock make it more challenging to install.

4.2.2.4 Potential Impacts During Implementation

This alternative does not create potential exposure pathways for CCR materials; these remain in the ground under the soil cover. During installation of the upgradient wall and drain, the cap will be removed and a 50 to 70 ft wide path will be required to install the bench for construction. Exposure pathways are limited to direct contact with groundwater, which is a much less concentrated source of CCR constituents than the CCR itself. Because of limited site disturbance, there is minimum risk of ecological exposure to fill material. The primary exposure pathway would occur via discharge of treated groundwater into the Clinch River. This risk will be mitigated by a permit, and the proper frequency of effluent testing to demonstrate compliance with the permit.

The COCs that exceed their respective site-specific GWPS included barium, cobalt, lead, lithium, molybdenum and nickel. Influent characteristics from the extraction system were based on the mean and maximum concentrations at the waste management unit boundary wells in each formation. Those concentrations were proportioned relative to the number of wells in each formation to estimate metals concentrations in the combined influent. The estimated concentrations were compared with MCLs or RSLs as a human health criterion and either AWQC from similar criteria of other states where VDEQ has not promulgated aquatic life AWQC. For certain constituents, comparison was also made with Tier 2 protection of aquatic life values.

The projected concentrations of both lead and molybdenum in the combined extracted groundwater were below both human health and protection of aquatic life criteria. Although these metals are COCs exceeding GWPS their concentrations in the discharge would not present any unacceptable risks to receptors. Comparison of the concentrations of the COC in the combined extracted groundwater with human health criteria, AWQC for protection of aquatic life or Tier 2 values for protection of aquatic life indicated that barium, cobalt, lithium, nickel and silver may exceed one of those values

Virginia has not promulgated AWQC for lithium. The state of Michigan has promulgated a final chronic value for lithium for aquatic life of 440 µg/L and an aquatic life maximum of 910 µg/L. Toxicity study data provided an estimated Tier 2 final chronic value for lithium of 431 µg/L. The combined extracted groundwater lithium concentrations were estimated to range from 113 to 171 µg/L which are below chronic values for protection of aquatic life. The maximum projected concentration of cobalt in the extracted groundwater was below AWQC for protection of aquatic life.

The projected concentrations of both cobalt and lithium in the combined extracted groundwater exceeded a tapwater RSL. The tapwater RSL is a risk screening value considered appropriate at the end of pipe and is not applicable as an in-stream concentration. The general method for calculation of an allowable discharge concentration is based on proportion of the in-stream concentration, 7Q10 low stream flow and the discharge flow. As noted, the 7Q 10 low flow for the Clinch River above the site is 56 cfs or 25,132 gpm. Based on the ratio of the discharge rate and stream flow, discharge of the combined extracted groundwater would be far below the RSL.

The maximum projected influent concentration for silver exceeded the lower bound hardness adjusted acute water quality criteria for aquatic life. Data from the upstream monitoring station provided in AEPs VPDES permit indicated an upstream value of 147 mg/L. The corresponding acute AWQC for silver for protection of aquatic life for that hardness value is 7.87 µg/L. The projected influent concentrations are below that threshold and therefore the concentrations of silver in the discharge would not present unacceptable risks to aquatic receptors.

The estimated concentrations of barium and nickel in the combined extracted groundwater were below human health protection criteria but somewhat above the aquatic life AWQC. This alternative provides treatment for these two metals that will reduce their concentrations to levels below or near the AWQC. Based on the ratio of the discharge rate and stream flow, discharge of the treated effluent would be far below the AWQC for these metals.

For Alternative 2C, the metals that are extracted from groundwater that were above human health criterion or aquatic life AWQC were arsenic, barium, lithium, and silver. The projected influent concentration of lithium was below Tier 2 values or chronic water quality criteria published from Michigan and only exceeded a tapwater RSL. The tapwater RSL is a risk screening value considered appropriate at the end of pipe and is not applicable as an in-stream concentration. As noted for Alternative 2A, the discharge of the extracted water would not result in an in-stream concentration of lithium above the RSL based on the ration of the 7Q10 low flow and discharge rate.

The maximum projected influent concentration for silver very slightly exceeded the lower bound hardness adjusted acute water quality criteria for aquatic life. However, based on the upstream hardness the discharge would not exceed the hardness adjusted acute AWQC and therefore the concentration of silver in the groundwater extracted from upgradient of the site does not present unacceptable risks to aquatic receptors.

The maximum projected combined influent concentration for arsenic was above the MCL and the projected barium concentration was above the AWQC for protection of aquatic life. Treatment will remove both of these species to levels at or below the MCL or aquatic life AWQC. Based on the ratio of the discharge rate and stream flow, discharge of the treated effluent would be far below the AWQC for these metals.

4.2.2.5 Ability of the Remedy to Control Exposure to Groundwater Contaminants

Extraction of contaminated groundwater will limit its migration beyond the property boundaries and ensure that surface water discharge limits are maintained at acceptable concentrations through the VPDES permit.

4.2.2.6 Remedy Start-Up Time

Start-up of a groundwater extraction and treatment system involves a timeline controlled primarily by obtaining a VPDES discharge permit, following by standard construction times. Installation of the extraction system, slurry wall (if selected), infrastructure and treatment system are anticipated to be completed within one construction season and would take on the order of six to ten months to complete, depending on site conditions.

4.2.2.7 Time Required to Complete Groundwater Remedy

The time required for downgradient extraction to achieve the GWPS cannot currently be estimated because data for source depletion modeling is being obtained during the ongoing NES. Alternative 2A has been estimated to operate for 100 years but that estimate does not predict when GWPS will be attained at the waste management unit boundary wells.

Alternative 2B will provide a significant depression of the water table in the ash and will dewater as much as 80 to 90% of the ash volume. Although Alternative 2B will provide improved groundwater quality in a shorter timeframe than Alternative 2A, prediction of the time required to attain the GWPS at the waste management boundary wells cannot be completed at this time.

Alternative 2C provides depression of the water table below the bottom of the Pond for almost the entire Pond area. Groundwater modeling of Alternative 2 C predicted that 98 % of the ash volume would be above the elevation of the resulting water table. As previously noted, source concentration data are not yet available to allow source depletion predictions.

Contaminant concentrations currently observed at the waste management boundary wells results from the flux vertically through the cap combined with the flux horizontally through the ash. Recharge through the cap is at a percolation rate of 0.0004 in /year or about 2.5 gpm. Therefore, the primary flow transporting contaminants to the waste management unit boundary wells is flow from upgradient water through the ash. In the simplistic sense upgradient extraction creates a contaminant flux at the waste management boundary wells that equals the vertical contaminant flux plus 2 to 5% of the current horizontal contaminant flux. It is anticipated that groundwater quality will achieve compliance with the GWPS one to two years of extraction system startup.

4.2.2.8 Institutional Requirements

This alternative will require a VPDES discharge permit for stormwater during construction, and a separate VPDES permit for the groundwater treatment system. Ongoing groundwater monitoring to assess improvements to groundwater quality will involve the collection of purge water from monitoring wells which will be collected and treated in the plant's onsite AWWTP as is currently done now.

4.2.2.9 Addresses Community Concerns

Groundwater extraction and above-ground treatment should address community concerns about migration of CCR impacts from Pond 1. This alternative presents the least disruption to the community while addressing concerns regarding groundwater quality and surface water impacts.

5.0 Summary

Two broad classes of alternatives have been identified which are capable of meeting the objectives of corrected action. In general, these are described below:

- Alternative 1: Removal of CCR Material from Pond 1, in conjunction with monitored natural attenuation (MNA) to reduce residual concentrations remaining in the groundwater.
- Alternative 2: Extraction of groundwater to limit the amount of flow through the fill material, and to remove impacted groundwater from the bedrock flow system. Three variations were considered to implement this alternative.
  - 2A: Groundwater Extraction and Treatment at the Downgradient Edge of the Unit
  - 2B: Groundwater Extraction and Treatment at the Downgradient Edge of the Unit with an Upgradient Barrier
  - 2C: Groundwater Extraction and Treatment at the Upgradient Unit Boundary.

The results of the detailed analysis in **Section 4** can be summarized below.

5.1 Alternative 1: Source Removal with Monitored Natural Attenuation

Removal of source material is an effective technology for mitigating groundwater impacts. Following removal of the source material, natural attenuation will generally reduce concentrations of COCs to levels below the GWPS over time. The length of time needed for natural attenuation to achieve GWPS in the downgradient aquifer is a function of both advective flow and the geochemical conditions in the aquifer, but GWPSs should be achieved within one or two years following removal of source material.

Disadvantages to this alternative includes:

- Exposure to workers at the Clinch River Plant and at the disposal facility to CCR constituents throughout the project life (about 13 years); CCR materials are currently isolated from direct contact.
- Disruption to the local community during removal, including road closures, traffic increase, and exposure to noise and diesel emissions.

5.2 Alternative 2: Groundwater Extraction, Treatment and Surface Water Discharge

This alternative consists of groundwater extraction from the fill material and bedrock flow system, followed by wastewater treatment prior to direct discharge to the Clinch River under an VPDES permit. It is also an effective technology for control groundwater impacts and meeting the corrective action objectives. Additional information will be required to estimate the time it will take to achieve these objectives for Alternatives 2A and 2B; corrective action objectives should be achieved within one to two years for Alternative 2C.

The primary disadvantage to this alternative is that groundwater control must be maintained for a long time, possibly as long as the waste is in place.

6.0 References

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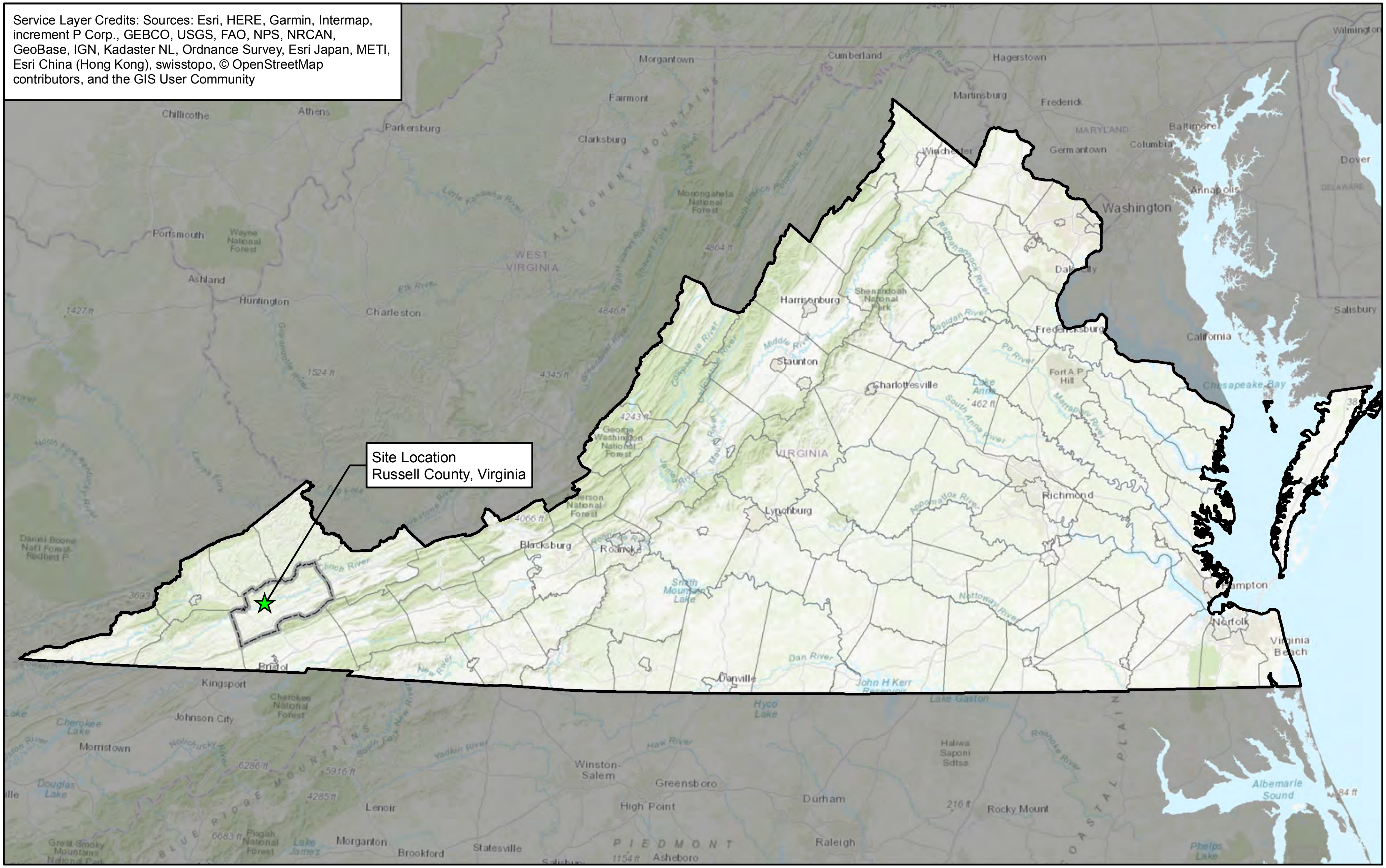
Figures



