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Nov 05 2020

synTerra

CORRECTIVE ACTION PLAN UPDATE

Site Name and Location:	**Cliffside Steam Station** **573 Duke Power Road** **Mooresboro, NC 28114-7754**
Groundwater Incident No.:	Not Assigned
NPDES Permit No.:	NC0005088
NCDEQ CCR Impoundment Ranking: Active Ash Basin Former Units 1-4 Ash Basin Unit 5 Inactive Ash Basin	 Low-Risk Low-Risk Low-Risk
Date of Report:	December 31, 2019
Permittee and Current Property Owner:	Duke Energy Carolinas, LLC 526 South Church Street Charlotte, NC 28202-1803 (855) 355-7042
Consultant Information:	SynTerra Corporation 148 River Street, Suite 220 Greenville, SC 29601-2567 (864) 421-9999
Latitude and Longitude of Facility:	N 35.209267/W -81.761258

Scott A. Spinner, NC LG 2243
Project Manager

James E. Clemmer, NC PE 18673
Project Engineer

NORTH CAROLINA LICENSED SEAL 2243 GEOLOGIST SCOTT A. SPINNER

NORTH CAROLINA PROFESSIONAL SEAL 18673 ENGINEER JAMES E. CLEMMER

Note to the Reader from Duke Energy

Duke Energy Carolinas, LLC (Duke Energy) is pleased to submit the attached groundwater Corrective Action Plan (CAP) for the Rogers Energy Complex - Cliffside Steam Station (CSS) located in Rutherford and Cleveland Counties, North Carolina. Since 2010, Duke Energy has been engaged in extensive site investigation activities to comprehensively characterize environmental conditions in soil, groundwater, surface water and sediments associated with the presence of coal combustion residual (CCR) in and around the CSS coal ash basins. Activities have been performed in compliance with the 2014 North Carolina Coal Ash Management Act (CAMA) as well as the United States Environmental Protection Agency (USEPA) CCR Rule. In 2018, the North Carolina Department of Environmental Quality (NCDEQ) ranked the CSS as a low-risk site per CAMA.

Thousands of multi-media samples have been collected at the CSS yielding over 250,000 individual analyte results. All of this work has been coordinated with the NCDEQ, which has provided review, comments, and approvals of plans and reports related to these activities. This CAP provides the results of these extensive assessment activities, and presents a robust corrective action program to address groundwater conditions where concentrations of constituents of interest (COI) are greater than applicable regulatory criteria. Closure plan(s) to address the ash basin source areas are submitted separately.

As detailed in this CAP, we have begun to implement, and will continue implementing, source control and remediation measures at the site on a basin-specific basis, as follows:

> Active Ash Basin – We will (i) complete ash basin decanting to remove the hydraulic head, thereby mitigating the risk of potential COI migration into groundwater; and (ii) complete ash basin closure. In addition, we intend to implement a robust groundwater remediation program that includes actively addressing COI in groundwater above applicable standards at or beyond the compliance boundary using a combination of groundwater extraction and clean water infiltration. These corrective action measures will most effectively achieve remediation of the groundwater through the installation of groundwater extraction and infiltration wells between the Active Ash Basin and the Broad River within the excavated ash storage area. Significantly, groundwater modeling simulations indicate (i) these measures will control COI discharge at or beyond the compliance boundary, and (ii) at such time the site-specific considerations detailed within this CAP have been satisfied, including, but not

limited to, securing all required state approvals, installing the necessary equipment, and commencing full-scale system operation, COI at or beyond the compliance boundary will meet the remedial objectives between five and nine years.

Units 1-4 Ash Basin – We closed the ash basin by excavation in February 2018, thereby mitigating the risk of potential COI migration into groundwater. In addition, we intend to install phytoremediation trees and tree wells over acreage northeast of the basin. These corrective action measures will most effectively achieve remediation of the groundwater. Significantly, (i) these measures will control potential COI presence at or beyond the compliance boundary, and (ii) at such time the site-specific considerations detailed within this CAP have been satisfied, including, but not limited to, securing all required state approvals, installing the necessary equipment, and planting the trees, COI above applicable regulatory standards will be mitigated at or beyond the compliance boundary in three years (three growing seasons).

Unit 5 Inactive Ash Basin – We will (i) complete ash basin closure; and (ii) implement a groundwater extraction system. These corrective action measures will most effectively achieve remediation of the groundwater through the installation of groundwater extraction wells northeast of the Unit 5 Inactive Ash Basin saddle dam. Significantly, groundwater modeling simulations indicate (i) these measures will control COI at or beyond the compliance boundary, and (ii) at such time the site-specific considerations detailed within this CAP have been satisfied, including, but not limited to, securing all required state approvals, installing the necessary equipment, and commencing full-scale system operation, COI migration will be contained within the compliance boundary.

This CAP contains over 2,500 pages of technical information that we believe represents one of the most detailed and well supported corrective action plans ever submitted to the NCDEQ and forms the basis of the robust groundwater remediation approach described above. Thousands of labor hours by PhD-level scientists, engineers, and geologists have been performed to obtain and evaluate the large amount of data generated at the CSS and inform this CAP. This combined effort has enabled a comprehensive understanding of site conditions, creation of a highly detailed three-dimensional groundwater flow and solute transport model used to simulate remediation scenarios, and evaluation and selection of a site-specific corrective action

program for the CSS. Duke Energy believes it is also important to provide a science-based perspective on these extensive studies, which include the following key findings:

- **The human health and ecological risk assessments performed for the CSS using USEPA guidance demonstrate that risks to potential human health and ecological receptors associated with the coal ash basins are not measurably greater than risks posed by naturally occurring background conditions.**

- **Ash basin-related constituents have not affected, nor are they predicted to affect, off-site water supply wells. This has been confirmed by analytical results from groundwater samples and water level measurements collected from over 290 monitoring wells over 30 separate monitoring events, and performing over 200 groundwater and geochemical modeling simulations**.

In addition, even though no off-site wells were impacted, Duke Energy has already provided owners of surrounding properties within 0.5-mile radius of the ash compliance boundaries with municipal water connections under a program approved by the NCDEQ that provides additional peace of mind for our neighbors. Also, ongoing multi-media sampling of the nearby surface water aquatic systems, including the Broad River, confirm that this surface water system is healthy with robust fish populations.

Duke Energy looks forward to proactively implementing this CAP.

EXECUTIVE SUMMARY

(CAP Content Section Executive Summary)

ES.1 Introduction

SynTerra prepared this groundwater Corrective Action Plan (CAP) Update on behalf of Duke Energy Carolinas, LLC (Duke Energy). The plan pertains to the Rogers Energy Complex – Cliffside Steam Station (Cliffside, CSS, Station or Site) coal combustion residuals (CCR) ash basins. The Site is located in Rutherford and Cleveland counties, North Carolina (**Figure ES-1).** The ash storage area (ASA) located adjacent to and downgradient of the active ash basin (AAB) is considered a component of the CAP Update.

This CAP Update addresses the requirements of Section 130A-309.211 (b) of the North Carolina General Statutes (G.S.), as amended by the Coal Ash Management Act (CAMA) of 2014. The CAP Update is consistent with North Carolina Administrative Code (NCAC), Title 15A, Subchapter 02L. 0106 corrective action requirements, and with the CAP guidance that was provided by the North Carolina Department of Environmental Quality (NCDEQ) in a letter to Duke Energy, dated April 27, 2018 and adjusted on September 10, 2019 (**Appendix A**).

This CAP Update evaluates remedies for constituents of interest (COIs) in groundwater associated with the CSS ash basins and ASA.

Specifically, this CAP Update focuses on constituents detected at concentrations greater than applicable North Carolina groundwater standards [NCAC Title 15A, Subchapter 02L, Groundwater Classification and Standards (02L); Interim Maximum Allowable Concentration (IMAC); or background values, whichever is greater] at or beyond the compliance boundaries.

- north of the AAB, between the basin and the Broad River within the ASA,
- northeast of the former Units 1-4 ash basin (U1-4 AB), and
- northeast of the Unit 5 inactive ash basin (U5 AB)

In accordance with G.S. requirements, a CAP pertaining to CSS was previously submitted to the NCDEQ in two parts, as follows:

- *Corrective Action Plan Part 1 – Cliffside Steam Station Ash Basins* (HDR, 2015b)
- *Corrective Action Plan Part 2 (included CSA Supplement 1 as Appendix A) – Cliffside Steam Station Ash Basins* (HDR, 2016a)

This CAP Update considers data collected through June 2019, with the exception of data related to the low pH area near the U5 AB saddle dam collected through October 2019, and AAB decanting data collected through December 1, 2019.

Ash basin closure for the AAB, ASA, and U5 AB is detailed in separate documents prepared by AECOM and Wood Environment & Infrastructure Solutions, Inc. (Wood). Closure options evaluated in this CAP update include closure-in-place and closure-by-excavation scenarios for the ash basins. Therefore, the groundwater remediation alternatives evaluated and recommended in this CAP Update consider both of these closure scenarios. Groundwater modeling simulations consistently indicate the closure-in-place and closure-by-excavation scenarios have a similar effect on the concentrations of COIs in groundwater.

Summary of CAP Approach

As stated above, this CAP Update meets the corrective action requirements under G.S. and Subchapter 02L. 0106. The preferred groundwater remediation approaches assume source control under the ash basin closure-in-place or closure-by-excavation scenarios. Both closure scenarios provide similar source control by reducing and/or eliminating further releases of COIs to groundwater. The groundwater remediation approach presented in this CAP Update can be implemented under either ash basin closure scenario and can achieve 2L .0202 groundwater quality standards based on groundwater modeling simulations. The focus of groundwater corrective action at Cliffside is reducing COIs to concentrations less than applicable criteria at or beyond the compliance boundary consistent with Subchapter 02L .0106(e)(4) and to address Subchapter 02L. 106(j). Applicable criteria in this case is defined as the 02L groundwater standard, IMAC, or background values, whichever is greatest, defined as the COI criterion. If a COI does not have an 02L standard or IMAC, then the background value defines the COI criteria.

Duke Energy has implemented, or plans to implement the following multi-component Corrective Action Plan at Cliffside:

Source Control Measures

- Completion of AAB decanting, currently underway, will reduce the hydraulic head in the dam areas, thereby significantly reducing the hydraulic driving force for potential COI migration in groundwater to the west, northwest, north, and northeast of the basin. As of December 1, 2019, 269,600,000 gallons of water have been removed from the AAB and the water elevation has decreased by 28.9 feet. Completion of decanting is projected to occur on or

before March 31, 2020. Decanting will have an effect on the groundwater flow field because the ponded water will be lowered by approximately 66 feet.

Groundwater Remediation Measures

A robust groundwater remediation approach planned for the Site includes actively addressing COIs with concentrations greater than applicable standards at or beyond the compliance boundaries using a variety of remediation technologies. Site data and groundwater models were used to evaluate and optimize an effective remedial approach to reduce COI concentrations. The following is a summary of components of the preferred remediation systems:

- The preferred groundwater remediation approach north of the AAB within the ASA includes:
  - 23 vertical groundwater extraction wells
  - 46 vertical clean water infiltration wells
  - One horizontal clean water infiltration well
- The preferred groundwater remediation approach at the U1-4 AB includes 285 phytoremediation TreeWells™ over 2.56 acres to extract groundwater and remove COI mass
- The preferred groundwater remediation approach at the U5 AB consists of:
  - 12 vertical groundwater extraction wells
  - A source control trench for COI mass removal.

Effectiveness Monitoring Plan (EMP)

- Duke Energy has prepared an effectiveness monitoring plan (EMP) summarized in **Sections 6.8.6.1, 6.17.4.1,** and **6.26.3.1** and provided in **Appendix O** of this CAP Update. The EMP includes an optimized groundwater monitoring network for the ash basins based on Site-specific COI mobility and distribution. The EMP is also designed to be adaptable and to address areas where changes to groundwater conditions are likely to occur due to additional corrective action implementation or basin closure activities. The plan includes provisions for a post-closure monitoring program in accordance with G.S. Section 130A-309.214(a)(4)(k) upon completion of basin closure activities.

Details and rationale for CAP activities are provided within this report and summarized in the following sections.

ES.2 Background

Plant Operations

Electrical power generation operations began at CSS with the use of coal-fired steam Units 1, 2, 3, and 4 in July 1940. Operation of Unit 5 began in 1972, and operation of Unit 6, a clean coal unit, began in 2012. Units 1 through 4 were retired from service in October 2011. CCR materials, composed primarily of fly ash and bottom ash were hydraulically sluiced to the AAB until 2018. Operation of Unit 5 and Unit 6 continues with dry bottom ash and dry fly ash handling; the ash is disposed on-Site at the Coal Combustion Products (CCP) Landfill. The CSS is covered under a National Pollution Discharge Elimination System (NPDES) permit issued by the NCDEQ Division of Water Resources (DWR).

Pursuant to N.C. General Statue Section 130A-309.213(d)(1), a November 13, 2018 letter from NCDEQ to Duke Energy documented the classification of the three CCR surface impoundments at Cliffside (AAB, U1-4 AB, and U5 AB) as low-risk (**Appendix A**). The letter cited that Duke Energy has "established permanent water supplies as required by G.S. Section 130A-309.211(cl)" and has "rectified any deficiencies identified by, and otherwise complied with the requirements of, any dam safety order issued by the Environmental Management Commission…pursuant to G.S. Section 143-215.32." The relevant closure requirements for low-risk impoundments are in G.S. Section 130A-309.214(a)(3), which states low-risk impoundments shall be closed as soon as practicable, but no later than December 31, 2029.

Source Areas

The AAB, U1-4 AB, and U5 AB are the primary source areas evaluated in this CAP Update.

The AAB is located on the eastern portion of the Site, east, and southeast of Units 5 and 6. Construction of the first phase of the AAB was completed in 1975 when it began receiving sluiced ash from Unit 5. The AAB expanded in 1980 to its current footprint. CCR was hydraulically sluiced to the AAB from Unit 5 until 2018. Units 5 and 6 currently operate with dry bottom ash and dry fly ash handling and ash from the units is beneficially reused or disposed of in the on-Site CCP Landfill. The AAB contains ponded water that is divided into a settling pond to the south the main pond to the north. Decanting of ponded water in the AAB began on March 31, 2019 and will be completed on or before March 31, 2020.

The U1-4 AB is located immediately east of the retired Units 1-4. It was constructed in 1957 and began operations the same year. The U1-4 AB was retired in 1977 when it

reached capacity. The CCR historically deposited in the basin began in October 2015 and concluded in February 2018. An lined retention basin (LRB) and wastewater treatment plant were constructed within the U1-4 AB footprint and began operating on March 31, 2019.

The U5 AB is located on the western portion of the Site, west and southwest of Units 5 and 6. This ash basin was constructed in 1970 (in advance of Unit 5 operations) and received sluiced ash from Unit 5 from 1972 until 1980 when it reached capacity. It is currently covered with a layer of topsoil, stable with vegetation, and used as a laydown yard for the Station.

Additional Source Area

The unlined ASA is located north of and adjacent to the AAB. A spoil area that was previously referred to as the eastern ASA, is located to the east of the ASA. Although the source of the spoil material is undetermined, it consists of soil, possibly from the AAB embankment dam construction. The spoil area appears to contain only benign fill material and the groundwater quality results are not a concern identified in the CAP Update. The heavily vegetated ASA is located between the AAB and the Broad River. The ash in the ASA was removed from the U1-4 AB and placed in its current location in the 1970s. The ASA will be excavated as part of the AAB closure activities.

A portion compliance boundary for the AAB is located within the central portion of the ASA. Groundwater from the central portion of the AAB flows to the north toward the ASA where corrective action is planned; therefore, the ASA is included in the groundwater CAP.

Pre-Basin Closure Activities

To accommodate closure of the AAB, decanting (removal) of free water from the basin began on March 31, 2019 as required by a Special Order by Consent (SOC) issued through the North Carolina Environmental Management Commission (EMC) on April 25, 2018 (EMC SOC WQ S17-009, Appendix B of **Appendix J**). The SOC requires completion of decanting by March 31, 2020. Decanting of ponded water from the AAB before closure will reduce or eliminate seepage from constructed or non-constructed seeps. Constructed seeps are seeps on or within the dam structure that convey wastewater via a pipe or constructed channel to an NPDES-regulated receiving water. Seeps that do not meet the constructed seep definition are considered non-constructed seeps. Decanting is considered an important component of the corrective action strategy for the AAB because it will significantly reduce the hydraulic head and gradients, thereby reducing the groundwater flow velocity and COI migration potential associated with the AAB. As of December 1, 2019, approximately 269,600,000 gallons of water

have been removed from the AAB and the water elevation has decreased by approximately 28.9 feet.

Basis for CAP Development

A substantial amount of data related to the ash basins, ASA, and the general CSS site has been collected to date. A summary of the CSS assessment documentation used to prepare this CAP Update is presented in **Table ES-1**.

TABLE ES-1
SUMMARY OF CSS ASSESSMENT DOCUMENTATION

Comprehensive Site Assessment Report - Cliffside Steam Station Ash Basin [HDR Engineering, Inc. of the Carolinas (SynTerra, 2017a)]
Corrective Action Plan Part 1 - Cliffside Steam Station Ash Basins (HDR, 2015b)
Ash Basin Closure Plan Report, 100% Draft Closure Plan for CCR Posting - Cliffside Steam Station (AECOM, 2016)
Corrective Action Plan Part 2 (included CSA Supplement 1 as Appendix A) - Cliffside Steam Station Ash Basin (HDR, 2016a)
Comprehensive Site Assessment Supplement 2 - Cliffside Steam Station Ash Basin (HDR, 2016c)
Surface Water Sampling to Assess 15A NCAC 2B Compliance for Implementation of Corrective Action Under 15A NCAC 02L .0106 – Rogers Energy Complex, Cliffside Steam Station (SynTerra, 2017)
Comprehensive Site Assessment Update - Cliffside Steam Station Ash Basins (SynTerra, 2018a)
Preliminary Updated Groundwater Flow and Transport Modeling Report - Cliffside Steam Station (Falta Environmental et al., 2018)
Human Health and Ecological Risk Assessment Summary Update – Cliffside Steam Station (SynTerra, 2018b)
Community Impact Analysis of Ash Basin Closure Options at Cliffside Steam Station (Exponent, 2018)
Rogers Energy Complex (Cliffside Steam Station) HB630 Provision of Permanent Water Supply Completion Documentation (Duke Energy, 2018a)
Rogers Energy Complex – Cliffside Steam Station Active Ash Basin – Closure Options Evaluation – Summary Report (AECOM, 2018a)
Rogers Energy Complex – Cliffside Steam Station Unit 5 Inactive Ash Basin – Closure Options Evaluation – Summary Report (AECOM, 2018b)
Ash Basin Pumping Test Summary Report - Cliffside Steam Station (SynTerra, 2019a).
2018 Annual Groundwater Monitoring Report (SynTerra, 2019b)
Updated Background Threshold Values for Constituent Concentrations in Soils and Groundwater (SynTerra, 2019c)

Prepared by: SAS Checked by: TJG

NCDEQ reviewed the January 31, 2018 Comprehensive Site Assessment (CSA) Update report, and in a June 29, 2018 letter to Duke Energy, NCDEQ stated that sufficient information was provided to allow the preparation of this CAP Update (**Appendix A**).

The assessment work referenced in the documents listed in **Table ES-1** has resulted in a very large dataset that has informed the development of this CAP Update. The following site assessment related activities have been completed and are summarized in **Table ES-2.** The table is current as of June 2019 and does not include sampling of the low pH area in the ditch around the Unit 5 cooling tower. However, data related to this area is evaluated and included within this CAP Update.

TABLE ES-2
SUMMARY OF CSS ASSESSMENT ACTIVITIES

Tasks	Total
Total Monitoring Wells Installed (CAMA and CCR Wells around basins)	292
Groundwater Monitoring Events	30
Groundwater Samples Collected	4,236
Individual Analyte Results	257,226
Off-Site Water Supply Well Sampling (Total inorganic analysis) - Number of Analyses	1,685
Ash Pore Water - Number of Analyses (Total and dissolved)	10,547
Ash Pore Water Sampling Events	15
Surface Water Monitoring Events	15
Surface Water Sample Locations	39
Area of Wetness Sample Events	21
Ash Samples (Within ash basin analyzed for SPLP)	8
Soil Samples Collected	333
Soil Sample Locations	122
Sediment Sample Locations	50
Geotechnical Soil Sample Locations	58
Geochemical Ash, Soil, Partially Weathered Rock, Whole Rock Samples	121
Hydraulic Conductivity Tests (Slug Tests, Pumping Tests, Packer Tests, FLASH Analysis of Bedrock HPF Data)	285
Groundwater Flow & Transport Simulations	103
PHREEQC Geochemical Simulations	82

Prepared by: SAS Checked by: TJG

Notes:
Data available to SynTerra as of June 2019
FLASH – Flow-Log Analysis of Single Holes
HPF – Heat Pulse Flow
SPLP – Synthetic Precipitation Leaching Procedure
PHREEQC – pH Redox Equilibrium in computer code C

A COI management process was developed by Duke Energy at the request of NCDEQ to gain understanding of the COI behavior and distribution in groundwater and to aid in selection of the appropriate remedial approach. The COI management process consists of three steps:

1. Perform a detailed review of the applicable regulatory requirements under NCAC, Title 15A, Subchapter 02L
2. Understand the potential mobility of Site-related COIs in groundwater based on site hydrogeology and geochemical conditions
3. Determine the COI distribution at the CSS ash basins and ASA under current or predicted future conditions.

This COI management process is supported by multiple lines of technical evidence including empirical data collected at the Site, geochemical modeling and groundwater flow and transport modeling. This approach has been used to understand and predict COI behavior in the subsurface related to the ash basins and ASA, or to identify COIs that are naturally occurring. COIs that have migrated at or beyond the compliance boundaries at concentrations greater than 02L standards, IMACs and background values that are related to an ash basin would be subject to corrective action. COIs that are naturally occurring at concentrations greater than the 02L standards or IMAC do not require corrective action. Details of the COI management approach are presented in **Section 6.**

Groundwater

In conformance with the requirements of G.S. Section 130A-309.211, groundwater corrective action is the main focus of this CAP Update. Groundwater COIs to be addressed with corrective action are those detected in groundwater at or beyond the compliance boundaries at concentrations greater than the 02L standard, IMAC, or background concentrations, whichever is greater.

Soil

Data indicate that unsaturated soil COI concentrations are generally consistent with background concentrations or are less than regulatory screening values. In the few instances where unsaturated soil COI concentrations are greater than the Preliminary Soil Remediation Goal (PSRG) Protection of Groundwater (POG) standards or background values, COI concentrations are within the range of background dataset concentrations or there are no mechanisms by which the COIs could have been transported from the ash basins or ASA to the unsaturated soils. Therefore, this CAP

Update focuses on remediation of groundwater associated with the ash basins and ash storage area.

Risk Assessment

The human health and ecological risk assessments, prepared based on state and federal guidance, demonstrated no measurable difference in modeled risks to potential human or ecological receptors compared with background concentrations. The updated risk assessments for the CSS ash basins and ASA are presented in **Section 6** of this CAP Update. Data from water supply wells, the Broad River, and Suck Creek indicate no evidence of increased risk posed by groundwater migration associated with the ash basins and ASA based on evaluation of concentrations of CCR constituents in environmental media and potential receptors.

Risk Ranking

In accordance with G.S. Section 130A-309.211(c1) of House Bill 630 (2016) Duke Energy connected 65 eligible households to the public water supply at surrounding properties within a 0.5-mile radius of the ash basin compliance boundaries. Providing connections to the public water supply along with certain improvements to the CSS dams completed by Duke Energy, resulted in the ash basins being ranked as low-risk.

ES.3 CSM Overview

The Conceptual Site Model (CSM) is a written and graphical representation of the hydrogeologic conditions and COI interactions specific to the Site and is critical to understanding the subsurface conditions related to the ash basins and ASA. The updated CSM developed for CSS included in this CAP Update is based on a United States Environmental Protection Agency (USEPA) document titled "Environmental Cleanup Best Management Practices: Effective Use of the Project Life Cycle Conceptual Site Model" (EPA, 2011). This document describes six CSM stages for a project life cycle. The CSM is an iterative tool designed to assist in the decision-making process for Site characterization and remediation as the Site progresses through the project life cycle and new data become available. The current Cliffside CSM is consistent with Stage 4 "Design CSM". Stage 4 allows for iterative improvement of the site CSM during design of the remedy while also supporting the development of the basis for the remedy design (USEPA, 2011).

Multiple lines of evidence have been used to develop the CSM based on the large CSS data set generated. The remedial action evaluation to meet the effectiveness criteria in the CAP guidance provided by NCDEQ is also based on the updated CSM (NCDEQ, 2019).

The following provides an overview of the updated CSM for the CSS ash basins, ASA, and the surrounding area which forms the basis of this CAP Update. Supporting details for the CSM are presented in **Section 5**.

Key conclusions of the CSM include the following:

- **No material increases to risk to human health related to the ash basins and ASA have been identified. The Site-specific risk assessment conducted for the ash basins and ASA indicates no measurable difference between evaluated Site-related risks and risks imposed by background concentrations.** Site-specific risk assessments indicate incomplete potential exposure pathways and no risk to residential receptors near the ash basins and the ASA (no completed exposure pathways).
- **The ash basins and ASA do not increase risks to ecological receptors.** The assessment did not indicate an increase of risks to ecological receptors (mallard duck, great blue heron, muskrat, river otter, and killdeer bird) that might access surface water and sediments downgradient of the ash basins and ASA.
- **Groundwater from the ash basins and ASA has not and does not flow towards any water supply wells based on groundwater flow patterns, the location of water supply wells in the area, and an evaluation of groundwater analytical data.** Groundwater data collected from water supply wells and on-Site monitoring wells, groundwater elevation measurements from 30 monitoring events, and groundwater flow and transport modeling results all indicate that Site COIs are not affecting, and have not affected, water supply wells.
- **The permanent water solution implemented by Duke Energy provides a municipal water connection to owners of surrounding properties with water supply wells within a 0.5-mile radius of the ash basin compliance boundaries.** The hydrogeologic data collected at the CSS confirms that Site-related COIs are not affecting off-Site water supply well users. Modeling predicts that Site-related COIs will not affect off-Site water supply users. However, Duke Energy connected 65 eligible households to the Grassy Pond Water Company public water supply (two homes will receive a connection once the homes are in a state of readiness, two households were not responsive, and two households opted out of a permanent water solution) at surrounding properties in accordance with G.S. Section 130A-309.211(c1).
- **The hydrogeologic setting of the CSS ash basins and ASA limits COI transport.** The Site, located in the Piedmont Physiographic Province, conforms

to the general hydrogeologic framework for sites in the Blue Ridge/Piedmont area, which is characterized by groundwater flow in a slope-aquifer system within a local drainage basin with a perennial stream (LeGrand, 2004). Predictive groundwater flow and transport model simulations indicate that AAB decanting will affect groundwater flow patterns within the AAB by lowering hydraulic heads in and around the ash basin dams, which will reduce the rate of COI transport. As of December 1, 2019, approximately 269,600,000 gallons of water have been removed from the AAB and the water elevation has decreased by 28.9 feet.

- **The physical setting and hydraulic processes control the COI flow pattern within the ash basins, underlying groundwater system, and downgradient areas.** The ash basins are predominantly horizontal water flow-through systems. Groundwater enters the upgradient sides of the ash basins; is supplemented by rainfall infiltration and flows laterally through the middle of the ash basins under a low horizontal gradient (near zero), and then flows downward near the dams. These flow systems result in limited downward migration of COIs into the underlying saprolite upgradient from the dams. Near the dams, COIs in water either discharge through an NPDES permitted outfall or flow downward out of the basin and under the dams. Beyond the dams, groundwater flows laterally or upward toward the Broad River or Suck Creek, limiting downward migration of COIs to the areas proximate to the dams.
- **Horizontal distribution of COIs in groundwater at or beyond the ash basin compliance boundaries is limited spatially.** The physical extent of constituent migration to the north, northeast, and northwest of the AAB, northeast of the U1-4 AB, and to the north and northeast of the U5 AB is limited and controlled by hydrologic divides, dilution from unaffected groundwater and the groundwater-to-surface water discharge zones.
- **Geochemical processes stabilize and limit certain constituent migration along the flow paths.** Each COI exhibits a unique geochemical behavior related to the specific constituent partition coefficient (K_d), a response to changing geochemical parameters (*i.e.*, pH and oxidation/reduction potential (E_h)), and the sorption capacity of the soil and/or rock.

  Based on geochemical modeling:

  - Non-conservative, reactive COIs (i.e., arsenic, chromium, strontium, and vanadium) will remain in mineral phase assemblages that are stable under

variable Site conditions downgradient of the basins, demonstrating sorption as an effective attenuation mechanism.

- Variably reactive COIs (i.e., hexavalent chromium, cobalt, iron, manganese, radium, and thallium) can exhibit mobility depending on geochemical conditions and availability of sorption sites.
- Conservative, non-reactive COIs (i.e., boron, lithium, sulfate, and total dissolved solids) migrate in groundwater as soluble species and are not strongly attenuated by reactions with solids but are reduced in concentration with distance primarily by physical processes such as mechanical mixing (dispersion), dilution, and diffusion into less permeable zones. Sorption of boron to clay particles might occur, especially for groundwater with slightly alkaline to alkaline pH values. Maximum boron sorption occurs at pH values between 7.5 standard units (S.U.) and 10 S.U., then decreases at pH values greater than 10 S.U. (Electric Power Research Institute (EPRI) 2005, ATSDR 2010).

The groundwater corrective action strategies evaluated herein consider the potential for dynamic geochemical conditions under basin closure scenarios, currently under appeal, and account for potential mobilization of COIs.

- **COIs in groundwater are contained within Duke Energy's property.** COI distributions in groundwater extend from the ash basins and ASA downgradient toward the Broad River. Groundwater flow and transport modeling results predict that COI concentrations greater than comparative criteria will extend at or beyond portions of the compliance boundaries on Duke Energy's property. However, hydrologic divides and the Broad River prevent COI migration in groundwater beyond Duke Energy property.
- **Groundwater-to-surface water interaction has not caused, and is not predicted to cause, concentrations of COIs greater than NCAC, Title 15A Subchapter 02B, Surface Water and Wetland Standards (02B).** Analytical results for surface water samples collected from the Broad River, Suck Creek, and the unnamed tributary west of the U5 AB indicate that these water bodies meet 02B standards under current conditions. Evaluation of future surface water quality conditions of basin-related jurisdictional streams was conducted using a surface water mixing model with closure option model simulation inputs. The evaluation indicates that no future groundwater COI migration would result in constituent concentrations greater than applicable 02B surface water criteria.

- **The aquatic systems of the Broad River and Suck Creek adjacent to the Site are healthy based on multiple lines of evidence including robust fish populations, species variety, and other indicators based on years of sampling data**. Multiple water quality and biological assessments conducted by Duke Energy as part of the NDPES monitoring program, combined with the results of the ecological risk assessment, indicate that there are no adverse ecological effects to the main surface water systems proximate to the ash basins or ASA.
- **Most of the COIs identified in the CSA Update occur naturally in groundwater, some at concentrations greater than the 02L standard or IMAC.** Groundwater at the CSS naturally contains antimony, cobalt, iron, manganese, thallium, and vanadium at concentrations greater than or similar to applicable 02L standards or IMAC. The occurrence of inorganic constituents in groundwater of the Piedmont Physiographic Province is well documented in the literature. For example, iron and manganese have natural background concentrations in all flow zones at the Site greater than their 02L standards, and cobalt and vanadium have natural background concentrations in all flow zones at the Site greater than their IMAC. For the CSS CAP Update, cobalt, iron, manganese, and vanadium are evaluated based on their Site-specific statistically derived background values, and on additional lines of evidence to determine whether constituent concentrations represent migration from the ash basins or ASA, or are naturally occurring.

These CSM aspects, combined with the updated human health and ecological risk assessments, provide the basis for the corrective action plan developed for the ash basins and ASA.

ES.4 Corrective Action Approach

Corrective Action Objectives and Zones Requiring Corrective Action

Migration of COIs related to the ash basins in groundwater at or beyond the ash basin compliance boundaries occurs in localized areas downgradient of the ash basins. The ASA is planned to be excavated under both the closure-in-place and closure-by-excavation scenarios. Because the ASA is within the drainage network of the AAB, and groundwater flow from the AAB and ASA is northward, groundwater from the ASA will be captured through the planned groundwater remediation system, north of the AAB within the former footprint of the ASA after excavation. To satisfy G.S. and maintain compliance with 02L, the corrective action approach planned for the ash basins focuses on restoring ash basin-affected groundwater at or beyond the compliance

boundaries. The following remedial objectives address the regulatory requirements of NCAC Title 15A Subchapter 02L for the Cliffside CAP Update:

- Restore groundwater quality at or beyond the compliance boundaries by returning COIs to the 02L standards/IMAC, or applicable background concentrations (whichever are greater), or as close thereto as is economically and technologically feasible consistent with Subchapter 02L .0106(a).
- Use a phased CAP approach that includes initial active remediation with effectiveness monitoring of remedy implementation followed by monitored natural attenuation (MNA) as provided in Subchapter 02L .0106(j) and (l).
- If appropriate given future Site conditions, Duke Energy may seek approval of an alternate plan that does not require meeting groundwater 02L standard/IMAC/applicable background values after satisfying the requirements set out in Subchapter 02L .0106(k).

The compliance boundaries for the CSS ash basins are shown in **Figure ES-1**. Groundwater concentrations greater than 02L standard/IMAC/applicable background values occur at or beyond the compliance boundary north of the AAB, northeast of the U1-4 AB, and northeast of the U5 AB.

The areas of proposed corrective action are shown on **Figure ES-2a** for the AAB and ASA, **Figure ES-2b** for the U1-4 AB, and **Figure ES-2c** for the U5 AB**.**

Summary of Source Control and Corrective Measures

It is critical to take into account the various activities Duke Energy has/will perform to improve subsurface conditions at Cliffside related to the ash basins and ASA. The remedial program incorporates source control by basin decanting and closure, active groundwater remediation and effectiveness monitoring. **Table ES-3** below summarizes the discrete components of the planned corrective action for COI-affected groundwater.

TABLE ES-3
COMPONENTS OF SOURCE CONTROL, ACTIVE REMEDIATION, AND MONITORING

Groundwater Remedy Component	Rationale
Source Control Activities	
Ash Basin Decanting - AAB	Active source remediation by removing ponded water in the AAB. Decanting will lower the hydraulic head within the AAB and reduce hydraulic gradients, reducing groundwater seepage velocities and COI transport potential. Decanting will reduce the component of groundwater flow to the east and northeast of the AAB and will return the flow direction more to a more natural condition, flowing toward the axis of the former Suck Creek channel in the AAB, then north toward the Broad River. Decanting was initiated on March 31, 2019. As of December 1, 2019, approximately 269,600,000 gallons of water have been removed from the AAB with a corresponding reduction of approximately 28.9 feet in elevation. Decanting is scheduled to be completed on or before March 31, 2020. In addition, ash basin decanting is expected to be effective in reducing or eliminating seeps identified under the Special Order by Consent.
Ash Basins and ASA Closure	The closure-in-place and closure-by-excavation scenarios are considered source control/removal activities. Extensive groundwater modeling indicates that either method results in similar effects with respect to groundwater remediation. Duke Energy plans to excavate the ASA as part of the AAB closure plan(s) as part of either closure scenario.

TABLE ES-3
COMPONENTS OF SOURCE CONTROL, ACTIVE REMEDIATION, AND MONITORING

Groundwater Remedy Component	Rationale
Active Groundwater Remediation Activities	
Active Groundwater Remediation	Groundwater remediation focused on meeting the stated remedial objectives at and beyond the ash basin compliance boundaries is planned. These efforts will focus on the areas north of the AAB, northeast of the U1-4 AB, and northeast of the U5 AB where COIs are detected in groundwater at concentrations greater than applicable criteria. To meet the above-referenced CAP objectives north of the AAB, 23 extraction wells, 46 clean water infiltration wells, and one horizontal clean water infiltration well are planned. To meet the above-referenced CAP objectives northeast of the U1-4 AB, 285 TreeWells™are planned. To meet the above-referenced CAP objectives northeast of the U5 AB, 12 vertical groundwater extraction wells and the installation of a groundwater extraction trench are planned. This approach may include (i) adjustments to the groundwater remedy, if necessary, based on new data, or if conditions change; or (ii) an alternate groundwater standard for boron of 4,000 µg/L (USEPA tap water regional screening level) pursuant to NCDEQ's authority under 15A NCAC 02L .0106(k).
Institutional Controls and Monitoring	
Permanent Water Solution for Water Supply Well Users within a 0.5-mile radius of the Coal Ash Basin Compliance Boundaries	Groundwater data at the Site indicate that surrounding water supply wells have not been affected by Site-related COIs. However, connections to the Grassy Pond Water Company public water supply for 65 surrounding properties has been completed by Duke Energy and approved by NCDEQ to address current and future stakeholder concerns. Two additional households will receive a connection to the public water supply once the households are in a state of readiness for the connections.