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

SYMBOL KEY

★ Site Location

N

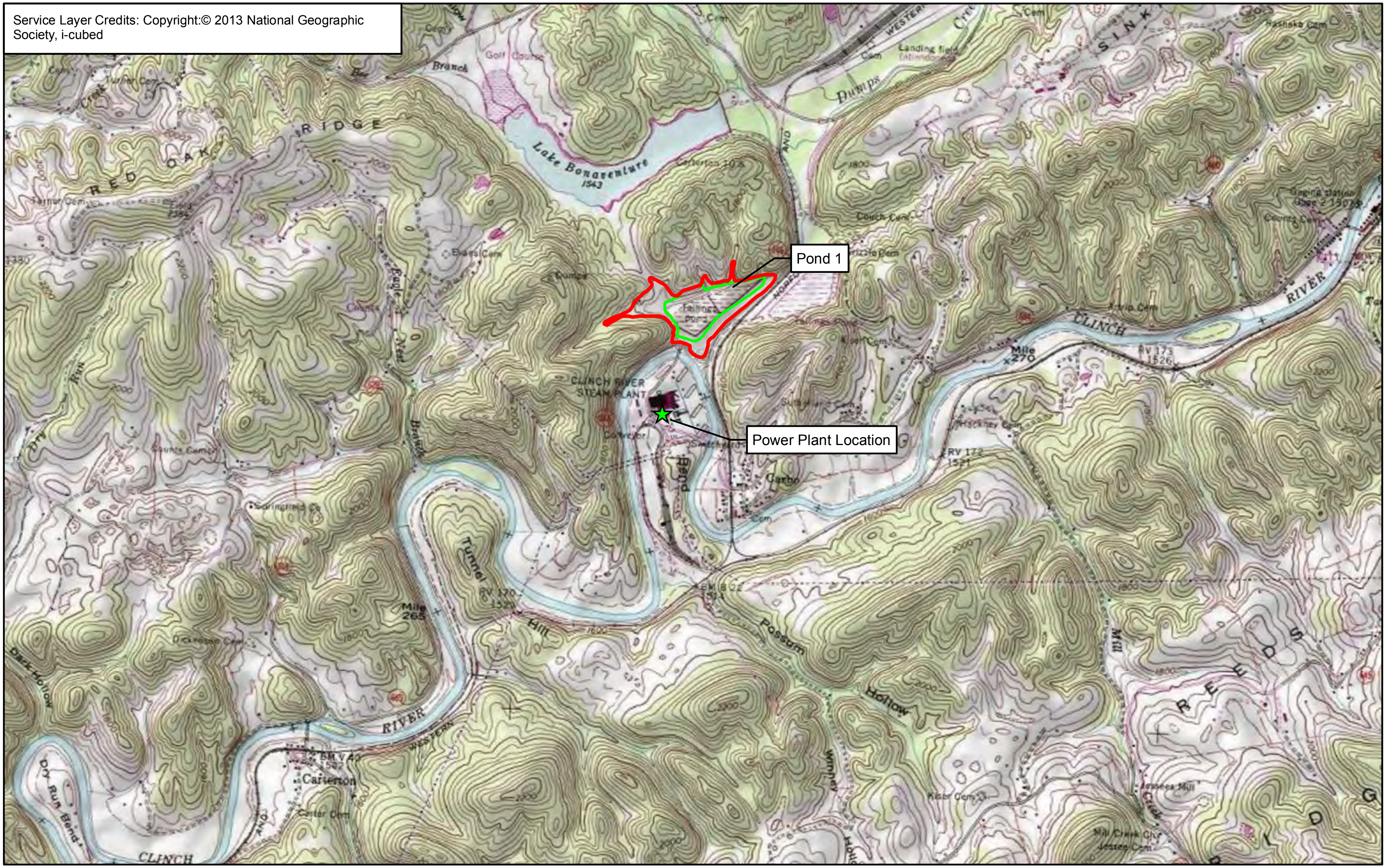
0 25 50 100 150 200 250 Kilometers

0 25 50 75 100 125 150 Miles

FIGURE 1
Site Location Map

American Electric Power, Clinch River Plant
Carbo, Virginia

03/06/2019	F1_AEP_Carbo_Site_Location
PROJ: 7362192727	Drawn: EK



Service Layer Credits: Copyright:© 2013 National Geographic Society, i-cubed

SYMBOL KEY

- ★ Power Plant Location
- 🟥 Pond 1 VA Permit SWP620 Boundary
- 🟩 Pond 1 CCR Unit Boundary

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wood.

N

0 250 500 1,000 1,500 2,000 2,500 Meters

0 1,000 2,000 4,000 6,000 8,000 Feet

FIGURE 2
Regional Topographic Map

American Electric Power, Clinch River Plant
Carbo, Virginia

03/07/2019	F2_AEP_Carbo_Topographic
PROJ: 7362192727	Drawn: EK

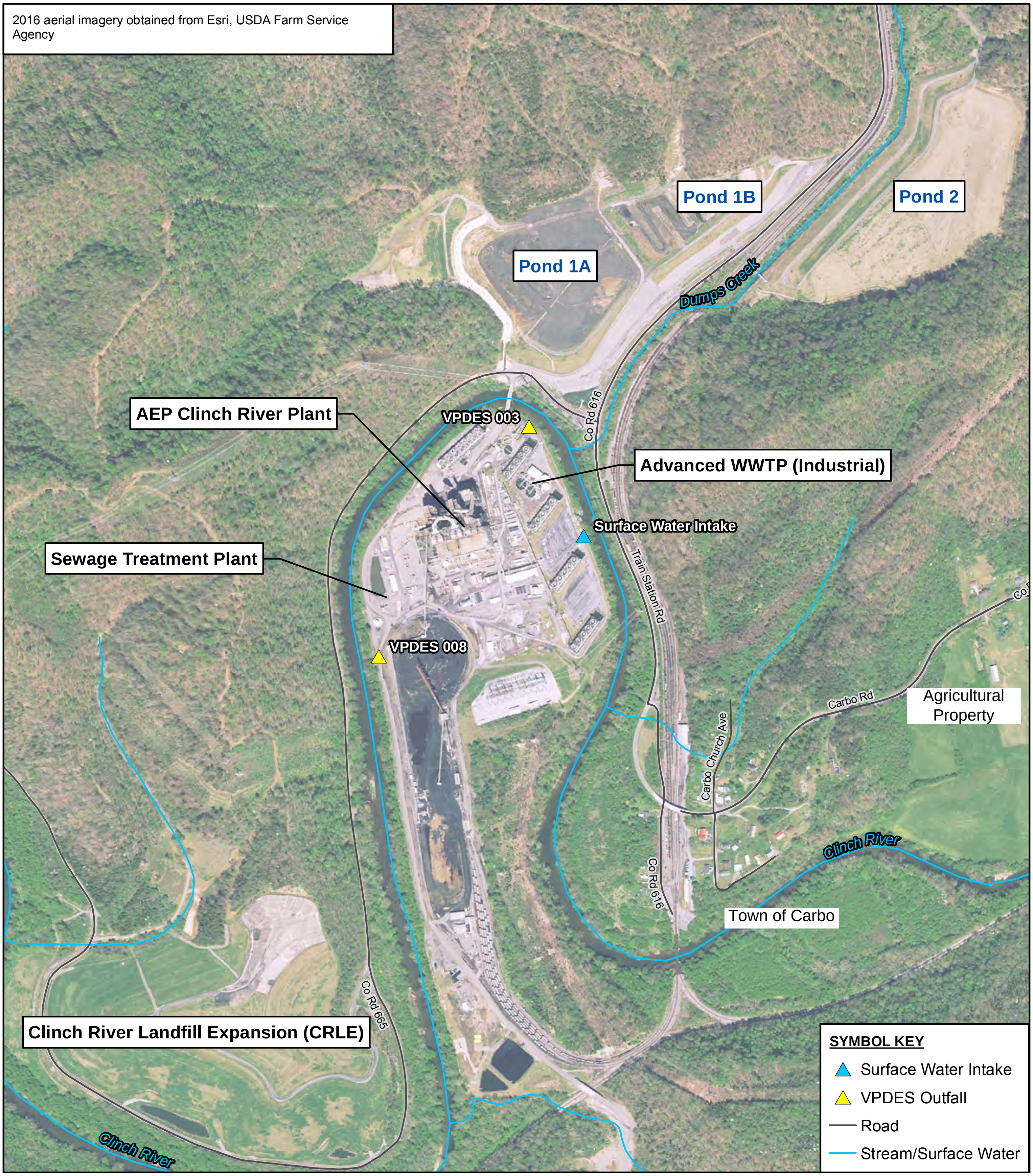

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FIGURE 3
Site Layout Map
American Electric Power, Clinch River Plant
Carbo, Virginia

0 100 200 400 600 800 Meters

0 800 1,600 2,400 3,200 Feet

03/11/2019

F3_AEP_Carbo_Site_Layout_Map

PROJ: 7362192727

Drawn: EK


2007 aerial imagery obtained from the USGS National Map Online Viewer and Download Platform
* During the installation of proposed wells, two wells (1 shallow, 1 deep) will be installed at the same location

SYMBOL KEY

- ⊕ Monitoring Well
- ● Piezometer
- ● Historical Soil Boring
- Stream/Surface Water
- Road
- Toe Drain
- 18" Pipe (Diversion)
- 30" Pipe
- 36" Pipe
- 🟥 Pond 1 VA Permit SWP620 Boundary
- 🟩 Pond 1 CCR Unit Boundary

0 50 100 200 300 Meters

0 225 450 675 900 1,125 Feet

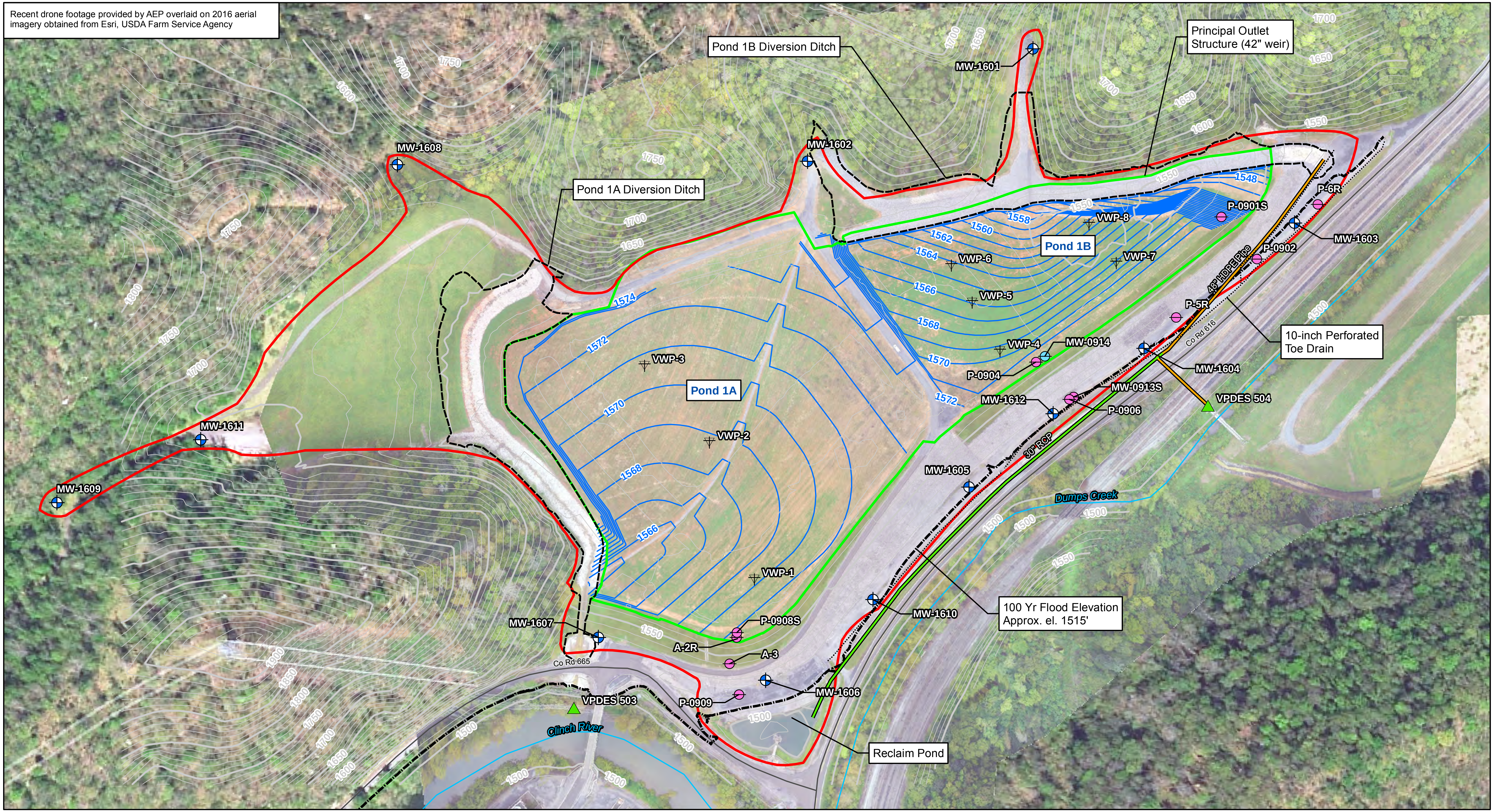
N

FIGURE 4
Pond 1 Layout (Pre-Closure)

American Electric Power, Clinch River Plant
Carbo, Virginia

03/18/2019
F4_11x17_AEP_Carbo_Pond1Pre-C
PROJ: 7362192727
Drawn: EK

Recent drone footage provided by AEP overlaid on 2016 aerial imagery obtained from Esri, USDA Farm Service Agency



SYMBOL KEY

- Monitoring Well
- Piezometer (Bedrock)
- Piezometer (Overburden)
- Vibrating Wire Piezometer
- VPDES Stormwater Outfall
- Toe Drain
- 48" HDPE Pipe
- 30" Pipe
- 100 yr Flood Approx F.L. 1505'
- Road
- Stream/Surface Water
- Post- Closure Topo Contour (ft amsl)
- Existing Topo Contour (ft amsl)
- Diversion Ditch
- Pond 1 VA Permit SWP620 Boundary
- Pond 1 CCR Unit Boundary

0 50 100 200 300 Meters

0 225 450 675 900 1,125 Feet

N

FIGURE 5

Pond 1 Layout (Post-Closure)

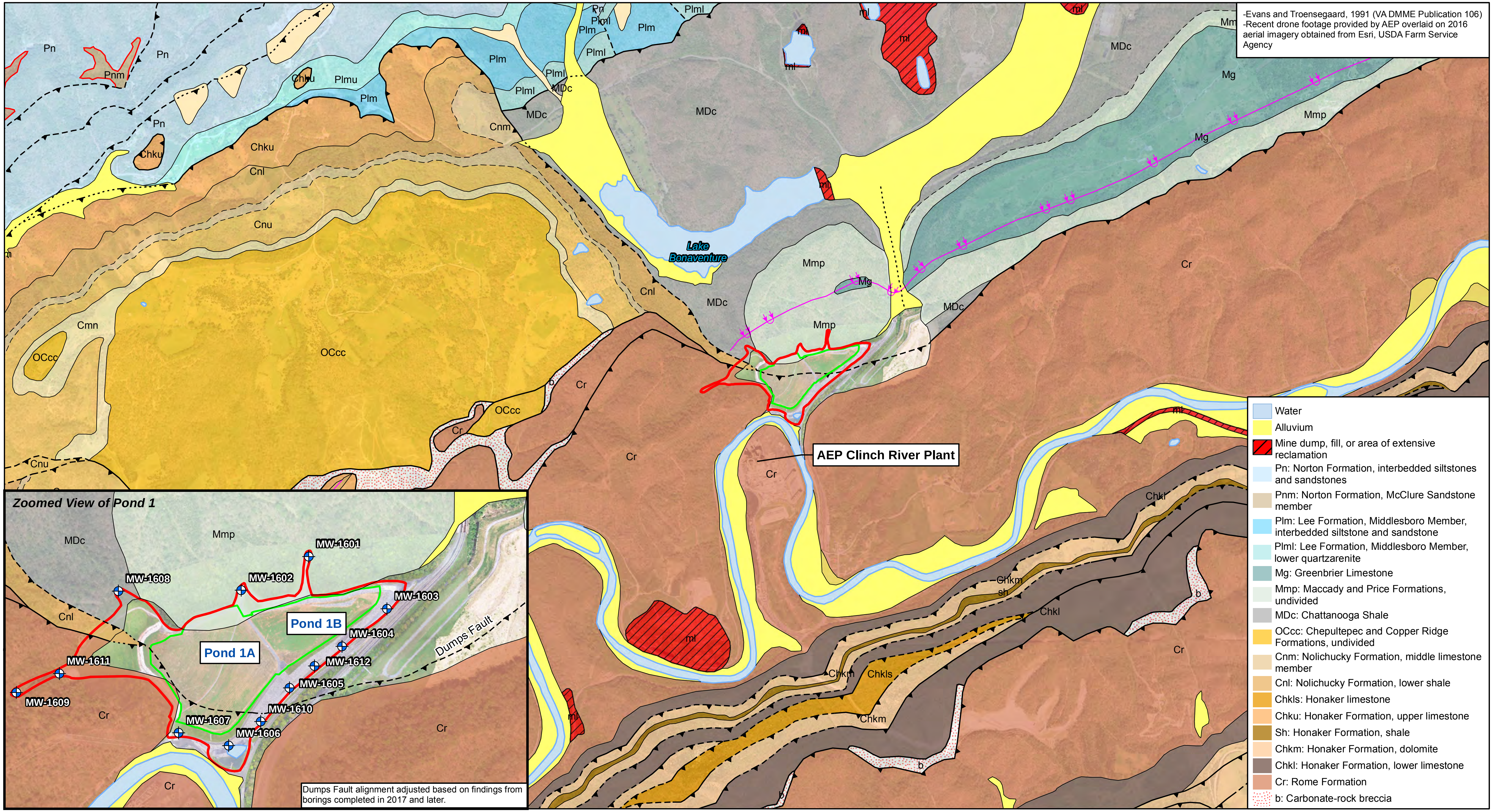
American Electric Power, Clinch River Plant
Carbo, Virginia

04/15/2019

F5_11x17_AEP_Carbo_Pond1Post-C

PROJ: 7362192727

Drawn: EK



SYMBOL KEY

🟥 Pond 1 VA Permit SWP620 Boundary

🟩 Pond 1 CCR Unit Boundary

Monitoring Well

Fault

Trace of overturned syncline axis; direction of plunge

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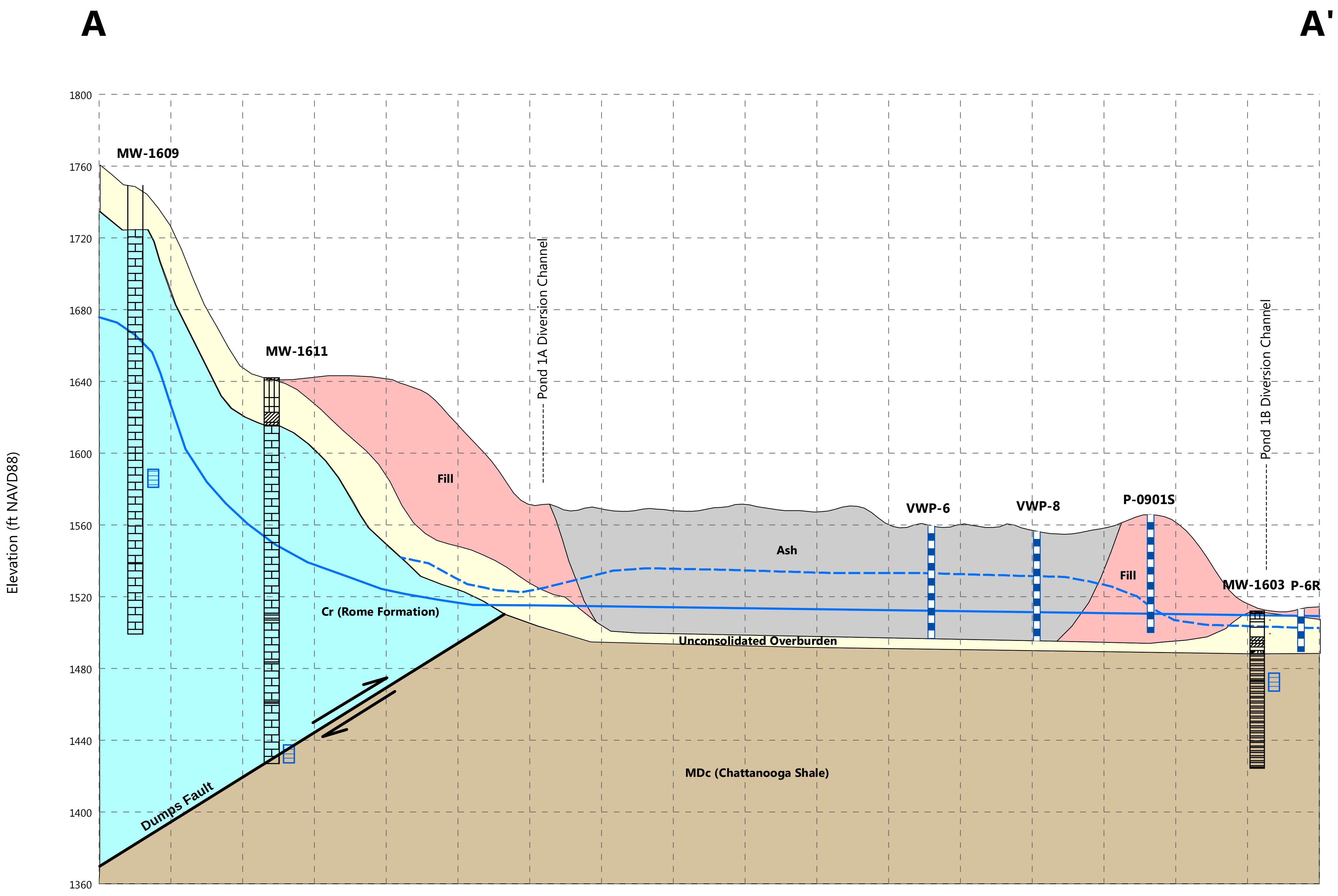
0 150 300 600 900 1,200 1,500 1,800 2,100 2,400 Meters

0 750 1,500 2,250 3,000 3,750 4,500 5,250 6,000 6,750 7,500 8,250 9,000 Feet

FIGURE 6
Site Specific Geology Map

American Electric Power, Clinch River Plant
Carbo, Virginia

03/18/2019	F8_11x17_SiteSpecificGeologyMap
PROJ: 7362192727	Drawn: EK



- ▨ Ash
- 🟥
- ▨ Unconsolidated
- 🟩 Mmp (Maccrady and Price Formations)
- ▨ MDc (Chattanooga
- ▨ Cr (Rome
- ▤ Well Screen
- ▪ Piezometer
- — Dumps Fault
- - - Unconsolidated Potentiometric Surface
- — Bedrock Potentiometric Surface

Data Sources

Borehole log data was exported from gINT. Log details are available in 2017 Monitoring Well Installation Report (Wood, 2017).

Geologic surface data was compiled from historical borehole logs and generated in Earth Volumetric Studio (EVS).

The topographic surface was generated in ArcGIS using the USGS National Elevation Dataset for Russel County, Virginia.

VERTICAL EXAGGERATION: 5X

0 100 200
SCALE IN FEET

CROSS-SECTION A - A'

AEP - CARBO, VIRGINIA

PROJECT NUMBER: 7362192727

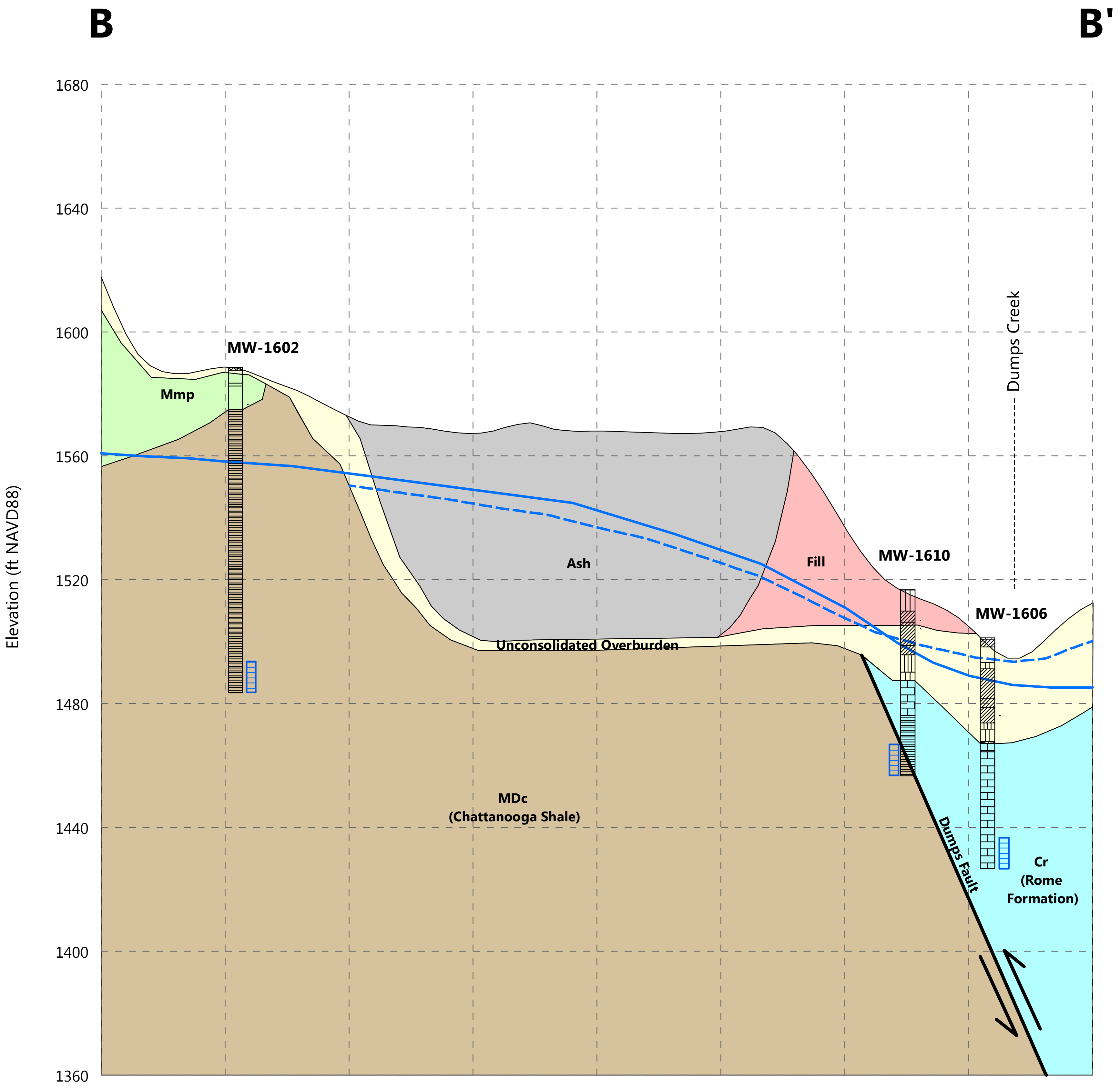
SCALE	1" = 300'
DATE	6/6/2019
DRAWN BY	TMR
APPROVED BY	KDR

FIG.
7

wood.