TABLE ES-3
COMPONENTS OF SOURCE CONTROL, ACTIVE REMEDIATION, AND MONITORING

Groundwater Remedy Component	Rationale
Maintain Ownership and Institutional Controls (ICs) Consisting of a Land Use Restriction	ICs in the form of a Declaration of Perpetual Land Use Restrictions might be requested in the future based on the results of groundwater remediation activities.
Effectiveness Groundwater Monitoring	Duke Energy plans to monitor groundwater to confirm the corrective action objectives are met and maintained over time. This monitoring program includes provisions for monitoring COIs within the compliance boundary as required under NCAC Title 15A .0107(k)(2). Flow and transport and geochemical modeling have been conducted to predict future groundwater conditions after closure. Effectiveness monitoring will provide data to validate modeling or provide input for model refinement in the future. The CAP Update includes a comprehensive review of groundwater data collected through June 2019 and a plan to optimize the monitoring program. Within thirty (30) days of CAP approval, Duke Energy would implement the effectiveness monitoring program.
Provision for Adaptive Management of Groundwater Remedies	The CSS ash basins and surrounding area is a complex site; therefore, Duke Energy believes it is important to allow for an adaptive approach during implementation of this CAP. This approach is consistent with the Interstate Technology and Regulatory Council (ITRC) document titled *Remediation Management of Complex Sites* (ITRC, 2017). This approach might include (i) adjustments to the groundwater remedy, if necessary, based on new data, or if conditions change; or (ii) an alternate groundwater standard for boron of 4,000 µg/L (US EPA tap water regional screening level) pursuant to NCDEQ's authority under 15A NCAC 02L .0106(k).

Prepared by: SAS Checked by: TJG

Notes:
COI – Constituents of Interest
NCDEQ – North Carolina Department of Environmental Quality
ICs – Institutional Controls
CAP – Corrective Action Plan

Corrective Action at Remediation Zones

The areas proposed for groundwater remediation in accordance with 02L requirements are north of the AAB within the ASA, northeast of the U1-4 AB, and northeast of the U5 AB (**Figures ES-2a/b/c**). A wide variety of potential groundwater remedial technologies were initially screened as part of the CAP Update to identify the most applicable remedial methods based upon Site-specific hydrogeologic conditions and COI distribution in groundwater. After initial screening, the following remedial alternatives were further evaluated in detail:

AAB:

- Remedial Alternative 1: Monitored natural attenuation
- Remedial Alternative 2: Groundwater extraction and infiltration wells
- Remedial Alternative 3: Groundwater extraction and infiltration wells/gallery

U1-4 AB:

- Remedial Alternative 1: Monitored natural attenuation
- Remedial Alternative 2: Phytoremediation and TreeWell™ technology

U5 AB:

- Remedial Alternative 1: Monitored natural attenuation
- Remedial Alternative 2: pH adjustment gallery
- Remedial Alternative 3: Groundwater extraction

The remedial alternatives were further screened against the following criteria outlined in Section 6.D.iv. (1-10) of the CAP guidance (NCDEQ, 2019):

- Protection of human health and the environment
- Compliance with applicable federal, state, and local regulations
- Long-term effectiveness and permanence
- Reduction of COI toxicity and mobility, and volume of COI-affected groundwater
- Short-term effectiveness at minimizing effects on the environment and local community
- Technical and logistical feasibility
- Time required to initiate

- Predicted time required to meet remediation goals
- Cost
- Sustainability
- Community acceptance

AAB and ASA:

Groundwater modeling simulations were performed to evaluate the effectiveness of the remedial alternatives and to develop the most effective approach. The results of the analysis indicate that Alternative 2: groundwater extraction and infiltration north of the AAB in the ASA, will most effectively achieve the remedial objectives presented above. The well layout for Alternative 2 is depicted in **Figure ES-3a**. This alternative consists of:

- 23 vertical extraction wells between the AAB and Broad River
- 46 clean water infiltration wells between the AAB and Broad River
- One horizontal clean water infiltration well between the AAB and Broad River

It is anticipated that the proposed groundwater extraction wells will be screened within the shallow and deep flow zones, with depths ranging from approximately 27 feet below ground surface (bgs) to 133 feet bgs.

The flow and transport model predicts the groundwater remediation system will have total infiltration rate of 240 gallons per minute (gpm) and a total groundwater extraction rate of approximately 140 gpm. Treated water would be supplied to the infiltration system. Extracted groundwater would be pumped to the Site wastewater treatment plant (WWTP) and discharged via NPDES Outfall 005. It is expected that the NPDES Permit will be modified to allow extracted groundwater to be discharged to Outfall 005.

It is recommended that prior to implementation, pilot testing of the proposed alternative will be conducted at the areas within the ASA. Pilot testing and treatment tests to be conducted include: 1) groundwater extraction and clean water infiltration, 2) treatment testing of extraction and clean water infiltration water. Pilot study results will inform the design of the full-scale system. Planned activities prior to full-scale implementation, where either submittal of the remedial performance monitoring plan (*i.e.,* effectiveness monitoring plan), or the pilot test work plan and permit applications (as applicable) will be submitted to NCDEQ within 30 days of CAP approval to fulfill

G.S. Section 130A-309.211(b)(3). Remedial performance monitoring will be performed to evaluate remedy effectiveness as described in **Section 6.8** of this CAP Update.

U1-4 AB:

The results of the analysis indicate that Alternative 2: phytoremediation and TreeWell™ technology northeast of the U1-4 AB, will best achieve the remedial objectives presented above. The TreeWells™ will improve the quality of groundwater underlying the U1-4 AB and mitigate the migration of groundwater COIs. The proposed corrective action plan well layout is depicted on **Figure ES-3b**. This alternative consists of:

- 285 phytoremediation TreeWells™ installed over 2.56 acres northeast of the U1-4 AB
- Approximately half (142) of the TreeWells™ installed to the shallow (saprolite) flow zone and half (143) of the TreeWells™ installed to the deep (transition zone) flow zone

It is recommended that prior to implementation, bench-scale and pilot testing of the proposed alternative be conducted. Bench-scale testing is recommended to determine which tree species respond most favorably to U1-4 AB groundwater. Pilot testing would be conducted at the areas north and northwest of the dam. Selection of phytoremediation trees for pilot testing would be based on bench-scale testing results. Pilot testing would be conducted over two years to determine which tree species perform best under Site conditions. Pilot testing results will inform the design of the full scale system. Planned activities prior to full-scale implementation, where either submittal of the remedial performance monitoring plan (*i.e.,* effectiveness monitoring plan), or the pilot test work plan and permit applications (as applicable) will be submitted to NCDEQ within 30 days of CAP approval to fulfill G.S. Section 130A-309.211(b)(3). Remedial performance monitoring will be performed to evaluate remedy effectiveness as described in **Section 6.17** of this CAP Update.

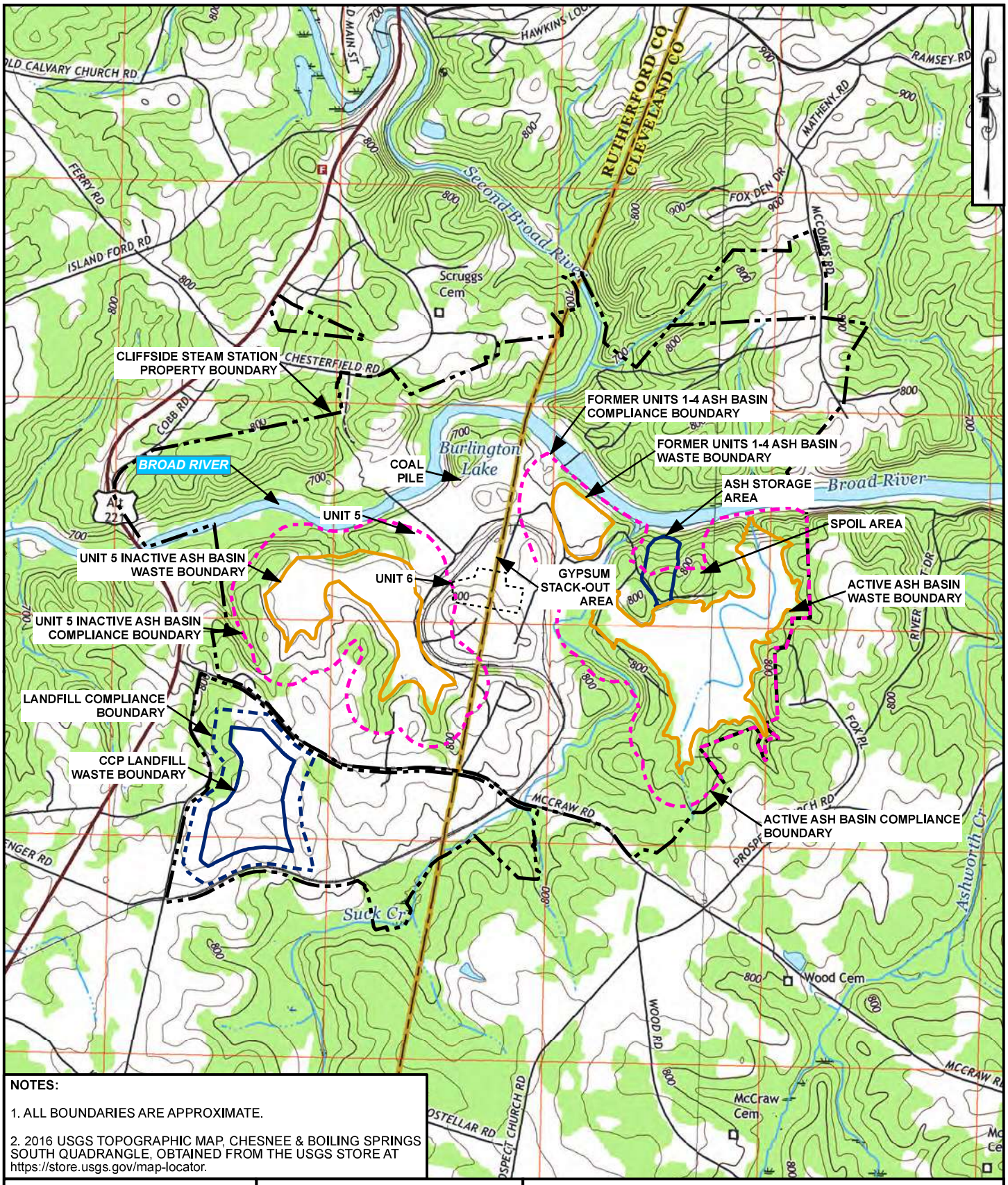
U5 AB:

The results of the analysis indicate that Alternative 3: groundwater extraction, northeast of the U5 AB saddle dam, will best achieve the remedial objectives presented above. The proposed corrective action plan well layout is depicted on **Figure ES-3c**. This alternative consists of:

- Pumping tests to determine the final number and locations of groundwater extraction wells

- Installation of 12 vertical groundwater extraction wells screened in the deep and shallow flow zones
- Installation of a groundwater extraction trench to eliminate low pH surface water discharging south and west of Cooling Tower B and to hydraulically control local groundwater in the shallow flow zone
- Groundwater and surface water from the extraction trench and groundwater from the 12 extraction wells would be discharged to an existing storm water drain that discharges to the Basement Basin (Holding Cell). The water would be treated and discharged to the Broad River through Outfall 005

It is recommended that prior to implementation, pumping tests are planned north and northwest of the dam. Pumping test results will inform the design of the full-scale system. Planned activities prior to full-scale implementation, where either submittal of the remedial performance monitoring plan (*i.e.,* effectiveness monitoring plan), or the pilot test work plan and permit applications (as applicable) will be submitted to NCDEQ within 30 days of CAP approval to fulfill G.S. Section 130A-309.211(b)(3). Remedial performance monitoring will be performed to evaluate remedy effectiveness as described in **Section 6.26** of this CAP Update.



NOTES:

1. ALL BOUNDARIES ARE APPROXIMATE.

2. 2016 USGS TOPOGRAPHIC MAP, CHESNEE & BOILING SPRINGS SOUTH QUADRANGLE, OBTAINED FROM THE USGS STORE AT https://store.usgs.gov/map-locator.

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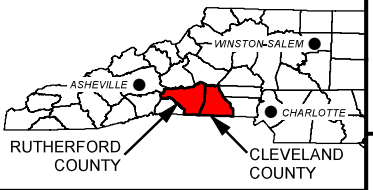

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FIGURE ES-1
USGS LOCATION MAP
CORRECTIVE ACTION PLAN UPDATE
CLIFFSIDE STEAM STATION
MOORESBORO, NORTH CAROLINA

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REVISED BY: C. DAVIS	DATE: 12/27/2019
CHECKED BY: T. GRANT	DATE: 12/27/2019
APPROVED BY: T. GRANT	DATE: 12/27/2019
PROJECT MANAGER: S. SPINNER	

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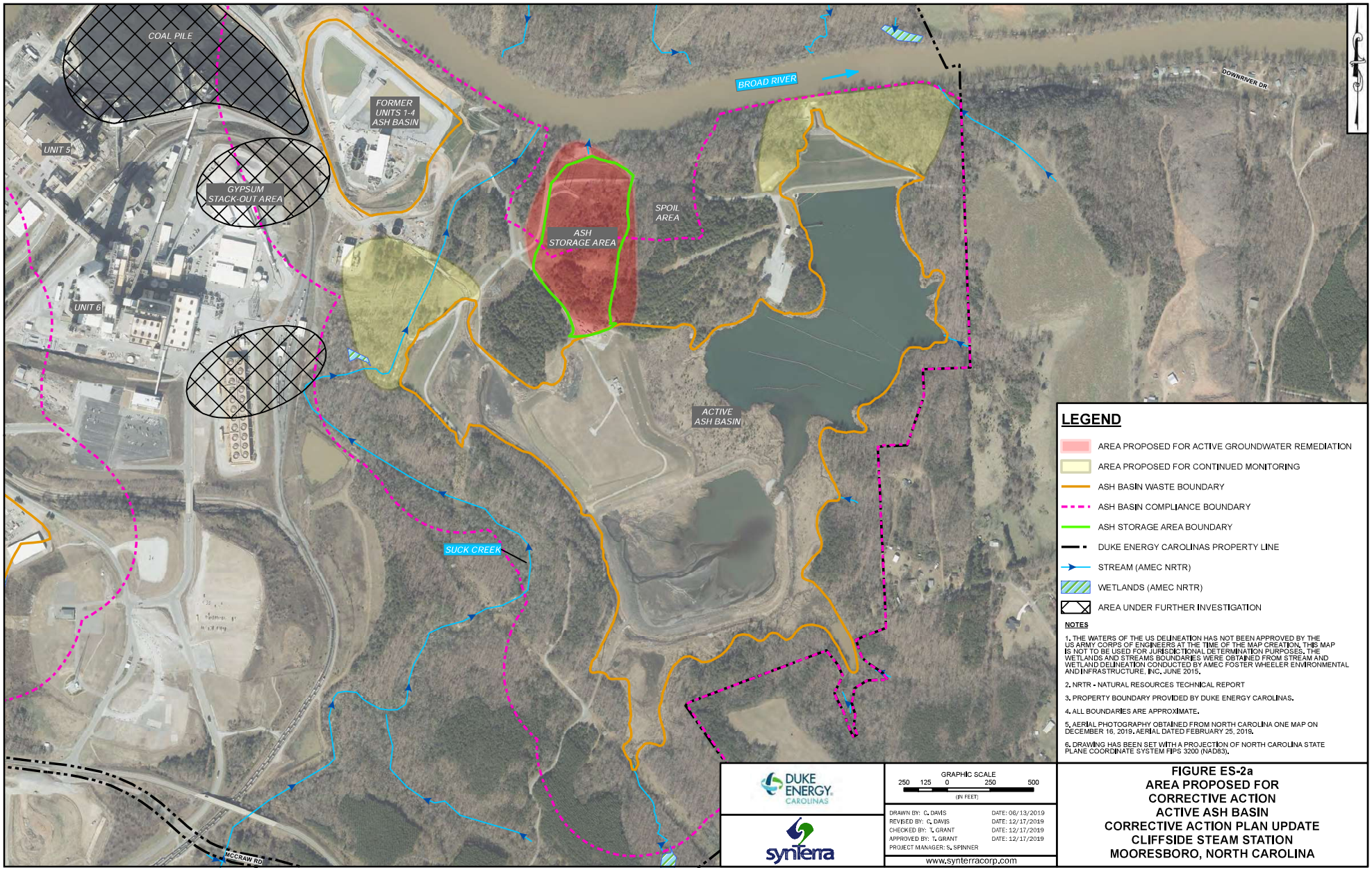
(IN FEET)



LEGEND

- AREA PROPOSED FOR ACTIVE GROUNDWATER REMEDIATION
- AREA PROPOSED FOR CONTINUED MONITORING
- ASH BASIN WASTE BOUNDARY
- ASH BASIN COMPLIANCE BOUNDARY
- ASH STORAGE AREA BOUNDARY
- DUKE ENERGY CAROLINAS PROPERTY LINE
- STREAM (AMEC NRTR)
- WETLANDS (AMEC NRTR)
- AREA UNDER FURTHER INVESTIGATION

NOTES

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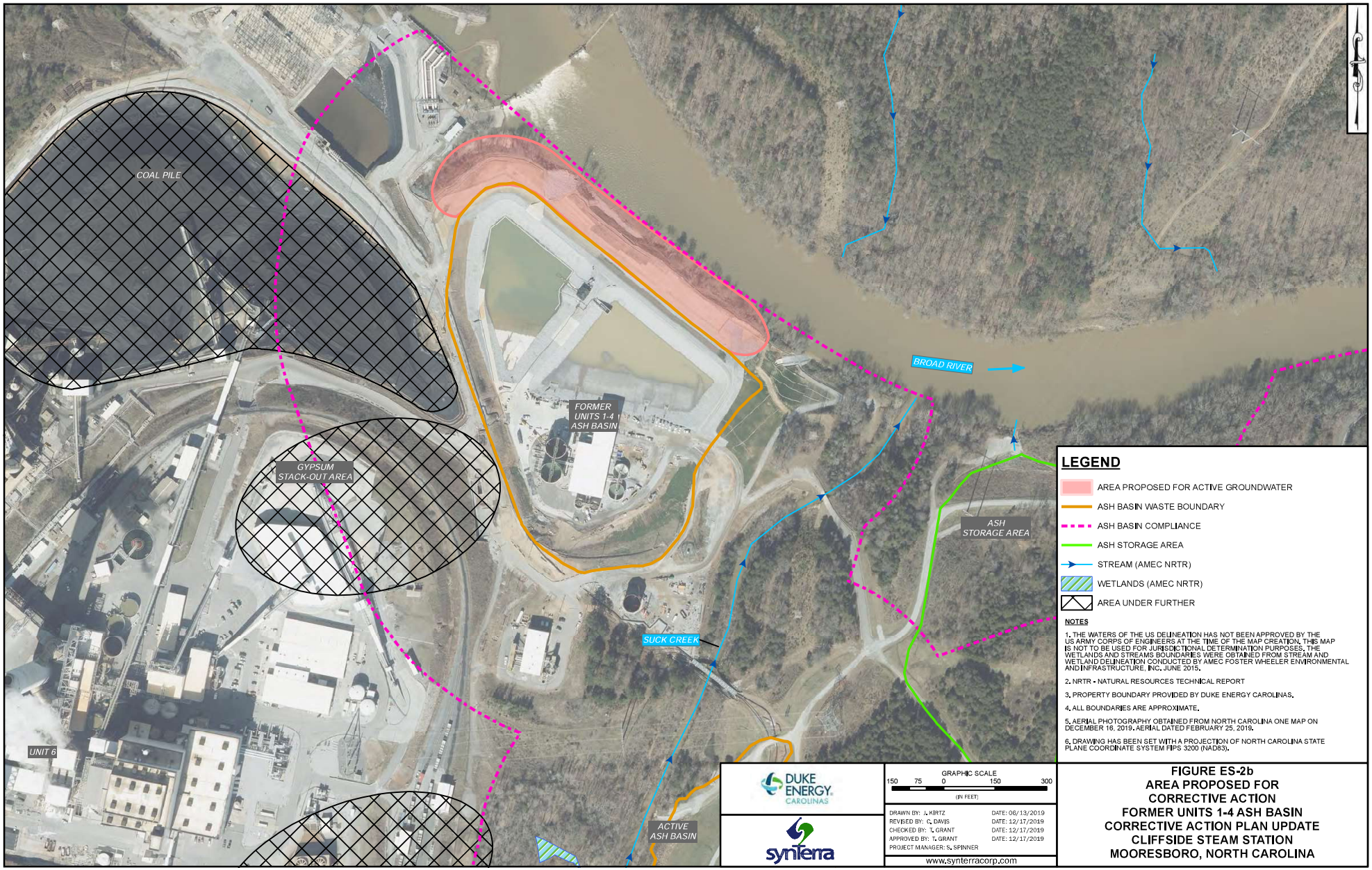
FIGURE ES-2a
AREA PROPOSED FOR CORRECTIVE ACTION ACTIVE ASH BASIN
CORRECTIVE ACTION PLAN UPDATE
CLIFFSIDE STEAM STATION
MOORESBORO, NORTH CAROLINA



LEGEND

- AREA PROPOSED FOR ACTIVE GROUNDWATER
- ASH BASIN WASTE BOUNDARY
- ASH BASIN COMPLIANCE
- ASH STORAGE AREA
- STREAM (AMEC NRTR)
- WETLANDS (AMEC NRTR)
- AREA UNDER FURTHER

NOTES

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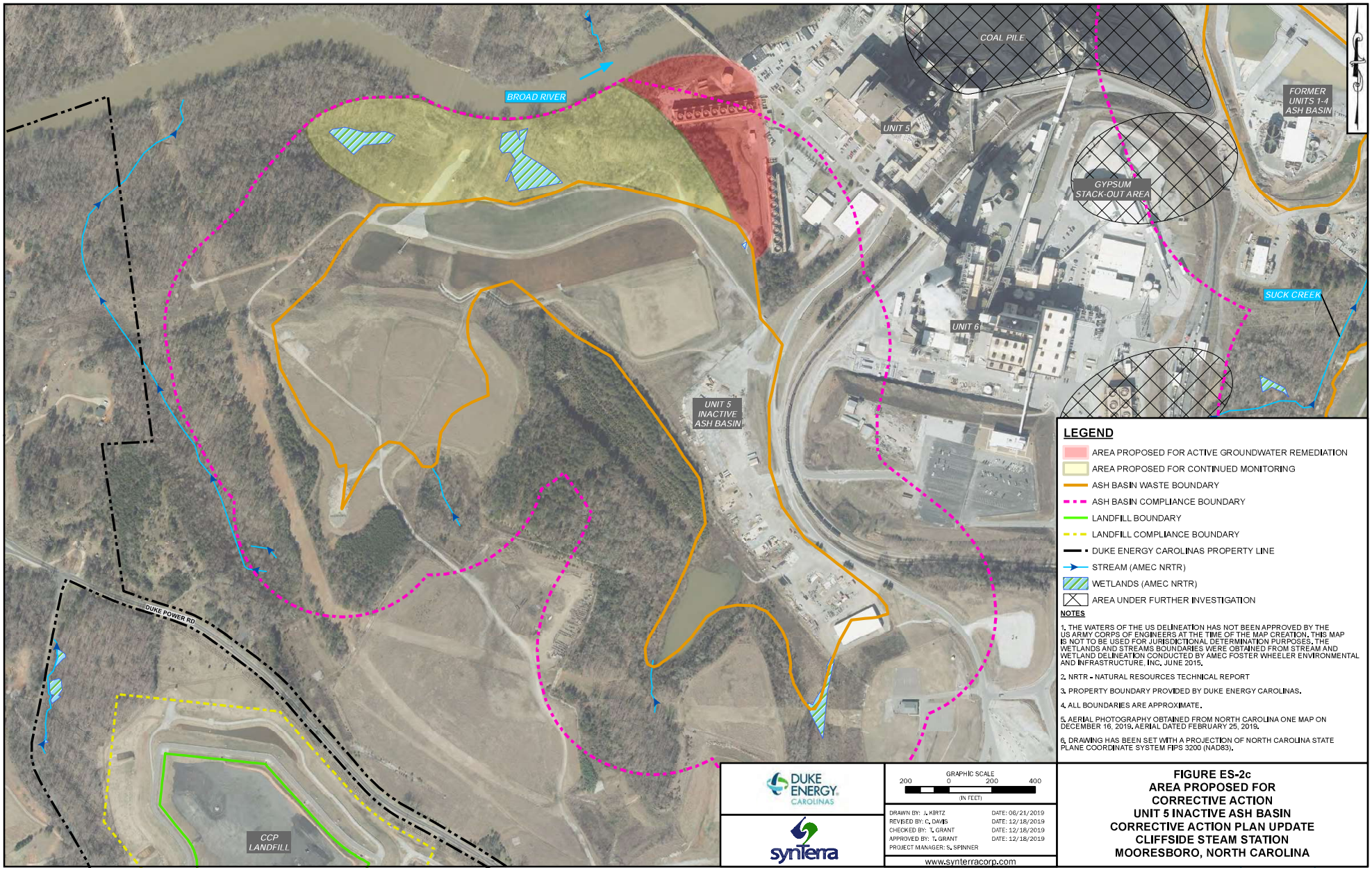
FIGURE ES-2b
AREA PROPOSED FOR CORRECTIVE ACTION
FORMER UNITS 1-4 ASH BASIN
CORRECTIVE ACTION PLAN UPDATE
CLIFFSIDE STEAM STATION
MOORESBORO, NORTH CAROLINA



LEGEND

- AREA PROPOSED FOR ACTIVE GROUNDWATER REMEDIATION
- AREA PROPOSED FOR CONTINUED MONITORING
- ASH BASIN WASTE BOUNDARY
- ASH BASIN COMPLIANCE BOUNDARY
- LANDFILL BOUNDARY
- LANDFILL COMPLIANCE BOUNDARY
- DUKE ENERGY CAROLINAS PROPERTY LINE
- STREAM (AMEC NRTR)
- WETLANDS (AMEC NRTR)
- AREA UNDER FURTHER INVESTIGATION

NOTES

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FIGURE ES-2c
AREA PROPOSED FOR CORRECTIVE ACTION
UNIT 5 INACTIVE ASH BASIN
CORRECTIVE ACTION PLAN UPDATE
CLIFFSIDE STEAM STATION
MOORESBORO, NORTH CAROLINA

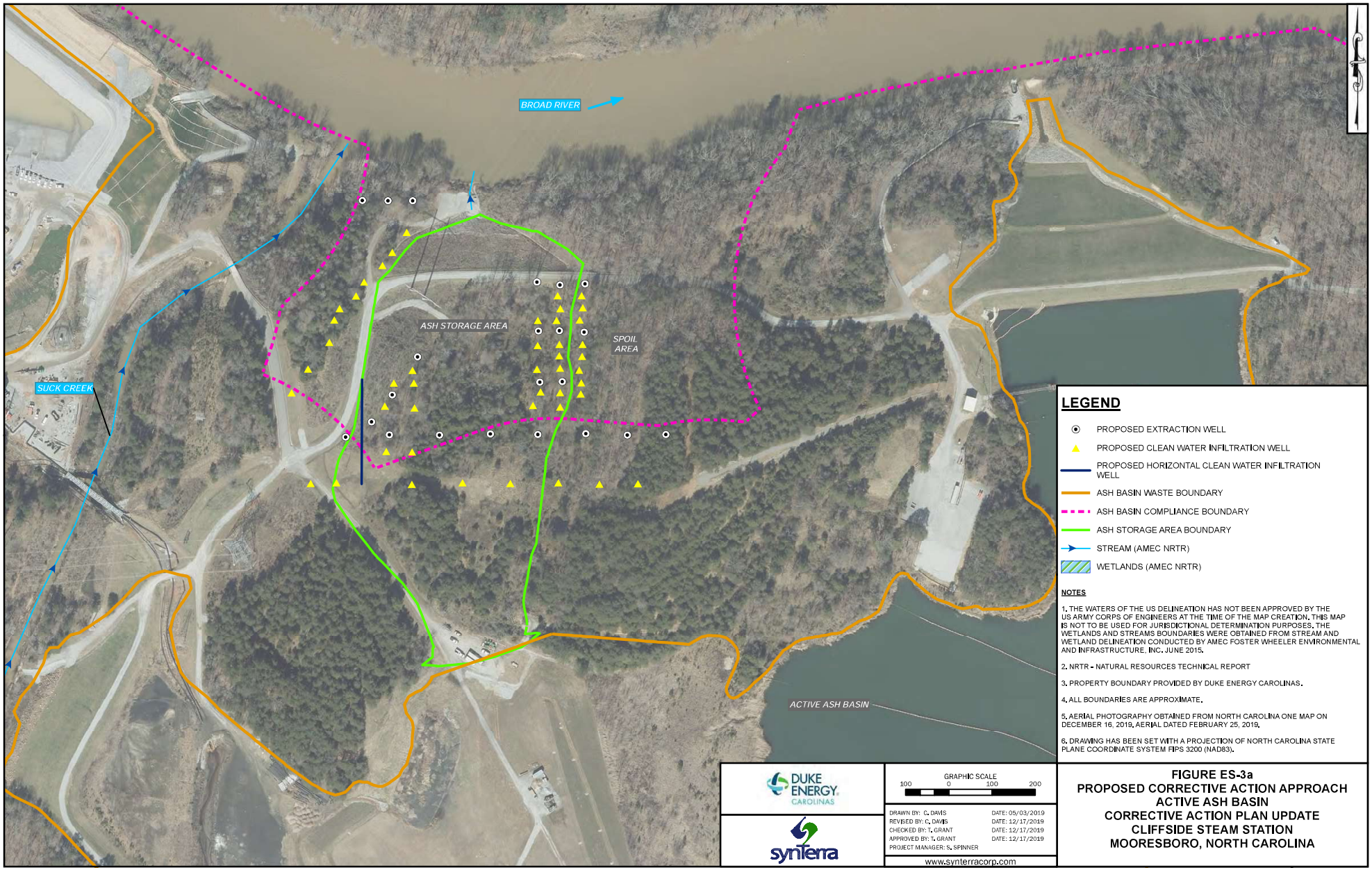
BROAD RIVER
SUCK CREEK
ASH STORAGE AREA
SPOIL AREA
ACTIVE ASH BASIN
LEGEND
PROPOSED EXTRACTION WELL
PROPOSED CLEAN WATER INFILTRATION WELL
PROPOSED HORIZONTAL CLEAN WATER INFILTRATION WELL
ASH BASIN WASTE BOUNDARY
ASH BASIN COMPLIANCE BOUNDARY
ASH STORAGE AREA BOUNDARY
STREAM (AMEC NRTR)
WETLANDS (AMEC NRTR)
NOTES
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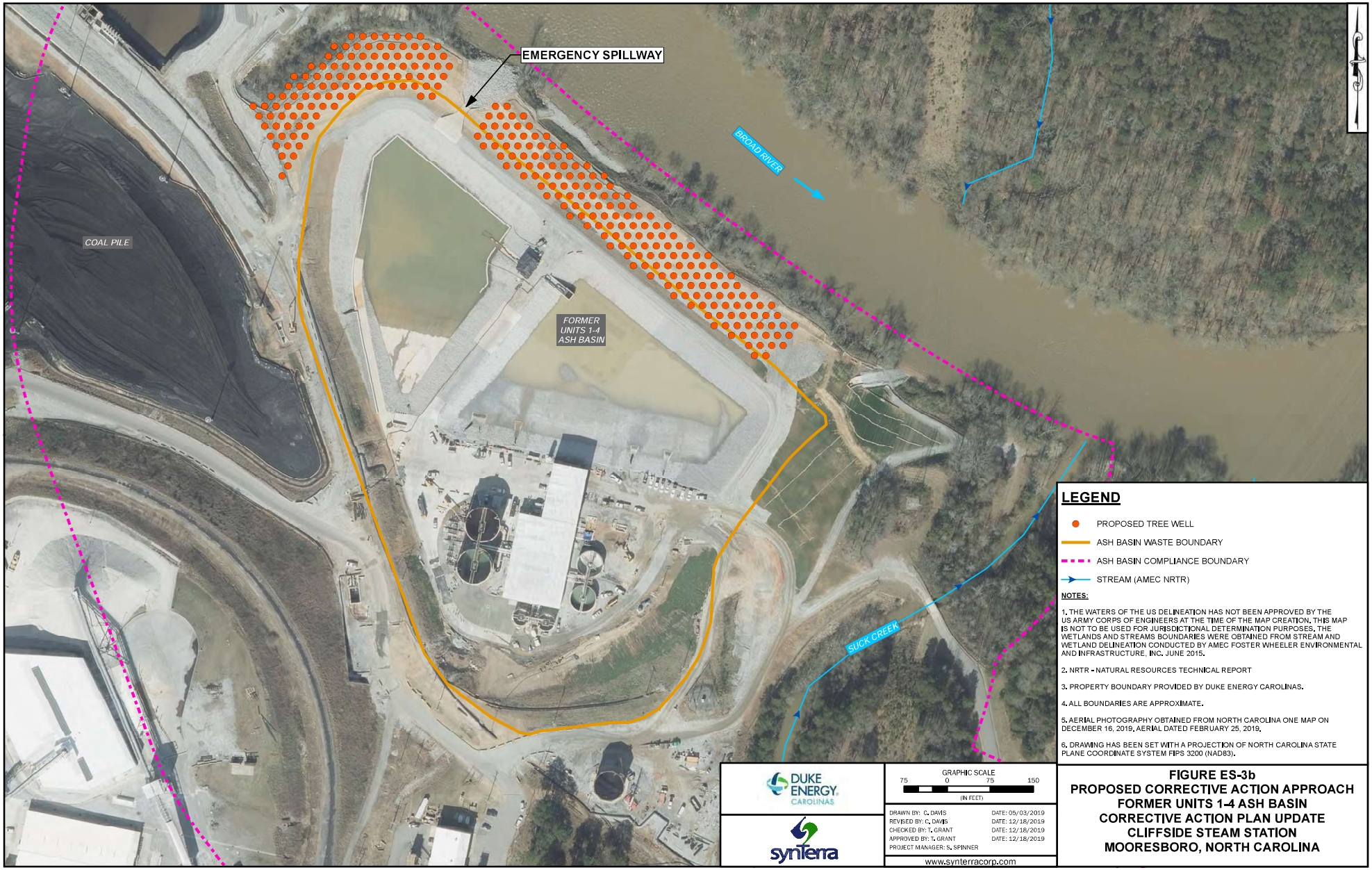
FIGURE ES-3a
PROPOSED CORRECTIVE ACTION APPROACH
ACTIVE ASH BASIN
CORRECTIVE ACTION PLAN UPDATE
CLIFFSIDE STEAM STATION
MOORESBORO, NORTH CAROLINA



LEGEND

- PROPOSED TREE WELL
- ASH BASIN WASTE BOUNDARY
- ASH BASIN COMPLIANCE BOUNDARY
- STREAM (AMEC NRTR)

NOTES:

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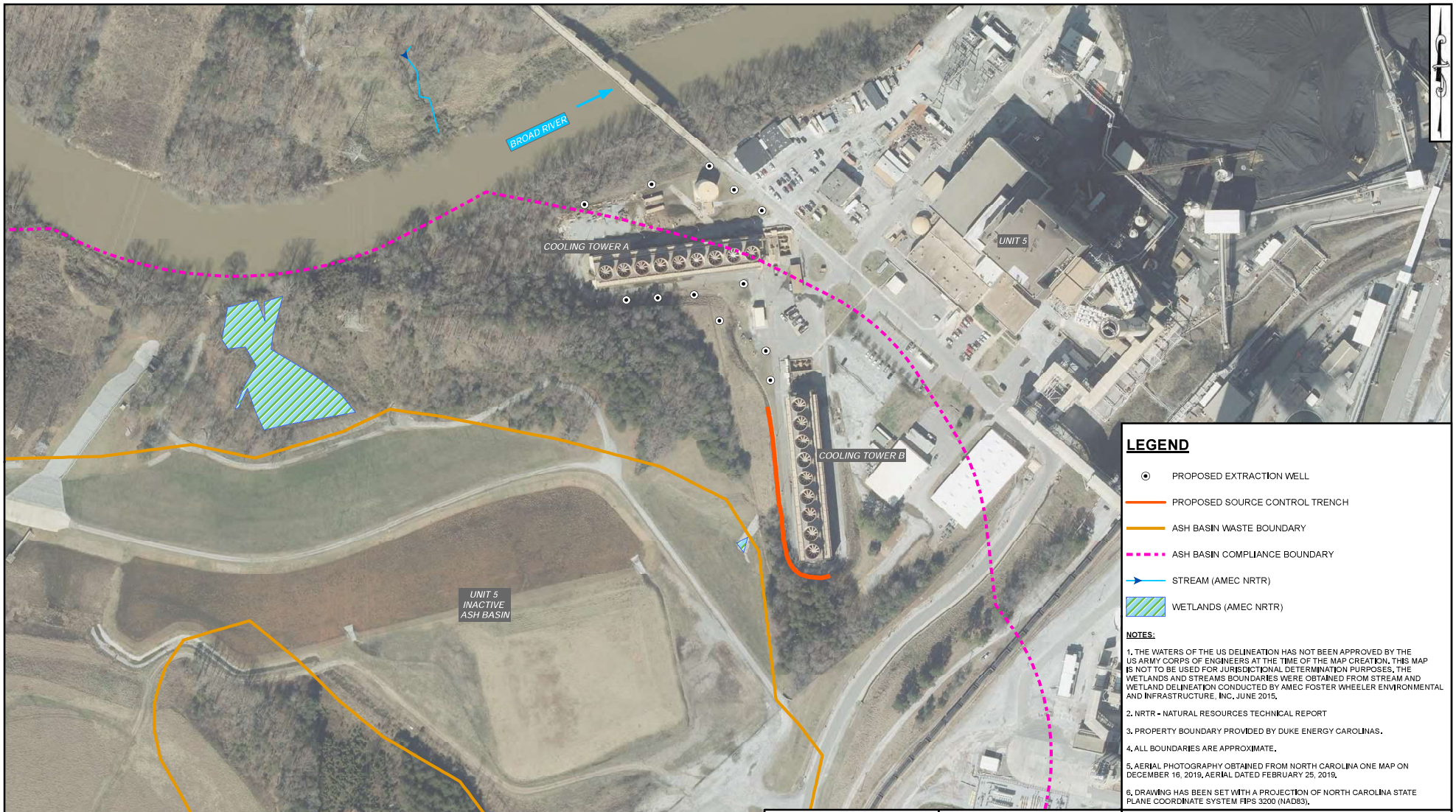
FIGURE ES-3b
PROPOSED CORRECTIVE ACTION APPROACH
FORMER UNITS 1-4 ASH BASIN
CORRECTIVE ACTION PLAN UPDATE
CLIFFSIDE STEAM STATION
MOORESBORO, NORTH CAROLINA



LEGEND

- PROPOSED EXTRACTION WELL
- PROPOSED SOURCE CONTROL TRENCH
- ASH BASIN WASTE BOUNDARY
- ASH BASIN COMPLIANCE BOUNDARY
- STREAM (AMEC NRTR)
- WETLANDS (AMEC NRTR)

NOTES:

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100 0 100 200

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FIGURE ES-3c
PROPOSED CORRECTIVE ACTION APPROACH
UNIT 5 INACTIVE ASH BASIN
CORRECTIVE ACTION PLAN UPDATE
CLIFFSIDE STEAM STATION
MOORESBORO, NORTH CAROLINA

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LIST OF ACRONYMS

02B	NCAC Title 15A, Subchapter 02B. Surface Water and Wetland Standards
02L	NCAC Title 15A, Subchapter 02L. Groundwater Classification and Standards
AAB	Active ash basin
AOW	Area of Wetness
ASA	Ash storage area
ASTM	American Society for Testing and Materials
bgs	Below Ground Surface
BR	Bedrock
BTV	Background Threshold Value
CAMA	Coal Ash Management Act of 2014
CAP	Corrective Action Plan
CBD	Citrate-Bicarbonate-Dithionite
CCP	Coal Combustion Products
CCR	Coal Combustion Residuals
CFR	Code of Federal Register
COI	Constituent of Interest
CSA	Comprehensive Site Assessment
CSM	Conceptual Site Model
CSS	Cliffside Steam Station
Duke Energy	Duke Energy Carolinas, LLC
DWM	Division of Waste Management
E_H	Oxidation/reduction potential
EMP	Effectiveness Monitoring Program
EMC	Environmental Management Commission
EPRI	Electric Power Research Institute
FGD	Flue Gas Desulfurization
Ft/day	feet per day
Ft/ft	feet per foot
Ft/yr	feet per year
gpd	gallons per day
gpm	gallons per minute
G.S.	General Statute(s)
GWPS	Groundwater Protection Standard

LIST OF ACRONYMS (CONTINUED)

HAO	Hydrous Aluminum Oxide
HDPE	High-Density Polyethylene
HFO	Hydrous Ferric Oxide
HQs	Hazard quotients
IMAC	Interim Maximum Allowable Concentration
IMP	Interim Monitoring Plan
ISV	In-situ vitrification
K_d	Partition Coefficient
Kg/yr	kilograms per year
LEAF	Leaching environmental assessment framework
LOAELs	Lowest observed adverse effects levels
LPB	Low permeability barrier
LRB	Lined Retention Basin
MGD	Million gallons per day
mg/L	Milligrams per liter
mm	Millimeter
MW	Megawatts
MNA	Monitored Natural Attenuation
NAVD 88	North American Vertical Datum of 1988
NCAC	North Carolina Administrative Code
NCDENR	North Carolina Department of Environment and Natural Resources
NCDEQ	North Carolina Department of Environmental Quality
NOAELs	No observed adverse effects levels
NORR	Notice of Regulatory Requirements
NPDES	National Pollutant Discharge Elimination System
NRTR	National Resource Technical Report
NTU	Nephelometric Turbidity Units
O&M	Operation and Maintenance
PRB	Permeable Reactive Barrier
PBTV	Provisional Background Threshold Value
POG	Protection of Groundwater
POTW	Publicly owned treatment works
PSRG	Preliminary Soil Remediation Goal
RO	Reverse osmosis

LIST OF ACRONYMS (CONTINUED)

RQD	Rock Quality Designation
RS	Restricted (designation)
SAC	Strong acid cation
SAP	Sampling and Analysis Plan
SBA	Strong base anion
Site	Cliffside Steam Station
SSL	Statistically significant level
SOC	Special Order by Consent
SPLP	Synthetic Precipitation Leaching Procedure
S.U.	Standard Units
SW	Surface Water
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TZ	Transition Zone
USEPA	U.S. Environmental Protection Agency
USDA	U.S. Department of Agriculture
UIC	Underground injection control
USGS	United States Geological Survey
WAC	Weak acid cation
WBA	Weak base anion
WWTP	Wastewater treatment plant
WWTS	Wastewater treatment system
ZVI	Zero-valence iron

1.0 INTRODUCTION

(CAP Content Section 1)

SynTerra prepared this groundwater corrective action plan (CAP) Update on behalf of Duke Energy Carolinas, LLC (Duke Energy). The plan pertains to the Rogers Energy Complex – Cliffside Steam Station (Cliffside, CSS, Station, or Site) coal combustion residual (CCR) ash basins. Duke Energy owns and operates CSS, located in Mooresboro, in Rutherford and Cleveland counties, North Carolina (**Figure 1-1**).

In accordance with Section 130A-309.211 (b) of the North Carolina General Statutes (G.S.), as enacted by the Coal Ash Management Act of 2014 (CAMA), Duke Energy is submitting this groundwater CAP Update to prescribe methods and materials to restore groundwater quality associated with CAMA-regulated units. The CAP considers constituent concentrations detected greater than applicable North Carolina groundwater standards [NC Administrative Code, Title 15A, Subchapter 02L, Groundwater Classification and Standards (02L); Interim Maximum Allowable Concentrations (IMAC); or background values, whichever is greater], at or beyond the compliance boundaries.

In accordance with G.S. requirements, a CAP for CSS was previously submitted to the North Carolina Department of Environmental Quality (NCDEQ) in two parts:

- *Corrective Action Plan Part 1 – Cliffside Steam Station Ash Basins* (HDR, 2015b)
- *Corrective Action Plan Part 2 (included in CSA Supplement 1 as Appendix A) – Cliffside Steam Station Ash Basins* (HDR, 2016a).

This CAP Update is being submitted to NCDEQ as originally requested in a June 2, 2017, letter from NCDEQ to Duke Energy. In an April 5, 2019, letter to Duke Energy, NCDEQ issued revised CAP deliverable schedules and requested assessment of additional potential sources of constituents to groundwater at Cliffside stating that sources hydrologically connected to the ash basins are to be assessed and included in an updated CAP. The ASA was included as an additional source hydrologically connected to the AAB.

For the U1-4 AB (referred to in previous reports as the Units 1-4 inactive ash basin or the former Units 1-4 ash basin), the *Excavation Soil Sampling Plan Rogers Energy Complex Units 1-4 Inactive Ash Basin For Ash Basin Excavation, Rev. 0* (Duke Energy, 2017) was submitted to NCDEQ. The U1-4 AB was subsequently excavated and the *Coal Combustion Residuals (CCR) Visual Removal Verification, Rogers Energy Complex – Cliffside*

Steam Station, Units 1-4 Inactive Ash Basin report (Duke Energy, 2018b) was submitted to NCDEQ.

In addition to the CAP Update, Duke Energy will be submitting a CCR Surface Impoundment Closure Plan(s) to NCDEQ on/before December 31, 2019. Duke Energy is required to submit final closure plan consistent with the detailed requirements of the CAMA which is provided under separate cover. This CAP Update has been developed to be effective with the various closure scenarios determined for the Site.

The CAP content and submittal schedule are in accordance with subsequent correspondence between NCDEQ and Duke Energy, including AP content guidance issued by NCDEQ on April 27, 2018 and adjusted on September 10, 2019. This CAP Update includes section references to the document, *Corrective Action Plan Content for Duke Energy Coal Ash Facilities* (provided in **Appendix A**), beneath report section headings and within text in parentheses to facilitate the review process.

1.1 Background

(CAP Content Section 1.A)

A substantial amount of assessment data has been collected for the CSS ash basins and ash storage area (ASA) to support this CAP Update. Site assessment was performed and the CSS Comprehensive Site Assessment (CSA) Update Report, dated January 31, 2018 (SynTerra 2018a) was prepared and submitted in accordance with the requirements in Subchapter 02L .0106 (g). The CSA:

- Identified the source(s) and causes of constituents of interest (COIs) in groundwater.
- Found no imminent hazards to public health and safety.
- Identified receptors and potential exposure pathways.
- Sufficiently determined the horizontal and vertical extent of COIs in soil and groundwater.
- Determined the geological and hydrogeological features influencing the movement, chemical makeup, and physical characteristics of COIs.

NCDEQ provided review of the CSA Update to Duke Energy in a letter dated June 29, 2018 and stated that the information provided sufficiently warranted preparation of this CAP Update (**Appendix A**). This CAP Update builds on previous documents to provide a CAP for addressing the requirements in Subchapter 02L .0106 for corrective action and the restoration of groundwater quality.

Detailed descriptions of Site operational history, the conceptual Site model, physical setting and features, geology/hydrogeology, and findings of the CSA and other CAMA-related work are documented in the following reports:

- *Comprehensive Site Assessment Report – Cliffside Steam Station Ash Basins* (HDR Engineering, Inc. of the Carolinas (HDR, 2015a).
- *Corrective Action Plan Part 1 – Cliffside Steam Station Ash Basins* (HDR, 2015b).
- *Corrective Action Plan Part 2 - Cliffside Steam Station Ash Basins* (included in CSA Supplement 1 as Appendix A) – (HDR, 2016a).
- *Comprehensive Site Assessment Supplement 2 – Cliffside Steam Station Ash Basins* (HDR, 2016c).
- *Surface Water Sampling to Assess 15A NCAC 2B Compliance for Implementation of Corrective Action Under 15A NCAC 02L.0106 – Rogers Energy Complex - Cliffside Steam Station* (SynTerra, 2017)
- *Comprehensive Site Assessment Update – Cliffside Steam Station Ash Basins* (SynTerra, 2018a).
- *Ash Basin Pumping Test Report – Cliffside Steam Station* (SynTerra 2019a)
- *2018 CAMA Annual Interim Monitoring Report* (SynTerra 2019c)

1.2 Purpose and Scope

(CAP Content Section 1.B)

The purposes of this corrective action approach are the following:

- Restore groundwater affected by the ash basins and ASA at or beyond the compliance boundaries to the applicable groundwater standards, or as close to the standards as is economically and technically feasible, in accordance with 15A Subchapter 02L .0106(a).
- Address response requirements contained within 15A North Carolina Administrative Code (NCAC) 02L .0107(k) for exceedances of standards (1) in adjoining classified groundwater, (2) presenting an imminent hazard to public health and safety, and/or (3) in bedrock groundwater that may potentially affect a water supply well.
- Meet the requirements for corrective action plans specified in G.S. Section 130A-309.211 (b).

The scope of the CAP and this CAP Update is defined by G.S. Section 130A-309.211. The legislation required, among other items, assessment of groundwater at coal combustion residual impoundments and corrective action in conformance with the requirements of Subchapter 02L. The corrective actions for restoration of groundwater quality requirements were codified into G.S. Section 130A-309.211 which was further amended by House Bill 630 to require a provision for alternate water supply for receptors within 0.5-mile downgradient from the established compliance boundaries.

Based on conditions and results from the Site investigations, the CAP Update develops and compares alternative methods for corrective action and presents the recommended plan. This CAP Update presents a holistic, multi-component corrective action approach for groundwater COIs associated with the AAB, U1-4 AB, and U5 AB at and beyond the compliance boundaries. Design information and steps necessary for implementation are included in the CAP Update. Once the CAP is approved by NCDEQ, implementation is planned to begin within 30 days as required by G.S. 130A-309.211(b)(3).

1.3 Regulatory Basis for Corrective Action

(CAP Content Section 1.C)

Comprehensive groundwater assessment activities, conducted in accordance with a Notice of Regulatory Requirements (NORR) issued to Duke Energy on August 13, 2014 by the North Carolina Department of Environment and Natural Resources (NCDENR) (**Appendix A**), indicate the coal ash basin and the related contiguous unit — the ASA — have demonstrated constituent concentrations in groundwater greater than applicable regulatory standards at or beyond the ash basin compliance boundaries.

The regulatory requirements for corrective action at coal combustion residuals surface impoundments under CAMA are in G.S. Section 130A-309.211(b), (c), and (c1). Section (b) of G.S. Section 130A-309.211 requires that the CAP shall provide for groundwater restoration in conformance with the requirements of Subchapter L of Chapter 2 of Title 15A of the North Carolina Administrative Code (15A NCAC Subchapter 02L). In accordance with G.S. Section 130A-309.211(b)(1), the groundwater CAP shall include, at a minimum, all of the following (*CAP Content Section 1.C.a*):

- A description of all exceedances of the groundwater quality standards, including any exceedances that the owner asserts are the result of natural background conditions
- A description of the methods for restoring groundwater in conformance with the requirements of Subchapter L of Chapter 2 of Title 15A of the NCAC and a detailed explanation of the reasons for selecting these methods

- Specific plans, including engineering details, for restoring groundwater quality
- A schedule for implementation of the groundwater corrective action plan
- A monitoring plan for evaluating the effectiveness of the proposed corrective action and detecting movement of any constituent plumes
- Any other information related to groundwater assessment required by NCDEQ

In addition to CAMA, requirements for CAPs are also contained in Subchapter 02L .0106 (e), (h) and (i).

Section 02L .0106(e)(4) requires implementation of an approved CAP for restoration of groundwater quality at or beyond the compliance boundary in accordance with a schedule established by the Secretary.

To comply with 02L .0106(h), CAPs must include *(CAP Content Section 1.C.b):*

- A description of the proposed corrective action and reasons for its selection
- Specific plans, including engineering details where applicable, for restoring groundwater quality
- A schedule for the implementation and operation of the proposed plan
- A monitoring plan for evaluating the effectiveness of the proposed corrective action and the movement of the constituent plume

This CAP Update presents an evaluation of the options available for corrective action under 15A NCAC 02L .0106(j), (k), and (l).

- Under paragraph (j), corrective action would be implemented using remedial technology for restoration of groundwater quality to the standards (02L).
- Under paragraph (k), a request for approval of a corrective action plan may be submitted without requiring groundwater remediation to the standards (02L) if the requirements in (k) are met.
- Under paragraph (l), a request for approval of a corrective action plan may be submitted based on natural processes of degradation and attenuation if the requirements in (l) are met.

This CAP Update has been prepared in general accordance the NCDEQ guidance document titled *Corrective Action Plan Content for Duke Energy Coal Ash Facilities* which

provides an outline of the technical content and format presented in the NCDEQ's letter dated September 10, 2019, provided in (**Appendix A**). (*CAP Content Section 1.C.c*).

In addition to the groundwater CAP, the Cliffside ash basins are subject to closure requirements under CAMA. Basin closure activities will provide source control within the ash basins and are considered a component of the overall corrective action for the site. It is important to note that the CSS ash basins meet the low-risk classification criteria set forth in CAMA for CCR surface impoundments. On November 13, 2018, NCDEQ confirmed that Duke Energy had established permanent water supplies for surrounding properties and rectified prior dam safety deficiencies. NCDEQ provided final classification of the AAB, U1-4 AB, and the U5 AB as "low-risk". Under CAMA, a low-risk coal combustion residuals surface impoundment may be closed by excavation, closure-in-place, or a hybrid approach.

On April 1, 2019, the NCDEQ issued a determination that the AAB and U5 AB at CSS are to be closed using the excavation approach (the U1-4 AB has been previously closed by excavation) (**Appendix A**). The CAP approach described herein can be implemented under either scenario.

1.4 List of Considerations by the Secretary for Evaluation of Corrective Action Plans

(CAP Content Section 1.D.a though g)

Potential active remedial alternatives were developed using the criteria included in the NCDEQ's CAP Guidance (NCDEQ, 2019). An evaluation of remedial alternatives was performed based on the following criteria:

- Protection of human health and the environment
- Compliance with applicable federal, state, and local regulations
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, and volume
- Short-term effectiveness at minimizing effects on the environment and local community
- Technical and logistical feasibility
- Time required to initiate
- Predicted time required to meet remediation goals
- Cost

- Community acceptance

In the evaluation of CAPs as specified in 02L .0106(i), the criteria includes:

- A consideration of the extent of any violations
- The extent of any threat to human health or safety
- The extent of damage or potential adverse effects to the environment
- Technology available to accomplish restoration
- The potential for degradation of the constituents in the environment
- The time and costs estimated to achieve groundwater quality restoration
- The public and economic benefits to be derived from groundwater quality restoration

These 02L .0106(i) criteria form the basis for defining the screening criteria outlined in **Sections 6.6, 6.15**, and **6.24** for use in evaluating remedial alternatives in **Sections 6.7, 6.16**, and **6.25.**

In addition, institutional controls [provided by the restricted designation (RS)] may be proposed by Duke Energy to limit access to groundwater use (Subchapter 02L .0104). The restricted designation (RS) may be requested for areas outside of an established compliance boundary when groundwater may not be suitable for use as drinking water supply without treatment. RS designation is a temporary designation and removed by the NCDEQ Director upon a determination that the quality of the groundwater has been restored to the applicable standards or when the groundwater has been reclassified by the NCDEQ. NCDEQ is authorized to designate existing or potential drinking water (Class GA groundwater) as RS where the Director has approved a CAP, or the termination of corrective action, that will not result in the immediate restoration of such groundwater to the standards established in 02L.

1.5 Facility Description

(CAP Content Section 1.E)

1.5.1 Location and History of Land Use

(CAP Content Section 1.E.a)

CSS is located on the south side of the Broad River on Duke Power Road (McCraw Road) in Mooresboro, located in Cleveland and Rutherford Counties, North Carolina **(Figure 1-1).** CSS is a coal-fired and natural gas-fired electricity generating facility with a current capacity of 1,381 megawatts (MW). The Station

began commercial operations in July 1940 with Units 1, 2, 3, and 4 (198 MW total). Unit 5 (556 MW) began operations in 1972, increasing the total plant capacity to 754 MW. Construction of Unit 6, an 825 MW clean-coal unit, began in 2008, and the unit began commercial operations in 2012. Units 1 through 4 were retired from service in October 2011. Natural gas infrastructure was completed to co-fire up to 40 percent natural gas on Unit 5 and up to 100 percent on Unit 6. The first fire for natural gas at Unit 5 occurred on October 31, 2018 and the first fire for natural gas at Unit 6 occurred on November 25, 2018.

The area surrounding the CSS ash basins generally consists of residential properties, undeveloped land, and the Broad River (**Figure 1-2**). Duke Power Road (McCraw Road) runs from northwest to southeast in the vicinity of the Site. Suck Creek, located west of the active ash basin (AAB), transects the Site generally from south to north, discharging to the Broad River. Topography at the CSS site ranges from approximate high elevations of 832 feet southwest of the AAB and 856 feet southwest of the U5 AB, to a low elevation of 656 feet at the interface with the Broad River on the northern extent of the Site.

Topography generally slopes from south-to-north across the Site with an elevation difference of approximately 190 feet over an approximate distance of 4,000 feet. Surface water drainage generally follows Site topography and flows from the south to the north across the Site except where the ash basins or other construction have modified natural drainage patterns. Unnamed drainage features, located near the western and eastern edges of the Site, generally flow north to the Broad River. The approximate historical pond elevation for the AAB was 762 feet. The elevation of the Broad River at the Site is approximately 656 feet.

The station and supporting facilities, which occupy approximately 1,000 acres, are owned by Duke Energy. Based on a review of available historical aerial photography, the Site consisted of rural residential (assumed to be housing for plant workers) and woodlands as early as 1955. **Figure 1-3** presents an aerial photograph from 1955, which shows the development of the Site including Units 1-4 and the coal pile. This photograph is prior to construction of the Site ash basins.

The U1-4 AB is located immediately east of the retired Units 1-4. It was constructed in 1957 and began operations the same year. The U1-4 AB was

retired in 1977 when it reached capacity. Excavation of ash from the basin was completed in February 2018.

The U5 AB is located on the western portion of the Site, west and southwest of Units 5 and 6. The U5 AB is currently used as a laydown yard for the Station. This ash basin was constructed in 1970 (in advance of Unit 5 operations) and received sluiced ash from Unit 5 from 1972 until 1980 when it reached capacity. It is currently covered with a layer of topsoil and is stable with vegetation. The basin currently receives storm water from a localized drainage area. Storm water from the U5 AB is discharged through National Pollutant Discharge Elimination System (NPDES) storm water outfall SW009.

The AAB is located on the eastern portion of the Site, east, and southeast of Units 5 and 6. Construction of the first phase of the AAB was completed in 1975, and it began receiving sluiced ash from Unit 5. The AAB expanded in 1980 to its current footprint. CCR was hydraulically sluiced to the AAB from Unit 5 until 2018. Unit 5 and 6 currently operate with dry bottom ash and dry fly ash handling and ash from the units is beneficially reused or disposed of in the on-Site Coal Combustion Products (CCP) Landfill. Decanting from the AAB commenced on March 31, 2019, and is ongoing.

On March 31, 2019, all Station wastewater flows were routed to the either the Basement Basin (Holding Cell) or two new lined Holding Basins located in the U1-4 AB footprint. The effluent from the Basement Basin (Holding Cell) and the Holding Basins are discharged to the new wastewater treatment plant (WWTP), which is a physical/chemical treatment system consisting of pH adjustment, coagulation and flocculation. Solids are removed from the wastewater using high-rate clarifiers and polishing filters, if necessary. Wastewater is discharged to the Broad River through NPDES Outfall 005 (**Figure 1-4**).

An unlined ASA is located adjacent to the north end of the AAB. The ash in the ASA was removed from the U1-4 AB and placed in the ASA in the 1970s. A spoil area, that was previously thought to also be an ash storage area, is located to the east of the ASA and may contain soil from the AAB embankment dam construction. The spoil area is not considered a source area in this CAP Update. Site features are depicted in **Figure 1-2.**

1.5.2 Operations and Waste Streams Coincident with the Ash Basins

(CAP Content Section 1.E.b)

Coal-Related Operational Storage and Waste Streams Coincident with the Ash Basins

Coal is a highly combustible sedimentary or metamorphic rock typically dark in coloration and present in rock strata known as coal beds or seams. Coal is predominantly made up of carbon and other elements such as hydrogen, oxygen, nitrogen, and sulfur as well as trace metals. The composition of coal makes it useful as a fossil fuel for combustion processes. Coal results from the conversion of dead vegetative matter into peat and lignite. The exact composition of coal varies depending on the environmental and temporal factors associated with its formation.

Coal has arrived at CSS through rail transportation since operations began. Coal storage has historically occurred at the Site's coal pile located immediately northeast of Unit 5 and north of the gypsum stack-out area (**Figure 1-2**). The coal pile is not within the scope of this CAP (see **Section 3.0**). The coal is stored in the coal pile until it is conveyed via transfer belts to the Units, where it is pulverized before being utilized in the boilers for combustion in the steam generation process of producing electricity. Coal ash and other CCR are produced from coal combustion. The smaller ash particles (fly ash) are carried upward in the flue gas and are captured by an air pollution control device, such as an electrostatic precipitator. The larger ash particles (bottom ash) fall to the bottom of the boiler.

Approximately 70 percent to 80 percent of ash produced during coal combustion is fly ash (EPRI, 1995). Typically, 65 to 90 percent of fly ash has particle sizes that are less than 0.010 millimeters (mm). In general, fly ash has a grain size distribution similar to silt. The remaining 20 percent to 30 percent of ash produced is considered bottom ash. Bottom ash consists of angular particles with a porous surface and is usually gray to black in color. Bottom ash particle diameters can vary from approximately 38 mm to 0.05 mm. In general, bottom ash has a grain size distribution similar to fine gravel to medium sand (EPRI, 1995).

Non-Coal-Related Operational Storage and Waste Coincident with the Ash Basins

No non-coal related waste streams or environmental incidents (*i.e.*, releases that initiated notification to NCDEQ) are known to have occurred in the vicinity of

the ash basins or ASA; therefore, no environmental incidents at the CSS are relevant to this CAP Update. Incidents that initiated notifications to NCDEQ have only occurred in the vicinity of the Plant area, and consisted of minor releases of fuel oil associated with fuel storage tanks and/or associated piping, hydraulic oil spills, and storm water and leachate releases to surface water and are not relevant to this CAP. None of these incidents had an effect on the ash basin COI distribution in groundwater because none of these incidents are hydraulically connected to the ash basins as to have an effect on the remedial approach or geochemistry in the areas identified for remediation.

1.5.3 Overview of Existing Permits and Special Orders by Consent

(CAP Content Section 1.E.c)

NPDES Permit

Duke Energy is authorized to discharge wastewater from the CSS AAB to the Broad River (Outfall 002) in accordance with NPDES Permit NC0005088, which was issued on September 1, 2018, and expires on August 31, 2023.

The sources of wastewater previously sluiced to the AAB include low volume wastes, coal pile runoff, metal cleaning wastes, treated domestic wastewater, chemical metal cleaning wastes, water treatment system wastewaters, ash transport water, landfill leachate [landfill contains fly and bottom ash, gypsum from the flue gas desulfurization (FGD) system, and other permitted wastes], cooling towers blowdown, and storm water runoff from limestone stacking area and gypsum stacking area. Inflows to Outfalls 002 and 005 are shown on **Figure 1-4**:

The CSS operates the following outfalls:

- ***Outfall 002:*** Ash Basin Treatment System: *Continue to discharge treated wastewater from the ash basin through outfall 002, containing low volume wastes, coal pile runoff, metal cleaning wastes, treated domestic wastewater, chemical metal cleaning wastes, water treatment system wastewaters, ash transport water, landfill leachate (landfill contains fly and bottom ash, and gypsum from FGD system), cooling towers blowdown, runoff from limestone stacking area and gypsum stacking area. Upon commencement of the discharge from Outfall 005 Wastewater Treatment System discharge wastewater from the ash basin decanting and dewatering.*

- ***Internal Outfall 004:*** *Flue Gas Desulfurization Treatment System: CSS continues to operate a FGD wet scrubber treatment system consisting of equalization tank, reaction tank, clarifier, filters, and effluent tank formerly discharging to the AAB (Outfall 002). On commencement of the discharge from Outfall 005 (WWTS discharge) the effluent from the FGD treatment system and the heat exchanger non-contact cooling water combined with the effluent of the Wastewater Treatment System (Outfall 005) is discharged through Outfall 004.*
- ***Outfall 005:*** *Upon commencement of the discharge from the new Wastewater Treatment System, discharge holding basin effluent (Outfall 002C - Unit 5 fly ash silo sump, coal pile runoff, gypsum pile runoff and limestone pile runoff), Basement Basin effluent (RO reject, Unit 5 process and stormwater and Unit 6 sanitary system), Unit 6 cooling tower blowdown, landfill leachate, Unit 6 process sump (mechanical drag chain overflow, and cooling tower raw water treatment wastwaters, Unit 5 process sump (sanitary system, low volume wastes, mechanical drag chain overflow and cooling tower blowdown), ash basin dewatering/decanting. The FGD WWTS discharge (Internal Outfall 004) and heat exchanger non-contact cooling water will be combined with the discharge from the WWTS before discharge to the Broad River*
- ***Outfall 002B:*** *Basement Basin Overflow: Discharge overflow from a 100 year 24 hour storm event. The Basement Basin receives wastewater from the Unit 6 sanitary system, Unit 5 stormwater and low volume wastes and RO reject. This outfall discharges to the Broad River.*
- ***Outfall 002C:*** *Holding Basin Emergency Overflow – Discharge overflow from a 100-year, 24-hour storm event from the Holding Basin. The Holding Basin receives wastewater from the coal pile runoff, gypsum pile runoff, limestone pile runoff, Unit 5 fly ash silo sump and Basement Basin auxiliary basin overflow. This outfall discharges to the Broad River.*
- ***Outfalls 104 and 106:*** *Constructed Seeps: Continue to discharge seepage from Outfall 104 (latitude 35° 13′ 3.5″ longitude 81° 45′ 9.3″) and Outfall 106 (latitude 35° 13′ 6.3″ longitude 81° 44′ 53.7″). Outfall 104 discharges to the Broad River, and Outfall 106 discharges to an unnamed tributary of the Broad River.*

Special Order by Consent

A Special Order by Consent (SOC) was issued to Duke Energy on April 25, 2018, to address the elimination of seeps from Duke Energy's coal ash basins during the separate and independent process of ash basin closure. The locations

included in the SOC are subject to the monitoring and evaluation requirements contained in the SOC. The SOC provided the definition for constructed seeps [seeps that (1) are on or within the dam structures, and (2) convey wastewater via a pipe or constructed channel directly to a receiving water] or non-constructed seeps (seeps that do not meet the "constructed seep" definition). Ash basin decanting, now under way, is expected to substantially reduce or eliminate discharge from the seeps near the AAB.

The SOC requires Duke Energy to accelerate ash basin decanting. After completion of decanting, remaining seeps, if not dispositioned in accordance with the SOC, are to be characterized. After post-decanting seep characterization, an amendment to the CAP and /or Closure Plan(s) may be required to address remaining seeps. The SOC terminates 180 days after decanting or 30 days after approval of the amended CAP. AAB decanting began on March 31, 2019. As of December 1, 2019, approximately 269,600,000 gallons of water have been removed from the AAB and the water elevation has decreased by 28.9 feet. The SOC requires completion of decanting of the AAB by March 31, 2020.

Permitted Solid Waste Facilities

There is one solid waste facility associated with CSS:

- James E. Rogers Energy Complex Coal Combustion Products (CCP) Landfill (NCDEQ Permit No. 8106-INDUS)

The CCP Landfill is located south of the U5 AB on the south side of Duke Power Road (**Figure 1-2**). The CCP Landfill is not located within the ash basin groundwater drainage systems and is not addressed as part of this CAP Update.

Additional Permits

In addition to NPDES wastewater and solid waste permits, CSS has an air permit (04044T39), an active Underground Storage Tank Permit (No. 0-008944), and an Asbestos Non Schedule Abatement Permit (NC24923).

CSS is subject to federal NPDES storm water discharge permit requirements per 40 Code of Federal Register (CFR) §122.26 (b)(14)(vii). The current NPDES Industrial Storm Water Permit, NCS000571, became effective on October 1, 2015. The permit expires on September 30, 2020. Storm water at the Site discharges to Suck Creek and the Broad River, a class WS-IV water in the Broad River Basin.

Erosion and sediment control (E&SC) permits are required for construction and excavation related activities including general construction projects and environmental assessment and remediation projects if the area of disturbance is greater than one acre. Multiple E&SC permits have been obtained for various projects implemented at the Site, including environmental related projects, such as well installation and access road construction. Most of the E&SC permits are closed as the related projects are completed. E&SC permits will continue to be obtained prior to implementation of additional construction projects, as appropriate.

2.0 RESPONSE TO CSA UPDATE COMMENTS

(CAP Content Section 2)

2.1 Facility-Specific CSA Update Comment Letter and Specific Comments

(CAP Content Section 2.A.)

Duke Energy submitted a 2018 CSA Update (Synterra, 2018a) to NCDEQ. In a letter from NCDEQ to Duke Energy dated June 29, 2018, NCDEQ stated that sufficient information had been provided in the 2018 CSA Update to allow preparation for the CAP Update. The letter also provided a number of CSA-related comments and items required to be addressed prior to or as part of the CAP Update submittal (**Appendix A**).

On July 17, 2018, Landon Davidson with the NCDEQ Asheville Regional Office (ARO) submitted an electronic mail with the subject: *Specific comments (28 pages in total) Pertinent to Individual Source Areas and to the report titled 'Cliffside CSA Update' (Synterra, January 31, 2018)* to Ryan Czop with Duke Energy. The 28 page document attached to the July 17, 2018 email outlines additional specific comments to the 2018 CSA Update (**Appendix A**).

2.2 Duke Energy's Response to NCDEQ CSA Update Comments

(CAP Content Section 2.B., 2.B.a, and 2.B.b)

Responses to NCDEQ comments within the June 29, 2018 letter are summarized in **Appendix B**. Responses to the July 17, 2018 electronic mail specific comments are provided in **Appendix B**. The responses provide references to the sections and elements of the CAP Update where the comments are addressed and/or provide additional supporting information to address the comments. Additional content related to NCDEQ's comments are either included within sections of this CAP Update or as standalone appendices to this CAP Update, such as the groundwater modeling reports and surface water evaluation reports.

Activities that directly addressed NCDEQ comments include:

- Additional monitoring wells were installed within the shallow, deep, and bedrock flow zones to refine the delineation of groundwater COIs. The locations of the monitoring wells are presented on **Figure 1-2**. Comprehensive groundwater analytical data are included in **Appendix C**, Table 1. Discussion of groundwater COI extent is included in **Sections 6.1.4, 6.10.4,** and **6.19.4**.
- Presenting conclusive data analysis and interpretation of site conditions.

- A description of the major factors that control COI distribution and transport within each source area are provided in the CAP Update (**Section 5**). The Cliffside flow and transport model and geochemical model were updated to incorporate additional assessment data and information. The models were used to evaluate current and predicted future Site conditions. The flow and transport model report is provided as **Appendix G**. The geochemical model report is provided as **Appendix H**.
- Updating concentration versus time and concentration versus distance figures. The monitored natural attenuation (MNA) report provides updated figures and interpretations of COI transport (**Appendix I**).
- Updated groundwater level maps based on a site-wide groundwater elevation data and concurrent surface water level data is provided in **Figures 5-4a** through **5-5c.** These figures include water levels from newly installed monitoring wells to refine the understanding of groundwater flow at the Site.
- The CAP Update report is separated and discussed by source area. The AAB and adjacent ASA (**Section 6.1** through **6.9**), U1-4 AB (**Section 6.10** through **6.18**), and U5 AB (**Section 6.19** through **6.27**) are described and assessed individually in the report with the format and content requested by NCDEQ in the 2019 CAP guidance.
- An additional evaluation of analytical results in samples collected from private water supply wells near CSS is presented in **Sections 6.2.2** (AAB and ASA), **6.11.2** (U1-4 AB), and **6.20.2** (U5 AB) of the CAP Update. A well-by-well summary of COI exceedances and characterization is provided in CAP Update **Table 6-9**. The findings of the water supply well evaluation found that no private drinking water wells are impacted by COIs attributable to the CSS ash basins.