2456 Fortune Drive, Suite 100
Lexington, Kentucky 40509
Phone: (859) 255-3308

Document Path: P:\GIS Projects\AEP\Clinch River\mxd\CSM Cross-Section Rev1.mxd



▨ Ash

🟥

▨ Unconsolidated

🟩 Mmp (Maccrady and Price Formations)

▨ MDc (Chattanooga

▨ Cr (Rome

▤ Well Screen

▬ Piezometer

— Dumps Fault

- - - Unconsolidated Potentiometric Surface

— Bedrock Potentiometric Surface

Data Sources

Borehole log data was exported from gINT. Log details are available in 2017 Monitoring Well Installation Report (Wood, 2017).

Geologic surface data was compiled from historical borehole logs and generated in Earth Volumetric Studio (EVS).

The topographic surface was generated in ArcGIS using the USGS National Elevation Dataset for Russel County, Virginia.

VERTICAL EXAGGERATION: 5X

0 100 200

SCALE IN FEET

CROSS-SECTION B - B'

AEP - CARBO, VIRGINIA

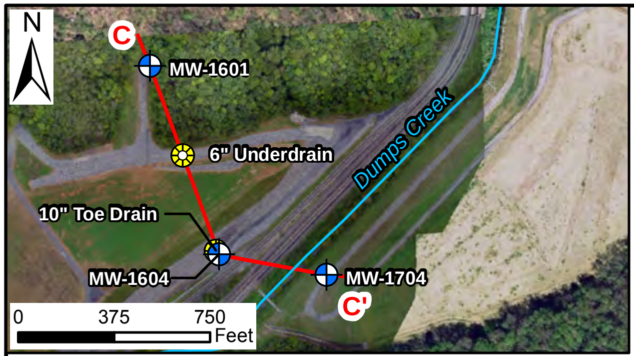
PROJECT NUMBER: 7362192727

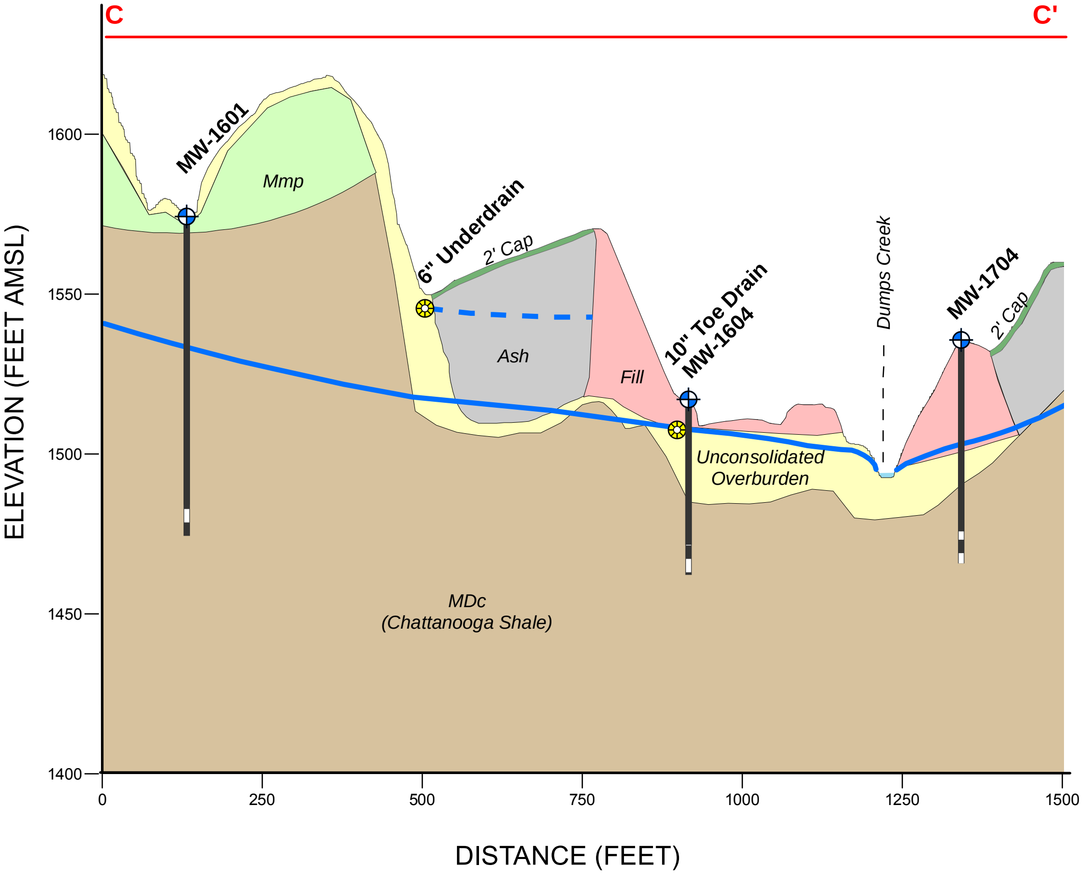
SCALE	1" = 200'	FIG. 8
DATE	6/6/2019	
DRAWN BY	TMR	
APPROVED BY	KDR	

wood.

2456 Fortune Drive, Suite 100
Lexington, Kentucky 40509
Phone: (859) 255-3308

Document Path: P:\GIS Projects\AEP\Clinch River\mxd\CSM Cross-Section Rev1.mxd





SYMBOL KEY

- ⊕ Monitoring Well
- ✹ Drain
- ━ Cross Section
- ━ Well Casing
- ▬ Well Screen
- ╌ Ash Potentiometric Surface
- ━ Bedrock Potentiometric Surface
- 🟩 Maccrady Price
- 🟥 Fill
- ▨ Ash
- 🟫 Chattanooga Shale
- 🟨 Unconsolidated Overburden

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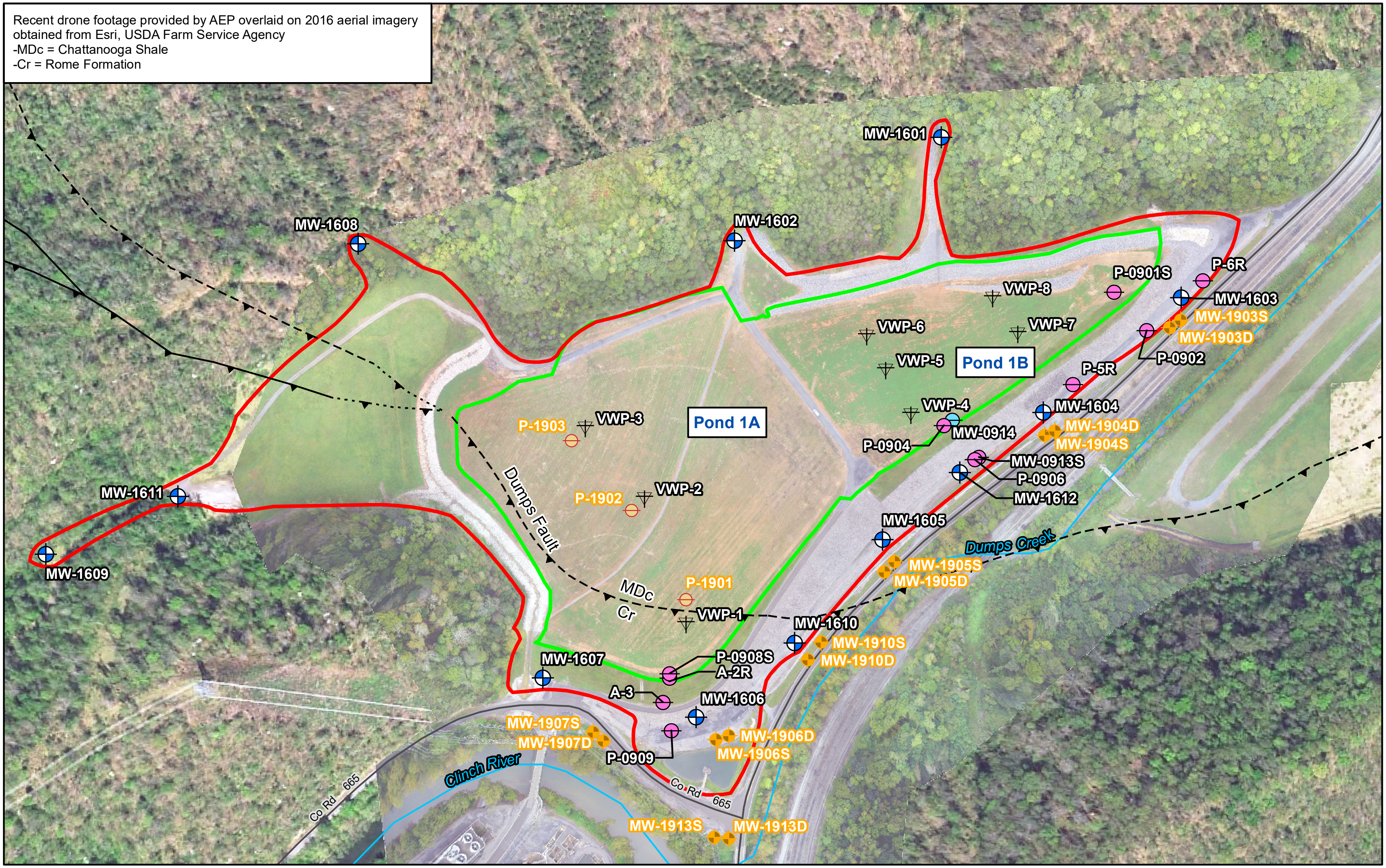
FIGURE 9
Cross Section C - C'
American Electric Power, Clinch River Plant
Carbo, Virginia

Horizontal Scale: 1" = 300 feet   Vertical Exaggeration: x5

10/18/2019	CrossSectionScale300
PROJ: 7362192727	Drawn: EK CHK: KQ



Recent drone footage provided by AEP overlaid on 2016 aerial imagery obtained from Esri, USDA Farm Service Agency
-MDc = Chattanooga Shale
-Cr = Rome Formation

SYMBOL KEY

- ⊕ Monitoring Well
- ● Piezometer (Bedrock)
- ● Piezometer (Overburden)
- Vibrating Wire Piezometer
- ◆ Proposed NES Well Location
- ○ Proposed Piezometer
- Fault
- Road
- Stream/Surface Water
- 🟥 Pond 1 VA Permit SWP620 Boundary
- 🟩 Pond 1 CCR Unit Boundary

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0 50 100 200 300 Meters

0 150 300 600 900 1,200 Feet

FIGURE 10
Groundwater Monitoring Network

American Electric Power, Clinch River Plant
Carbo, Virginia

10/29/2019

F10_AEP_Carbo_GWMW_NES

PROJ: 7362192727

Drawn: KQ

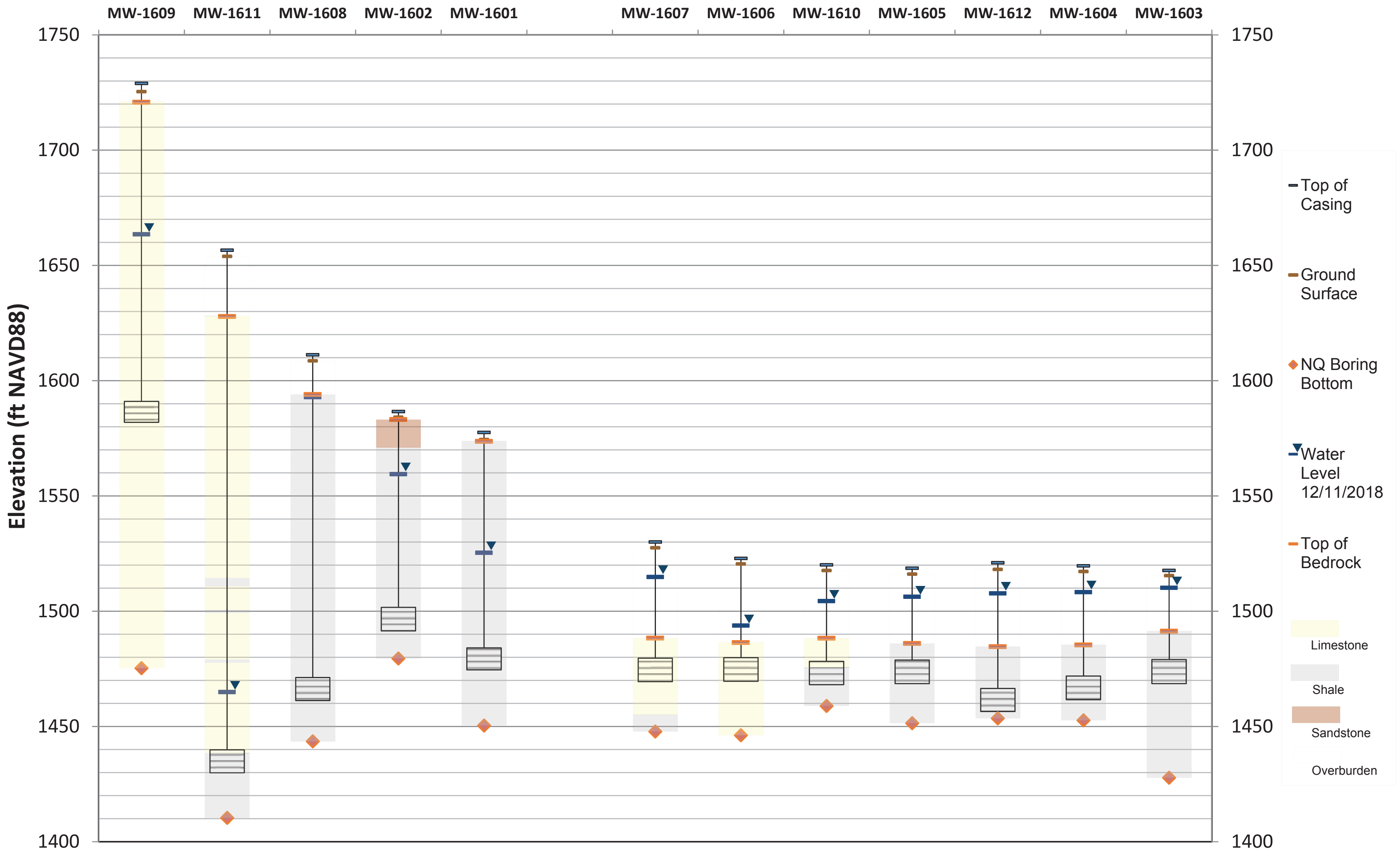

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FIGURE 11

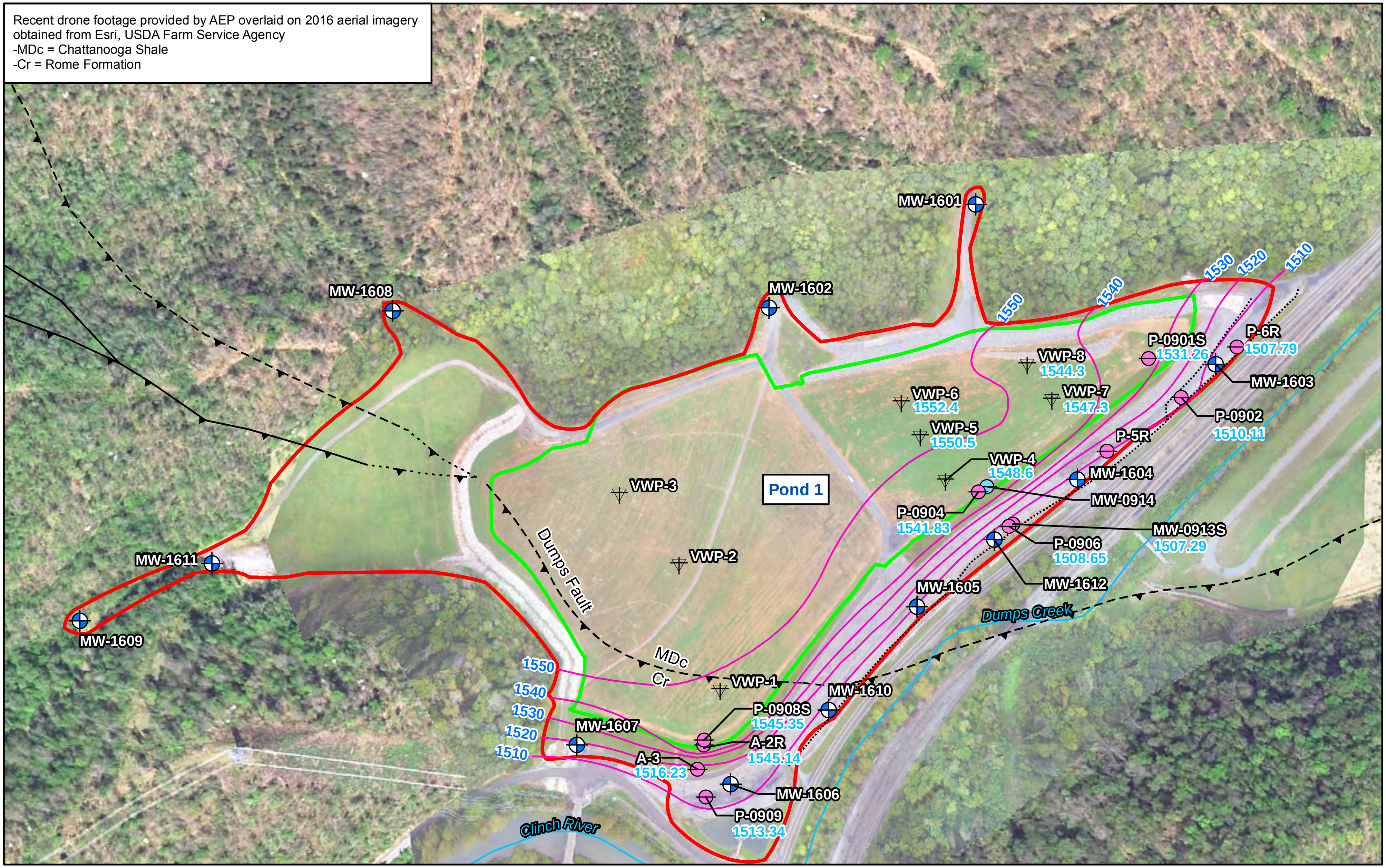
Pond 1 Monitoring Well Construction and Geology Diagram

American Electric Power, Clinch River Plant
Carbo, Virginia

0 50 100 200 300 Meters
0 150 300 600 900 1,200 Feet

03/06/2019	F9_MWConstDiagram
PROJ: 7362192727	Drawn: EK

Recent drone footage provided by AEP overlaid on 2016 aerial imagery obtained from Esri, USDA Farm Service Agency
-MDc = Chattanooga Shale
-Cr = Rome Formation



SYMBOL KEY

- ⊕ Monitoring Well
- ● Piezometer (Bedrock)
- ● Piezometer (Overburden)
- ⊕ Vibrating Wire Piezometer
- ▲ Fault
- .... Toe Drain
- — Stream/Surface Water
- 1545.35 Water Level Elevation (feet)
- 1550 Potentiometric Contour Line, elevation in feet, contour interval: 10 ft
- 🟥 Pond 1 VA Permit SWP620 Boundary
- 🟩 Pond 1 CCR Unit Boundary

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FIGURE 12
Potentiometric Surface Map (Overburden Wells)
27 December 2018
American Electric Power, Clinch River Plant
Carbo, Virginia

0 50 100 200 300 Meters

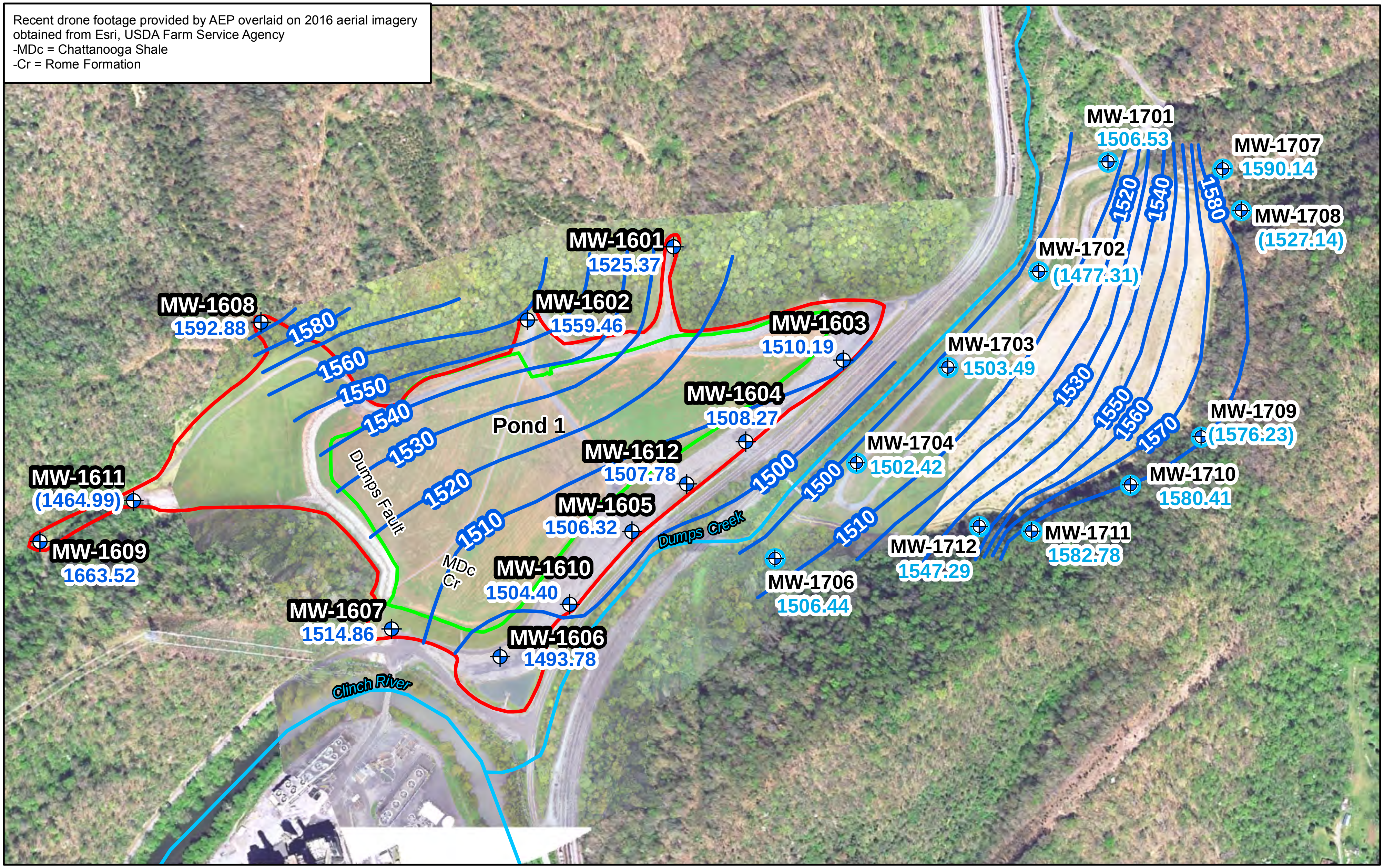
0 150 300 600 900 1,200 Feet

04/15/2019

F14_PotentioOverburden

PROJ: 7362192727

Drawn: EK



Recent drone footage provided by AEP overlaid on 2016 aerial imagery obtained from Esri, USDA Farm Service Agency
-MDc = Chattanooga Shale
-Cr = Rome Formation

SYMBOL KEY

- ⊕ Pond 1 Monitoring Well
- ⊕ Pond 2 Monitoring Well
- — Stream/Surface Water
- 🟥 Pond 1 VA Permit SWP620 Boundary
- 🟩 Pond 1 CCR Unit Boundary

1514.86	Water Level Elevation (Values in parentheses are considered non-representative and were disregarded in mapping contour lines)
1550	Potentiometric Contour Line, elevation in feet, contour interval: 10 ft
▲	Fault

wood.

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0 50 100 200 300 Meters

0 150 300 600 900 1,200 Feet

FIGURE 13
Potentiometric Surface Map (Bedrock Wells)
11 December 2018

American Electric Power, Clinch River Plant
Carbo, Virginia

10/18/2019	Proposed_NES_Wells
PROJ: 7362192727	Drawn: EK

Service Layer Credits:
ArcGIS Image Service (https://gis.apfo.usda.gov/arcgis/services/NAIP_Historical/VA_NAIP/ImageServer)
Source of Photography: USDA FSA NAIP
Date of Photography: 27 August 2018

NORTH

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Lexington, Kentucky 40509
Phone: (859) 255-3308

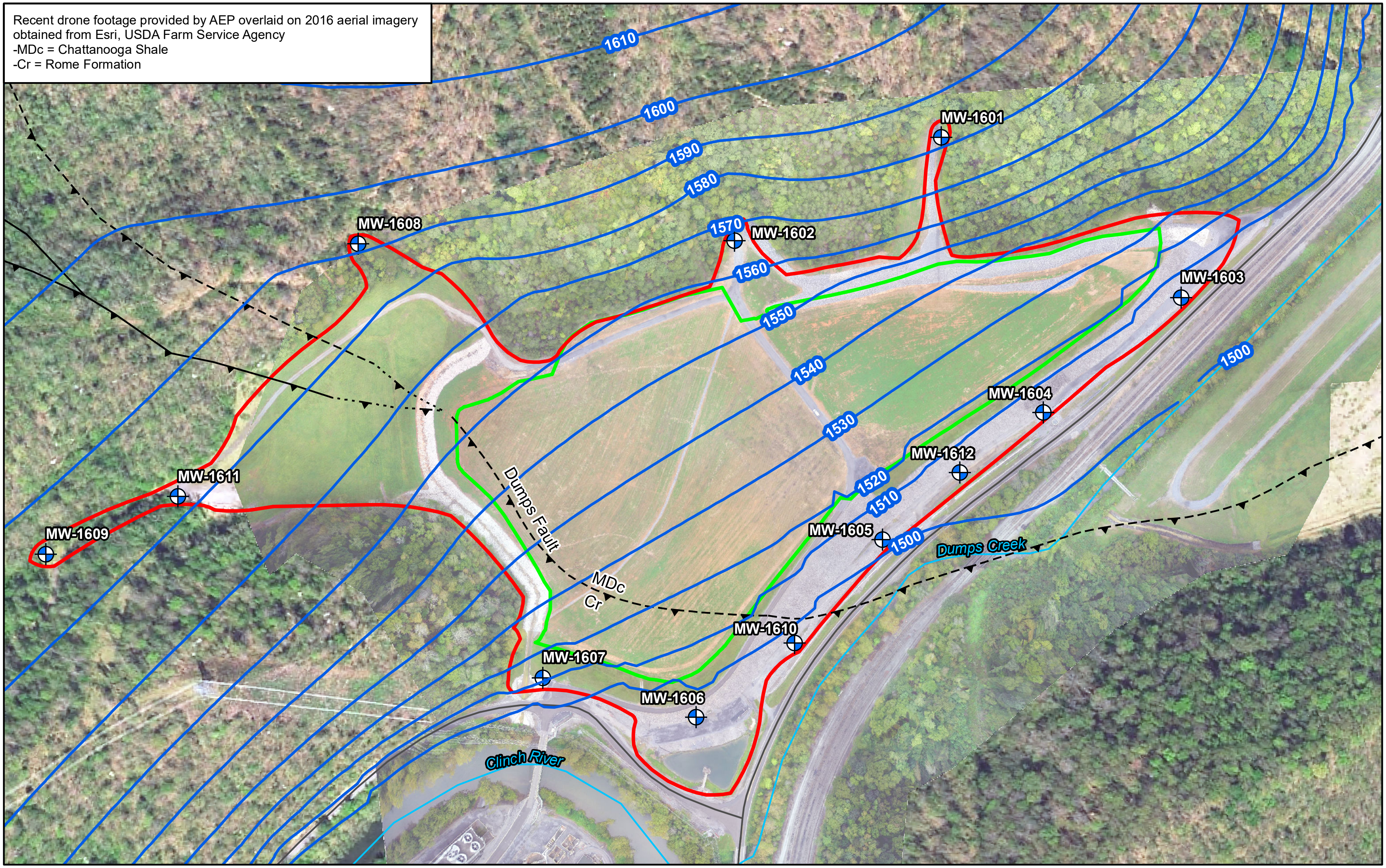
Surface Water Sampling Locations

American Electric Power
Clinch River Plant
Carbo, Virginia

PROJECT NUMBER: 7362192727

SCALE	1" = 400'
DATE	11/27/2019
DRAWN BY	TMR
APPROVED BY	KDR

FIG. 14



Recent drone footage provided by AEP overlaid on 2016 aerial imagery
obtained from Esri, USDA Farm Service Agency
-MDc = Chattanooga Shale
-Cr = Rome Formation