3.0 OVERVIEW OF SOURCE AREAS BEING PROPOSED FOR CORRECTIVE ACTION

(CAP Content Section 3)

The CSS AAB, U1-4 AB, and U5 AB are the CAMA-regulated units at the Site. The only additional source located within or adjacent to the ash basins and addressed under this CAP Update includes the ASA. **Figure 1-2** shows the location of the ash basin waste boundaries and compliance boundaries, and the ASA waste boundary *(CAP Content Section 3.A and 3.A.a).*

Other facilities at the Site are not part of the source areas addressed herein. A consensus reached with the NCDEQ DWR regarding sources not considered for corrective action as part of this CAP Update, which was provided in a letter from NCDEQ to Duke Energy dated April 5, 2019 (**Appendix A).** Brief descriptions of these facilities, their status of inclusion or exclusion as part of the source areas, and the rationale for inclusion or exclusion is provided in **Table 3-1** (*CAP Content Section 3.B)***.**

The Cliffside AAB, U1-4 AB, and U5 AB are source areas carried forward as part of this CAP Update. The ASA is located adjacent to the AAB and is also a source carried forward as part of this CAP Update. Groundwater sampling data indicate constituents similar to COIs identified from CAMA groundwater monitoring of the AAB (*e.g.* boron) are present in groundwater beneath the ASA footprint. The AAB compliance boundary passes through the central portion of the ASA in an east to west orientation (**Figure 1-2**). Groundwater COI migration from the AAB comingles with the COIs in groundwater emanating from and beneath the ASA. The ASA contains ash that is both within and beyond the AAB compliance boundary. Groundwater COI migration from the AAB is predicted to continue to migrate beyond the compliance boundary in the ASA in the future. Groundwater from the northwestern portion of the AAB primarily flows north, through the ASA, where corrective action is planned. The corrective action approach for the AAB and ASA is discussed in detail in **Section 6.5.2**.

Sources Not Connected to the Ash Basins/To Be Addressed in Subsequent CSAs

(CAP Content Section 3.B)

Other facilities at the Site are not part of the source area addressed herein. A consensus was reached with the NCDEQ DWR regarding sources not considered for corrective action as part of this CAP Update was provided in a letter from NCDEQ to Duke Energy dated April 5, 2019 (**Appendix A**). Brief descriptions of these facilities, their status of inclusion or exclusion as part of the source area, and the rationale for inclusion or exclusion is provided in the **Table 3-1** (*CAP Content Section 3.B*). Corrective action approach for the ash basins and coal piles is discussed in detail in **Section 6.0**.

4.0 SUMMARY OF BACKGROUND DETERMINATIONS

(CAP Content Section 4)

Metals and inorganic constituents, typically associated with CCR material, are naturally occurring and present in the Piedmont physiographic province of north-central North Carolina. The metals and inorganic constituents occur in soil, groundwater, surface water, and sediment. Background analytical results are used to compare detected constituent concentration ranges from the source area relative to native conditions.

The statistically derived background values for the site are used for screening of assessment data collected in areas of potential migration of COIs from a source area. If the assessment data concentrations are less than background, it is likely COI migration has not occurred in the area. If the assessment data concentrations are greater than background, additional lines of evidence are used to determine whether the concentrations represent migration from a source area. Additional lines of evidence include, but may not be limited to:

- Evaluation of whether the concentration is within the range concentrations detected at the Site, or within the range for the region
- Evaluation of whether there is a migration mechanism through the use and interpretation of hydraulic mapping (across multiple flow zones), flow and transport modeling, and understanding of the conceptual site model (CSM)
- Evaluation of concentration patterns (i.e., do the patterns represent a discernable plume or migration pattern?)
- Consideration of natural variations in Site geology or geochemical conditions between upgradient (background locations) and downgradient area
- Consideration of other constituents present at concentrations greater than background values

The CSS and nine other Duke Energy facilities (Allen Steam Station, Belews Creek Steam Station, Buck Steam Station, Cape Fear Steam Electric Plant, Dan River Steam Station, Marshall Steam Station, Mayo Steam Electric Plant, Riverbend Steam Station, and Roxboro Steam Electric Plant) are situated in the Piedmont physiographic province of north-central North Carolina. The nine Duke Energy facilities are located within a 185-mile radius from Cliffside. Statistically derived background values from these facilities provide a geographic regional background range for comparison. Generally background values derived from the Piedmont facilities are similar, with some exceptions.

As more background data become available, the background values may be updated to continue to refine the understanding of background conditions. However, these multiple lines of evidence, and additional steps in the evaluation process, will continue to be important tools to distinguish between background conditions and areas affected by constituent migration.

Background sample locations were selected in areas that represent native conditions, not affected by the Site coal ash basins or additional source areas. A map showing background locations for all media including groundwater, surface water, soil, and sediments are shown in **Figure 4-1** (*CAP Content Section 4.A*). Tables referenced in this section present background datasets for each media, statistically calculated background values for soil and groundwater, and background dataset ranges for surface water and sediment.

Background soil and groundwater locations approved by NCDEQ, as well as statistically derived background values, are detailed in **Sections 4.1 and 4.2**. Background values were not calculated for surface water and sediment; however, background locations for surface water and sediment were approved by NCDEQ as part of the evaluation of potential groundwater migration to surface water (**Appendix J**) and are detailed in **Sections 4.3** and **4.4**.

4.1 Background Concentrations for Soil

The locations of the background soil borings are shown on **Figure 4-1**. The soil background dataset with the appropriate PSRG protection of groundwater (POG) standards and background values are included in **Appendix C,** Table 4 (*CAP Content Section 4.B*). Background soil samples were collected from multiple unsaturated depth intervals (**Table 4-1**). All samples were collected from depth intervals greater than 0.5 feet below ground surface and greater than one foot above the seasonal high water table. The CSS background soil boring locations, unsaturated soil depth interval, and number of discreet samples collected from each unsaturated soil depth interval are included in **Table 4-1**.

The suitability of each of these locations for evaluating background conditions was assessed in a technical memorandum dated May 26, 2017. In a response letter dated July 7, 2017, NCDEQ approved use of the soil data for determination of background threshold values (BTVs) (NCDEQ, 2017). BTVs were calculated using data from background unsaturated soil samples collected June 2015 to April 2017 and in accordance with the *Revised Statistical Methods for Developing Reference Background Concentrations for Groundwater and Soil at Coal Ash Facilities* (HDR and SynTerra, 2017).

Calculated soil BTVs were submitted to NCDEQ in an *Updated Background Threshold Values for Soil Technical Memorandum*, dated September 5, 2017. NCDEQ DWR provided a response letter (Zimmerman to Draovitch, October 11, 2017) for 10 of the Duke Energy facilities. The letter provided comments and approved provisional background threshold values (PBTVs) for CSS (**Appendix A**). Additional soil samples were collected on October 17 and 19, 2017, to satisfy the requirement concerning the minimum number of soil samples, and to analyze antimony and thallium with laboratory limits less than the PSRG POG standards.

NCDEQ provided comments pertaining to the background dataset presented in the CSA Update (SynTerra, 2018a) in a letter dated May 14, 2018. In those comments, NCDEQ stated that some BTVs for the subject sites were unacceptable (**Appendix A**). These included soil BTVs for antimony, boron, cadmium, mercury, and molybdenum at CSS. Duke Energy agreed with NCDEQ modifications to soil BTVs in email correspondence (Czop and Campbell, August 9, 2018). In a letter dated May 23, 2019 NCDEQ approved the CSS soil BTVs for antimony, boron, cadmium, mercury, and molybdenum (**Appendix A**). DWR recognized that as new data are gathered, refinement of the BTVs might be necessary. Thus, periodic review of the soil dataset and recalculation of the soil BTVs may occur.

Soil BTVs for CSS were updated in 2019 and are provided, along with the original soil BTVs for comparison, in **Table 4-2**. The updated BTVs were calculated using data from background unsaturated soil samples collected June 2015 to April 2017 but the 2019 dataset retained extreme outlier concentrations when data validation and geochemical analysis of background groundwater concentrations indicated that those outlying concentrations did not result from sampling error or laboratory analytical error. The approach used to evaluate whether extreme outlier concentrations should be retained in background soil datasets is presented the technical memorandum prepared by Arcadis titled, "*Background Threshold Value Statistical Outlier Evaluation – Allen, Belews Creek, Cliffside, Marshall, Mayo, and Roxboro Sites,"*, which was provided as an attachment to the *Updated Background Threshold Values for Constituent Concentrations in Groundwater* (SynTerra, 2019e). The updated BTVs were calculated in accordance with the *Revised Statistical Methods for Developing Reference Background Concentrations for Groundwater and Soil at Coal Ash Facilities* (HDR and SynTerra, 2017).

4.2 Background Concentrations for Groundwater

The groundwater system beneath the Site is divided into the following three flow zones (layers) to distinguish the interconnected aquifer system: the shallow flow layer, deep

(transition zone) flow layer, and the bedrock flow layer. The CSS flow zones and background groundwater monitoring wells installed within each flow zone include:

- Shallow flow zone: BG-1S, GWA-24S, GWA-25S, GWA-30S, MW-30S, and MW-32S
- Deep flow zone: BG-1D, CCPMW-1S, GWA-24D, MW-24D, MW-30D, MW-30DA, and MW-32D
- Bedrock flow zone: CCPMW-1D, GWA-24BR, GWA-30BR, MW-22BR, MW-22DR, MW-24DR, and MW-32BR

The locations of the background monitoring wells are shown in **Figure 4-1**. The groundwater background dataset with the appropriate 02L standards, IMAC, and background values is included in **Appendix C,** Table 1 (*CAP Content Section 4.C*). The suitability of each of these locations for background purposes was evaluated in the *Updated Background Threshold Values for Groundwater* technical memorandum (May 26, 2017). Identified groundwater data appropriate for inclusion in the statistical analysis to BTVs was approved by NCDEQ in a response letter dated July 7, 2017 (NCDEQ, 2017) provided in **Appendix A**.

Groundwater BTVs related to COIs at the CSS were initially calculated and submitted to NCDEQ in an *Updated Background Threshold Values for Groundwater Technical Memorandum*, dated August 30, 2017. NCDEQ DWR provided comments and approval of BTVs in a response letter dated October 11, 2017, provided in **Appendix A**. Groundwater background values for each groundwater flow zone at CSS were updated in 2019 and are provided, along with the original groundwater BTVs for comparison, in **Table 4-3** (*CAP Content Section 4.C*).

The updated background dataset was calculated using concentration data from background groundwater samples collected from 2011 to 2018. Background values were calculated in accordance with the *Revised Statistical Methods for Developing Reference Background Concentrations for Groundwater and Soil at Coal Ash Facilities* (HDR and SynTerra, 2017). The updated background datasets for each flow system used to statistically assess naturally occurring concentrations of inorganic constituents in groundwater are presented in the report *Updated Background Threshold Values for Constituent Concentrations in Groundwater* (SynTerra, 2019d) provided to NCDEQ on June 13, 2019. The updated background dataset for each hydrogeologic flow zone consists of an aggregate of total (non-filtered) concentration data pooled across background monitoring wells installed within that flow layer. The use of updated groundwater BTVs is currently under appeal.

4.3 Background Concentrations for Surface Water

Background surface water sample locations in the Broad River and Suck Creek are located upstream, or outside potential groundwater impact from the source areas to surface water. Surface water background sample locations are outside of future groundwater to surface water migration pathways as determined by predictive groundwater modeling results.

Background surface water sample locations include three locations from the Broad River, one location from the Second Broad River, and four locations from Suck Creek. Background surface water sample locations are shown in **Figure 4-1**. Locations are summarized below with the surface water body and spatial distribution relative to the source area:

- Broad River sample locations upstream of potential groundwater impact to surface water from the source areas: SW-9, SW-BRBG, and A_2_UP.
- Second Broad River sample location upstream of potential groundwater impact to surface water from the source areas: SW-SBRBG.
- Suck Creek sample locations upstream of potential groundwater impact to surface water from the source areas: SW-2 and SC_2_UP.
- Suck Creek sample locations routinely collected as part of the CCP Landfill monitoring program upstream of potential groundwater impact to surface water from the source areas: CCPSW-1 and CCPSW-2.

Background surface water data are used for general comparative purposes. The analytical results provide a comparative range of naturally occurring constituent concentrations present at background locations. Background surface water analytical dataset ranges compared to 02B and United States Environmental Protection Agency (USEPA) criteria are included in **Table 4-4** (*CAP Content Section 4.D*). The surface water background dataset with the appropriate 02B standards is included in **Appendix C**, Table 2 *(CAP Content Section 4.D).*

Background data sets from each location include data from four or more sampling events. Surface water samples from background locations have been collected in accordance with NCDEQ guidance as part periodic sampling events, which include the comprehensive sampling event in January 2017 and February 2017 used to assess surface water compliance for implementation of corrective action under 15A NCAC 02L .0106 (k) and (l). Analytical results from background surface water sample locations in the Broad River indicate all constituent concentrations are less than 02B standards with

the exception of turbidity (2 results) and total dissolved solids (TDS) (1 result). All constituent concentrations from the background surface water sample location in the Second Broad River are less than 02B standards. Constituent concentrations from background surface water sample locations in Suck Creek are less than the 02B standards with the exception of turbidity (2 results), mercury (1 result), dissolved copper (2 results) and dissolved lead (1 result).

4.4 Background Concentrations for Sediment

Background sediment sample locations are generally co-located with background surface water sample locations in the Broad River, Second Broad River, and Suck Creek. Background sediment sample locations are located upstream, or outside potential groundwater to surface water impact, from the source areas. Background sediment sample locations remain outside of future migration areas as determined by groundwater predictive modeling.

Background sediment sample locations (**Figure 4-1)** include:

- Broad River: SED-1 (located near background surface water sample locations SW-BRBG and A_2_UP).
- Second Broad River: SED-4 (located near background surface water sample location SW-SBRBG)
- Suck Creek: SED-16 (located near background surface water sample location SC_2_UP).

Background sediment data are used for general comparative purposes. The analytical results provide a comparative range of naturally occurring constituent concentrations present at background locations. Background sediment analytical dataset ranges are presented in **Table 4-5** (*CAP Content Section 4.E*). The sediment background dataset with the appropriate comparative standards is included in **Appendix C**, Table 5 *(CAP Content Section 4.E).*

Background data sets include one sample collected from each location. Sediment samples were collected concurrently with a background surface water sample.

5.0 CONCEPTUAL SITE MODEL

(CAP Content Section 5)

The CSM is a descriptive and illustrative representation of the hydrogeologic conditions and COI interactions specific to the Site. The purpose of the CSM pertaining to the Cliffside ash basins and ASA is to provide a current understanding of the distribution of constituents with regard to the Site-specific geology/hydrogeology and geochemical processes that control the transport and potential impacts of COIs in various media. This information is also considered with respect to exposure pathways to human and ecological receptors.

The CSM presented in this section is based on an United States Environmental Protection Agency (USEPA) document titled *Environmental Cleanup Best Management Practices: Effective Use of the Project Life Cycle Conceptual Site Model* (USEPA, 2011). That document describes six CSM stages for an environmental project life cycle and is an iterative tool to assist in the decision process for characterization and remediation during the life cycle of a project as new data become available. The six CSM stages for an environmental project life cycle are described below:

1. **Preliminary CSM Stage** – Site representation based on existing data; conducted prior to systematic planning efforts.
2. **Baseline CSM Stage** – Site representation used to gain stakeholder consensus or disagreement, identifies data gaps and uncertainties; conducted as part of the systematic planning process.
3. **Characterization CSM Stage** – Continual updating of the CSM as new data or information is received during investigations; supports remedy decision making.
4. **Design CSM Stage** – Targeted updating of the CSM to support remedy design.
5. **Remediation/Mitigation CSM Stage** – Continual updating of the CSM during remedy implementation; and providing the basis for demonstrating the attainment of cleanup objectives.
6. **Post Remedy CSM Stage** – The CSM at this stage is used to support reuse planning and placement of institutional controls if warranted.

The current CSS CSM is consistent with Stage 4 "Design CSM", which allows for iterative improvement of the site CSM during design of the remedy while supporting development of remedy design basis (USEPA, 2011). A three-dimensional depiction of

the CSM under conditions prior to decanting and basin closure is presented as **Figure 5-1**.

Anticipated changes to Site conditions, such as with decanting and basin closure, have been incorporated into the CSM based on groundwater modeling simulations. Predicted and observed effects will be compared on an ongoing basis to further refine the CSM.

5.1 Site Geologic and Hydrogeologic Setting

(CAP Content Section 5.A.a)

5.1.1 Site Geologic Setting

(CAP Content Section 5.A.a)

The groundwater system at the ash basins and ASA is divided into the following three layers (zones) to distinguish the interconnected groundwater system: the shallow flow layer, deep (transition zone) flow layer, and the bedrock flow layer. The following is a summary of the natural hydrostratigraphic unit assessment observations:

- **Shallow flow layer:** Shallow soil and aquifer materials include fill, regolith, and saprolite. Fill material, used in the construction of the dams, generally consisted of reworked silty sand, clayey sand, and sand with clay and gravel. The regolith, in-place soil that develops by weathering, consists primarily of micaceous silty sand, micaceous silt, and clayey sand. Thickness of regolith — directly related to topography, type of parent rock, and geologic history —is relatively thin at the Site. Saprolite is soil developed by in-place weathering of rock that retains remnant bedrock structure. Saprolite consists primarily of dense to very dense silty sand and silty sand with gravel noted as micaceous in some boring logs. The shallow flow layer might or might not be saturated depending on the topographic area of the Site. Shallow flow layer wells are typically labeled with an "S", "AL", or "I" designation, although there are some exceptions in which "S" wells are screened in ash.
- **Deep/transition zone flow layer:** The deep flow layer (transition zone) consists of a relatively transmissive zone of partially weathered and significantly fractured bedrock encountered below the shallow zone as defined by drilling method refusal (*e.g.*, auger, casing advancer). Observations of core recovered from this zone included rock fragments, unconsolidated material, and highly oxidized bedrock material. Deep

flow layer wells are typically labeled with a "D", "DA", "BRU", or "BRUA" designation.

- **Bedrock flow layer:** Bedrock is defined as sound rock, based on sample rock quality designation (RQD)/recovery, generally slightly weathered to fresh and fractured. The main rock types at the Site consist of biotite gneiss and sillimanite schist. The biotite gneiss is predominantly gray to dark gray, fine to medium grained with some coarse grained zones, and thinly to medium banded. The biotite gneiss consists of quartz, plagioclase, biotite, and minor amounts of muscovite and garnet. The sillimanite schist is gray to light gray, fine to medium grained and consists of sillimanite, muscovite, quartz, and subordinate amounts of feldspar. It generally occurs as interlayers in the biotite gneiss. Groundwater movement in the bedrock occurs primarily in secondary porosity represented by fractures. Water-bearing fractures encountered are only mildly productive (providing water to wells). In areas where a preferential fracture sets exist, groundwater flow may be anisotropic and occur preferentially parallel to the predominant strke of bedrock fractures. The majority of water-producing fracture zones were found within the top 50 feet of competent rock. Cliffside bedrock fracture orientation and flow profile characterization data sets support overall fracturing and fracture aperture decreases with increasing depth, and a general decline in hydraulic conductivity with increasing depth below the top of bedrock. Bedrock wells are typically labeled with a "BR", "BRA", "BRB" or "BRL" designation. A detailed evaluation of bedrock conditions is located in **Appendix F**.

5.1.2 Site Hydrogeologic Setting

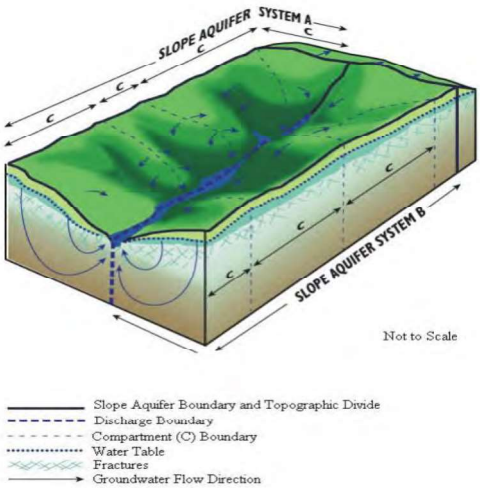
(CAP Content Section 5.A.a)

The groundwater system in the natural materials (saprolite/transition zone/bedrock) is consistent with the regolith-fractured rock system and is characterized as an unconfined, interconnected aquifer system typical of the Piedmont Physiographic Province.

A conceptual model of groundwater flow in the Piedmont, which applies to the CSS site, was developed by LeGrand (1988, 1989) and Daniel and Harned (1992) (**Figure 5-2**). The model assumes a regolith and bedrock drainage basin with a perennial stream. The model describes conditions before ash-basin construction, but the general groundwater flow directions are still relevant under current conditions. Groundwater is recharged by rainfall infiltration in the upland areas

followed by discharge to the perennial stream. Flow in the regolith follows porous media principals, while flow in bedrock occurs in fractures. Rarely does groundwater move beneath a perennial stream to another more distant stream or across drainage divides (LeGrand 1989).

FIGURE 5-2
LEGRAND SLOPE AQUIFER SYSTEM



Topographic drainage divides represent the natural groundwater divides within the slope-aquifer system. The areas between the topographic divides are flow compartments that are open-ended down slope. Compartmented groundwater flow, applicable to the ash basins and ASA, is described in detail in *A Master Conceptual Model for Hydrogeological Site Characterization in the Piedmont and Mountain Region of North Carolina* (LeGrand, 2004).

5.1.2.1 Groundwater Flow Direction

(CAP Content Section 5.A.a.i)

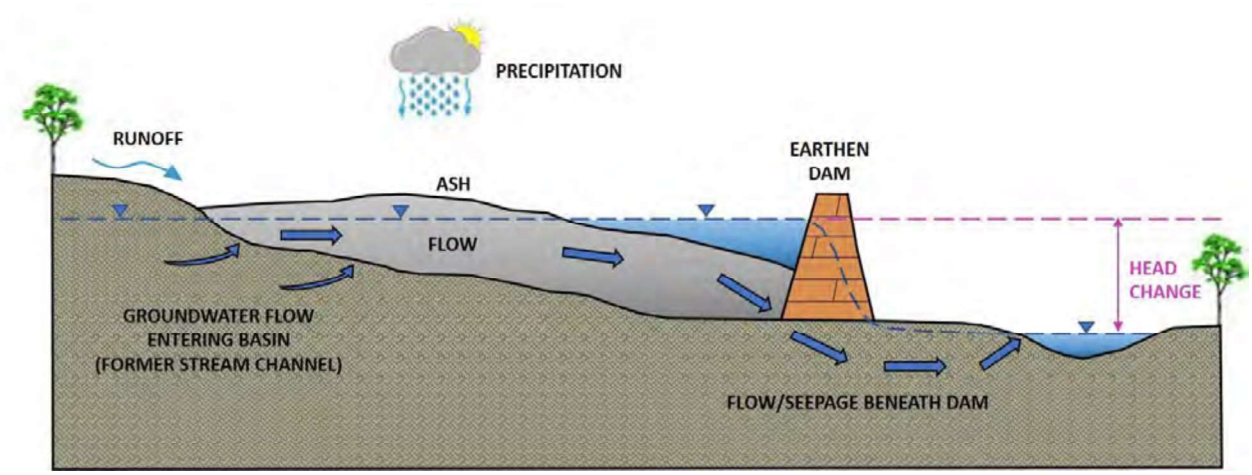
Groundwater divides are observed south, east, and west of the Site. A portion of the divide follows Duke Power Road (McCraw Road) along the southern portion of the Site. A divide is also present on the east side of the Site, between the AAB and the off-Site water supply wells to the east. A groundwater divide is also located west of the U5 AB. Groundwater on the basin sides of the groundwater divides flows toward the middle of the Site toward the ash basins while groundwater on the opposite sides of the groundwater divides flows away from the basins. The groundwater flow direction provides natural hydraulic control of ash basin constituent migration within the stream valley system. The predominant direction of groundwater flow at the Site is north toward the Broad River, with a portion of groundwater flow in the central part of the Site flowing toward Suck Creek and then north to the Broad River.

The AAB and U5 AB were constructed by damming former perennial stream valleys. Suck Creek was diverted from its original stream channel during construction of the AAB. The original channel flowed through the current location of the AAB upstream dam, meandered through the current

AAB footprint, and discharged to the Broad river near the location of the AAB downstream dam (**Figure 1-3**). The U1-4 AB was constructed in a low-lying area along the Broad River. The former stream valleys are bound by natural ridges. The stream valley system generally slopes to the north toward the Broad River. The groundwater flow direction provides natural control of potential COI migration within the former stream valley system.

The physical settings of the ash basins are flow-through water systems with groundwater migration into the upgradient ends, flowing laterally through the middle regions, and migrating downward near the dams. Near the AAB dams, vertical hydraulic gradients, imposed by hydraulic pressure of basin water, promote downward vertical gradients into the groundwater system. Beyond the dams, groundwater flows upward toward Suck Creek and the Broad River. Generally, the physical setting of the ash basins within a perennial stream valley limits the horizontal and vertical migration of constituents to areas near and directly downgradient of the basins' dams. The primary flow path of the groundwater remains in the basins' stream valley system. Therefore, areas upgradient and side-gradient of the basins have groundwater divides that limit groundwater flow in these directions.

FIGURE 5-3
GENERAL PROFILE OF ASH BASIN PRE-DECANTING FLOW CONDITIONS IN THE PIEDMONT



Note:
Drawing is not to scale

Water-level maps for each groundwater flow zone were constructed from groundwater and surface water elevations, obtained in April 2019 (**Figures 5-4a/b/c** and **Figures 5-5a/b/c**). April 2019 water level measurements and elevations are presented in **Table 5-1.** General groundwater flow directions can be inferred from the water-level contours. The groundwater flow direction for each flow zone at the Site is generally from south to north, with shallow groundwater in the central portion of the Site flowing toward Suck Creek and then north to the Broad River.

Based on the updated groundwater level maps, shallow groundwater flows out radially from the ash stockpile located in the AAB. Groundwater generally flows to the north, northwest, and southwest from the stockpile. The groundwater on the north side of the stockpile flows north to the Broad River, with a portion of the water flowing to the northwest toward Suck Creek. Groundwater on the northwest side of the stockpile flows northwest, through the AAB upstream dam toward Suck Creek. Groundwater on the west side of the stockpile flows generally southwest to Suck Creek. Groundwater to the east of the stockpile flows generally northeast through the AAB and ultimately to the Broad River.

The groundwater boundary that would be expected to be established by Suck Creek is not fully established at the AAB upstream dam. This is the portion of the creek that was re-routed for the construction of the AAB. Based on the groundwater and surface water elevations there appears to be underflow of Suck Creek at the AAB upstream dam in the deep and bedrock flow layers.

Groundwater in the deep and bedrock flow layers underflows the current, redirected Suck Creek channel northwest of the AAB upstream dam and flows toward the U1-4 AB before discharging to the Broad River. Shallow groundwater discharges to Suck Creek from the east and west (**Figure 5-4a**). **Figure 5-6** depicts a cross-sectional view of the AAB upstream dam area with groundwater elevations gauged during the April 2019 comprehensive groundwater gauging event. Based on these groundwater and surface water elevations, groundwater is controlled by Suck Creek in the shallow flow layer and does not flow under the creek from the AAB under the creek to the northwest.

To further assess the groundwater flow and COI transport at the AAB upstream dam, recent boron concentrations and generalized vertical gradients were plotted in each flow layer (**Figure 5-7**). Boron is reported primarily in the deep and bedrock flow layers in the monitoring wells west of Suck Creek (GWA-33BR, GWA-57BRU/BR, GWA-58BR, and GWA-62BRU/BR) and not in the shallow flow layer except for GWA-43S. These boron concentrations do not appear to be originating from the southwest in the area of the GWA-60, GWA-61, GWA-44, and MW-23 well clusters, which do not have the same elevated boron signature. GWA-44BR in the bedrock flow layer does have boron reported at a concentration (55 µg/L) slightly greater than the background value (50 µg/L), but the MW-23 well cluster is located between GWA-44BR and the AAB indicating the source of boron in this well is not the AAB.

Suck Creek establishes a weak groundwater hydraulic control at the AAB upstream dam. Suck Creek appears to hydraulically control shallow groundwater but not groundwater in the deep or bedrock flow layers. The predominant downward vertical gradients in this area indicate that deep and bedrock groundwater is continuing north towards the Broad river and not discharging to Suck Creek.

Predictive flow and transport model simulations indicate that the cessation of sluicing and subsequent decanting in the AAB will reduce the potential for COI transport prior to complete closure of the basin. Model simulations predict downward migration of groundwater below the dams north and west of the AAB will be limited without the presence of ponded water in the basin.

The following are conclusions pertaining to groundwater flow beneath the Site:

- Horizontal groundwater flow velocities in areas with ponded water within the AAB are less than those seen upgradient of the basin and below the ash basin dams.
- Downward vertical gradients occur just upstream of the ash basin dams.
- Upward vertical gradients occur beyond or downstream of the dams, which are the main groundwater discharge zones.

Empirical Site data from over 30 monitoring events over multiple seasonal variations and groundwater flow and transport modeling simulations support groundwater flow is away from water supply wells and that there are no exposure pathways between the ash basins and ASA and the pumping wells used for water supply in the vicinity of the Site. Water supply wells are now connected to the municipal water system or are outside, or upgradient of the groundwater flow system containing the ash basins and ASA. Domestic water supply wells are not affected by constituents released from the ash basins or ASA or by the different closure options, according to groundwater flow and transport model simulations.

5.1.2.2 Groundwater Seepage Velocities

(CAP Content Section 5.A.a.i)

Groundwater seepage velocities were calculated for current conditions using horizontal hydraulic gradients determined from measurements collected in April 2019 (**Table 5-1**). Hydraulic conductivity *(K)* and effective porosity (n_e) values were taken from the updated flow and transport model (**Appendix G**). Calibrated conductivity and porosity values for each flow layer were used in an effort to align velocity calculations with model predictions.

The flow and transport model uses subdivided horizontal hydraulic conductivity zones and a calibrated hydraulic conductivity for each zone and model flow layer. Simulated hydraulic conductivity values ranges from 0.28 to 42.5 feet per day (ft/day) in the shallow flow zone, from 0.0007 to 45.4 ft/day for the deep flow zone, and 0.001 to 126 ft/day for the bedrock flow zone. Hydraulic conductivity values used in calculating seepage velocity were selected based on an area's location within or proximity to subdivided hydraulic conductivity zones. The flow and transport model uses estimated effective porosity values of 30 percent for the shallow and deep flow zone, and 1 percent for the bedrock flow zone (**Appendix G**).

The horizontal groundwater seepage flow velocity (v_s) can be estimated using a modified form of the Darcy Equation:

$$v_s = \frac{K}{n_e}\left(\frac{dh}{dl}\right)$$

Using the April 2019 groundwater elevation data, the average horizontal groundwater flow velocity in the vicinity of the AAB was:

- 0.21 ft/day [77.32 feet per year (ft/yr)] in the shallow flow zone
- 0.25 ft/day (92.52 ft/yr) in the deep flow zone
- 0.23 ft/day (83.74ft/yr) in the bedrock flow zone

In the vicinity of the U1-4 AB, the horizontal groundwater flow velocity was:

- 0.43 ft/day (155.83 ft/yr) in the shallow flow zone
- 0.42 ft/day (153.79 ft/yr) in the deep flow zone
- 0.32 ft/day (117.42 ft/yr) in the bedrock flow zone

In the vicinity of the U5 AB, the average horizontal groundwater flow velocity was:

- 0.48 ft/day (175.73 ft/yr) in the shallow flow zone
- 0.52 ft/day (187.96 ft/yr) in the deep flow zone
- 0.48 ft/day (175.08 ft/yr) in the bedrock flow zone

Groundwater modeling predicts groundwater elevation changes associated with closure activities will change groundwater flow direction and velocity near the ash basins, especially near the AAB. As of December 1, 2019, approximately 269,600,000 gallons of water have been removed from the AAB. The water elevation in the basin has decreased by 28.9 feet in response to decanting, indicating significant water level changes in the basin has already occurred. For visualization, velocity vector maps depicting groundwater under pre-decanting and future conditions were developed.

The pre-decanting conditions velocity vector map was created from comprehensive Site data incorporated into the calibrated flow and transport model. The future condition velocity vector maps were created using predicted flow fields for the closure-in-place and the closure-by-excavation scenarios. **Figures 5-8a** through **5-9c** illustrate the potential future changes in groundwater flow compared to the current groundwater flow at the Site. Deep flow layers (transition zone modeled Layer 15 and upper bedrock modeled Layer 17) were selected for the velocity vector maps due to the aerial coverage of the vectors and the relatively high hydraulic conductivity of the deep flow layer.

- Vector velocity map for groundwater in the deep flow zone (modeled Layer 15) under current, pre-decanting conditions – **Figure 5-8a**
- Vector velocity map for groundwater in the deep flow zone (modeled Layer 15) under closure-by-excavation conditions – **Figure 5-8b**
- Vector velocity map for groundwater in the deep flow zone (modeled Layer 15) under closure-in-place conditions – **Figure 5-8c**
- Vector velocity map for groundwater in the deep flow zone (modeled Layer 17) under current, pre-decanting conditions – **Figure 5-9a**
- Vector velocity map for groundwater in the deep flow zone (modeled Layer 17) under closure-by-excavation conditions – **Figure 5-9b**
- Vector velocity map for groundwater in the deep flow zone (modeled Layer 17) under closure-in-place conditions – **Figure 5-9c**

These depictions illustrate potential future changes in groundwater flow compared with pre-decanting groundwater flow throughout the Site.

Key conclusions regarding groundwater flow direction and velocity based upon predictive model simulation results of future ash basin closure conditions are as follows:

AAB and ASA

- The former Suck Creek channel is predicted to re-form post-closure in the closure-by-excavation scenario beneath eastern and northeastern portions of the AAB. A tributary to the reformed Suck Creek channel is predicted to form beneath the southern portion of the AAB (**Figures 5-8b** and **5-9b**). These features can be inferred by the converging of velocity vectors in these areas.
- Groundwater flow patterns change in response to the reformed Suck Creek stream channel in the closure-by-excavation scenario. Post-closure flow directions within the basin (**Figures 5-8b** and **5-9b**) are toward the channel, with the central portion of the basin flowing more prominently to the east compared to current conditions (**Figure 5-8a** and **5-9a**) and the northern portion of the basin flowing more

prominently toward the Suck Creek channel and the AAB downstream dam.

- The groundwater flow direction in the northeast portion of the AAB shifts westward (and away from off-Site parcels) in both future closure scenarios (**Figures 5-8b/c** and **5-9b/c)** compared to current conditions (**Figure 5-8a** and **5-9a**).
- Groundwater flow velocities beneath the AAB upgradient of the AAB dams generally increase in both future closure scenarios (**Figures 5-8b/c** and **5-9b/c)** compared to current conditions (**Figure 5-8a** and **5-9a**). The AAB flow-through system currently restricts groundwater recharge beneath the AAB, as described in the CSM. These conditions change post-closure.
- Groundwater flow velocities near the AAB upstream dam and downstream dam generally decrease in both future closure scenarios (**Figures 5-8b/c** and **5-9b/c)** compared to current conditions (**Figure 5-8a** and **5-9a**). as a result of removal of the operating hydraulic head in the AAB. Significant downward vertical gradients and increased groundwater flow currently occur immediately beneath and surrounding the dams, which act as barriers to groundwater migration, as described in the CSM. These conditions change post-closure.
- Groundwater flow within the deep flow zone reduces and essentially ceases post-closure (as indicated by lack of vector arrows within dark blue regions) in natural topographic ridges near the AAB waste boundary, such as the spoil area, the eastern abutment of the AAB downstream dam, and the western edge of the AAB (**Figures 5-8b** and **5-8c**).
- Groundwater flow velocities remain similar and strongly northward toward the Broad River near the ASA under the post-closure scenarios.
- Velocity vector depictions for current and future post-closure conditions support that the Broad River and Suck Creek remain the only groundwater receptors downgradient of the AAB.
- Velocity vector depictions for current and future post-closure conditions support that groundwater flow from the AAB and ASA

does not and will not flow in the direction of residential areas and water supply wells to the southwest, southeast, east, or northeast.

U1-4 AB

The U1-4 AB excavation was completed in 2018; the excavation scenario (**Figures 5-8b** and **5-9b**) best illustrates the current velocity vectors for the U1-4AB. As modeling efforts began prior to completion of the basin excavation, the current conditions figures (**Figures 5-8a** and **5-9a**) include ash thicknesses that were present in the basin prior to excavation and are not representative of the current fully excavated condition of the U1-4 AB.