SYMBOL KEY

- ⊕ Monitoring Well
- Groundwater Contour
- Fault
- Road
- Stream/Surface Water
- 🟥 Pond 1 VA Permit SWP620 Boundary
- 🟩 Pond 1 CCR Unit Boundary

0 50 100 200 300 Meters

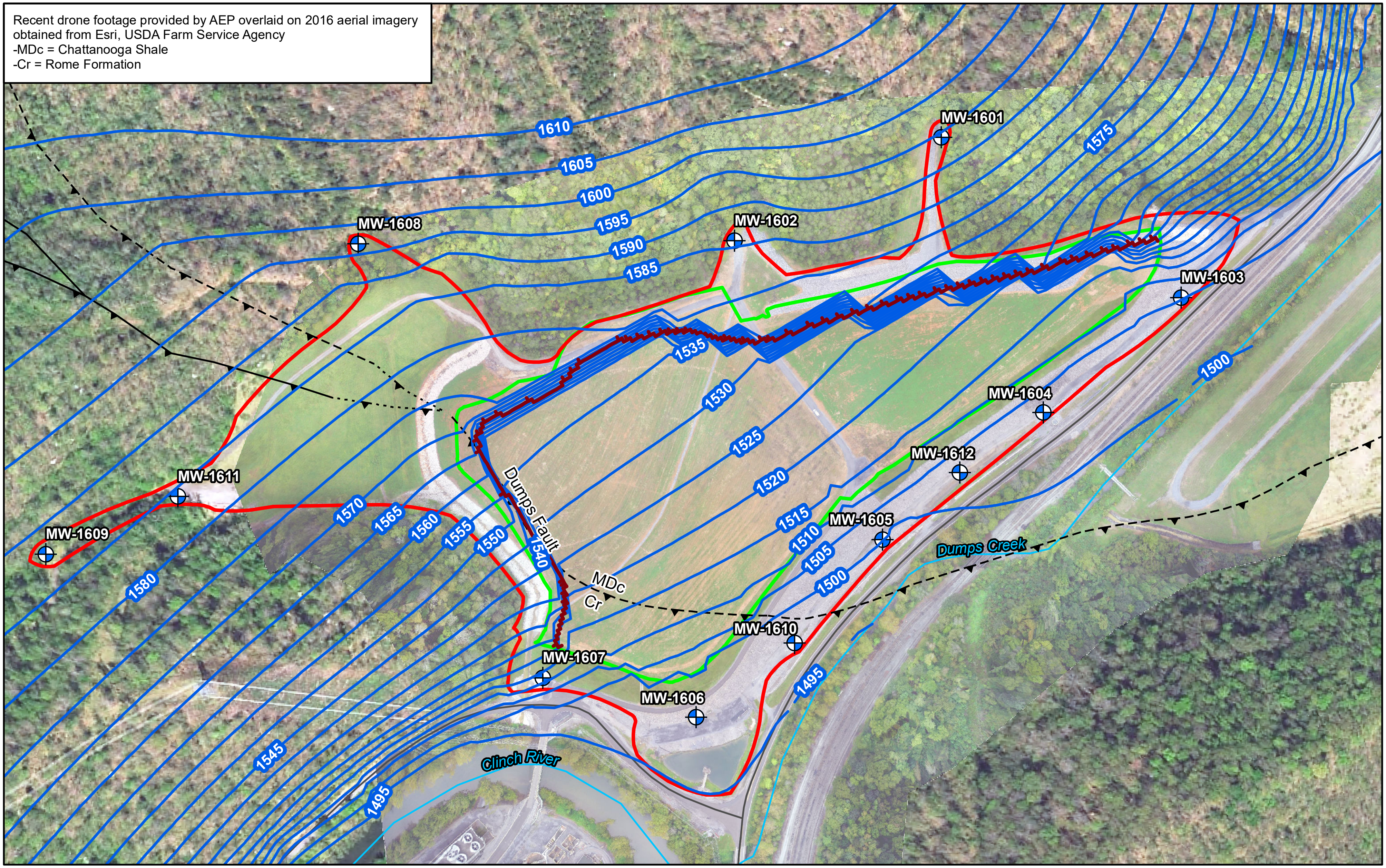
0 150 300 600 900 1,200 Feet

N

FIGURE 15
Current Condition Model Groundwater Contours

American Electric Power, Clinch River Plant
Carbo, Virginia

12/02/2019	AEP_Pond1_ACM_Fig15
PROJ: 7362192727	Drawn: KQ



Recent drone footage provided by AEP overlaid on 2016 aerial imagery obtained from Esri, USDA Farm Service Agency
-MDc = Chattanooga Shale
-Cr = Rome Formation

SYMBOL KEY

- ⊕ Monitoring Well
- Barrier Wall
- Groundwater Contour
- Fault
- Road
- Stream/Surface Water
- 🟥 Pond 1 VA Permit SWP620 Boundary
- 🟩 Pond 1 CCR Unit Boundary

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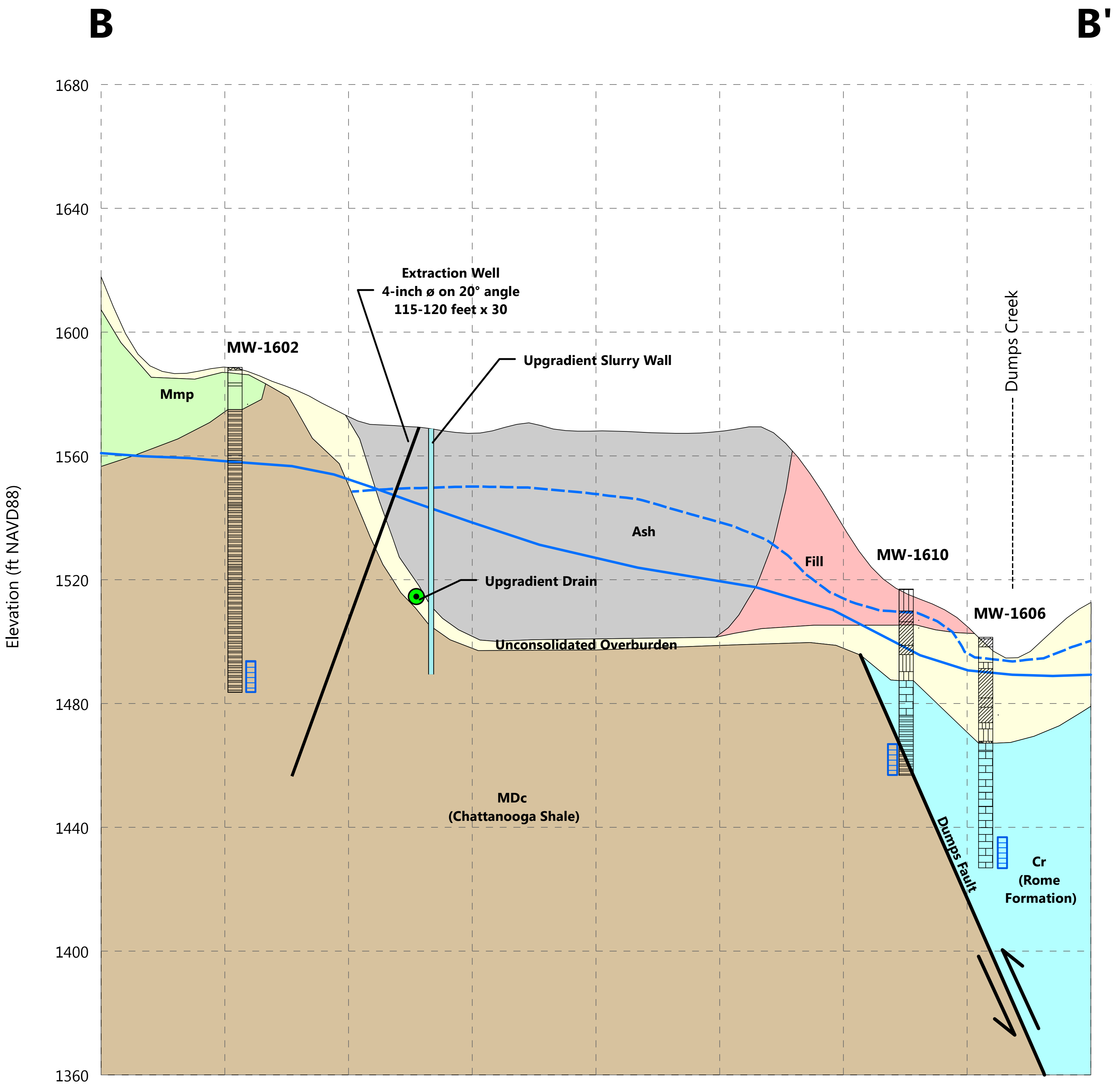
FIGURE 16
Model Results with Barrier Wall

American Electric Power, Clinch River Plant
Carbo, Virginia

0 50 100 200 300 Meters

0 150 300 600 900 1,200 Feet

12/02/2019	AEP_Pond1_ACM_Fig16
PROJ: 7362192727	Drawn: KQ



Legend

- ▨ Ash
- ▨ Fill
- ▨ Unconsolidated Overburden
- ▨ Mmp (Maccrady and Price Formations)
- ▨ MDc (Chattanooga Shale)
- ▨ Cr (Rome Formation)
- ▤ Well Screen
- — Extraction Well
- — Slurry Wall
- ■ Piezometer
- — Dumps Fault
- - - Unconsolidated Potentiometric Surface
- — Bedrock Potentiometric Surface

Data Sources

Borehole log data was exported from gINT. Log details are available in 2017 Monitoring Well Installation Report (Wood, 2017).

Geologic surface data was compiled from historical borehole logs and generated in Earth Volumetric Studio (EVS).

The topographic surface was generated in ArcGIS using the USGS National Elevation Dataset for Russel County, Virginia.

VERTICAL EXAGGERATION: 5X

0 150 300
SCALE IN FEET

CROSS-SECTION B - B'

AEP - CARBO, VIRGINIA

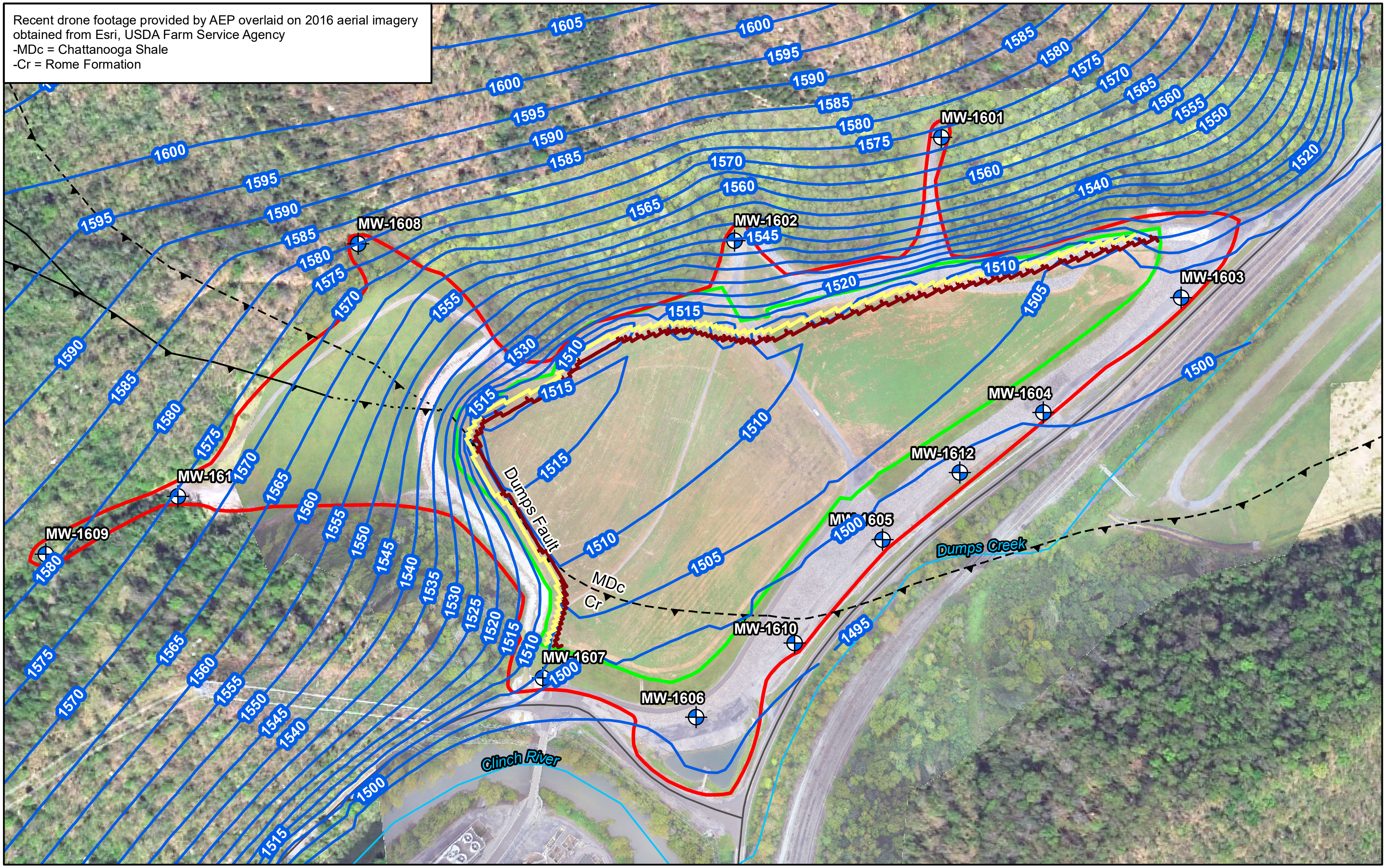
PROJECT NUMBER: 7362172422

SCALE	1" = 200'	FIG. 17
DATE	12/3/2019	
DRAWN BY	TMR	
APPROVED BY	KDR	

wood.

2456 Fortune Drive, Suite 100
Lexington, Kentucky 40509
Phone: (859) 255-3308

Document Path: P:\GIS Projects\AEP\Clinch River\mxd\CSM Cross-Section Rev1.mxd



Recent drone footage provided by AEP overlaid on 2016 aerial imagery obtained from Esri, USDA Farm Service Agency
-MDc = Chattanooga Shale
-Cr = Rome Formation

SYMBOL KEY

- ⊕ Monitoring Well
- Barrier Wall
- Groundwater Contour
- Drain
- Fault
- Road
- Stream/Surface Water
- 🟥 Pond 1 VA Permit SWP620 Boundary
- 🟩 Pond 1 CCR Unit Boundary

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wood.

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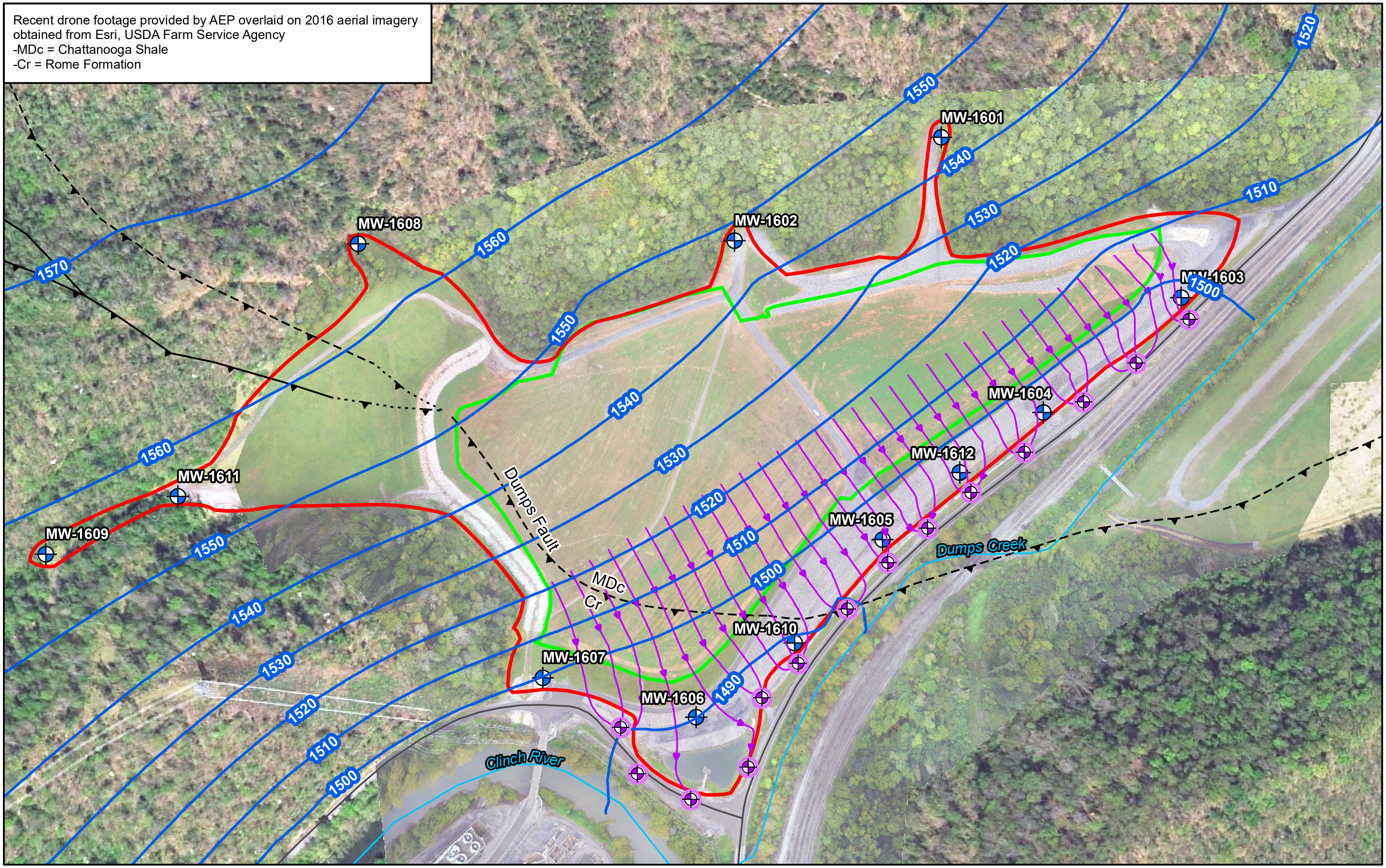
FIGURE 18
Model Results with Barrier Wall and Drain

American Electric Power, Clinch River Plant
Carbo, Virginia

0 50 100 200 300 Meters

0 150 300 600 900 1,200 Feet

12/02/2019	AEP_Pond1_ACM_Fig17
PROJ: 7362192727	Drawn: KQ



Recent drone footage provided by AEP overlaid on 2016 aerial imagery obtained from Esri, USDA Farm Service Agency
-MDc = Chattanooga Shale
-Cr = Rome Formation

SYMBOL KEY

- Monitoring Well
- Groundwater Contour
- Downgradient Extraction Well
- 30 Day Particle Trace
- Fault
- Road
- Stream/Surface Water
- 🟥 Pond 1 VA Permit SWP620 Boundary
- 🟩 Pond 1 CCR Unit Boundary

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0 50 100 200 300 Meters

0 150 300 600 900 1,200 Feet

FIGURE 19
Model Results with Extraction Wells Only

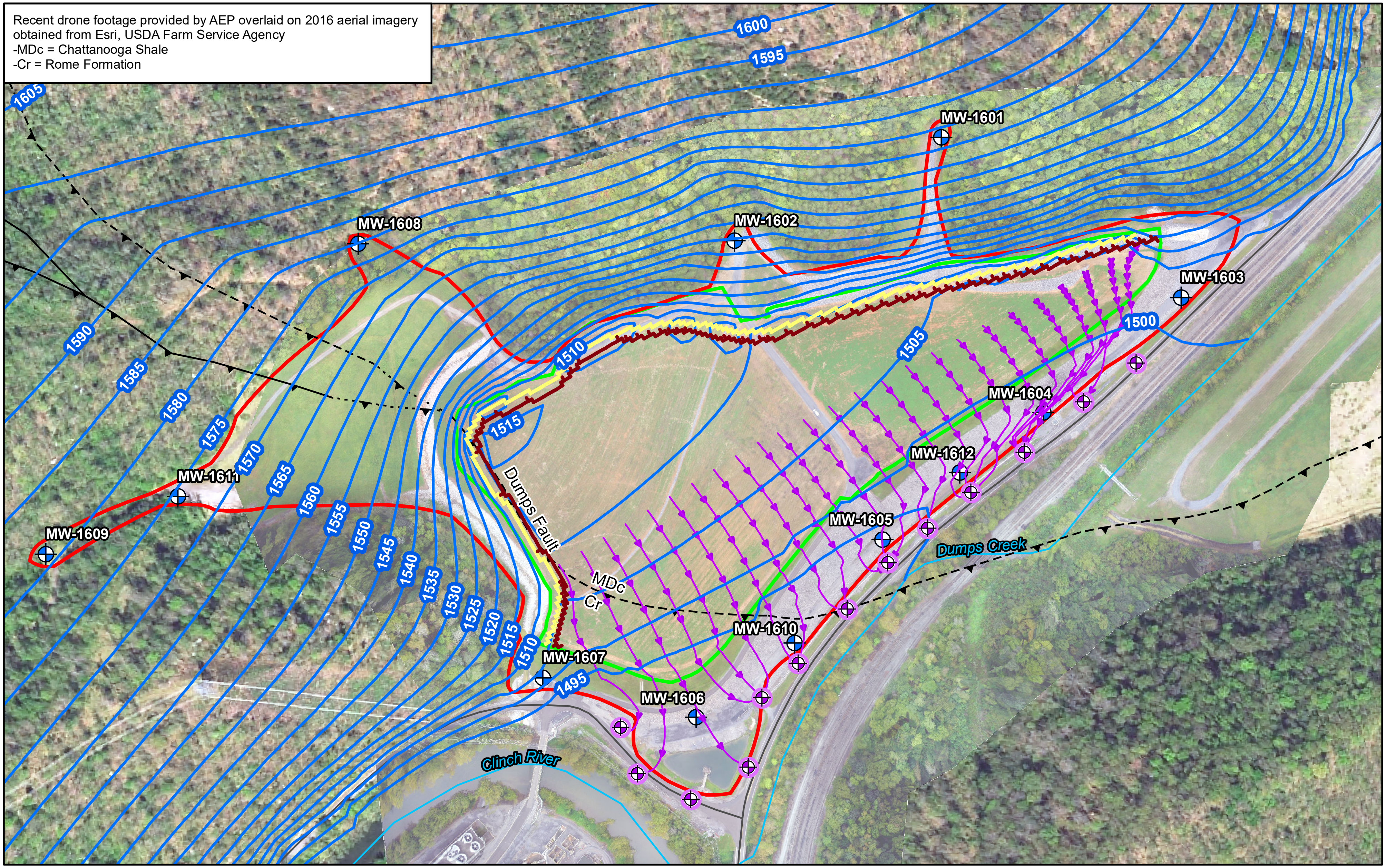
American Electric Power, Clinch River Plant
Carbo, Virginia

12/02/2019

AEP_Pond1_ACM_Fig19

PROJ: 7362192727

Drawn: KQ



Recent drone footage provided by AEP overlaid on 2016 aerial imagery obtained from Esri, USDA Farm Service Agency
-MDc = Chattanooga Shale
-Cr = Rome Formation

SYMBOL KEY

- ⊕ Monitoring Well
- ━ Barrier Wall
- ━ Groundwater Contour
- ━ Drain
- ⊕ Downgradient Extraction Well
- ━ 30 Day Particle Traces
- ▲ Fault
- ━ Road
- ━ Stream/Surface Water
- ▭ Pond 1 VA Permit SWP620 Boundary
- ▭ Pond 1 CCR Unit Boundary