U5 AB

- The former drainage channel is predicted to return beneath the southeastern and eastern portions of the U5 AB under the closure-by-excavation scenario. The groundwater flow direction in the southeastern and eastern portions of the U5 AB shifts westward (and away from CSS infrastructure) in both future closure scenarios (**Figures 5-8b/c** and **5-9b/c)** compared to current conditions (**Figure 5-8a** and **5-9a**). The westward shift in flow direction is more pronounced in the closure-by-excavation scenario (**Figure 5-8b** and **5-9b**) than the closure-in-place scenario (**Figure 5-8c** and **5-9c**). The closure approach will affect the direction of the low pH in groundwater flow direction. Under closure by excavation the groundwater would no longer daylight to the surface, and under closure-in-place the reduced recharge would reduce but not eliminate flow to the surface.
- Groundwater flow velocities beneath the U5 AB upgradient of the U5 AB dams generally similar between both future closure scenarios (**Figures 5-8b/c** and **5-9b/c)** compared to current conditions (**Figure 5-8a** and **5-9a**). The U5 AB has currently does not have an operating hydraulic head due to lack of ponded water in the basin. The U5 AB also currently has a soil and vegetative cover. These conditions mean current and post-closure flow conditions within the basin footprint should not change significantly.
- Groundwater flow velocities near the U5 AB main dam and saddle dam generally decrease slightly in both future closure scenarios (**Figures 5-8b/c** and **5-9b/c)** compared to current conditions (**Figure 5-**

8a and **5-9a**). These slight decreases in flow velocities are likely as a result of removal of the dams (in the closure-by-excavation scenario, **Figures 5-8b** and **5-9b**) and a result of a reduction in groundwater elevations upgradient of the the dams in response to an engineered cover and reduced infiltration (in the closure-in-place scenario, **Figures 5-8c** and **5-9c**).

- Groundwater flow velocities post-closure remain similar and strongly northward toward the Broad River near the U5 AB.
- Velocity vector depictions for current and future post-closure conditions support that the Broad River remains the only groundwater receptor downgradient of the U5 AB.
- Velocity vector depictions for current and future post-closure conditions support that groundwater flow from the U5 AB does not and will not flow in the direction of off-Site residential areas and water supply wells to the southwest, southeast, or east.

5.1.2.3 Hydraulic Gradients

(CAP Content Section 5.A.a.i)

Across the Site the average horizontal hydraulic gradient (measured in feet/foot) for each flow zone is: 0.03 feet per foot (ft/ft) (shallow flow zone), 0.04 ft/ft (deep flow zone), and 0.03 ft/ft (bedrock flow zone) based on hydraulic gradient calculations using April 2019 groundwater elevation data and are consistent with gradients calculated from other monitoring events, including data presented in the 2018 CAMA Annual Interim Monitoring Report (SynTerra, 2019e). Hydraulic gradients are neutral across large areas of the AAB due to the influence of standing water.

Vertical hydraulic gradients were calculated at clustered wells from the water level data and the midpoint elevations of the well screens. Within the AAB, small upward gradients are consistently observed between the ash pore water and underlying matrix: AB-4LA15/D (-0.0158 ft/ft), AB-5S/BRU (-0.0168 ft/ft), and AB-6S/D (-0.0099 ft/ft). At the upstream and downstream dams of the AAB, downward gradients are observed at AB-1S/D (0.3468 ft/ft), MW-11S/DA (0.0730 ft/ft), AB-2S/D (0.2602 ft/ft), and GWA-20S/D (0.2472 ft/ft). Upward gradients are observed between the deep and bedrock flow zones below the dams at GWA-20D/BR (-0.1890 ft/ft) and GWA-21BRU/BR (-0.2734 ft/ft). Newly installed bedrock well GWA-21BRL is an artesian well. A downward vertical gradient is expected, with support from

flow and transport modeling, to be present in the shallow, deep, and bedrock flow zones on the upstream side of the AAB dams. However, there are no monitoring wells in the areas approaching the dam, due to the presence of ponded water, to provide physical confirmation.

Within and downgradient of the ASA, downward vertical gradients are prevalent between all flow zones: AS-1SB/D (0.0664 ft/ft), AS-7S/D (0.1165 ft/ft), AS-7D/BRA (0.3887 ft/ft), AS-8S/D (0.3096 ft/ft), AS-2S/D (0.2025 ft/ft), and AS-2D/BR (0.2312 ft/ft).

Downgradient of the U1-4 AB, a slight upward gradient is observed between the shallow and deep flow zones at GWA-10S/D (-0.0128 ft/ft) and CCR-IB-1S/D (-0.0250), while a downward gradient is observed between the shallow and deep flow zones at GWA-11S/BRU (0.0108 ft/ft).

Within the U5 AB, a downward vertical gradient was observed from ash pore water to the deep flow zone at U5-2S-SLB/D (0.1920). Beneath the U5 AB, a slightly upward vertical gradient was observed from the deep flow zone to the shallow flow zone at U5-8S/D (-0.0523 ft/ft); slightly downward vertical gradients were observed from the deep flow zone to the bedrock flow zone at U5-2D/BR and U5-8D/BR.

Within the U5 AB main dam, downward vertical gradients were observed between the shallow and deep flow zones: U5-4S/D (0.0777 ft/ft), and upward gradients between the deep and bedrock flow zones U5-4D/BRA (-1.3303 ft/ft). Below the U5 AB main dam, a downward vertical gradient was observed between the shallow and deep flow zones at GWA-35S/D (0.0182 ft/ft).

Within the U5 AB saddle dam, an upward vertical gradient was observed between the shallow and deep flow zones at U5-6S/D (-0.0320 ft/ft). Immediately downgradient of the saddle dam and adjacent to the standing water near the Unit 5 cooling towers, a downward vertical gradient was observed between the shallow and deep flow zones at GWA-4S/D (0.0533 ft/ft). Farther downgradient of the saddle dam, upward vertical gradients were observed between the shallow and deep flow zones at GWA-36S/D (-0.0150 ft/ft) and GWA-37S/D (-0.0789 ft/ft).

There are limited exceptions to the CSM. An important exception is the area northwest of the AAB Upstream Dam. The dam diverted the flow of

Suck Creek toward the northeast. The operating hydraulic head of the basin combined with the natural subsurface flow direction created a condition of underflow below Suck Creek. Groundwater in the shallow flow layer seeps and discharges into Suck Creek as would be expected; however, groundwater in the deep and bedrock flow layers is interpreted to flow under the current stream channel and continue north and northwest toward the U1-4 AB, and then to the Broad River *(CAP Content Section 5.A.a.iii).* Groundwater level maps depicting the groundwater flow in this area are presented as **Figures 5-4a/b/c**.

5.1.2.4 Particle Tracking Results

(CAP Content Section 5.A.a.ii)

For the U5 AB, particle tracking and water table contours were used rather than flow and transport modeling to assess the effectiveness of the remedial alternatives northeast of the U5 AB saddle dam. The flow and transport modeling report prepared for Cliffside is presented in **Appendix G.**

5.1.2.5 Subsurface Heterogeneities

(CAP Content Section 5.A.a.iii)

The nature of groundwater flow across the Site is based on the character and configuration of the ash basins and ASA relative to specific Site features such as manmade and natural drainage features, engineered drains, streams, and rivers; hydraulic boundary conditions; and subsurface media properties.

Natural subsurface heterogeneities at the Site are represented by three flow zones that distinguish the interconnected groundwater system: the shallow flow zone, deep flow zone, and the bedrock flow zone. The shallow flow zone is composed of residual soil/saprolite. Typically, the residual soil/saprolite is partially saturated and the water table fluctuates within it with the exception of localized areas on the site where the shallow flow zone is unsaturated. Water movement is generally preferential through the weathered/fractured and fractured bedrock of the transition zone where permeability and seepage velocity is enhanced. Groundwater within the Site area exists under unconfined, or water table, conditions within the saprolite, transition zone and in fractures and joints of the underlying bedrock. The shallow water table and bedrock water-bearing zones are interconnected. The saprolite, where saturated thickness is sufficient, acts as a reservoir for supplying groundwater to the fractures and joints in the

bedrock. Based on the orientations of lineaments and open bedrock fractures at Cliffside, horizontal groundwater flow within the bedrock should occur approximately parallel to the hydraulic gradient, with no preferential flow direction (**Appendix F**). Consistent with this interpretation, the current groundwater flow model for CSS does not simulate plan-view anisotropy.

NORR CSA guidance requires a "site map showing location of subsurface structures (e.g., sewers, utility lines, conduits, basements, septic tanks, drain fields, etc.) within a minimum of 1,500 feet of the known extent of contamination" in order to evaluate the potential for preferential pathways. Identification of piping near and around the ash basins and ASA was conducted by Stantec in 2014 and 2015, and utilities at the Site were also included on a 2015 topographic map by WSP USA, Inc. (CSA Update, 2018a).

Based on groundwater flow direction at the Site and identified subsurface underground utilities present at the site, there are no potential preferential pathways for contaminant migration through underground utility corridors

5.1.2.6 Bedrock Matrix Diffusion and Flow

(CAP Content Section 5.A.a.iv)

Matrix Diffusion Principles

When solute plumes migrate through fractures, a solute concentration gradient occurs between the plume within the fracture versus the initially clean groundwater in the unfractured bedrock matrix next to the fracture. If the matrix has pore spaces connected to the fracture, a portion of the solute mass will move by molecular diffusion from the fracture into the matrix. This mass is therefore removed, at least temporarily, from the flow regime in the open fracture. This effect is known as matrix diffusion (Freeze and Cherry 1979). When the plume concentrations later decline in the fractures (e.g., during plume attenuation and/or remediation), the concentration gradient reverses and solute mass that has diffused into the matrix begins to diffuse back out into the fractures. This effect is sometimes referred to as reverse diffusion.

Matrix diffusion causes the bulk mass of the advancing solute plume in the fracture to advance slower than would occur in the absence of mass transfer into the matrix. This effect retards the advance of any solute, including

relatively non-reactive solutes like chloride, bromide and boron. The magnitude of plume retardation increases with increasing plume length, because longer plumes have more contact for diffusion to transfer solute mass from the fracture to the matrix (Lipson et al 2005). The magnitude of plume retardation also increases with increasing matrix porosity.

If the solute sorbs to solids, the retarding effect increases. Sorption of solutes that have diffused into the matrix within the matrix occurs on a much larger surface area than would be the case if the solute mass remained entirely within the fracture. The combined effect of adsorption on the fracture surface and adsorption in the matrix further enhances plume retardation relative to the advance that would occur in the absence of adsorption. If sorption is reversible, when reverse diffusion occurs the sorbed mass can desorb and transfer back into the aqueous phase and diffuse back to the fractures. Solute mass that has been converted into stable mineral species would not undergo desorption.

Site-Specific Data Pertaining to Matrix Diffusion

Overall, the bedrock hydraulic conductivity at the Site and calculated fracture apertures decrease with increasing depth below the top of rock (**Appendix F**). The observed decline in bedrock hydraulic conductivity and hydraulic aperture with increasing depth is consistent with expectations based on the literature (Gale, 1982, Neretnieks, 1985, and Snow 1968), and indicates that the overall volumetric rate of groundwater flow in the bedrock decreases with depth (**Appendix F**).

The available data indicate that north of the AAB, the predominant strike of bedrock fractures is toward the east-northeast. However, most of the logged fractures in that area have relatively gentle dip angles. In addition, the lineaments in that area have variable orientations, with a central tendency of approximately north-northwest. Therefore, preferential flow (anisotropy) in the horizontal plane in this area is likely to be weak; the overall groundwater flow direction is interpreted to be approximately parallel to the hydraulic gradient, i.e., northward toward the Broad River.

In the area west of the AAB, fracture orientations are highly variable (GWA-65BRL) or strike toward the east-northeast/west-southwest, and dip gently to steeply toward the north-northwest (GWA-66BRL). In this area, horizontal groundwater flow in the bedrock may have a slight anisotropy toward the east-northeast or west-southwest.

The available data do not indicate any predominant bedrock fracture sets at the U1-4 AB. Overall, a wide range of open fracture dip angles and dip directions is observed. Based on the orientations of lineaments and open bedrock fractures, horizontal groundwater flow within the bedrock should occur approximately parallel to the hydraulic gradient, with no preferential flow direction (i.e., no expected, significant anisotropy) (**Appendix F**). Consistent with this interpretation, the current groundwater flow model for the U1-4 AB does not simulate a high degree of anisotropy.

Near U5 AB, fracture orientations are highly variable (GWA-67BRL) or strike toward the north-northwest, and dip gently to steeply toward the east-northeast (GWA-68BRL). Lineaments in this area have variable orientations, with a central tendency of approximately north. Thus, bedrock groundwater in this area is expected to flow in the general direction of the hydraulic gradient, which is to the north or north-northwest toward the Broad River.

Rock core samples from bedrock locations which represent areas of affected groundwater migration are interpreted to coincide with zones of preferential groundwater flow were analyzed for porosity, bulk density and thin section petrography.

The reported matrix porosity values ranged from 0.62 percent to 4.87 percent with an average of 1.59 percent. Bulk density ranged from 2.593 grams per cubic centimeter (g/cm^3) to 2.783 g/cm^3, with an average of 2.701 g/cm^3 (**Appendix F**).

Petrographic evaluation classified the samples as tonalite and granite. The principal minerals are plagioclase, quartz, K-feldspar, biotite, and muscovite. Accessory minerals consist of pyrite, zircon, apatite, magnetite, epidote, garnet, pyroxene, and sphene. Plagioclase crystals are heavily altered into sericite/illitic clays in several samples, and all samples showed some degree of alteration. Rare to minor biotite crystals are altered into chlorite, Rare FE-dolomite/dolomite is present in a few samples. (**Appendix F**).

The bedrock beneath CSS is crystalline, and consists of and granite, gneiss and schist. Solid samples of unfractured metamorphic rock and plutonic igneous rock have low porosities - rarely larger than 2%. In general, crystallite rock porosity is much lower than that of sedimentary rocks. The

reported matrix porosity values are within the range of those reported for crystalline rocks in the literature (Freeze and Cherry, 1979; Löfgren, 2004; Zhou and others, 2008; Ademeso and others, 2012). The presence of measurable matrix porosity suggests that matrix diffusion contributes to plume retardation at the site (Lipson and others, 2005). The influences of matrix diffusion and sorption are implicitly included in the groundwater fate and transport model as a component of the constituent partition coefficient (K_d) term used for the bedrock layers model.

5.1.2.7 Onsite and Offsite Pumping Influences

(CAP Content Section 5.A.a.v)

There is no current onsite pumping within the groundwater flow system containing the ash basins or ASA. Decanting of the AAB was initiated on March 31, 2019. As of December 1, 2019, approximately 269,600,000 gallons of water have been removed from the AAB and the water elevation has decreased by approximately 28.9 feet.

Because much of the area surrounding the ash basins and ASA is either residential properties, farm land, or undeveloped land, potential offsite pumping influences would be limited to domestic and public water supply wells. Water supply wells are outside, or upgradient of the groundwater flow system containing the ash basins and ASA. Flow and transport modeling indicated private water wells within the model area remove only a small amount of water from the overall hydrologic system (**Appendix G**).

5.1.2.8 Groundwater Water Balance

(CAP Content Section 5.A.a.vi)

The ash basins and ASA are located within a single watershed and groundwater flow system. The flow and transport model was used to evaluate the ash basin hydraulic conditions prior to decanting, post decanting and post closure (both closure-in-place and closure-by-excavation). Each scenario water balance was developed for using the results from flow and transport model current and predicated groundwater simulations (**Appendix G**). The approximate groundwater flow budget in the ash basin watershed under each simulated scenario is summarized in **Table 5-2**.

Pre-Decanting Conditions Groundwater Water Balance

Under pre-decanting conditions, the watershed area contributing groundwater recharge and discharge in the vicinity of the ash basins, ASA,

and adjacent receiving water bodies (Broad River and Suck Creek) is estimated at approximately 1,590 acres. Excluding the ash basins, lined areas, buildings, and Suck Creek, the net watershed area contributing to groundwater infiltration is approximately 1,297 acres.

Groundwater recharge from the infiltrative watershed is estimated to be 562 gallons per minute (gpm). An additional 65 gpm of recharge (leakage) is contributed by the AAB. The following describes the watershed area under pre-decanting conditions:

- Because the Suck Creek watershed extends south beyond the edge of the model domain, a flow of approximately 24 gpm is removed by the general head edge of the model.
- Groundwater recharge from the infiltrative watershed area of 1,297 acres is estimated to be 562 gpm.
- Groundwater discharged to surface water features or extracted by water supply wells within the watershed area remove approximately 337 gpm from the groundwater system.
- Suck Creek recharges approximately 4 gpm to groundwater within the watershed area.
- Approximately 65 gpm of recharge (leakage) from the AAB is contributed to the groundwater system within the watershed area.
- Approximately 10 gpm of groundwater from the system is discharged to the U5 AB near the toe drains downgradient of the basin. The remaining 260 gpm of groundwater flows through deep bedrock to the north, that discharges to the Broad River.

Post Decanting and Closure-by-Excavation Groundwater Water Balance

The flow and transport model was used to evaluate the hydraulic conditions that would occur after decanting the AAB and closure-by-excavation of the AAB, ASA, and the U5 AB. A water balance was developed for the simulated groundwater system under post-closure conditions. The following describes the watershed area under post-decanting and closure-by-excavation of the ash basins:

Groundwater divide depths and widths would change due to decanting the AAB and closure-by-excavation of the AAB, U5 AB, and ASA. Under

simulated post-closure conditions, the net watershed area contributing infiltration (which excludes lined areas, buildings at the Site and Suck Creek) is approximately 1,462 acres. The following describes the watershed post decanting and after closure-by-excavation of the basins:

- Because the Suck Creek watershed extends south beyond the edge of the model domain, a flow of approximately 24 gpm is removed by the general head edge of the model.
- Groundwater recharge from the infiltrative watershed area of 1,462 acres is estimated to be 567 gpm.
- Groundwater discharged to surface water features or extracted by water supply wells within the watershed area remove approximately 251 gpm from the groundwater system.
- Suck Creek recharges approximately 17 gpm to groundwater within the watershed area.
- Approximately 114 gpm of groundwater from the system is discharged in the form of surface water features that emanate within the AAB footprint after excavation of the basin.
- Approximately 56 gpm of groundwater from the system is discharged in the form of surface water features that emanate within the U5 AB footprint after excavation of the basin.

The remaining 139 gpm of groundwater flows through deep bedrock to the north, discharging to the Broad River.

Post-Decanting and Closure-in-Place Groundwater Water Balance

The flow and transport model was used to evaluate the hydraulic conditions that would occur after decanting the AAB and closure-in-place of the AAB and the U5 AB (the ASA will be excavated under this closure scenario). A water balance was developed for the simulated groundwater system under post-closure conditions.

Groundwater divide depths and widths would change due to decanting the AAB and closure-in-place of the AAB and U5 AB. Under simulated post-closure conditions, the net watershed area contributing infiltration (which excludes capped ash basins, lined areas and buildings at the Site, and Suck

Creek) is approximately 1,319 acres. The following describes the watershed post decanting and after closure-by-excavation of the basins:

- Because the Suck Creek watershed extends south beyond the edge of the model domain, a flow of approximately 26 gpm is removed by the general head edge of the model.
- Groundwater recharge from the infiltrative watershed area of 1,462 acres is estimated to be 511 gpm.
- Groundwater discharged to surface water features or extracted by water supply wells within the watershed area remove approximately 287 gpm from the groundwater system.
- Suck Creek recharges approximately 9 gpm to groundwater within the watershed area.
- Approximately 10 gpm of recharge is contributed to the groundwater system from capped areas (*i.e.*, the AAB and U5 AB) after closure-in-place.
- Approximately 47 gpm of groundwater is removed from the system from drains associated with the capped AAB after closure-in-place.
- Approximately 18 gpm of groundwater is removed from the system from drains associated with the capped U5 AB after closure-in-place.
- Approximately 6.5 gpm of groundwater is removed from the system from drains associated with the capped ASA after closure-in-place.

The remaining 145.5 gpm of groundwater flows through deep bedrock to the north, discharging to the Broad River.

The estimated net groundwater discharge through deep bedrock to the Broad River within the watershed area is reduced from approximately 260 gpm during pre-decanting and closure conditions to approximately 139 gpm after closure-by-excavation; the estimated groundwater discharge to the Broad River is reduced to approximately 145.5 gpm after closure-in-place. The anticipated reduction in deep bedrock groundwater discharge to the Broad River within the watershed from pre-decanting conditions to post-closure conditions primarily results from decanting of the AAB and changes to infiltrative capacities within the former basin footprints.

5.1.2.9 Effects of Naturally Occurring Constituents

(CAP Content Section 5.A.a.vii)

Metals and inorganic constituents, typically associated with CCR material, are naturally occurring and present in the Piedmont physiographic province of north-central North Carolina. The metals and inorganic constituents occur in soil, bedrock, groundwater, surface water, and sediment. During the Cliffside CSA assessment, samples of soil and rock were collected during drilling activities and analyzed for metals and inorganic constituents. Results indicate that soil and rock at CSS contain naturally occurring constituents that are also typically related to CCR material and likely effect the chemistry of groundwater at the Site. Arsenic, chromium, cobalt, iron, manganese, selenium and thallium were present in background soil and rock samples at concentrations greater than the PSRG POG values (**Table 4-2**).

These results suggest that arsenic, chromium, cobalt, iron, manganese, selenium and thallium might occur naturally in groundwater at the Site. Analytical results for groundwater at background locations indicate that chromium, cobalt, iron, manganese, and vanadium are present at concentrations greater than their applicable 02L standard or IMAC in one or more flow zones (**Table 4-3**). Therefore, downgradient concentrations of these constituents are compared to background values for corresponding flow zone.

The horizontal flow-through water system related to the ash basins described in the CSM has resulted in limited transport of constituents from the ash basin into underlying groundwater. Near the dams, affected groundwater flows under the dams and discharges to the underlying groundwater system. Beyond the dams, groundwater flows upward toward the Broad River or Suck Creek, limiting downward migration of constituents to the area in close proximity to the dams. The constituent management process and a detailed discussion of constituent migration and distribution are presented in **Sections 6.1, 6.10, and 6.19**.

5.2 Source Area Location

(CAP Content Section 5.A.b)

The ash basins and ASA are located on the south side of the Broad River on Duke Power Road (McCraw Road) **(Figure 1-2).** Duke Power Road (McCraw Road) runs from northwest to southeast in the vicinity of the Site. Suck Creek, located west of the

AAB, transects the Site generally from south to north, discharging to the Broad River. Topography at the CSS site ranges from approximate high elevations of 832 feet southwest of the AAB and 856 feet southwest of the U5 AB, to a low elevation of 656 feet at the interface with the Broad River on the northern extent of the Site. Topography generally slopes from south-to-north across the Site with an elevation difference of approximately 190 feet over an approximate distance of 4,000 feet. Surface water drainage generally follows Site topography and flows from the south to the north across the Site except where the ash basins or other construction have modified natural drainage patterns. Unnamed drainage features, located near the western and eastern edges of the Site, generally flow north to the Broad River.

5.3 Summary of Potential Receptors

(CAP Content Section 5.A.c)

G.S. Section 130A-309.201(13) amended by CAMA defines receptor as "*any human, plant, animal, or structure which is, or has the potential to be, affected by the release or migration of contaminants. Any well constructed for the purpose of monitoring groundwater and contaminant concentrations shall not be considered a receptor.*" In accordance with the NORR CSA guidance, receptors cited in this section refer to public and private water supply wells and surface water features.

The site-specific risk assessment conducted for the ash basins and ASA indicates no measurable difference between evaluated Site-related risks and risks imposed by background concentrations (**Appendix E**). It is determined that there is no identified material increases in risks to human health related to the ash basins and ASA. Additionally, multiple lines of evidence support that groundwater from the ash basin areas has not and does not flow towards any water supply wells based on groundwater flow patterns and the location of water supply wells in the area. However, Duke Energy has implemented a permanent water solution which provides owners of surrounding properties with municipal water supply connections within a 0.5-mile radius of the ash compliance boundaries.

The site-specific risk assessment conducted for the ash basins and ASA also indicates that there is no increase in risks to ecological receptors. The Broad River aquatic system surrounding the CSS is healthy based on multiple lines of evidence including robust fish populations, species variety and other indicators based on years of sampling data.

5.3.1 Surface Water

The Site is located in the Broad River watershed. The ash basins and ASA are located south of the Broad River, with Suck Creek transecting the Site, with the U1-4 AB and U5 AB to the west, and the AAB and ASA to the east. The surface

water classifications of the surrounding surface water bodies are included in **Table 5-3**.

The only surface water intake located in the vicinity of CSS is the intake on the Broad River near the low-head dam used to pump water for plant operations.

A depiction of surface water features — including wetlands, ponds, unnamed tributaries, seeps, streams, and rivers —within a 0.5-mile radius of the pre-2018 compliance boundaries is provided in **Figure 5-10** (*CAP Content Section 5.B*). The surface water information is provided from the Natural Resources Technical Report (NRTR) prepared by AMEC Foster Wheeler (AMEC, 2015). In addition, permitted outfalls under the NPDES and the SOC locations are shown on **Figure 5-8**. Non-constructed and dispositioned seep sample locations between the ash basins and the ASA, and the Broad River and Suck Creek are managed by the SOC and are subject to the monitoring and evaluation requirements contained in the SOC.

5.3.1.1 Environmental Assessment of the Broad River

The NPDES permit for Broad River and Rogers Energy Complex - Cliffside Steam Station (NPDES No. NC0005088) requires Duke Energy to conduct quarterly outfall and instream water quality monitoring at four locations including within the Broad River. Trace elements (arsenic, selenium) monitoring in fish muscle tissue is also conducted annually in accordance with a study plan approved by the NCDEQ.

The Broad River has been monitored by Duke Energy for 30 years. Over the years, specific assessments have been conducted for water quality and chemistry as well as abundance and species composition of macroinvertebrates, fish, and aquatic wildlife. These assessments have all demonstrated that the Broad River has been an environmentally healthy and functioning ecosystem, and ongoing sampling programs have been established to ensure the health of these systems will continue. Furthermore, these data indicate that there have been no significant effects to the local aquatic systems related to coal ash constituents over the last 30 years. More information related environmental health assessments conducted for the Broad River, including sampling programs, water quality and fish community assessments, and fish tissue analysis, can be found in **Appendix E**.

5.3.2 Availability of Public Water Supply

The Grassy Pond Water Company (GPWC) has existing potable water supply lines that serve CSS, as well as residences to the west, south, and east of the Site. To the west, water lines run along US-221 Alt and Old US-221A. Water lines also run along McCraw Road (Duke Power Road) south and east of CSS.

5.3.3 Water Supply Wells

No public or private drinking water wells or wellhead protection areas were found to be located downgradient of the ash basins or ASA. A total of 71 private water supply wells were identified within the 0.5-mile radius of the pre-2018 ash basin compliance boundaries. Most of these water supply wells were located south, southeast, east, and northeast of the AAB off of McCraw Road, Prospect Church Road, Fox Place, and Riverfront Drive, west and southwest of the U5 AB along Duke Power Road, US-221A, and Old US-221A; and north of the Broad River (**Figure 5-12**).

Discussion, with supporting material and data, of alternative water supply provisions provided by Duke Energy for surrounding occupied residences and findings of the drinking water supply well survey are included in **Sections 6.2.2, 6.11.2,** and **6.20.2.**

5.3.4 Surrounding Land Use

Land use within the 0.5-mile radius of the CSS ash basin compliance boundaries generally consists of residential properties, undeveloped land, and the Broad River. McCraw Road (Duke Power Road) runs from northwest to southeast in the vicinity of the Site. Suck Creek, located west of the AAB, transects the Site generally from south to north, discharging to the Broad River.

5.3.5 Future Groundwater Use Area

Duke Energy owns the land and controls the use of groundwater on the land downgradient of the ash basins and ASA at and beyond the predicted area of potential affected groundwater. Therefore, no future groundwater use areas are anticipated downgradient of the ash basins or ASA.

Under G.S. Section 130A-309.211(c1), Duke Energy provided permanent water solutions to all eligible households within a 0.5-mile radius of the ash basin compliance boundaries. It is anticipated that private properties within a 0.5-mile of the ash basin compliance boundaries will continue to rely on groundwater resources for water supply for the foreseeable future.

5.4 Human Health and Ecological Risk Assessment Results

(CAP Content Section 5.A.d)

A human health and ecological risk assessment pertaining to the Cliffside was prepared and is included in **Appendix E**. The risk assessment focuses on the potential effects of CCR constituents from the Cliffside ash basins and ASA on groundwater, surface water, and sediment. Groundwater flow information was used to focus the risk assessment on areas where exposure of humans and wildlife to CCR constituents could occur. Primary conclusions of the risk assessment include: 1) there is no evidence of risks to on-Site or off-Site human receptors potentially exposed to CCR constituents that may have migrated from the ash basins or ASA; and 2) there is no evidence of risks to ecological receptors potentially exposed to CCR constituents that may have migrated from the ash basins or ASA. This risk assessment uses analytical results from groundwater, surface water, and sediment samples collected March 2015 through June 2019.

Evaluation of risks associated with area of wetness (AOW) locations and soil beneath the ash basins and ASA are not subject to this assessment and will be evaluated independent from the CAP. Consistent with the iterative risk assessment process and guidance, updates to the risk assessment have been made to the original 2016 risk assessment (HDR, 2016c) in order to incorporate new site data and refine conceptual site models. The original risk assessment was prepared in accordance with a work plan for risk assessment of CCR-affected media at Duke Energy sites (Haley & Aldrich, 2015).

The following risk assessment reports have been prepared:

1. *Baseline Human Health and Ecological Risk Assessment*, Appendix F of the *CAP Part 2* (HDR, 2016c)
2. *Comprehensive Site Assessment (CSA) Update* (SynTerra, 2017)
3. *Human Health and Ecological Risk Assessment Summary Update for Cliffside Steam Station*, Appendix B of *Community Impact Analysis of Ash Basin Closure Options at the Cliffside Steam Station* (Exponent, 2018)

To help evaluate options for groundwater corrective action, this risk assessment characterized potential effects on human health and the environment related to naturally occurring elements, associated with coal ash, present in environmental media. This risk assessment follows the methods of the 2016 risk assessment (HDR, 2016c), and is based on NCDENR, 2003; NCDEQ, 2017; and USEPA risk assessment guidance (USEPA, 1989; 1991a; 1998).

Human health and ecological CSMs were developed and further refined to guide identification of exposure pathways, exposure routes, and potential receptors for evaluation. Additional information regarding groundwater flow and the treatment of source areas other than the ash basin was incorporated into the refinement of CSMs presented in **Appendix E**.

Environmental data evaluated in the risk assessment were compared to human health and ecological screening values. Risk assessment constituents of potential concern (COPCs) are different than COIs in that COPC are those elements in which the maximum detected concentration exceeded human health or ecological screening values. COPCs are carried forward for further evaluation in the deterministic risk assessment. Constituents remaining as a result of the screening were carried forward in the baseline assessment. **Appendix E** contains the results of the screening assessment.

No unacceptable risks from exposure to environmental media were identified. Results of the human health risk assessment indicate the following:

- On-site groundwater poses no evidence of carcinogenic or non-carcinogenic construction worker under these exposure scenarios.
- No evidence of carcinogenic or non-carcinogenic risks for recreational swimmer, wader, or boater exposure scenarios was identified.
- No evidence of carcinogenic or non-carcinogenic risks associated with the recreational fisher exposure scenario was identified.
- There is no evidence of carcinogenic risk cancer risks for the subsistence fisher exposure scenario attributable to the ash basin. Hexavalent chromium concentrations in upstream surface water samples also resulted in estimated values within USEPA's range for excess lifetime cancer risk (ELCR). The modeled concentration of hexavalent chromium in fish tissue is likely overestimated.
- Potential non-carcinogenic risks from consumption of fish containing cobalt (modeled from surface water concentrations) were modeled for the subsistence fisher. The fisher exposure scenarios overestimate risks based on exposure model assumptions of bioconcentration and fish consumption rates. There is not likely to be any material increase in non-carcinogenic risks for the subsistence fisher scenario.

Findings of the baseline ecological risk assessment include the following:

Ecological Exposure Area 1:

- No hazard quotients (HQs) based on no observed adverse effects levels (NOAELS) or Lowest observed adverse effects levels (LOAELs) were greater than unity for wildlife receptors (mallard duck, great blue heron, muskrat, river otter) exposed to surface water and sediments.
- Modeled risk estimates resulted in aluminum HQs greater than 1 based on the NOAEL and LOAEL for the killdeer and muskrat. The modeled risk is considered negligible given the natural occurrence of aluminum in surface water, sediment, and soil in the region.
- Modeled risk estimates resulted in barium and chromium LOAEL based HQs greater than unity for the killdeer; however, the NOAEL based HQs for these constituents were greater than unity. The modeled risk is considered negligible.

Ecological Exposure Area 2:

- No HQs based on NOAELS or LOAELs were greater than unity for wildlife receptors (mallard duck, great blue heron, muskrat, river otter) exposed to surface water and sediments.
- Modeled risk estimates resulted in aluminum HQs greater than 1 based on the NOAEL and LOAEL for the killdeer and based on NOAELs for the muskrat. The modeled risk is considered negligible given the natural occurrence of aluminum in surface water, sediment, and soil in the region.
- The NOAEL and LOAEL based HQ for the killdeer exposure to aluminum in Ecological Exposure Area 2 was greater than unity (HQ =10.7 and 1.1). The model likely overstates risk. As previously stated, aluminum occurs naturally in soil, sediment, and surface water in this area.

Ecological Exposure Area 4:

- No HQs based on NOAELS or LOAELs were greater than unity for wildlife receptors (mallard duck, great blue heron, muskrat, river otter) exposed to surface water and sediments.
- Modeled risk estimates resulted in aluminum HQs greater than 1 based on the NOAEL and LOAEL for the killdeer and based on NOAELs for the

muskrat. The modeled risk is considered negligible given the natural occurrence of aluminum in surface water, sediment, and soil in the region.

In summary, there is no evidence of unacceptable risks to human and ecological receptors exposed to environmental media potentially affected by CCR constituents at Cliffside. This conclusion is further supported by multiple water quality and biological assessments conducted by Duke Energy as part of the NDPES monitoring program.

5.5 CSM Summary

The Cliffside CSM presented herein describes and illustrates geologic and hydrogeologic conditions and constituent interactions specific to the Site. The CSM presents an understanding of the distribution of constituents with regard to the Site-specific geological/hydrogeological and geochemical processes that control the transport and potential effects of constituents in various media and potential exposure pathways to human and ecological receptors.

In summary, the AAB and U5 AB were constructed within former perennial stream valleys and the U1-4 within a low lying region along the Broad River in the Piedmont of North Carolina. The ash basins exhibit limited horizontal and vertical constituent migration, with the predominant area of migration occurring near and downgradient of the ash basin dams. The upward flow of water into the basin minimizes downward vertical constituent migration to groundwater immediately underlying saturated ash in the upgradient ends of the basins. Due to the prevailing horizontal flow within the ash basins, there is limited vertical flow of ash basin pore water into the underlying groundwater. The elevated constituent concentrations found in groundwater near the AAB dams are due to the operating hydraulic head in the basin. The ponded water in the basin is the most important factor contributing to constituent migration in groundwater.

Based on empirical Site data from over 30 monitoring events over multiple seasonal variations and groundwater flow and transport modeling simulations support groundwater flow is away from water supply wells and that there are no exposure pathways between the ash basin and the pumping wells used for water supply in the vicinity of the Site.

Through AAB decanting and closure of the U5 AB and AAB, the hydraulic head and the rate of constituent migration from the basins to the groundwater system will be reduced based on basin hydrogeology described above. Either closure scenario considered by Duke Energy will significantly reduce infiltration to the remaining ash, reducing the rate of constituent migration. Based on future predicted groundwater flow patterns,

under post ash basin closure conditions, and the location of water supply wells in the area, groundwater flow direction from the ash basins is expected to be further contained within the stream valley and continue flowing north of the ash basin footprints, and therefore will not flow towards any water supply wells.

Multiple lines of evidence have been used to develop the CSM based on the large data set generated for CSS. The CSM provides the basis for this CAP Update developed for the CSS ash basins and ASA to comply with G.S. Section 130A-309.211, amended by CAMA.

6.0 CORRECTIVE ACTION APPROACH FOR SOURCE AREAS

(CAP Content Section 6)

Groundwater contains varying concentrations of naturally occurring inorganic constituents. Constituents in groundwater with sporadic and low concentrations greater than the corresponding criteria (02L standard/IMAC/background value, as applicable) do not necessarily demonstrate horizontal or vertical distribution of COI-affected groundwater migration from the source areas. Constituents with concentrations greater than corresponding criteria were evaluated to determine if the level of concentration is present due to the source areas. COIs are those constituents identified from the "constituent management process" described below and are specific to individual source areas, not the Site. This evaluation assisted in identifying if a source area is subject to corrective action under G.S. Section 130A-309.211 and 15A NCAC 02L .0106.

A COI Management Plan was developed at the request of NCDEQ to evaluate and summarize COI concentrations in groundwater at the Site (**Appendix H**). Results of this COI Management Plan are used to identify areas that may require corrective action and to determine appropriate Site-specific mapping of COI concentrations on figures based on the actual distribution of each COI in Site groundwater.