0 50 100 200 300 Meters

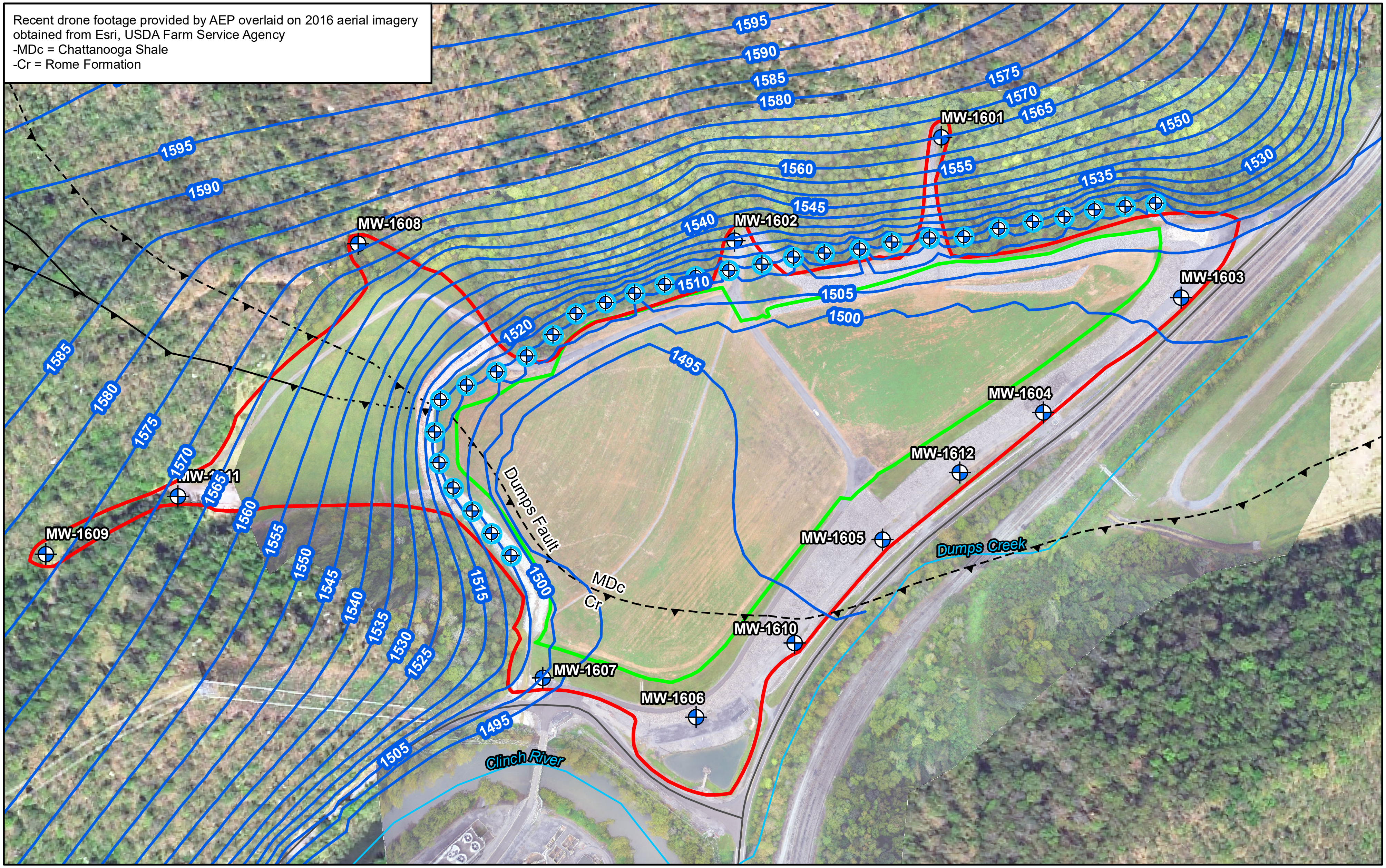
0 150 300 600 900 1,200 Feet

N

FIGURE 20
Model Results with Barrier Wall, Drain and Wells

American Electric Power, Clinch River Plant
Carbo, Virginia

12/02/2019	AEP_Pond1_ACM_Fig18
PROJ: 7362192727	Drawn: KQ


Recent drone footage provided by AEP overlaid on 2016 aerial imagery obtained from Esri, USDA Farm Service Agency
-MDc = Chattanooga Shale
-Cr = Rome Formation

SYMBOL KEY

⊕ Monitoring Well
— Groundwater Contour
⊕ Downgradient Extraction Well
— 30 Day Particle Trace
▲ Fault
— Road
— Stream/Surface Water
🟥 Pond 1 VA Permit SWP620 Boundary
🟩 Pond 1 CCR Unit Boundary

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wood.

N

0 50 100 200 300 Meters

0 150 300 600 900 1,200 Feet

FIGURE 21
Model Results with Dewatering Wells Only

American Electric Power, Clinch River Plant
Carbo, Virginia

12/02/2019	AEP_Pond1_ACM_Fig20
PROJ: 7362192727	Drawn: KQ

Tables

Table 6
Screening and Evaluation of Remedial Technologies
Ash Pond System
Clinch River Power Plant, Cleveland, Virginia

General Response Action	Remedial Action Technology Type	Process Options	Description	Relative Performance/ Reliability/ Ease of Implementation (Low-Medium-High)	Potential Safety Impacts, Cross-Media Impacts, and Control of Exposure to Residual Contamination (Low-Medium-High)	Relative Time Required to Begin and Complete Remedy (Short-Medium-Long)	Institutional Requirements that May Affect Implementation (Few-Some-Many)	Result of Screening
Source Removal with Monitored Natural Attenuation (MNA)	Excavation and Removal	• Disposal in offsite permitted landfill. • Groundwater monitoring until GPSs are achieved.	Material is excavated from Pond 1 and transported offsite to a permitted landfill Periodic monitoring of groundwater at the waste boundary and in the plume is conducted until GPSs are achieved.	High/High/Very Low • Removal of source material is extremely effective and reliable in eliminating additional groundwater impacts. • Removal is a time-consuming and difficult option. Employs standard construction techniques. Requires removal of millions of gallons pore water via multiple techniques that will change over duration. Will require wastewater treatment system that may need to be modular to address changing conditions. • MNA following removal highly effective once source material is removed.	Medium/Low/Very High • Option has elevated health and safety risks compared to normal excavation project due to physical characteristics of saturated fill material. • Offsite transportation of material to disposal facility by truck will cause increased vehicle emissions and increase risk for roadway accidents. • Potential air emissions of particulates during removal is possible, but easily controlled during construction. • Removal of waste to secure offsite permitted landfill eliminates exposure to residual contamination on the property.	Short/Medium to Long • Effective as soon as removal is completed. • Removal duration affected by pore dewatering and weather conditions.	Some • No onsite disposal capacity is available. Offsite transportation of dewatered CCR materials is required, and may be objectionable to neighbors. • Requires VPDES for stormwater from construction activity. • Requires revised VPDES permit for dewatering during construction.	Removal and MNA are evaluated are retained as a corrective action option.
In-Situ Treatment	Water Treatment through Reagent Injection Into Flow Zone (Physical-Chemical Processes)	Precipitation, or Co-Precipitation and Adsorption	Treatment chemicals injected into the groundwater flow zone within the plume. COCs are transformed into insoluble compounds that are trapped within the solid matrix in the flow zone. Highly soluble COCs such as lithium, are adsorbed on the reactive media	Low/Low/Low • In-situ methods are demonstrated for some COCs, have not been proven for lithium. Lack of commercially available or effective reagents for lithium removal. Lithium removal is by adsorption necessitating intimate contacting with reagent making loading requirements very high. • Reliability (permanence) is unknown for lithium. • Groundwater impacts are present in bedrock flow system, which will make injection difficult. Additional injections may be required depending upon system performance.	Low/Low/Medium • In-situ methods are relatively safe in comparison to other subsurface drilling and construction activities. • Injected reagents could daylight into surface water system. • Very little contact with contaminated groundwater during injections. Main exposure route is surface water system, which is reduced with in-situ treatment is effective.	Long/Medium • Little to impede the start of the injection process. However, limited conductivity of bedrock, many points would be needed and process would be very time consuming. • Time to complete the remedy is not proven for lithium, but estimated to be relatively medium, depending on the effectiveness of injectates on lithium removal.	Low • In-Situ injections require an underground injection control permit.	Not retained, since technology for lithium removal is unproven. In addition, site physical setting of the makes implementation difficult. May not be possible to get good contact with reagents and impacted groundwater.

Table 6
Screening and Evaluation of Remedial Technologies
Ash Pond System
Clinch River Power Plant, Cleveland, Virginia

General Response Action	Remedial Action Technology Type	Process Options	Description	Relative Performance/ Reliability/ Ease of Implementation (Low-Medium-High)	Potential Safety Impacts, Cross-Media Impacts, and Control of Exposure to Residual Contamination (Low-Medium-High)	Relative Time Required to Begin and Complete Remedy (Short-Medium-Long)	Institutional Requirements that May Affect Implementation (Few-Some-Many)	Result of Screening
Hydraulic Containment	Groundwater Extraction	Extraction Wells	Extraction wells near the downgradient CCR unit boundary are used to capture impacted groundwater and transfer it to the surface.	High/High/(Med-High) • Pumping is effective, but many well points are required to capture groundwater in the bedrock flow system. • Mechanical system needs basic O&M monitoring. Addition of new wells or revision of extraction well field commonly required where duration is extended • Easy to implement using standard construction techniques.	Low/Low/Medium • Construction of extraction wells are relatively safe in comparison to other subsurface drilling and construction activities. • Very low likelihood for cross-media impacts. • Very little contact with contaminated groundwater during well construction. Limits migration of groundwater into surface water system.	Short/Very Long • Relatively easy to initiate. Capture is effective soon after system is installed and started up. • Anticipated to operate for a very long time due to continued contact of groundwater with source material. Source may eventually deplete, but monitoring will be required to assess.	Few Limited permitting required for extraction.	Retained. Can meet CAOs. Estimates for time to complete can be adjusted with empirical data after remedy in place. Will require O&M for duration.
	Upgradient Barrier Groundwater Extraction	Slurry Wall Extraction Wells	A barrier wall is constructed on the upgradient side of the fill and tied to bedrock. Groundwater upgradient of barrier is collected and managed at the surface. Extraction wells near the downgradient CCR unit boundary are used to capture impacted groundwater and transfer it to the surface. Benefit is reduced mass loading to treatment system, decreased volume of groundwater contacting fill material.	Medium/High/Low • Remedy depends on reducing the amount of groundwater passing through the fill. Additional data must be collected for effective design of barrier wall. Groundwater will have a tendency to bypass the wall if appropriate drains or extraction techniques are not applied appropriately. • Once installed and operating properly, barrier wall is very reliable. Mechanical system needs basic O&M monitoring. • Extraction wells are easy to implement using standard construction techniques. Construction of upgradient barrier wall will be expensive and challenging.	Medium/Low/Medium • Construction of extraction wells are relatively safe in comparison to other subsurface drilling and construction activities. Excavation for barrier wall will be challenging and may present additional safety concerns. • Very low likelihood for cross-media impacts. • Potential contact with contaminated groundwater during construction of barrier wall. Otherwise, minimal contact anticipated. Limits migration of groundwater into surface water system.	Long/Medium Effective as soon as construction is completed, but construction would be time-consuming. Effective immediately downgradient of barrier, but upgradient of barrier, cleanup relies on MNA. If placed upgradient of leading edge of plume a portion of groundwater not treated.	Some • Requires stormwater VPDES for construction activity. • Requires revised VPDES permit. • Requires UIC permit for if injections are needed to construct barrier wall.	Retained. Can meet CAOs. Most costly of containment technologies to implement. Will require O&M for duration.

Table 6
Screening and Evaluation of Remedial Technologies
Ash Pond System
Clinch River Power Plant, Cleveland, Virginia

General Response Action	Remedial Action Technology Type	Process Options	Description	Relative Performance/ Reliability/ Ease of Implementation (Low-Medium-High)	Potential Safety Impacts, Cross-Media Impacts, and Control of Exposure to Residual Contamination (Low-Medium-High)	Relative Time Required to Begin and Complete Remedy (Short-Medium-Long)	Institutional Requirements that May Affect Implementation (Few-Some-Many)	Result of Screening
Hydraulic Containment	Upgradient Groundwater Extraction	Extraction Wells	Extraction wells installed into hillside upgradient of Pond 1. Groundwater extraction draws down water table so that most of groundwater surface is below waste material. Minor downgradient pumping may be required on northern-most end of Pond.	High/High/High • Pumping is effective, but many well points are required to capture groundwater in the bedrock flow system. • Mechanical system needs basic O&M monitoring. Addition of new wells or revision of extraction well field commonly required where duration is extended • Easy to implement using standard construction techniques.	Low/Low/Medium • Construction of extraction wells are relatively safe in comparison to other subsurface drilling and construction activities. • Very low likelihood for cross-media impacts. • Very little contact with contaminated groundwater during well construction. Limits migration of groundwater into surface water system. • Drawing down top of water table eliminates contact with much of CCR material.	Short/Very Long • Relatively easy to initiate. Capture is effective soon after system is installed and started up. • Anticipated to operate for a very long time due to continued contact of groundwater with source material. Source may eventually deplete, but monitoring will be required to assess.	Few • Limited permitting required for extraction.	Retained. Can meet CAOs relatively quickly at relatively low cost. Extracted groundwater will require less treatment initially, and may require none. System must be operated as long as waste is in place. Will require O&M for duration.
Ex-situ Treatment	Water Treatment after Groundwater Extraction (Physical-Chemical Processes)	Onsite Treatment Followed by Direct Discharge to Surface Water	Extracted groundwater treated to reduce TDS and metals concentrations using conventional coagulation and direct filtration techniques.	High/High/High • Physical/chemical treatment technologies have a long history of success for all COCs. Discharge limits in VPDES permit will establish required treatment processes. • Mechanical system needs ongoing O&M and active monitoring of treatment process. • Construction of treatment systems is routine and uses standard construction techniques.	Medium/Low/Medium • Similar health and safety risks associated with an standard construction activity. • Treatment will be designed to ensure compliance with warm water aquatic criteria and VPDES discharge limits. Very low likelihood for cross-media impacts. • Potential contact with contaminated groundwater during operation. Operators will have appropriate training and PPE.	Medium /Long VPDES permit limits must be established for all COCs prior to design in order to select appropriate treatment processes. Design process may require treatability studies or additional sampling. Once constructed, length of remedy depends upon effectiveness of groundwater extraction.	Some Treatment systems for direct discharge require a VPDES permit prior to construction, which has routine and ongoing reporting requirements.	Retained. In conjunction with hydraulic containment, can meet CAOs, but may require operation for many years. Will require O&M for duration.