- Groundwater COIs to be addressed with corrective action are those which exhibit concentrations in groundwater at or beyond the compliance boundary greater than the 02L standard, IMAC, or background value, whichever is greatest. **Tables 6-6, 6-21,** and **6-32** present the COI management matrix for determining COIs subject to corrective action at Cliffside.
- The COI Management Plan is also used to discern constituents at naturally occurring concentrations greater than comparison criteria that would not be subject to corrective action. Examples include naturally occurring COIs that do not exhibit a discernable plume or COIs that have no correlation with other soluble constituents associated with coal ash or another primary source (e.g., boron or sulfate).

A three-step process was utilized in the COI Management Plan approach:

- An evaluation of the applicable regulatory context
- An evaluation of the mobility of target constituents
- A determination of the distribution of constituents within Site groundwater

The primary goal of the COI Management Plan is to utilize science-based evidence to determine the realistic distribution and behavior of coal ash-related constituents in groundwater. The COI Management Plan presents multiple lines of evidence used to understand the actual COI presence in the subsurface at the Site, uses results from the COI Management Plan approach to identify Site-specific COIs for inclusion for corrective action planning, and presents the COI mapping approach for the CAP. The COI Management Plan approach is described in detail in (**Appendix H**) and summarized below.

Numerous Site-assessment activities have been completed to date and support the CSM, as described in **Section 5**. Data generated from these Site assessment activities have been considered within the COI Management Plan approach. Components of the Site assessment activities and data evaluations utilized within the COI Management Plan include the hydrogeologic setting, groundwater hydraulics, constituent concentrations, groundwater flow and transport modeling results, geochemical modeling results, and groundwater geochemical conditions.

Step 1: Regulatory Review

Step 1 of the COI Management Plan process considers the relevant regulatory references listed in **Appendix H**. The regulatory analysis starts with the current COI list identified in the CSA Update (SynTerra, 2019 and 2019 IMP submitted by Duke Energy, March 20, 2019, and approved by NCDEQ April 20, 2019. COI concentrations were screened against their respective COI criterion defined as the maximum of the 02L groundwater quality standard, IMAC, and background values. COI concentrations were screened against their respective COI criterion for groundwater monitoring locations at or beyond the compliance boundary. Groundwater COI concentrations used in the screening are based on a calculated central tendency value (mean) including data from 2018 through the 2nd quarter of 2019. Arithmetic mean COI concentrations were calculated when the range in COI concentrations was less than one order of magnitude. A geometric mean COI concentration was calculated when the range in COI concentrations was greater than one order of magnitude.

NCDEQ recommended use of a lower confidence limit (LCL95) concentration rather than the central tendency value (NCDEQ, 2019). LCL95 concentrations were calculated for each COI and the LCL95 concentration for the sample with the highest COI LCL95 concentration is provided in Table 1 of the COI Management Approach (**Appendix H)** for comparison to the maximum COI mean concentration. Table 2 of the COI Management Approach (**Appendix H**)

provides a comparison of the maximum COI central tendency concentrations compared with the maximum COI LCL95 concentration for wells located at or beyond the compliance boundary for the Allen Steam Station, Belews Creek Steam Station, Cliffside Steam Station, Marshall Steam Station, Mayo Steam Electric Plant, and Roxboro Steam Electric Plant Sites. The COI LCL95 concentrations were typically lower than the COI central tendency value with very few exceptions. The number of wells exceeding COI criteria using the COI LCL95 concentration was typically equal to or less than the number of wells exceeding COI criteria using the COI central tendency concentration. There were no increases in the number of wells exceeding COI criteria for the Site when comparing the LCL95 to the COI criterion and the number of exceedances was typically less for LCL95. Use of the COI central tendency concentrations in the COI Management Plan process provides conservative estimate of the extent of COI in Site groundwater.

Step 2: COI Mobility

Step 2 of the COI Management Plan process evaluates the COI mobility to identify hydrogeologic and geochemical conditions and relative COI mobility based on:

- Review of regulatory agency and peer-reviewed literature to identify general geochemical characteristics of COI,
- Analysis of empirical data and results from geochemical and flow and transport modeling conducted for the Site, and
- Identification of COI-specific mobility as conservative (non-reactive), non-conservative (reactive), or variably reactive COIs based on results from geochemical modeling (**Appendix H**).

Site-specific groundwater geochemical conditions that may affect COI transport and distribution are described in Table 1 of the COI Management Approach (**Appendix H**).

Step 3: COI Distribution

Step 3 of the COI Management Plan process evaluates the relative presence of COI in Site groundwater. Descriptions of the horizontal and vertical distribution of COI with mean concentrations above their respective COI criterion at and beyond the compliance boundary are summarized in Table 1 of the COI Management Approach (**Appendix H**) and provided in more detail in **Tables 6-**

6, 6-21, and **6-32** . The COI Management Plan approach considers the distribution of COI on a Site-wide basis. These distributions are used for planning appropriate corrective action as well as determining which COI to map on figures.

Primary descriptions of COI distributions include plume-like distributions for relatively mobile COI such as boron and sulfate and isolated location(s) for COI that do not exhibit plume-like distributions. Boron and sulfate are the COIs with the most plume-like distributions. Some COIs with isolated exceedances of COI criteria are not associated with the boron plume and these exceedances are described in more detail in **Tables 6-6, 6-21,** and **6-32** to place these exceedances within the context of the Site CSM.

Rationale for inclusion or exclusion of COI from mapping on figures in the 2019 CAP Update is based on the horizontal and vertical distribution of COI with concentrations greater than their respective COI criterion. All wells that have COI mean concentration(s) greater than the COI criterion are listed in **Tables 6-6, 6-21,** and **6-32**.

Outcome of COI Management Plan Process

Constituents with concentrations greater than the COI criterion beyond the compliance boundary were grouped by geochemical behavior and mobility. A comprehensive evaluation (i.e., means and groupings) of available data was used to demonstrate constituent distribution and correlation with other soluble constituents associated with coal ash, and to evaluate the spatial occurrence with a discernable COI plume in the direction of groundwater flow downgradient of the source area. This evaluation emphasizes the depiction of those constituents that have migrated downgradient of the source area, in the direction of groundwater flow at concentrations greater than the COI criterion with a discernable plume that correlates with other soluble constituents.

COI were assigned to mobility categories based on geochemical modeling results and information derived from peer-reviewed literature. COI mobility categories are based on the concept of conservative versus non-conservative COI introduced by NCDEQ in the January 23, 2019 CAP content guidance document. The use of three mobility categories for COI was first introduced during in-person COI Management meetings held with NCDEQ in September 2019 for the Allen, Marshall, Mayo, and Roxboro Sites. Based on geochemical modeling results, COI mobility categories were expanded from conservative versus non-conservative to include the following:

- Conservative, Non-reactive COI: boron, lithium, sulfate, and TDS. Geochemical model simulations support that these constituents would transport conservatively (K_d values <1 L/kg) as soluble species under most conditions, and that the mobility of these constituents will not change significantly due to current geochemical conditions or potential geochemical changes related to remedial actions.
- Non-Conservative, Reactive COI: arsenic, chromium, strontium, uranium, and vanadium. Geochemical model simulations support that these constituents are subject to significant attenuation in most cases and have high K_d values indicating the mobility of these constituents is unlikely to be geochemically affected by current geochemical conditions or potential geochemical changes related to remedial actions.
- Variably Reactive COI: cobalt, hexavalent chromium, iron, manganese, radium, and thallium. Geochemical model simulations, and resulting K_d values, support these constituents may be non-reactive or reactive in relation to geochemical changes and are dependent on the pH and E_H of the system. The sensitivity of these constituents to the groundwater pH and E_h indicates that these constituents could respond to natural changes under current conditions, such as water level fluctuations imposed by seasonality, and decanting or source control activities that have the potential to change the groundwater pH or E_h.

As discussed in the CSA Update (SynTerra, 2018a) and the 2018 CAMA Annual Interim Monitoring Report (SynTerra, 2019e), not all constituents with results greater than background values can be attributed to the ash basin or another source area. Naturally occurring groundwater contains varying concentrations of inorganic constituents. Sporadic and low-concentration occurrences of these constituents in the groundwater data do not necessarily demonstrate horizontal or vertical distribution of COI-affected groundwater migration from the ash basin [and other source areas, as appropriate].

COI Management Plan Summary

A three-step process was utilized for the COI Management Plan approach considering the regulatory context, the mobility of constituents, and the distribution of constituents within Site groundwater. A comprehensive, multiple lines of evidence approach was followed utilizing extensive Site data. The COI Management Plan approach incorporated numerous components of the Site CSM in a holistic manner. Clear rationale was provided for every step of the COI Management process.

For the regulatory review portion of the COI Management Plan, mean COI concentrations were compared with COI criteria to identify COI that exceeded their

respective COI criterion. Use of the COI central tendency concentrations in the COI Management Plan process was shown to provide a conservative estimate of the extent of COI in Site groundwater. Exceedance ratio values indicate COI concentrations that exceed COI criteria are typically within one order of magnitude (ER <10) to two orders of magnitude (ER <100) above the COI criterion.

Results of the COI Management Plan evaluation were used to identify COI for mapping on figures in the CAP Update. COIs to be mapped include boron, iron, lithium, manganese, strontium, sulfate, and total dissolved solids. The following COIs have no exceedances of COI criteria or have isolated exceedances without a discernable plume, at or beyond the compliance boundaries: antimony, arsenic, barium, beryllium, cadmium, total chromium, hexavalent chromium, molybdenum, nickel, selenium, and vanadium. These constituents will not be mapped on figures in the 2019 CAP Update.

Results of the COI Management Plan evaluation were also used to identify areas that require groundwater corrective action as described in **Sections 6.1.3, 6.10.3,** and **6.19.3** based on the actual distribution of each COI in Site groundwater.

SOURCE AREA 1 (SA1) – ACTIVE ASH BASIN AND ASH STORAGE AREA (AAB AND ASA)

This section provides an in-depth review of constituent characteristics associated with Source Area 1 (active ash basin and ash storage area) and the mobility, distribution and extent of constituent migration within, at, and beyond the point of compliance.

6.1 SA1 Extent of Constituent Distribution

6.1.1 Source Material within the Waste Boundary

(CAP Content Section 6.A.a)

The AAB and ASA waste boundaries are shown in **Figure 1-2**. An overview of the material within the AAB and ASA is presented in the following subsections.

6.1.1.1 Description of Waste Material and History of Placement

(CAP Content Section 6.A.a.i)

Active Ash Basin

The AAB (**Figure 1-2**) (*CAP Content Section 3.A*) is located approximately 1,700 feet to the east-southeast of CSS Units 5 and 6 and adjacent to the Broad River. The AAB is an unlined basin impounded by earthen dams located between the west portion of the basin and Suck Creek, and between the northeast portion of the basin and the Broad River. The waste boundary associated with the AAB, including associated dams and including the ASA waste boundary, is approximately 93 acres in area. When it was in operation, the approximate maximum pond elevation of the active ash basin was 770 feet. The main section of the pond was historically maintained at an elevation below 765 feet to have extra storage capacity during a significant flood event.

The AAB was constructed in two phases. The first phase consisted of the excavation of the Suck Creek diversion canal, construction of the upstream dam to an elevation of 745 feet, and construction of the downstream dam to an elevation of 725 feet. The first phase began in 1974 and was completed in 1975. The second phase consisted primarily of raising both dams to an elevation of 775 feet. The downstream dam was raised in two stages, with the first stage involving construction of the dam to a temporary elevation of 737 feet in late 1979. The second stage of construction was essentially completed in late 1980. In 2012, ash from within the southern portion of the AAB was removed and placed, dry, within an upland portion of the ash

basin footprint to create a settling cell. The ash stacked northwest of the settling cell was covered with a layer of soil and covered with vegetation.

The AAB was formed by construction of two earth fill dams across Suck Creek bracketing a nearly mile-long meandering reach of the natural stream valley. At the upstream dam, Suck Creek was diverted through a canal and away from the ash basin to the Broad River, its current configuration. The height of the upstream dam has reached a maximum of 60 feet above the exterior toe, approximately 65 feet above the interior toe, and has a crest length of 890 feet.

The AAB downstream dam, located just upstream of the original confluence of Suck Creek with the Broad River, has reached a maximum height of approximately 120 feet above the downstream toe, and has a crest length of 876 feet.

Both the upstream and downstream dams were designed to have 15-foot-wide crests at an elevation of 775 feet. The primary borrow area for construction of the embankment dams was material from within the basin footprint.

The outlet for the AAB (NPDES Outfall 002) is a reinforced concrete pipe (RCP) located in the northwest corner of the basin. The AAB previously received variable inflows from the Unit 5 fly ash handling system, Unit 5 bottom ash handling system, cooling tower blowdown, storm water runoff from yard drainage, coal pile runoff, gypsum pile runoff, limestone pile runoff, landfill leachate, and wastewater streams generated from emission monitoring equipment, precipitators, and the Selective Catalytic Reduction Unit. The AAB also received treated sanitary wastewater, miscellaneous cleaning wastes, domestic package plant wastewater (through the yard sumps) and water treatment system wastes (filter backwash, demineralizer regeneration waste, reverse osmosis rinse water, and clarifier solids). The discharge from the AAB is permitted by the NCDEQ DWR under NPDES Permit NC0005088.

Unit 5 converted to dry fly ash and dry bottom ash handling systems. Unit 6 has been dry ash handled since it came online. On March 31, 2019, all Plant wastewater flows were routed to the new wastewater treatment system, which includes a 14-acre lined retention basin (LRB) located in the U1-4 AB footprint. The LRB is lined with a dual liner system comprised of a

textured high-density polyethylene (HDPE) geomembrane liner over a geosynthetic clay liner (GCL). The effluent from the wastewater treatment system is discharged to the Broad River in accordance with NPDES Permit NC0005088. Decanting from the ash basin via the concrete discharge tower commenced on March 31, 2019 with discharge monitoring at Outfall 002 in accordance with NPDES Permit NC0005088.

Ash Storage Area

The unlined ASA is located north of and adjacent to the active ash basin (**Figure 1-2**) (*CAP Content Section 3.A)*. A spoil area that was previously referred to as an ash storage area, is located to the east of the ASA. It might contain soil from the AAB dam construction. The heavily vegetated ASA is located between the AAB and the Broad River. The ash in the ASA was removed from the U1-4 AB and placed in the ASA in the 1970s. The ASA footprint, approximately 7 acres, reportedly contains approximately 204,000 tons of ash material. The ash storage area will be excavated as part of the AAB closure activities.

6.1.1.2 Specific Waste Characteristics of Source Material

(CAP Content Section 6.A.a.ii)

Source characterization was performed through the completion of soil borings, installation of monitoring wells, and collection and analysis of associated solid matrix and aqueous samples. Source characterization was performed to identify the physical and chemical properties of the ash in the source areas. The source characterization involved determining physical properties of ash, identifying the constituents present in ash, measuring concentrations of constituents in the ash pore water, and performing laboratory analyses to estimate constituent concentrations from leaching of ash.

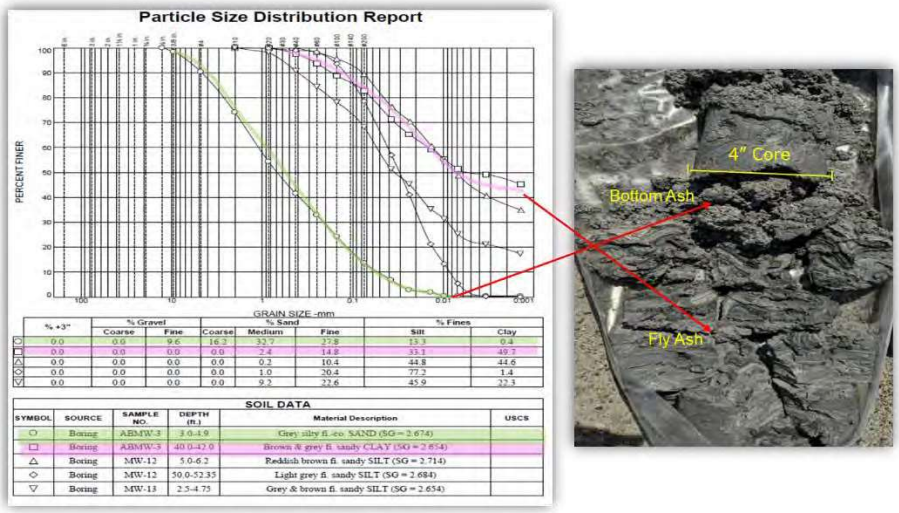
Twenty ash samples were collected from borings at five well cluster locations (AB-3, AB-4, AB-5, AB-6, and AS-7) within the AAB and ASA waste boundaries for chemical analyses (**Figure 1-2**). Borings at the AB-1 and AB-2 locations were advanced through the earthen dams without encountering ash. Ash was encountered in borings AB-3, AB-4, AB-5, AB-6, and AS-7 at varying intervals. Ash was not observed in borings outside the AAB and ASA with the exception of the U1-4 AB (prior to excavation) and the U5 AB.

The hydraulically sluiced deposits of ash consisted of interbedded fine- to coarse-grained fly ash and bottom ash materials. Ash was generally described as gray to dark gray, non-plastic, loose to medium density, dry to wet, fine- to coarse-grained sandy silt texture. Physical properties analyses (grain size, specific gravity, and moisture content) were performed on thirteen ash samples from the AAB and ASA using American Society for Testing and Materials (ASTM) methods. Fly ash is generally characterized as a moderately dense silty fine sand or silt. Bottom ash, while not sampled from the Site, is generally characterized as loose, poorly graded (fine- to course-grained) sand.

Based on published literature not specific to the CSS site, the specific gravity of fly ash typically ranges from 2.1 to 2.9, and the specific gravity of bottom ash typically ranges from 2.3 to 3.0. The permeability of fly ash and bottom ash vary based on material density but would be within the range of sand gravel with similar gradation, grain size distribution, and density (EPRI, 1995).

Within an ash basin, ash typically contains interbedded layers of fly ash and bottom ash as a result of the varying rates and pathways of bottom ash and fly ash settlement. A depiction of the typical interbedded nature of fly ash and bottom ash within an ash basin, as seen from an ash boring photograph can be found below (**Figure 6-1**). Layers of bottom ash are typically more permeable than layers of fly ash due to the coarser grain size of bottom ash.

FIGURE 6-1
FLY ASH AND BOTTOM ASH INTERBEDDED DEPICTION



6.1.1.3 Volume and Physical Horizontal and Vertical Extent of Source Material

(CAP Content Section 6.A.a.iii)

Active Ash Basin

Based on CCR inventory data and topographic and bathymetric surveys, the AAB is estimated to contain approximately 4,131,000 cubic yards (cy) of ash (AECOM, 2018a). The horizontal limit of the source material is depicted by the waste boundaries show on **Figure 1-2**. Based on borings and topographic surveys, and bathymetric surveys, the maximum depth of CCR within the AAB is estimated to be approximately 70 feet. Volume and extent of ash material in the AAB is presented in cross-section in **Figures 6-2, 6-4,** and **6-5.**

Ash Storage Area

Based on CCR inventory data and historical and current topographic surveys, the ASA is estimated to contain approximately 170,000 cy of ash (AECOM, 2018a). The horizontal limit of the source material is depicted by the waste boundary shown on **Figure 1-2**. Based on boring logs and historical and current topographic surveys, the maximum depth of CCR within the ASA is estimated to be approximately 60 feet. Volume and extent of ash material in the ASA is presented in cross-section in **Figures 6-3.**

6.1.1.4 Volume and Physical Horizontal and Vertical Extent of Anticipated Saturated Source Material

(CAP Content Section 6.A.a.iv)

Active Ash Basin

Volume and horizontal and vertical extent of saturated ash material under pre-decanting conditions, within the basin in plan-view is presented in **Figure 6-6** and in cross-section in **Figures 6-2, 6-4**, and **6-5.** Ash basin decanting was initiated on March 31, 2019. As of December 1, 2019, 269,600,000 gallons of water has been decanted and the corresponding pond water elevation has decreased by 28.9 feet.

Volume of and physical horizontal and vertical extent of saturated ash material anticipated under post-closure conditions decreases as the decanting and closure processes progress. The anticipated range of saturated ash thickness after closure by closure-in-place is between a few feet to 50 feet with the greatest volume of anticipated saturated ash in the

north central portion of the ash basin and lesser volumes in the southern and western portions of the basin (**Figure 6-6**). Closure-in-place simulated saturated ash thickness is based on closure model results. Under the closure-by-excavation scenario, it is anticipated all of the ash in the AAB would be excavated, and therefore no saturated ash would remain in the basin footprint.

Ash Storage Area

Based on information from field measurements and model outputs, the volume of saturated ash within the ASA waste boundary under current conditions is approximately 12,000 cy. The volume, horizontal extent, and vertical extent of saturated ash material under current conditions within the ASA are presented in plan view in **Figure 6-6** and in cross-section in **Figure 6-3**.

This saturated thickness of ash will decrease as the decanting of the AAB and closure processes progress. The ASA is planned to be excavated under both the closure-by-excavation and closure-in-place scenarios for the AAB. Therefore, all of the ash in the ASA would be excavated and no saturated ash would remain in the ASA footprint.

6.1.1.5 Saturated Ash and Groundwater

(CAP Content Section 6.A.a.v)

Based on the trend analysis results, the thickness of saturated ash remaining in place following closure (closure-in-place only) will have limited to no adverse effect on future groundwater quality. Layered ash within the AAB has resulted in relatively low vertical hydraulic conductivity, reducing the potential for downward flow of pore water into underlying residual material. The horizontal flow-through ash basin system results in low to non-detectable COI concentrations in groundwater underlying saturated ash within the basin except near the dam where downward vertical hydraulic gradients are observed. Using boron data, the horizontal flow-through system is consistent with Site-specific data as summarized in the **Table 6-1**.

In summary, of the 16 well locations within the AAB, 15 demonstrate minimal (<700 µg/l) to non-detectable boron concentrations consistent with the flow-through system, which suggests there is no correlation between the thickness of saturated ash and the underlying groundwater quality. The exception to the CSM in the AAB is the well screened in saprolite below ash

at the AB-8 location. This location is near the former Suck Creek channel and is close to the Suck Creek dam where a downward gradient exists.

A technical memorandum, titled *Saturated Ash Thickness and Underlying Groundwater Boron Concentrations – Allen, Belews Creek, Cliffside, Marshall, Mayo, and Roxboro Sites,* conducted linear regression analyses to evaluate the relationships between saturated ash thickness and concentrations of boron in ash pore water and underlying groundwater. The linear regression analysis was conducted using analytical data from Piedmont ash basins, including data from Cliffside.

Under pre-decanting conditions, the analysis demonstrates saturated ash and ash pore water are not significantly contributing COI concentrations to underlying groundwater except near dikes and dams, where downward vertical gradients exist. Pre-decanting conditions represent the greatest opportunity for COI migration to occur, not because of the volume of saturated ash, but because of the existing ash basin hydraulic head and the downward vertical hydraulic gradient near the dam. Under post-decanting, the hydraulic head of the ash basin will be reduced, therefore reducing the downward vertical gradient occurring near the dam and the rate of constituent migration from the ash basin to the groundwater system. Decanting the basin to reduce the vertical hydraulic gradient is the most important factor to limit further constituent migration in groundwater.

Two statistical methods (Mann-Kendall and linear regression trend analysis) methods were used to evaluate correlations between groundwater boron concentrations and saturated ash thickness, and between groundwater boron concentrations and ash pore water boron concentrations. Bedrock groundwater boron concentrations were negatively correlated with saturated ash thickness and ash pore water concentrations (groundwater boron concentrations decreased with increasing saturated ash thickness and with increasing ash pore water boron concentrations). For all groundwater zones, boron concentrations were negatively correlated with ash pore water concentrations (groundwater boron concentrations decreased with increasing ash pore water boron concentrations).

The maximum boron concentration in groundwater below the AAB is 94.4 µg/L. Given the low concentrations of boron beneath this ash basin, the negative correlations between groundwater boron concentrations and

saturated ash thickness/pore water concentrations suggest that boron concentrations in groundwater are not expected to increase based on decanting of the AAB or corrective actions for groundwater at the AAB. Data demonstrate that concentrations for other, less mobile, constituents are also low below saturated ash.

6.1.1.6 Chemistry within Waste Boundary

(CAP Content Section 6.A.a.vi)

Analytical sampling results associated with material from within the AAB and ASA waste boundaries are included in the following appendix tables or appendices:

1. Ash solid phase: **Appendix C**, Table 4 *(CAP Content Section 6.A.a.vi.1.1)*
2. Ash SPLP: **Appendix C**, Table 6 *(CAP Content Section 6.A.a.vi.1.2)*
3. Ash Leaching Environmental Assessment Framework: **Appendix H,** Attachment C *(CAP Content Section 6.A.a.vi.1.3)*
4. Soil: **Appendix C**, Table 4 *(CAP Content Section 6.A.a.vi 1.4)*
5. Ash pore water: **Appendix C**, Table 1 *(CAP Content Section 6.A.a.vi.1.6)*

Ash Solid Phase and Synthetic Precipitation Leaching Potential

(CAP Content Section 6.A.a.vi.1.1 and 6.A.a.vi.1.2)

Ash samples collected inside the AAB and ASA waste boundaries were analyzed for total extractable inorganic constituents using USEPA Methods 6010/6020. For information purposes, ash samples were compared with soil background values and PSRG POG. The ash analytical data do not represent soil conditions outside of or beneath the ash basin or ASA. Concentrations of arsenic, boron, selenium, and vanadium in ash samples were greater than background soil concentrations and PSRG POGs (**Appendix C,** Table 4).

In addition, five ash samples from the AAB and ASA were collected and analyzed for leachable inorganic using synthetic precipitation leaching procedures (SPLP) EPA Method 1312 (**Appendix C,** Table 6). The purpose of SPLP testing is to evaluate the potential for leaching of constituents that might result in concentrations greater than 02L standards or IMACs. SPLP

analytical results are compared with the 02L standard or IMAC comparative values to evaluate potential source contribution; the data do not represent groundwater conditions. The results of the SPLP analysis indicated that concentrations of antimony, arsenic, chromium, cobalt, iron, selenium, thallium, and vanadium were greater than the 02L standard or IMAC comparative value.

Ash Leaching Environmental Assessment Framework

(CAP Content Section 6.A.a.vi.1.3)

Ash samples were analyzed for extractable inorganics, including HFO (hydrous ferric oxide)/HAO (hydrous aluminum oxide), using the Citrate-Bicarbonate-Dithionite (CBD) method. Leaching environmental assessment framework (LEAF) is a leaching evaluation framework for estimating constituent release from solid materials. Leaching studies of consolidated ash samples from the CSS ash basins were conducted using two LEAF tests, EPA methods 1313 and 1316 (USEPA, 2012a, b). The data are presented and discussed in the Geochemical Modeling Report in **Appendix H,** Attachment C.

Leaching test results, using USEPA LEAF method 1316, indicate that, even for conservative COIs such as boron, the leachable concentration of boron present in ash from Cliffside is considerably lower than the total boron concentration (**Appendix H,** Attachment C). Cliffside data indicate that there is a process by which the COIs might become stable within the ash and would make the COI unavailable for leaching. The exact mechanisms of this process are unknown, however, literature suggests that incorporating COIs, such as boron, into the silicate mineral phases is a potential mechanism (Boyd, 2002). The leaching behavior of several COIs as a function of pH, examined using USEPA LEAF method 1313, demonstrated that for anionic COIs, the leaching increased with increasing pH and the cationic COIs showed the opposite trend (**Appendix H,** Attachment C).

Soil beneath Ash

(CAP Content Section 6.A.a.vi 1.4 and 6.A.a.vi 1.5)

Samples from soil collected beneath the AAB and the ASA were analyzed to understand and vertically delineate COI concentrations in soil. Soil samples within the waste boundary include samples collected from beneath the AAB and ASA and samples collected from the fill material within the AAB dams.

Constituents considered for soil evaluation were limited to constituents identified as COIs for the AAB and ASA source areas since soil impacts would be related to source area interactions to the underlying soils and groundwater, which may migrate beyond the source areas. The range of constituent concentrations in soils within the waste boundary, along with a comparison to soil background values and PSRG POG standards (NCDEQ May 2018), whichever is greater, is provided in **Appendix C**, Table 4.

For constituents lacking an established target concentration for soil remediation (*i.e.* sulfate), the following equation was used in general accordance with the references in 15A NCAC 02L.0202 to calculate a POG value.

$$C_{soil} = C_{gw}\,[k_d + (\theta_w + \theta_a H')/P_b]df$$

Where necessary, the PSRG POG values were calculated using laboratory testing and physical soil data for effective porosity (0.3) and dry bulk density (1.6 kg/L) prepared in part for flow and transport modeling for the Site. Soil water K_d were obtained from the *Groundwater Quality Signatures for Assessing Potential Impacts from Coal Combustion Product Leachate* (EPRI, 2012). Resulting PSRG POG calculated values for sulfate is 1,438 mg/kg (**Appendix C**, Table 4).

Affected saturated soil and rock is considered a component of the groundwater flow system and can serve as a source for groundwater COIs at the Site. The potential leaching and sorption of constituents in the saturated zone is included in the flow and transport and geochemical model evaluations (**Appendix G** and **H**) by continuously tracking the COI concentrations over time in the saprolite, transition zone, and bedrock materials throughout the models. Historical transport models simulate the migration of COIs through the soil and rock from the ash basin, and these results are used as the starting concentrations for the predictive simulations.

Saturated soil samples with values reported at greater than the PSRG POG or background value are vertically delineated by groundwater constituent concentrations in the corresponding flow layer of the soil sample depth.

Unsaturated soil and rock is considered a potential secondary source to groundwater. Constituents present in unsaturated soil or partially saturated soil (vadose zone) have the potential to leach into the groundwater system if

exposed to favorable geochemical conditions for chemical dissolution to occur. Constituent levels from unsaturated soil samples within the waste boundary were compared to PSRG for POG standards or background values. Concentrations of boron, cobalt, manganese, molybdenum, and thallium were greater than the PSRG for POG or background values, whichever is greater. Source control and ash basin closure activities will lower water elevations, reducing the potential for leaching constituents into the groundwater system. Analytical results for unsaturated soil data within the AAB and ASA waste boundaries can be found on **Table 6-3**.

The range of constituent concentrations in soils within the waste boundary, along with a comparison with soil background values, is provided in **Appendix C,** Table 4. Soil SPLP constituent concentrations within the waste boundary, along with a comparison to 02L/IMAC is provided in **Appendix C,** Table 6.

Ash Pore Water

(CAP Content Section 6.A.a.vi.1.6 and 6.A.a.vi.3)

The ash basins are wastewater treatment systems. Water within the ash basins is not groundwater; therefore, ash pore water isoconcentration maps were not prepared. Ash pore water data is provided for general information purposes only in **Appendix C**, Table 1. **Figures 6-2, 6-4, and 6-5** represent ash pore water constituent distribution in cross-section through the AAB. **Figure 6-3** represents ash pore water distribution in cross section through the ASA. These cross-sections represent the greatest horizontal and vertical extent and volume of source material in ash pore water and in groundwater below the AAB and ASA. For further discussion of geochemical trends within the ash pore water, see **Appendix H,** Section 2. All ash pore water sample locations are shown on **Figure 1-2**, and analytical results are proved in **Appendix C,** Table 1.

Nineteen groundwater monitoring wells located in areas that could be sensitive to changing Site conditions from AAB closure activities, including decanting, were selected for monitoring water elevation and geochemical parameters. Water elevations are monitored with pressure transducers and geochemical parameters, including pH, oxidation/reduction potential (E_H) and specific conductivity (three locations only), are monitored using multi parameter (or geochemical) sondes. Locations monitored with multi parameter sondes are depicted on **Figure 6-14**, and include:

- MW-10S: shallow flow zone monitoring well located north of the AAB
- MW-11S: shallow flow zone well located downgradient of the AAB, northeast of the AAB downstream dam
- GWA-21S: shallow flow zone monitoring well located downgradient and north of the AAB downstream dam

Hydrographs and geochemical water quality parameter time series plots for each location are included on **Figures 6-15a/b**. Observations of water elevation and multi parameter records from monitored locations include:

- Ash pore water, shallow, deep, and bedrock flow zone monitoring locations within the waste boundary show a response to ash basin decanting by reduced groundwater elevation levels (**Figures 6-15a/b**).
- Shallow, deep, and bedrock flow zone monitoring locations less than 500 feet downgradient of the ash basin show a response to ash basin decanting by reduced groundwater elevation levels (**Figures 6-15a/b**).
- Geochemical parameters pH and E_H do not show significant shifts or variability in records since ash basin decanting commenced (**Figures 6-15a/b**). This suggests geochemical conditions have remained stable under changing Site conditions at locations downgradient of the source area.

In general, ash pore water concentrations and groundwater geochemical parameters appear stable under changing site conditions. Ash pore water pH and ORP do not appear to be significantly affected by lowering the AAB pond's water level, and therefore represent stable conditions in which an increase in constituent dissolution and mobility is unlikely to occur. Additionally, groundwater pH and ORP, monitored beneath and downgradient of the ash AAB, are unaffected by even larger reductions in water levels, indicating stable geochemical conditions in which constituent dissolution and mobility are unlikely to occur.

In September, 2019, the geochemical sondes were relocated into monitoring wells AB-1S, MW-11DA, and GWA-21BRU at the AAB. The sondes were relocated due to the groundwater levels decreasing in the original wells

below the well screens due to continued decanting activities. Geochemical data is continuing to be collected from these wells and their suitability will continue to be assessed as decanting continues. If these wells become no longer viable due to the decrease in groundwater elevations, the sondes may be relocated into deeper nearby wells.

Ash Pore Water Piper Diagrams

(CAP Content Section 6.A.a.vi.2)

Piper diagrams can be used to differentiate water sources in hydrogeology (Domenico and Schwartz 1998). Piper diagrams of ash pore water monitoring data (**Figures 6-13a/b**) are used to assess the relative abundance of major cations (i.e., calcium, magnesium, potassium, and sodium) and major anions (i.e., chloride, sulfate, bicarbonate, and carbonate). Data used for the piper diagrams include ash pore water data between January 2018 and June 2019 with a charge balance between -10 and 10 %.

Ash pore water results tend to plot with higher proportions of sulfate, chloride, calcium, and magnesium, which is generally characteristic of ash pore water (EPRI, 2006). The area where ash pore water tends to plot on the piper diagram is identified as "affected" on **Figures 6-13a/b**. Ash pore water results from the AAB and ASA plot in the "affected," "generally unaffected," and the area in between identified as "potential mixing" (**Figures 6-13a/b**). The ash pore water distribution on the piper diagrams indicates that only general conclusions regarding impact to groundwater from the ash basin based on relative abundance of major cations and anions can be made.

6.1.1.7 Other Potential Source Material

(CAP Content Section 6.A.a.vii)

None of the data collected to date suggest that any source material other than the CCR associated with the AAB and ASA is contributing to the groundwater exceedances reported at or beyond the compliance boundary, with the exception of a portion of the groundwater criteria exceedances reported in some of the monitoring wells east of Unit 6 and west of Suck Creek. The COI concentrations in this area appear to be partly contributed to by an unknown source on the west side of Suck Creek. A CSA of the exceedances east of Unit 6 and west of Suck Creek not associated with the COIs under-flowing Suck Creek from the AAB will be submitted under separate cover.

6.1.1.8 Interim Response Actions

(CAP Content Section 6.A.a.viii)

Interim response actions to date include AAB decanting and source area stabilization. A summary of each interim action and the intended remedy are described in **Table 6-4**.

Active Ash Basin Decanting

(CAP Content Section 6.A.a.viii.1)

Ash basin decanting commenced on March 31, 2019, and is scheduled to be completed by March 31, 2020. Decanting is a form of active source remediation by removing ponded water in the ash basin, which is considered a critical component of reducing constituent migration from the ash basin. Reduction of constituent migration occurs through decanting by significantly reducing the hydraulic head and gradients, thereby reducing the groundwater seepage velocity and COI transport potential.

Prior to AAB closure, the operating level of the ash basin was maintained at approximately 760 feet. The flow and transport model predicts that the original stream channel of Suck Creek will reform as a result of lowering and removing the ash basin hydraulic head under the closure-by-excavation scenario. Water elevation of the ash basin was reduced by approximately 28.9 feet between the commencement of decanting in March 2019 and December 2019.

Four ponded water points from the ash basin fingers and 20 groundwater monitoring wells located north, east, south, and west of the AAB were selected for monitoring water elevations using pressure transducers to record changing site conditions from ash basin decanting (**Figure 6-14**). Ponded water and groundwater decanting network hydrographs, using water elevations recorded between January 2019 (May 2019 for ash basin fingers only) through September 2019 are depicted on **Figures 6-15a/b and 6-16**. Observations from hydrographs include:

- By September 2019, water level in the ash basin pond has decreased by approximately 15 feet since decanting started (**Figure 6-16**). As of December 1, 2019 the water level in the AAB pond has decreased by 28.9 feet (Note: the water elevations displayed on **Figure 6-16** are not current to December 1, 2019).

- Ash basin finger water levels at the South Finger and SE Finger locations have decreased by approximately less than one foot (**Figure 6-16**). The minimal drawdown of water levels observed in the ash basin fingers suggests the fingers are weakly connected to the pond. The SW Finger monitoring location has decreased by about 2 feet in elevation. This location shows more rainfall response and fluctuation in water levels during rain events. The Active South monitoring location had decreased by approximately two feet as of July 2019. Due to the sloughing event in the AAB on July 1, 2019, access to download the Active South transducer is no longer possible due to safety concerns at the AAB during the decanting process.
- All groundwater monitoring locations show a response to ash basin decanting by reduced groundwater elevation levels (**Figures 6-15a/b)**.
- Groundwater monitoring wells in and around the AAB showed varying degrees of response from decanting with elevation changes generally ranging approximately 2 to 10 feet. The largest degree of response from decanting was observed in monitoring well MW-11BRO with an approximate water level drop of 15 feet (**Figures 6-15a/b)**.
- Water elevation records from groundwater monitoring wells MW-11S, CCR-4D, and MW-10S indicate water levels decreased below the transducer elevation in May and June 2019 (**Figures 6-15a/b)**. Transducers were installed at elevations approximately in the middle of the monitoring well's 10 foot screened interval. Water levels recorded below transducer elevations suggests the monitoring wells are nearly dry (*i.e.* insufficient water available for monitoring purposes). The water level transducers were removed from these wells and were re-deployed into monitoring wells GWA-21BR, MW-11DA, and GWA-22BRU to continue to monitor water level elevations during decanting.

Source Area Stabilization

(CAP Content Section, 6.A.a.viii.2)

In an August 22, 2016 correspondence, NCDEQ provided a notice of deficiencies related to the AAB downstream dam including spillway and riser repair and the need for the installation of a new spillway. In response, Duke Energy undertook activities to correct the deficiencies.

Pursuant to G.S. Section 130A-309.213(d)(1) and based upon determinations in a letter dated November 13, 2018, NCDEQ has classified the CCR surface impoundments at CSS as low-risk (**Appendix A**). The relevant closure requirements for low-risk impoundments are in G.S. Section 130A-309.214(a)(3), which states low-risk impoundments shall be closed as soon as practicable, but no later than December 31, 2029.

6.1.2 Extent of Constituent Migration beyond the Compliance Boundary

(CAP Content Section 6.A.b)

This section is an overview of constituent occurrences beyond the point of compliance. The point of compliance at the AAB is the ash basin compliance boundary, and the point of compliance at the ASA is the waste boundary. The compliance boundary for groundwater quality at the AAB is defined in accordance with Subchapter 02L .0107(a) as being established at either 500 feet from the waste boundary or at the property boundary, whichever is closer to the waste. The CSS AAB ash basin compliance boundary encompasses the southern portion of the ASA (**Figure 1-2**).

Analytical sampling results associated with the source area: AAB and ASA for each media are included in the following tables and appendix tables:

1. Soil: **Appendix C**, Table 4 and **Table 6-3** *(CAP Content Section 6.A.b.ii.1)*
2. Groundwater: **Appendix C**, Table 1 and **Table 6-5** *(CAP Content Section 6.A.b.ii.2)*
3. Seeps: **Appendix C**, Table 3 *(CAP Content Section 6.A.b.ii.3)*
4. Surface water: **Appendix C**, Table 2 and **Appendix K** *(CAP Content Section 6.A.b.ii.4)*
5. Sediment: **Appendix C**, Table 5 *(CAP Content Section 6.A.b.ii.5)*

Soil Constituent Extent

Data indicate unsaturated soil constituent concentrations at or beyond the compliance boundary are generally consistent with background concentrations or are less than regulatory screening values (**Table 6-3**). Horizontal and vertical extent of COI concentrations in soil is discussed further in **Section 6.1.4**.

Groundwater Constituent Extent

The AAB compliance boundary extends 500 feet beyond the ash basin waste boundary, or to the property boundary, whichever is closer. Groundwater

concentrations greater than applicable 02L standard/IMAC/background values occur locally at or beyond the compliance boundary:

1. North of the AAB within the ASA

Groundwater concentrations greater than applicable 02L standard/IMAC/background values also occur locally near the compliance boundary:

1. North and northeast of the AAB downstream dam
2. Northwest of the AAB upstream dam

The maximum extent of affected groundwater migration for all flow zones is represented by boron concentration greater than background values. The boron extent greater than background extends to the north and northeast of the AAB downstream dam, north of the AAB in the ASA, and northwest of the AAB upstream dam, west of Suck Creek. Of these locations, boron has only migrated from the AAB to areas to the north, at or beyond the compliance boundary, greater than the 02L standard. Boron has not migrated at or beyond the point of compliance in any other areas. This is because groundwater divides in areas upgradient and side-gradient of the basin limit constituent transport to primary flow paths. Additionally, the Broad River downgradient of the basin is a groundwater discharge zone that limits the horizontal transport of constituents downgradient of the basin. Due to the limited presence and mobility of most constituents in the groundwater system, COI concentrations in groundwater have not caused, and will not cause, current surface water quality standards to be exceeded (**Appendix K**).

Arsenic, cobalt, iron, lithium, manganese, strontium, sulfate, thallium, TDS, uranium (total), and vanadium, have concentrations greater than their respective groundwater comparison criteria at or beyond the compliance boundary. Of these constituents, all concentrations greater than regulatory standards are generally at locations where boron concentrations are greater than background values. The distribution of these constituents is more localized and less widespread than the boron plume greater than background concentrations.

Section 6.1.3 includes a constituent management process for determining which groundwater constituents warrant corrective action, and **Section 6.1.4** provides isoconcentration maps and cross-sections depicting groundwater flow and

constituent distribution in groundwater at or beyond the compliance boundary *(CAP Content Section 6.A.b.i)*.

Seep Constituent Extent

(CAP Content Section 6.A.b.ii.3)

Seeps at Cliffside are subject to the monitoring and evaluation requirements contained in the SOC. The SOC states that the effects from non-constructed seeps should be monitored. Attachment A to the SOC identifies the following seeps:

- Non-constructed seeps to be monitored — S-2, S-3, S-7, S-14, S-15, S-16, S-18, S-19, S-19A, S-21, S-23, S-27, S-28, S-29, S-30, S-31, S-32 and S-36.
- Non-constructed seeps dispositioned — S-1, S-5, S-8, S-9, S-10, S-11, S-12, S-13, S-17, S-20, S-22, S-24, S-25, S-26, S-33, S-34, and S-35.

The SOC defines dispositioned:

1. The seep is dry for at least three consecutive quarters;
2. The seep does not flow to waters of the State;
3. The coal ash basin no longer impacts the seep for all COIs over four consecutive sampling events;
4. An engineering solution has eliminated the seep.

Non-dispositioned seeps, where monitoring conducted has indicated the presence of CCR affects, include: S-4, S-6, S-7, S-14, S-15, S-16, and S-21 (**Figure 1-2**). **Table 6-8** provides a summary of seep general location and approximate flow rate. Analytical results for these seep samples are included in **Appendix C,** Table 3.

Surface water sampling conducted downstream of non-dispositioned seep S-7 from the Broad River, demonstrate that flow from this seep has not caused constituent concentrations greater than 02B standards in the river. Surface water sampling conducted downstream of non-dispositioned seeps S-14, S-15, S-16, and S-21 from Suck Creek, demonstrate that flow from this seep has not caused constituent concentrations greater than 02B standards in the creek. Surface water samples collected from the Broad River and Suck Creek are shown on **Figure 1-2**. Surface water samples collected from the Broad River downstream of seep S-7 include SW-10A, SW-10B, SW-10C, and C_1_DN. Surface water samples collected from Suck Creek downstream of seeps S-14, S-15, S-16, and S-21 include

SW-3, SW-SC-6, and SW-SC-6A. Analytical results for these surface water samples are included in **Appendix C**, Table 2.

Surface Water Constituent Extent

(CAP Content Section 6.A.b.ii.4)

Surface water samples have been collected over multiple events from the Broad River and Suck Creek to confirm groundwater downgradient of the AAB and ASA has not resulted in surface water concentrations greater than 02B water quality standards. Surface water samples were collected to evaluate acute and chronic water quality values. Surface water samples were also collected at background locations (upgradient of potential migration areas) within the Broad River and Suck Creek. Analytical results were evaluated with respect to 02B water quality standards and background data. This data confirms that there are no surface water quality exceedances related to the AAB or ASA. Surface water sample locations are depicted on **Figure 1-2** and the surface water results are presented in **Appendix C**, Table 2. Surface water conditions is further discussed in **Section 6.2.1** and the full report for CSS surface water current conditions can be found in **Appendix J**.

Additionally, environmental assessments of the Broad River have all demonstrated that the river has been an environmentally healthy and functioning ecosystem, and ongoing sampling programs have been established to ensure the health of this system will continue. Furthermore, these data indicate that there have been no significant effects to the local aquatic systems related to coal ash constituents over the last 30 years. More information related environmental health assessments conducted for the Broad River, including sampling programs, water quality and fish community assessments, and fish tissue analysis, can be found in **Appendix E.**

Sediment Constituent Extent

(CAP Content Section 6.A.a.ii.5)

Assessment of constituents in sediment in the vicinity of the AAB was conducted through evaluation of data from 30 one-time grab samples at Cliffside. Similar to saturated soils and groundwater, sediment is considered a component of the surface water system, and the potential leaching and sorption of constituents in the saturated zone is related to water quality. Because no regulatory standards are established for sediment inorganic constituents, background sediment constituent concentration ranges are considered in this sediment evaluation. Analytical results for sediment samples is provided in **Appendix C,** Table 5

(CAP Content Section 6.A.b.ii.5). **Table 4-5** presents the sediment sample results from background sediment samples.

Sample locations shown on (**Figure 1-2**) included:

- Three background locations along the bank of Suck Creek, the Broad River, and the Second Broad River
- Eleven locations along the banks of Suck Creek and the Broad River downgradient of the AAB
- Sixteen seeps downgradient of the AAB

Sediment results from samples collected at locations upstream of the AAB (background data) were compared to results from samples collected at locations downstream of the AAB.

Chromium concentrations were above the detected background range in sediment from locations CLFSTR-65, CLFWW-57, SW-3, and SED-8, however these concentrations are similar to levels detected in background sediment.

Cobalt concentrations were above the detected background range in sediment from locations CLFSP-61, CLFWW-57, S-6, S-9, and SED-8, however these concentrations are similar to levels detected in background sediment.

Iron concentrations were above the detected background range in sediment from locations CLFSTR-65, CLFWW-57, S-6, S-9, S-15, S-16, S-22, SED-9, and SED-8, however these concentrations are similar to levels detected in background sediment.

Manganese concentrations were greater than the detected background range in sediment from locations CLFSP-59, S-6, S-12, S-22, and SED-8, however these concentrations are similar to levels detected in background sediment. Manganese in sediment collected at location S-9 was approximately 4.5 times greater than the highest detected background value. Location S-9 is located on a hill slope upgradient of Suck Creek. This location is near a surface water diversion ditch which could lead to excessive sediment buildup and deposition due to surface water runoff from the roadway and surrounding area.

The thallium concentration in a sample from location SED-8 was above the detected background range, but is within an order of magnitude.

A human health and ecological risk assessment pertaining to CSS was prepared and is included in **Appendix E**. The risk assessment focuses on the potential effects of CCR constituents from the Cliffside ash basins and ASA on groundwater, surface water, and sediment. The human health and ecological risk assessments demonstrated no measurable difference in modeled risks to potential human or ecological receptors compared with background concentrations. Based on this information, no COIs require remediation in sediments at the AAB or ASA.

6.1.2.1 Piper Diagrams

(CAP Content Section 6.A.b.iii)

Piper diagrams can be used to differentiate water sources in hydrogeology by assessing the relative abundance of major cations (*i.e.*, calcium, magnesium, potassium, and sodium) and major anions (*i.e.*, chloride, sulfate, bicarbonate, and carbonate) in water.

Groundwater Piper Diagrams

(CAP Content Section 6.A.a.vi.2)

Piper diagrams of groundwater monitoring data from shallow, deep and bedrock background locations and downgradient of the AAB and ASA are shown in **Figure 6-13a/b.** Data used for the piper diagrams include groundwater data between January 2018 and June 2019 with a charge balance between -10 and 10%.

- Background groundwater from each flow zone tends to plot central to the diagram indicating water quality is more balanced between major anions and cations. The area where background groundwater (or native groundwater) tends to plot on the piper diagram is identified as "generally unaffected" on **Figure 6-13a/b**.
- Along the east transect, shallow groundwater monitoring wells GWA-22S and MW-11S plot in the "affected" region of the piper diagrams (**Figure 6-13b**). Mean boron concentrations from each of these shallow monitoring wells are greater than background values and greater than the 02L standard in MW-11S (**Appendix C**, Table 1). No samples from deep or bedrock wells along the east transect plot in the "generally affected" region.
- Along the west transect, deep groundwater monitoring wells CCR-8D, GWA-20D, and GWA-27DA plot in the "affected" region of the piper diagrams (**Figure 6-13b**). Mean boron is detected at each of

these deep monitoring well locations at concentrations greater than the 02L standard (**Appendix C**, Table 1).

- Along the ASA transect, shallow groundwater monitoring wells AS-1SB and AS-2S plot in the "affected" region of the piper diagram (**Figure 6-13a**). Deep groundwater monitoring well CLMW-3D also plots in the "affected" region of the piper diagram (**Figure 6-13a)** Mean boron concentrations for each of these wells are greater than the 02L standard (**Appendix C**, Table 1).
- No results from bedrock groundwater monitoring wells from any transect plot in the "affected" region of the piper diagrams (**Figure 6-13a/b**).
- The distribution of ash pore water results on the piper diagrams in **Figure 6-13a/b** indicate that only general conclusions can be made regarding impact to groundwater from the ash basin based on piper diagram analysis. However, analysis of the piper diagrams combined with evaluation of boron concentrations in each well, indicate that shallow and deep groundwater monitoring wells downgradient of the AAB show impact from the source.

Seep and Surface Water Piper Diagrams

Piper diagrams of seep, Broad River and Suck Creek surface water monitoring data are included in **Figures 6-29a/b.** Data used for the piper diagrams include most recent available seep and surface water data (**Appendix C**, Tables 2 and 3) with a charge balance between -10 and 10%. From ash pore water and groundwater piper diagrams (**Figure 6-13a/b)** areas identified where ash pore water tends to plot is noted as "affected"; areas that show potential mixing with affected water is noted as "potential mixing", and areas that are similar to background (or native) water quality are noted as "generally unaffected".

- Free water within the AAB tends to plot with higher proportions of sulfate, chloride, calcium, and magnesium, just as ash pore water generally does (**Figures 6-29a/b**).
- In the area of the downstream dam of the AAB, seeps S-4, S-6, and S-7 plot within the "potential mixing" area between the region where ash pore water tends to plot and the region where background/unaffected water plots (**Figure 6-29a/b**). Each of these seeps are covered by the SOC.

- Two surface water samples (SW-BRAB-2 and SW-BRAB-3) from the Broad River also plot within the area of "potential mixing" (**Figure 6-29b**). Both surface water sample locations are located on the Broad River downstream of the AAB. Sample results from SW-BRAB-2 and SW-BRAB-3 are less than 02B Standards except for hardness (**Appendix C,** Table 2). Impact to SW-BRAB-2 and SW-BRAB-3 is likely due to NPDES permitted Outfall 002.
- Remaining seep and surface water samples near the downstream dam of the AAB and the Broad River plot with water quality in the region of generally unaffected (**Figure 6-29b**).
- In the area of the AAB upstream dam, three seeps (S-21, S-31, and S-27) plot with the source water results in the "affected" region of the piper diagram (**Figure 6-29a**). Seeps S-14, S-15, and S-16 plot within the "potential mixing" region of the piper diagram (**Figure 6-29a**). Each of these seeps are covered by the SOC and are within the compliance boundary.
- All surface water samples along Suck Creek near the AAB plot on the piper diagram in a cluster with majority of the sample results within the "potential mixing zone" (**Figure 6-29a**). The upstream and downstream samples are indistinguishable on the piper diagram; therefore, no inference regarding impact from the AAB can be made from analysis of **Figure 6-29a**.

6.1.3 Constituents of Interest (COIs)

(CAP Content Section 6.A.c)

This CAP Update evaluates the extent of, and remedies for constituents associated with the CSS AAB and ASA that are at or beyond the compliance boundary to the north and northeast of the AAB downstream dam, north of the AAB within the ASA, and northwest of the AAB upstream dam detected at concentrations greater than 02L standards, IMACs, or background values, whichever is greater.

Site-specific COIs were developed by evaluating groundwater sampling results with respect at concentrations greater than regulatory criteria or background values, whichever is greater. The distribution of constituents in relation to the source area, co-occurrence with CCR indicator constituents, such as boron, and migration directions based on groundwater flow direction are considered in determination of COIs.

The following list of COIs was developed as part of the CSA Update for Cliffside (SynTerra, 2018):

- Arsenic
- Boron
- Chromium (Total)
- Chromium (Hexavalent)
- Cobalt
- Iron
- Manganese
- pH
- Total Uranium
- Total Radium
- Strontium
- Sulfate
- Total Dissolved Solids
- Thallium
- Vanadium

Soil

(CAP Content Section 6.A.c.i.1)

Unsaturated soil at or beyond the compliance boundary is considered a potential secondary source to groundwater. Constituents present in unsaturated soil or partially saturated soil (vadose zone) have the potential to leach into the groundwater system if exposed to favorable geochemical conditions for chemical dissolution to occur. Constituents considered for unsaturated soil evaluation were limited to constituents identified as COIs for the AAB and ASA since soil impacts would be related to the interaction of ash pore water and underlying soil within the basins and groundwater migration beyond the ash basins.

Data indicate unsaturated soil COI concentrations are generally consistent with background concentrations or are less than regulatory screening values (**Table 6-3**). In the few instances where unsaturated soil COI concentrations are greater than PSRG POG standards or background values, COI concentrations are within range of background dataset concentrations or there are no mechanisms by which the COI could have been transported from the ash basin to the unsaturated soils. Horizontal and vertical extent of COI concentrations in soil, and reasons why no necessary corrective action for soils is identified at the Site, is discussed further in **Section 6.1.4**.

Groundwater

(CAP Content Section 6.A.c.i.2)

A measure of central tendency analysis of groundwater COI data (January 2018 to June 2019) was conducted and means were calculated to support the analysis of groundwater conditions to provide a basis for defining the extent of the COI migration at or beyond the compliance boundary. A measure of central tendency

analysis was completed to capture the appropriate measure of central tendency (arithmetic mean, geometric mean, or median) for each dataset of constituent concentrations. Constituent concentrations in a single well might vary over orders of magnitude; therefore, a single sample result might not be an accurate representation of the concentrations observed over several months to years of groundwater monitoring. Evaluating COI plume geometries with central tendency data minimizes the potential for incorporating occasions where COIs are reported at concentrations outside of the typical concentration range, and potentially greater than enforceable groundwater standards. Previous Site assessments might have overrepresented areas affected by the ash basin by posting a single data set on maps and cross-sections that might have included isolated data anomalies.

NCDEQ (October 24, 2019, **Appendix A**) recommended use of a lower confidence limit (LCL95) rather than the central tendency value. LCL95 concentration were calculated for each COI. The LCL95 concentration for the sample with the highest COI LCL95 concentration is provided for comparison to the COI mean concentration in Table 1 of the technical memorandum titled *COI Management Plan Approach – Cliffside Steam Station* (Arcadis, 2019) included within **Appendix H**. The mean COI concentration is typically greater than the LCL95 value, and therefore, is a more conservative approach for evaluation and comparison to applicable criteria.

The mean of up to six quarters of valid data was calculated for each identified COI to analyze groundwater conditions and define the extent of COI migration at or beyond the compliance boundary. At a minimum, four quarters of valid data were used for calculating means, however, if fewer than four quarters of valid data were available, the most recent valid sample result was reported. Less than four quarters of valid data were not available either because the well was recently installed or sample results from one or more quarters were excluded. For use in calculating means, nondetect values were assigned the laboratory reporting limit and estimated (J-flag) values were treated as the reported value. Procedures for excluding data from calculating means are based on USEPA's National Functional Guidelines (USEPA, 2017a, 2017b), published research about leaching of elements from coal combustion fly ash (Izquierdo, and others 2012), and professional judgement.

The following steps outline the approach followed in calculating central tendency values for constituent concentrations in groundwater:

1. If the maximum analytical value divided by the minimum value for each constituent was greater than or equal to 10 (*i.e.* the data set ranges over an order of magnitude), the geometric mean of the analytical values was used.
2. If the maximum analytical value divided by the minimum value for each constituent was less than 10 (*i.e.* the data set range is within an order of magnitude), the arithmetic mean is used.
3. The median of the data was used for records that contain zeros or negative values (e.g., total radium). Negative values were set to zero prior to calculating the median concentration.
4. If the dataset mode (most common) is equal to the RL, and the geometric mean or mean value is less than or equal to the dataset's mode, the value is reported as "<RL" (e.g. the reporting limit for boron is 50 µg/L; for wells with geomean or mean analysis results less than 50 µg/L the mean analysis result would be shown as "<50").

Sample results were excluded from calculations for the following conditions:

- Duplicate sampling events for a given location and date. The parent (CAMA) sample was retained.
- Turbidity was greater than 10 Nephelometric Turbidity Units (NTUs)
- Records where pH was greater than 10 standard units (S.U.). Data with pH greater than 10 S.U. might be related to grout from well construction
- Data flagged as unusable (R0 qualified)
- Data reported as non-detect with a reporting limit (RL) greater than the normal laboratory reporting limit
- Negative values for total radium were set equal to 0.

Table 6-5 presents the mean analysis results of the COI data using groundwater monitoring sampling results from January 2018 to June 2019. Where means could not be calculated, the most recent valid sample was evaluated to determine whether the sample result is an appropriate representation of the historical dataset. Data from **Table 6-5** are used in evaluating COI plume geometry in the vicinity of the AAB and ASA.

Constituent Management Approach

As discussed at the beginning of **Section 6**, a 'COI management process' was developed by Duke Energy at the request and acceptance of NCDEQ to gain understanding of the COI behavior and distribution in groundwater and to aid in selection of the appropriate remedial approach. Details of the COI management approach are provided in **Appendix H.** In general, the COI management process consists of three steps:

1. Performing a detailed review of the applicable regulatory requirements under NCAC, Title 15A, Subchapter 02L
2. Understand the potential mobility of site-related COIs in groundwater based on site hydrogeology and geochemical conditions
3. Determine the constituent distribution at the Cliffside AAB and ASA under current or predicted future conditions.

The management process uses a matrix evaluation [**Table 6-6** (*CAP Content Section 6.A.c.i.2*)**]**

This COI management process is supported by multiple lines of evidence including empirical data collected at the site, geochemical modeling, and groundwater flow and transport modeling. This approach has been used to understand and predict constituent behavior in the subsurface related to the AAB and ASA or constituents that are naturally occurring. Constituents that have migrated beyond the compliance boundary at concentrations greater than 02L standard, IMAC or background value, and that are related to the source area would be subject to corrective action. Constituents that are naturally occurring at concentrations greater than the 02L standard or IMAC do not warrant corrective action.

Using the constituent management process, three of 14 inorganic groundwater COIs (not including pH) identified in the CSA Update (CSA Update, 2018), exhibit mean concentrations that are currently less than background values, 02L standard, or IMAC at or beyond the compliance boundary, or have few concentrations greater than comparison criteria but with no discernable plume characteristics. These three constituents include:

- Chromium (total)
- Hexavalent chromium
- Radium (total)

These constituents are not expected to migrate distances at or beyond the compliance boundary or migrate distances that would present risk to potential receptors, and are predicted, based on geochemical modeling, to remain at stable concentrations, typically less than background values, 02L standard, or IMAC (**Appendix H**).

The remaining 11 COIs exhibit mean concentrations greater than background values, 02L standard, or IMAC downgradient of the ash basin at or beyond the compliance boundary. These constituents are as follows:

- Arsenic
- Boron
- Cobalt
- Iron
- Manganese
- Strontium
- Sulfate
- Total Dissolved Solids (TDS)
- Thallium
- Total Uranium
- Vanadium

Lithium has been added to the constituent list for the CSS AAB and ASA. Lithium was not previously analyzed for in collected groundwater samples until the second quarterly sampling event in 2018 (April 2018). This was after the submission of the CSA (CSA Update, 2018) and therefore lithium was not evaluated in that submittal.

As discussed in the CSA Update (SynTerra, 2018), not all constituents with results greater than background values can be attributed to the AAB and ASA. Naturally occurring groundwater contains varying concentrations of inorganic constituents. Sporadic and low-concentration occurrences of these constituents in the groundwater data do not necessarily demonstrate horizontal or vertical distribution of affected groundwater migration from the AAB or ASA.

6.1.4 Horizontal and Vertical Extent of COIs

(CAP Content Section 6.A.d)

The COIs at the CSS have been delineated horizontally and vertically in groundwater based on sampling and analysis data collected from 292 monitoring wells present at the site. The majority of COIs are either present below their applicable standards, do not exhibit discernable plumes, or have migrated a limited distance from the ash basins in groundwater. An evaluation of site data indicates that COI presence in groundwater decreases with depth. Supporting

information for these findings are presented in the COI management evaluation presented in **Section 6.1.3** and in **Appendix H.**

Boron, a conservative (non-reactive) constituent, is the main COI that is present in site groundwater in a discernable plume associated with the ash basins and ASA. Boron typically has greater concentrations in CCR than in native soil and is relatively soluble and mobile in groundwater (Chu et al., 2017). Sulfate and TDS are also conservative constituents that represent discernable COI plume geometries, but smaller in extent and plume footprint than boron. Additional constituent concentrations identified as being greater than their respective groundwater regulatory standards or background values, and are associated with COI-affected groundwater migration from the ash basin, are confined within the extent of the boron background plume at the Site. Therefore, the maximum extent of the boron plume greater than its background value (50 µg/L) was used to determine the maximum extent of COI-affected groundwater migration.

Since naturally occurring COIs might be present at concentrations greater than Site-specific background values, isoconcentration maps of primary CCR indicator COIs (*i.e.*, boron, lithium, sulfate, and TDS) are most representative of the groundwater COI plume extent in three-dimensional space.

Isoconcentration maps and cross-sections use groundwater analytical data to spatially and visually define areas where groundwater COI concentrations are greater than background values and/or 02L standards/IMAC. Geometric means of groundwater COI monitoring sampling results from January 2018 to June 2019 provide an understanding of groundwater flow dynamics and direction to define the horizontal and vertical extent of the COI plume. Horizontal extent of the COI plume is depicted on isoconcentration maps (**Figures 6-17** through **6-28**). Non-conservative constituents, boron, sulfate, and TDS, are mapped with empirical Site data and supplemented with flow and transport model simulated plume depictions where no data is available.

The flow and transport model calibration targets are boron, sulfate, and TDS concentrations measured in monitoring wells in the second quarter of 2019. All sampled wells are included in the calibration. Data that has been collected since that timeframe were not included in the updated model calibration process. Fall 2019 data from relatively newly installed wells suggest the model predictions are

accurate, or conservative; the model over-predicts the actual groundwater concentrations in some areas.

Vertical extent of the COI plume at the AAB and ASA is depicted on three generalized cross-sectional depictions. The geochemical groupings of COIs (conservative, non-conservative, and variable), along with the extent of boron are posted on the cross-sections. Six cross-sections (A-A′, B-B′, F-F′, I-I′, J-J′, and K-K′) were prepared near the AAB and ASA for previous CSA and CAP reports. Three of cross-sections (B-B′, F-F′, and I-I′) are oriented either at perpendicular or obtuse angles to the flow directions through the AAB or ASA. Therefore, those cross-sections have limited use in depicting flow and COI transport, and are not used in this CAP.

Four cross-sections (A-A′, J-J′, K-K′, and N-N′) are included in this CAP Update:

- Cross-section A-A′ (**Figure 6-2**) is oriented generally south to north from the southern end of the AAB, through the central portion of the basin to the Broad River to the north, and displays the AAB footprint, topography, and depth of saturated ash in the basin, and free water near the AAB downstream dam.
- Cross-section J-J′ (**Figures 6-3**) is oriented north to south and displays the ASA footprint, topography, and depth of saturated ash in the AAB and ASA.
- Cross-section K-K′ (**Figure 6-4**) is oriented generally northwest to southeast from the AAB upstream dam, through the ash stockpile and the central portion of the AAB, to the area east and upgradient of the basin, and displays the AAB footprint, topography, and depth of saturated ash in the AAB.
- Newly developed cross-section (N-N′) (**Figure 6-5**), is oriented generally east to west along a flowpath in the southern portion of the AAB from the upgradient land east of the AAB, through the southern end of the basin, to Suck Creek *(CAP Content Section 6.A.a.vi.3, 6.A.d, and 6.A.d.ii)*.

At or beyond the compliance boundary, the maximum extent of COI-groundwater affected by the ash basin occurs north of the AAB in the ASA. Near the compliance boundary, the maximum extent of COI-groundwater affected by the ash basin occurs north and northeast of the AAB downstream dam and northwest of the AAB upstream dam, west of Suck Creek.

Northeastern Extent of Constituent Affected Groundwater

North and northeast of the AAB downstream dam, the COIs near the compliance boundary include: arsenic, iron, manganese, strontium, thallium, uranium (total), and vanadium, which have been sporadically reported at concentrations greater than their groundwater comparison criteria.

COI Data Comparison to Criteria

Arsenic is not reported at concentrations greater than the groundwater comparison criterion in at the AAB downstream dam, and does not show evidence of a discernable plume attributable from the AAB. There is an isolated 02L Standard exceedance reported at GWA-21S but is not reported greater than the groundwater comparison criterion in the deep or bedrock flow layers at this well cluster.

Iron has reported exceedances of groundwater comparison criteria (background value) near the compliance boundary in the deep flow layer at monitoring well MW-20D, but not reported at concentrations greater than the comparison criteria near the compliance boundary in the shallow or bedrock flow layers.

Manganese is not reported greater than the groundwater comparison criteria (background value) in the shallow flow layer near the compliance boundary. An isolated exceedance near the compliance boundary is reported in the deep flow layer at MW-20D. Manganese groundwater criteria exceedances are reported at the AAB downstream dam and downgradient near the compliance boundary at GWA-21BR/BRL and MW-20DR.

Strontium is reported greater than its groundwater comparison criteria (background value) in the shallow flow layer near the compliance boundary at GWA-22S and GWA-21S. Strontium is reported near the compliance boundary in the deep flow layer at concentrations greater than comparison criteria at GWA-21BRU, MW-20D, and GWA-22BRU. Strontium concentrations are reported near the AAB compliance boundary in the bedrock flow layer at GWA-21BR/BRL and MW-20DR greater than groundwater comparison criteria. Strontium concentrations greater than the statistically derived background values are common at the Site and often are not located in flow paths reflective of migration from the ash basins or ASA. Therefore, the natural variability of strontium may not be accurately reflected by the current background dataset. As part of the effectiveness monitoring plan (EMP), a five year review process is

proposed which would include routine re-evaluation of background concentrations as additional data becomes available.

Thallium is reported in the shallow flow layer near the AAB compliance boundary greater than the IMAC at monitoring well GWA-21S. Thallium is reported at concentrations less than the IMAC in the deep and bedrock flow layers north and northeast of the AAB downstream dam.

Uranium (total) is reported in the shallow flow layer near the AAB compliance boundary greater than the groundwater comparison criteria (background value) at monitoring well GWA-21S. Uranium (total) is not reported in the deep or bedrock flow layers near the AAB compliance boundary at concentrations greater than the comparison criteria. Uranium (total) is not reported at concentrations greater than comparison criteria upgradient from the well in at the AAB downstream dam, and does not show evidence of a discernable plume attributable to the AAB.

Vanadium is reported in the shallow flow layer near the AAB compliance boundary greater than the comparison criteria (background value) at monitoring wells GWA-21S and GWA-22S. Vanadium is not reported in the deep or bedrock flow layers near the AAB compliance boundary at concentrations greater than the comparison criteria. Vanadium is not reported at concentrations greater than comparison criteria upgradient from the wells at the AAB downstream dam, and does not show evidence of a discernable plume attributable to the AAB.

Discussion

Based on findings from the MNA Evaluation (**Appendix I**), sorption, precipitation, dilution and other attenuation mechanisms will act to reduce concentrations as the constituents move in groundwater from the AAB. A downward concentration trend often following an exponential pattern is typical. **Table 6-5** shows geometric means for all 15 COIs in wells downgradient from the AAB downstream dam. Of the COIs discussed above:

- Arsenic, thallium and total uranium have geometric means less than the groundwater comparative criteria in downgradient wells
- Manganese and strontium have geometric means greater than the groundwater comparative criteria in a large number of downgradient wells

- Vanadium and iron have an intermediate number of geometric means greater than the groundwater comparative criteria
- None of these parameters exhibit a concentration pattern similar to a groundwater plume

Boron and lithium are classified as a conservative constituent while strontium is classified as non-conservative. Strontium and lithium are present in significant concentrations in downgradient wells. Trend analysis and results are prepared by Arcadis U.S. Inc. and included in a technical memorandum titled *Plume Stability Evaluation – Cliffside Steam Station* (Arcadis, 2019). The technical memorandum is included as in **Appendix I** as Attachment A.

Boron: None of the mean concentrations for boron have values exceeding the 02L standard of 700µg/L northeast of the AAB downstream dam near the compliance boundary. Monitoring wells with the greatest results reported in groundwater are located at well cluster AB-1 (569 and 401 µg/L), on the crest of the downstream dam. These elevated concentrations are expected given their proximity to the AAB. **Appendix I,** Figures 5-14 and 5-17 show that there is no correlation of boron concentrations with distance. This finding suggests that the releases and migration of boron have reached an equilibrium concentration of approximately 150µg/L. As indicated in the flow and transport model (**Appendix G**), this concentration will be reduced after ash basin decanting and closure.

Strontium: **Appendix I,** Figures 5-15 and 5-18 show plots of mean concentrations versus distance of monitoring wells from the waste boundary the AAB. As with boron, there is no correlation between distance and concentrations, and the midpoint of the range of values is about 250µg/L (regardless of distance). This may be more representative of the background condition in this portion of the Cliffside facility (i.e., near the Broad River). **Appendix I,** Table 5-8 of the CAP Update reports the geometric mean of site specific K_d values for strontium in each flow zone: shallow – 3410L/Kg, deep – 590L/Kg and bedrock – 27.6L/Kg. These values translate to elevated retardation coefficients (approximately 5 times the K_d values) and make migration of strontium improbable. However, as described in the geochemical modeling report for Cliffside (**Appendix H**), the presence of calcium and magnesium reduce the sorption capacity for strontium as the calcium and magnesium are preferentially tied up. The downgradient concentrations may have been impacted by strontium within the ash basin. The combination of strontium

transport and the background concentration being larger than currently reported explain the somewhat elevated results.

Lithium: Like boron and strontium, there is no correlation between lithium concentrations and distance from the basin (**Appendix I**, Figures 5-15 and 5-18). All monitoring wells in the three flow zones exhibit mean lithium concentrations below the background values with the exception of MW-11BRL, which has a very limited database and is very close to the AAB, and thus is considered a spurious result. This indicates that the plume has stabilized and that these values are representative of background conditions. Note that the midpoint of the range has been estimated at approximately 6µg/L. Lithium and boron do not appear to have a correlation between these two parameters. Given that the source area is the same for both constituents, it is expected that some correlation either positive or negative should be observed. Given that there is no correlation between lithium and boron further supports that lithium is not being transported from the AAB.

Key findings for the area north and northeast of the AAB downstream dam include:

- Boron, chromium, chromium (VI), sulfate, TDS, thallium and total uranium have geometric means less than their respective groundwater comparative criteria
- Cobalt, total radium and vanadium have three, one, and four groundwater criteria exceedances in this area of the site. However, none of the wells exhibit a concentration pattern that would be expected if the source was the ash basin (i.e., does not resemble a groundwater plume).
- Lithium does not have a 02L standard or IMAC value but does have a background value (**Table 4-3**). Groundwater conditions north and northeast from the AAB are reflective of background conditions.
- Iron and manganese exhibit wide ranges of results and no correlation between concentrations and distance from the AAB were observed. Also, when iron and manganese are plotted against boron no pattern is apparent
- Strontium is found in the AAB ash pore water at elevated concentrations and is present in downgradient wells above groundwater comparison

criteria. However, when strontium is plotted versus distance there is little or no indication of a decreasing trend.

Mann-Kendall trend analysis was performed using conservative constituent datasets for ash pore water and groundwater wells within the waste boundary, between the waste boundary and compliance boundary, and downgradient the source area, at or beyond the compliance boundary. Trend analysis and results are prepared by Arcadis U.S. Inc. and included in a technical memorandum titled *Plume Stability Evaluation – Cliffside Steam Station* (Arcadis, 2019). The technical memorandum is included as in **Appendix I** as Attachment A.

The analysis was performed using analytical results for samples collected from 2011 through 2019. Results of the Mann-Kendall trend analysis at the AAB and ASA include:

- Groundwater COI concentration trends with time were evaluated for 17 constituents for 135 wells for a total number of 2,295 trends. Trends that were not increasing accounted for 2,117 of the 2,295 trends evaluated (92% of total). Excluding trends that had greater than 50% non-detect values or insufficient number of valid samples to run a trend (n<4), 971 of 1,149 trends (85% of total) had statistically decreasing trends, stable trends, or no trends. These results demonstrate an overall decreasing to stable plume for constituents in groundwater at the AAB.
- Statistically increasing trends account for 178 of the 2,295 trends evaluated (8% of total) and 178 of the 1,149 trends (15%) excluding non-detects and data sets with too few data points. Constituents with increasing concentration trends and maximum concentrations greater than 50% of the COI criterion are located in areas where corrective action or continued monitoring are proposed.
- The limited occurrence of increasing constituent concentrations trends at the AAB upstream and AAB downstream dam supports continuing to monitor groundwater concentrations at these locations during the decanting process and through basin closure.

Summary

The concentrations of the COIs reported at the AAB downstream dam area do not decrease with distance downgradient of the source area; rather they generally fall within a narrow range of concentrations. This consistent pattern may be the result of groundwater quality reaching equilibrium conditions with

the mineralogical and geochemical environments downgradient of the ash basin. It may also be that the downgradient concentrations are representative of background conditions in the floodplain of the Broad River. It is expected that these concentrations will remain consistent until decanting and closure of the AAB. After decanting and closure hydraulic gradients and mass flux will be reduced and concentrations at these locations will diminish.

Boron, sulfate, lithium, and TDS are conservative constituents that are not reported at the AAB downstream dam or downgradient near the compliance boundary at concentrations greater than their groundwater comparison criteria. There is little indication of groundwater plumes located between the northeast portion of the AAB and the Broad River as concentrations of non-reactive parameters associated with CCR are nominally elevated downgradient of the basin in this area. The current and future conditions reports indicate that there are no and are not expected to be any 02B surface water exceedances in the Broad River associated with the AAB.

Results of the Mann-Kendall trend analysis indicate that the limited occurrence of increasing constituent concentrations trends at the AAB downstream dam supports continuing to monitor groundwater concentrations at this location during the decanting process and through basin closure.

Based on this data, near term corrective action for groundwater north and northeast of the AAB downstream dam is not warranted, and continued monitoring of groundwater in this area is recommended. Given the seepage velocities for the CCR constituents, ample time is available to implement an alternate approach without increasing the risk of affecting receptors should the groundwater monitoring wells show results which are in contrast to the predicted concentration trends for this area of the site.

Northwestern Extent of Constituent Affected Groundwater

Northwest of the AAB upstream dam, west of Suck Creek, COIs near the compliance boundary include: iron, lithium, manganese, and strontium reported at concentrations greater than their comparison criteria.

COI Data Comparison to Criteria

Iron in the shallow flow layer had an isolated exceedance of groundwater comparison criteria (background value) near the compliance boundary at GWA-33S. Iron exceedances are not reported greater than the groundwater

comparison criteria in the deep or bedrock flow layers near the compliance boundary. Iron concentrations west of Suck Creek in the vicinity of GWA-33S do not show evidence of a discernable plume attributable to the AAB.

Lithium in the shallow flow layer has an isolated exceedance of groundwater comparison criteria (background value) near the compliance boundary at GWA-33S. Lithium in the deep flow layer has exceedances of the groundwater comparison criteria near the compliance boundary at GWA-33D and GWA-62BRU. Lithium in the bedrock flow layer has an isolated exceedance of groundwater comparison criteria near the compliance boundary at GWA-33BR.

Manganese is not reported greater than the groundwater comparison criteria (background value) in the shallow flow layer near the AAB compliance boundary west of Suck Creek. Manganese is reported at an isolated exceedance of comparison criteria in the deep flow layer at GWA-62BRU and in the bedrock flow layer at GWA-33BR near the compliance boundary.

Strontium is reported greater than its comparison criteria (background value) near the compliance boundary at GWA-33S. Strontium is reported near the compliance boundary in the deep flow layer at concentrations greater than comparison criteria at GWA-33D and GWA-62BRU. Strontium concentrations greater than comparison criteria are reported near the AAB compliance boundary in the bedrock flow layer at GWA-33BR.

Discussion

Key findings from the MNA evaluation (**Appendix I**) include:

- Concentrations of arsenic, lithium, and vanadium in groundwater decrease significantly from ash pore water (source area) in the AAB to downgradient areas in all flow zones.
- The transport trends for manganese and cobalt are comparable, and similar to that of iron. This could indicate the concentrations of manganese, iron, and cobalt downgradient are controlled by dissolution of cobalt-bearing manganese and iron minerals.

Thirty-one monitoring wells on the west side of the AAB upstream dam were used to determine the potential for migration of COIs from the AAB. Of the COIs, four (arsenic, chromium, hexavalent chromium, and total uranium) have no exceedances of applicable groundwater criteria. Boron, sulfate, TDS, thallium,

total radium, and vanadium have limited groundwater criteria exceedances report in sporadic locations. The remaining parameters cobalt, iron, manganese and strontium have a greater number of exceedances of their respective comparative values.

In examining the parameters and monitoring wells with reported groundwater criteria exceedances, there is little correlation of exceedances and location with the exception of at monitoring wells GWA-20D, GWA-51D, GWA-58BRU, and GWA-59D, where there are four or five constituents with exceedances at each monitoring well. The location of each of these monitoring wells is within two hundred feet from the AAB waste boundary. **Figures 6-18a/b/c, 6-21a/b/c,** and **6-23a/b/c** show aerial views of this area and associated monitoring wells and the concentrations of boron, lithium, and strontium. **Appendix I,** Figures 5-20 and 5-21 show the concentration versus distance plots for boron, strontium and lithium.

Boron: Twenty-three (23) of the thirty-one (31) wells in this area of the site have geometric means of boron greater than 50µg/L and four of the 31 wells have boron concentrations greater than the 02L standard (700µg/L). These four wells are located within 200 feet of the AAB waste boundary near the upstream dam. **Figures 6-18a/b/c** show boron concentrations at the indicated wells.

Appendix I, Figure 5-20 shows a boron versus distance plot from within the AAB waste boundary There is a slight correlation (r^2 less than 0.2) between the geometric mean of boron concentrations and distance from the AAB Beyond 500 feet from the AAB waste boundary, boron is less than 100µg/L.

Strontium: All but three geometric means are greater than the comparison criteria in the three flow zones for the monitoring wells in this area. Beyond 250 feet from the AAB waste boundary, strontium values have a midpoint of approximately 200µg/L. **Appendix I**, Figure 5-21 shows these data. There is no sign of a correlation of concentration with distance from the AAB, further indicating mass flux has stabilized. If downgradient concentrations are controlled by the release of strontium from the AAB, then basin decanting and closure will result in a further reduction in concentrations. This concentration reduction is confirmed by the predicted outputs from the flow and transport model.

Lithium: **Appendix I**, Figure 5-21 shows downgradient lithium concentrations verses distance. There is no correlation of lithium concentrations with distance

in this area of the site. The downgradient values generally range from 5 to 10µg/L.

Key findings for this area include:

- None of the COIs reported in groundwater from the monitoring wells located northwest of the AAB upstream dam appear to resemble a plume of similar COI concentrations originating from the AAB. Boron, strontium and lithium concentrations are consistent throughout the monitoring area. Within 200 feet of the AAB waste boundary there are concentrations greater than background and comparison criteria; beyond 200 feet of the waste boundary the concentrations appear to be near background conditions.
- It is expected that for those parameters transported from the AAB, their concentrations will decrease once decanting and basin closure are complete.
- There are no current or predicted 02B surface water standard exceedances in Suck Creek.

Summary

Results of the Mann-Kendall trend analysis indicate that the limited occurrence of increasing constituent concentrations trends at the AAB upstream dam supports continuing to monitor groundwater concentrations at this location during the decanting process and through basin closure.

Based on this data, near term corrective action for groundwater northwest of the AAB upstream dam is not warranted, and continued monitoring of groundwater in this area is recommended. The continued monitoring network and analytical parameters are described in detail in **Section 6.8.6.1**. Monitoring wells proposed as part of the continued monitoring network are presented in **Figure 6-36.** Given the seepage velocities for the CCR constituents, ample time is available to implement an alternate approach without increasing the risk of affecting receptors should the monitored groundwater wells show results which are in contrast to the predicted concentration trends for this area of the site.

6.1.4.1 COIs in Unsaturated Soil

(CAP Content Section 6.A.d.i)

Unsaturated soil at or beyond the compliance boundary is considered a potential secondary source to groundwater. Constituents present in

unsaturated soil or partially saturated soil (vadose zone) have the potential to leach into the groundwater system if exposed to favorable geochemical conditions for chemical dissolution to occur. Therefore, constituents considered for unsaturated soil evaluation as related to the AAB and ASA were the same constituents identified as COIs for the AAB and ASA.

Cliffside samples of background soil and rock media indicate that some naturally occurring constituents that are also typically related to CCR material and likely effect the chemistry of groundwater at the Site, are present at concentrations greater than the PSRGs POG values (**Table 4-2**). Constituents with background values greater than PSRGs POG values include arsenic, cobalt, iron, manganese, and thallium.

Unsaturated soil samples from locations at or beyond the AAB compliance boundary were collected during well installation activities from borings at AS-1D, AB-4D, AB-5BRU, AB-6D, AB-7D, BGSB-BG-1, BG-1D, BGSB-BG-2, GWA-21BRU, GWA-22S, GWA-23D, GWA-25D, GWA-28D, and GWA-27D **(Figure 6-7).** COIs in saturated soil are considered and evaluted as part of the groundwater flow system, separate from this evaluation. An evaluation of the potential nature and extent of COIs in unsaturated soil at or beyond the AAB compliance boundary was conducted by comparing unstaurated soil concentrations with background values or PSRG POG standards, whichever is greater [**Table 6-3** (*CAP Content Section 6.A.d.i*)]. The PSRG POG standard for sulfate (1,438 mg/kg) was calculated (**Table 6-2**).

Constituents detected at concentrations greater than either background values or the PSRG POG standard, whichever is greater, in unsaturated soil samples (depth), upgradient or downgradient of the AAB, at or beyond the compliance boundary include:

- pH: AS-1D (58.5-60), GWA-21BRU (5-5), GWA-22S (3-5)
- Cobalt: GWA-27D (13.5-15), GWA-27 (24.9-24.9)
- Manganese: AB-6D (48.5-50), GWA-27D (13.5-15), GWA-27 (24.9-24.9)

No necessary corrective action for soils is identified at the Site where unsaturated soil COI concentrations are greater than the PSRG POG standards or background values because there is no mechanism by which

the COIs could have been transported from the ash basin to the unsaturated soils at these locations and depths.

6.1.4.2 Horizontal and Vertical Extent of Groundwater in Need of Restoration

(CAP Content Section 6.A.d.ii)

This section discusses the horizontal and vertical extent of groundwater in need of restoration associated with the AAB and ASA. Groundwater is not in need of restoration adjacent to the AAB to the south, east, and west due to the lack of COIs above applicable standards in these areas. A limited number of COIs in groundwater are present at or beyond the compliance boundary to the north of the AAB within the ASA. Additional detail for this area is provided below.

Northern Extent of COI-Affected Groundwater

North of the AAB, within the ASA, the COI plume at or beyond the compliance boundary is defined by boron, cobalt, iron, lithium, manganese, strontium, sulfate, thallium, TDS, and uranium at concentrations greater than their comparison criteria. The COIs generally are located within the boron plume greater than background values which is used to describe the extent of COIs at or beyond the compliance boundary.

Boron, iron, lithium, manganese, strontium, sulfate, thallium, and uranium mean concentrations at or beyond the compliance boundary support the following observations regarding the northern extent COI-affected by the ash basin groundwater (**Figures 6-17** through **6-27b**):

- Boron is reported at concentrations greater than the 02L standard at or beyond the AAB compliance boundary within the ASA in the shallow and deep flow layers. Boron exceedances of the 02L standard are not reported in the bedrock flow layer at or beyond the AAB compliance boundary in the ASA. The northernmost wells with 02L exceedances are AS-2S in the shallow flow layer and AS-8D in the deep flow layer.
- Iron has an isolated exceedance of comparison criteria (background value) in the shallow flow layer at AS-7I. Although there is not a discernable plume of iron from the AAB to AS-7I, this monitoring well location is located beneath the ash in the ASA. Iron has an isolated exceedance of comparison criteria in the deep flow layer at

AS-8D. Although there is not a discernable plume of iron from the AAB to AS-8D, this monitoring well location is located beneath the ash in the ASA. Iron exceedances of comparison criteria are not reported at or beyond the compliance boundary in the bedrock flow layer.

- Lithium has exceedances of comparison criteria (background value) in the shallow flow layer within the AAB compliance boundary and at and beyond the boundary in the ASA. A lithium concentration greater than comparison criteria is reported in shallow monitoring well AB-3I beneath the AAB, upgradient of the exceedances reported in the ASA that appear to form a plume in this area from the AAB. Lithium is reported at concentrations greater than the comparison criteria in the deep and bedrock flow zones in the northwest of the ASA.
- Manganese exceedances of the comparison criteria (background value) in the shallow and deep flow layers are reported beyond the AAB compliance boundary within and north of the ASA. Manganese exceedances of the comparison criteria in the bedrock flow layer are reported beyond the AAB compliance boundary, northwest of the ASA.
- Strontium is reported greater than its comparison criteria (background value) at or beyond the compliance boundary in the shallow, deep, and bedrock flow layers north of the AAB, within and north of the ASA. Strontium concentrations greater than the statistically derived background values are common at the Site and often are not located in flow paths reflective of migration from the ash basins or ASA. Therefore, the natural variability of strontium may not be accurately reflected by the current background dataset. As part of the EMP, a five year review process is proposed which would include routine re-evaluation of background concentrations as additional data becomes available.
- Sulfate is reported greater than the 02L standard at or beyond the AAB compliance boundary in the shallow flow layer within and north of the ASA. Sulfate is reported greater than the 02L standard near the AAB compliance boundary within the ASA in the deep flow layer at CLMW-3D. No sulfate 02L standard exceedances are reported in the bedrock flow layer in this area of the site.

- TDS is reported greater than the 02L standard at or beyond the AAB compliance boundary within the ASA in the shallow and deep flow layer. TDS exceedances of the 02L standard are not reported at or beyond the compliance boundary in the bedrock flow layer in this area of the Site.
- Thallium is reported greater than the IMAC at or beyond the AAB compliance boundary in the shallow flow layer within and north of the ASA. Thallium is reported at concentrations greater than the IMAC near the AAB compliance boundary within the ASA in the deep flow layer. Thallium exceedances of the IMAC are not reported at or beyond the compliance boundary in the bedrock flow layer in this area of the Site.
- Uranium (total) is reported in the shallow flow layer near the AAB compliance boundary greater than the comparison criteria (background value) at monitoring well AS-1SB. Uranium (total) is not reported in the deep flow layer near the AAB compliance boundary at concentrations greater than the comparison criteria. Uranium (total) is reported in the bedrock flow layer at and beyond the AAB compliance boundary greater than the comparison criteria within and north of the ASA.

6.1.5 COI Distribution in Groundwater

(CAP Content Section 6.A.e)

As part of the COI management process and geochemical modeling (**Appendix H**) constituents with concentrations greater than the 02L standard, IMAC, or background values beyond the compliance boundary were grouped by geochemical behavior and mobility. A comprehensive evaluation (*i.e.* mean analysis and groupings) of available data was used to demonstrate constituent distribution in groundwater to evaluate the spatial occurrence with a discernable plume in the direction of groundwater flow downgradient of the AAB and ASA. The groupings of constituents that were mapped and are considered for corrective action are as follows:

- **Conservative, non-reactive constituents:** boron, lithium, sulfate, and TDS. Geochemical model simulations support that these constituents would transport conservatively (K_d values <1 L/kg) as soluble species under most conditions, and that the mobility of these COIs will not change

significantly due to current geochemical conditions or potential geochemical changes related to remedial actions.

- **Non-conservative, reactive constituents:** arsenic, strontium, total uranium, and vanadium. Geochemical model simulations support that these constituents are subject to significant attenuation in most cases and have high K_d values indicating the mobility of these COIs is unlikely to be geochemically affected by current geochemical conditions or potential geochemical changes related to remedial actions.
- **Variably reactive constituents:** cobalt, iron, manganese, and thallium. Geochemical model simulations, and resulting K_d values, support these constituents may be non-reactive or reactive in relation to geochemical changes and are dependent on the pH and E_h of the system. The sensitivity of these COI to the groundwater pH and Eh indicates that these constituents could respond to natural changes under current conditions, such as water level fluctuations imposed by seasonality, and decanting or source control activities that have the potential to change the groundwater pH or E_h.

COIs identified in the CSA that are not mapped in this CAP Update generally not only have limited spatial occurrences within the compliance boundary, but are further spatially limited to isolated areas within the compliance boundary that do not have a discernable plume geometry.

6.1.5.1 Conservative Constituents

(CAP Content Section 6.A.e.i)

Boron, lithium, sulfate, and TDS mean isoconcentration maps (**Figures 6-18a/b/c, 6-21a/b/c, 6-24a/b/c**, and **6-25a/b/c**) and cross sections (**Figures 6-8a, 6-9a**, **6-10a** and **6-11a**) support the following observations regarding the extent of COI-affected groundwater represented by these conservative constituents:

- Boron is not reported in the shallow, deep, or bedrock flow layers greater than the 02L standard at or beyond the AAB compliance boundary north and northeast of the AAB downstream dam. Boron is reported in the shallow and deep flow layers greater than the 02L standard at or beyond the AAB compliance boundary north of the AAB in the ASA. Boron was not reported in the bedrock flow layer greater than the 2L standard at or beyond the AAB compliance boundary in this area. Boron is not reported in the shallow, deep, or

bedrock flow layers greater than the 02L standard at or beyond the AAB compliance boundary to the northwest of the AAB upstream dam, west of Suck Creek.

- Lithium is reported at or beyond the compliance boundary at concentrations greater than the comparison criteria (background values) in the shallow flow layer at GWA-21S, north of the AAB downstream dam. Lithium concentrations in the deep and bedrock flow layers do not extend at or beyond the AAB compliance boundary to the northeast. Lithium is reported at or beyond the compliance boundary at concentrations greater than the comparison criteria north of the AAB in the ASA in the shallow flow layer at CLMW-2 and AS-7I, in the deep flow layer at AS-2D, and in the bedrock flow layer at MW-2DA, AS-2BR, and GWA-54BRO. Lithium is reported at or beyond the compliance boundary northwest of the AAB upstream dam at concentrations greater than the comparison criteria in the deep flow layer at GWA-62BRU. Lithium is not reported in the shallow or bedrock flow layers at or beyond the AAB compliance boundary to the northwest.
- Sulfate is not reported at concentrations greater than the 02L standard at or beyond the compliance boundary in the shallow, deep, or bedrock flow layers north and northeast of the AAB downstream dam. Sulfate is reported at or beyond the compliance boundary at concentrations greater than the 02L standard in the shallow flow layer at CLMW-3S and AS-2S, north of the AAB in the ASA. Sulfate is reported at or beyond the compliance boundary at concentrations greater than the 02L standard in the deep flow layer at CLMW-3D north of the AAB in the ASA. Sulfate concentrations greater than the 02L standard are not reported in the bedrock flow layer at or beyond the AAB compliance boundary to the north in the ASA. Sulfate is not reported in the shallow, deep, or bedrock flow layers northwest of the AAB upstream dam at concentrations greater than the 02L standard.
- TDS is not reported in the shallow, deep, or bedrock flow layers northeast of the AAB downstream dam at concentrations greater than the 02L standard. TDS is reported at or beyond the compliance boundary at concentrations greater than the 02L standard in the shallow flow layer north of the AAB in the ASA at AS-2S. TDS is

reported at or beyond the compliance boundary at concentrations greater than the 02L standard in the deep flow layer north of the AAB in the ASA at CLMW-3D. TDS concentrations greater than the 02L standard are not reported in the bedrock flow layer north of the AAB. TDS is not reported in the shallow, deep, or bedrock flow layers northwest of the AAB upstream dam at concentrations greater than the 02L standard.

The maximum extent of COI-affected groundwater migration for all flow zones is generally represented by boron. Lithium, sulfate, and TDS concentrations identified as being greater than their respective groundwater regulatory standards are associated with COI-affected groundwater migration from the AAB but are generally confined within the extent of the boron plume.

Plume Behavior and Stability

(CAP Content Section 6.A.e.i.1)

Mann-Kendall trend analysis was performed using conservative constituent datasets for ash pore water and groundwater wells within the waste boundary, between the waste boundary and compliance boundary, and downgradient the source area, at or beyond the compliance boundary (**Table 6-7**). Trend analysis and results are prepared by Arcadis U.S. Inc. and included in a technical memorandum titled *Plume Stability Evaluation – Cliffsdie Steam Station* (Arcadis, 2019). The technical memorandum is included as in **Appendix I** as Attachment A.

The analysis was performed using analytical results for samples collected from 2011 through 2019. Trend analysis results are presented where at least four samples were available and frequency of detection was greater than 50%. Statistically significant trends are reported at the 95% confidence level. The analysis of constituent concentrations through time produced six possible results:

1. Statistically significant, decreasing concentration trend (D)
2. Statistically significant, increasing concentration trend (I)
3. Greater than 50% of concentrations were non-detect (ND)
4. Insufficient number of samples to evaluate trend (n <4) (NE)
5. No significant trend, and variability is high (NT)

6. Stable. No significant trend, and variability is low (S)

Results of the Mann-Kendall trend analysis indicate the following:

Groundwater COI concentration trends with time were evaluated for 17 constituents for 135 wells for a total number of 2,295 trends. Trends that were not increasing accounted for 2,117 of the 2,295 trends evaluated (92% of total). Excluding trends that had greater than 50% non-detect values or insufficient number of valid samples to run a trend (n<4), 971 of 1,149 trends (85% of total) had statistically decreasing trends, stable trends, or no trends. These results demonstrate an overall decreasing to stable plume for constituents in groundwater at the AAB and ASA.

Statistically increasing trends account for 178 of the 2,295 trends evaluated (8% of total) and 178 of the 1,149 trends (15%) excluding non-detects and data sets with too few data points. Constituents with increasing concentration trends and maximum concentrations greater than 50% of the COI criterion are located in areas where corrective action or continued monitoring are proposed. The limited occurrence of increasing constituent concentrations trends at the AAB upstream and AAB downstream dam supports continuing to monitor groundwater concentrations at these locations during the decanting process and through basin closure.

6.1.5.2 Non-Conservative Constituents

(CAP Content Section 6.A.e.ii)

Arsenic, strontium, total uranium, and vanadium isoconcentration maps (**Figures 6-17, 6-23a/b/c, 6-27a/b,** and **6-28**) and cross-sections (**Figures 6-8b, 6-9b,** and **6-10b**) support the following observations regarding the extent of COI-affected groundwater represented by these non-conservative constituents:

- Arsenic is reported as an isolated 02L standard exceedance in the shallow flow layer at GWA-21S, north of the AAB downstream dam near the compliance boundary. Arsenic is not reported at concentrations greater than the 02L standard north and northeast of the AAB downstream dam in the deep or bedrock flow layers. No 02L exceedances of arsenic are reported in the shallow, deep, or bedrock flow layers north of the AAB in the ASA or northwest of the AAB upstream dam.

- Strontium is reported at concentrations greater than comparison criteria (background value) in the shallow, deep and bedrock flow layers at or beyond the compliance boundary north and northeast of the AAB downstream dam, north of the AAB in the ASA, and northwest of the AAB upstream dam, west of Suck Creek. Strontium concentrations greater than the statistically derived background values are common at the Site and often are not located in flow paths reflective of migration from the ash basins or ASA. Therefore, the natural variability of strontium may not be accurately reflected by the current background dataset. As part of the EMP, a five year review process is proposed which would include routine re-evaluation of background concentrations as additional data becomes available.
- Total uranium is reported as an isolated exceedance of the comparison criteria (background value) in the shallow flow layer near the compliance boundary north of the AAB within the ASA. Total uranium is reported at concentrations greater than the comparison criteria at or beyond the compliance boundary north of the AAB within the ASA. Total uranium exceedances are not reported in the deep flow layer at or beyond the AAB compliance boundary.
- Vanadium is reported as an isolated exceedance of the comparison criteria (background value) in the shallow flow layer at or beyond the compliance boundary north and northeast of the AAB downstream dam. Vanadium exceedances are not reported in the deep or bedrock flow layers at or beyond the AAB compliance boundary in any other locations.

6.1.5.3 Variably Conservative Constituents

Cobalt, iron, manganese, and thallium isoconcentration maps (**Figures 6-19a/b, 6-20a/b/c, 6-22a/b/c**, and **6-26a/b**) and cross-sections (**Figures 6-8c, 6-9c**, and **6-10c**) support the following observations regarding the extent of COI-affected groundwater represented by these variable constituents:

- Cobalt is not reported at concentrations greater than the comparison criteria (background value) at or beyond the AAB compliance boundary in the shallow flow layer. Cobalt reported at concentrations greater than the comparison criteria at or beyond the

AAB compliance boundary in the deep flow layer north of the AAB within the ASA. Cobalt is not reported at concentrations greater than the comparison criteria at or beyond the AAB compliance boundary in the bedrock flow layer.

- Iron is reported in the shallow flow layer at concentrations which exceed the comparison criteria (background value) at or beyond the compliance boundary north of the AAB compliance boundary in the ASA and northwest of the AAB upstream dam, west of Suck Creek. Iron is reported in the deep flow layer at concentrations which exceed the comparison criteria at or beyond the compliance boundary northeast of the AAD downstream dam and north of the AAB compliance boundary in the ASA. Iron is not reported at concentrations greater than the comparison criteria at or beyond the AAB compliance boundary in the bedrock flow layer.
- Manganese is reported in the shallow flow layer at concentrations which exceed the comparison criteria (background value) at or beyond the compliance boundary north of the AAB compliance boundary in the ASA. Manganese is reported in the deep and bedrock flow layers at concentrations which exceed the comparison criteria at or beyond the compliance boundary northeast of the AAB downstream dam, north of the AAB compliance boundary in the ASA and northwest of the AAB upstream dam, west of Suck Creek.
- Thallium is reported in the shallow flow layer at concentrations which exceed the IMAC at or beyond the compliance boundary north of the AAB downstream dam and north of the AAB compliance boundary in the ASA. Thallium is not reported at concentrations greater than the IMAC at or beyond the AAB compliance boundary in the deep or bedrock flow layers.

6.2 SA1 Potential Receptors Associated with Source Area

(CAP Content Section 6.B)

CSA and ongoing monitoring data confirm that affected groundwater is located immediately downgradient of the AAB and ASA. COI-affected groundwater is limited to Duke Energy property. COI-affected groundwater from the AAB and ASA does not reach any water supply wells, and modeling indicates this will remain the case in the future. Therefore, potential receptors are limited to Suck Creek and the Broad River.

6.2.1 Surface Waters – Downgradient Within a 0.5-Mile Radius of Waste Boundary

(CAP Content Section 6.B.a)

A depiction of surface water features — including wetlands, ponds, unnamed tributaries, seeps, streams, lakes, and rivers — within a 0.5-mile radius of the ash basin compliance boundary along with permitted outfalls under the NPDES and the SOC locations are shown on **Figure 5-10** (*CAP Content Section 6.B.a.i and6.B.a.ii*). The 0.5-mile radius from the ash basin compliance boundary, for which data is evaluated and depicted on figures, includes surface water features within 0.5-mile radius of the waste boundary. The AAB and ASA are located south of the Broad River to the north. Suck Creek is located to the west of the AAB and ASA. Associated North Carolina surface water classifications for the Broad River and Suck Creek are summarized in **Section 5.3.1** and **Table 5-3** (*CAP Content Section 6.B.a.iii*).

For groundwater corrective action to be implemented under 15A NCAC .02L .0106(k), groundwater discharge to surface water cannot result in exceedances of standards for surface waters contained in 15A NCAC 02B .0200 (02B). Surface water samples were collected from the Broad River and Suck Creek to confirm groundwater downgradient of the AAB and ASA has not resulted in surface water concentrations greater than 02B water quality standards. A map of surface water sample locations for groundwater discharge to surface water evaluation is included in **Appendix J** (*CAP Content Section 6.B.a.iv*). Surface water samples were collected, using division approved protocols, to evaluate acute and chronic water quality values. Surface water samples were also collected at background locations (upgradient of potential migration areas) within the Broad River and Suck Creek. Analytical results were evaluated with respect to 02B water quality standards and background data.

Comparisons of surface water data with the applicable USEPA National Recommended Water Quality Criteria for Protection of Aquatic Life, Human Health and/or Water Supply (USEPA, 2015; 2018a; 2018b) was conducted on surface water samples from the Broad River and Suck Creek. As stated by the USEPA, these criteria are not a regulation, nor do they impose a legally-binding requirement. Therefore, comparisons with these criteria are only for situational context. The constituents that have corresponding USEPA criteria but do not have 02B criteria are alkalinity, aluminum, antimony, iron and manganese. The background ranges reported in Suck Creek and the Broad River were greater than the USEPA criteria with the exception of antimony which was non-detect in

surface water background location samples. Alkalinity had one result reported greater than the background range at SW-8 during the June 2016 sampling event. The other nine sampling events at this location have had alkalinity results within the range of surface water background concentrations. Manganese was reported in Broad River sample locations SW-BRAB-1, SW-BRAB-2, and SW-BRAB-3 at concentration greater than the range of background values during the January 2017 sampling event and less than the range of background values during the June 2019 sampling event.

The surface water samples were collected in accordance with NCDEQ DWR Internal Technical Guidance: Evaluating Impacts to Surface Water from Discharging Groundwater Plumes - October 31, 2017. The full report for CSS groundwater discharge to surface water and the evaluation of surface waters to evaluate compliance with 15A NCAC 02B .0200 was submitted to NCDEQ in March 2017 (**Appendix J**).

General findings of the evaluation of current surface water quality conditions at CSS include:

- Groundwater migration from the ash basin source area has not resulted in violations of the 15 NCAC 02B surface water quality standards in the Broad River.
- Groundwater migration from the ash basin source area has not resulted in violations of the 15 NCAC 02B surface water quality standards in Suck Creek.

An addendum to the current conditions surface water evaluation was completed to assess surface water at sample location SW-SC-6A (**Figure 1-2**). The result of the surface water quality standards addendum found that groundwater migration from the ash basins or ASA has not resulted in violations of the 15 NCAC 02B surface water quality standards in Suck Creek (**Appendix J**).

Surface Water - Future Conditions Evaluation

An evaluation of potential future groundwater migration to surface water was conducted to identify areas where further evaluation might be warranted. For areas of potential future groundwater migration to surface water, a mixing model approach was used for the evaluation of future surface water quality conditions. Flow and transport modeling results were used to determine where groundwater migration from the AAB and ASA might intersect surface water in

the future. Predictive groundwater modeling using boron as a proxy for COI plume migration demonstrated the Broad River to the north and Suck Creek to the northwest of the AAB could potentially be influenced by future groundwater migration. A groundwater to surface water mixing model approach was used to determine the potential surface water quality in the future groundwater discharge zones. The full report for CSS groundwater discharge to surface water under future conditions can be found in **Appendix J**.

General findings of the evaluation of future surface water conditions in potential groundwater discharge areas include:

- The surface water mixing model evaluation demonstrates that predicted constituent concentrations in surface waters are less than 02B surface water standards. Therefore, the criteria for compliance with 02B is met, allowing potential corrective action under Subchapter 02L .0106 (k), (l), or (m).
- Review of Site data and results from the flow and transport model indicate that affected groundwater migration would not reach Stream 12 on the west side of the Site.
- Seeps currently governed by the SOC that remain and are not dispositioned 90 days after completion of decanting would be characterized for determination of corrective action applicability. Where applicable, and accounting for seep jurisdictional status, corrective action planning at that time would occur.

6.2.2 Water Supply Wells

(CAP Content Section 6.B.b)

A total of 71 private water supply wells were identified within the 0.5-mile radius of the pre-2018 ash basin compliance boundaries. Most of these water supply wells were located south, southeast, east, and northeast of the AAB off of McCraw Road, Prospect Church Road, Fox Place, and Riverfront Drive, west and southwest of the U5 AB along Duke Power Road, US-221A, and Old US-221A; and north of the Broad River (**Figure 5-12**). The 0.5-mile radius from the ash basin compliance boundary, for which data is evaluated and depicted on figures, is greater than the required 0.5-mile radius from the waste boundary and is consistent with the drinking water well and receptor surveys.

No public or private drinking water wells or wellhead protection areas were found to be located downgradient of the AAB or ASA as discussed in **Section**

5.3. This finding has been supported by field observations, a review of public records, historical groundwater flow direction data and groundwater flow and transport modeling (**Appendix G**). The location and information pertaining to water wells located upgradient or side-gradient of the facility, within 0.5-miles of the compliance boundary, were included in the survey reports.

6.2.2.1 Provision of Alternative Water Supply

(CAP Content Section 6.B.b.i)

Although results from local water supply well testing do not indicate effects from the source areas at CSS, private water supply wells identified within the 0.5-mile radius of the pre-2018 compliance boundaries have been offered to be connected to an alternative water supply, per G.S. Section 130A-309.211(c1) requirements.

Duke Energy identified a total of 70 eligible private residences eligible for for a public water supply connection near CSS. Eligibility was contingent that the property did not include:

- A business
- A church
- A school
- Connection to the public water supplier
- An empty lot

Of the 70 eligible connections, one opted out of the option to connect to the public water system and two did not respond to the offer. Duke Energy connected 65 occupied residences to the public water system, and two will be connected in the future in accordance with G.S. 130A-309.211(c1).

On September 5, 2018, Duke Energy provided completion documentation to NCDEQ to fulfill the requirements of House Bill 630. NCDEQ provided correspondence, dated October 12, 2018, to confirm that Duke Energy satisfactorily completed the alternative water supply provisions under CAMA G.S. 130A-3099.211(c1) at CSS. Both documents are provided in **Appendix D**.

Figure 5-12 shows the private water supply well locations with reference to properties connected to the public water supply, along with vacant parcels and residential properties whose owners have either decided to opt-out of

the water treatment system program or did not respond to the offer. As discussed in **Section 5.3**, all of the private water supply wells are located either upgradient or side-gradient of the ash basins and all water supply wells are outside of the area of groundwater affected by ash basins or the ASA.

6.2.2.2 Findings of Drinking Water Supply Well Surveys

(CAP Content Section 6.B.b.ii)

The location and information pertaining to water supply wells located upgradient or side-gradient of the facility, within 0.5 miles of the ash basin compliance boundaries, were included in drinking water supply well survey reports. Results from surveys conducted to identify potential receptors for groundwater, including public and private water supply wells and surface water features within a 0.5-mile radius of the pre-2018 ash basin compliance boundaries, have been reported to NCDEQ:

- *Drinking Water Well and Receptor Survey – Cliffside Steam Station* (HDR, 2014a)
- *Supplement to Drinking Water Well and Receptor Survey – Cliffside Steam Station* (HDR, 2014b)
- *Comprehensive Site Assessment Report – Cliffside Steam Station Ash Basin* (HDR, 2015a)
- *Draft Drinking Water Well and Receptor Survey – Cliffside Steam Station* (HDR, 2016b)
- *Comprehensive Site Assessment Update Report – Cliffside Steam Station Ash Basins* (SynTerra 2018a)

As documented in the 2018 CSA Update, NCDEQ arranged for independent analytical laboratories to collect and analyze water samples in 2014 and 2015 from private wells identified during the well survey, if the owner agreed to have their well sampled. NCDEQ collected and analyzed 32 groundwater samples from 23 private water supply wells within a 0.5 mile radius of the CSS pre-2018 ash basin compliance boundaries.

Duke Energy collected samples from private water supply wells in 2016 and 2017 after the NCDEQ sampling effort. For many of the wells sampled in this program, as with standard practice, samples were split for analysis by

Duke Energy's certified (North Carolina Laboratory Certification #248) laboratory.

Table 6-9 (*CAP Content Section 6.B.b.ii*) provides tabulated results for the NCDENR and Duke Energy sampling results as well as identified exceedances of 02L standards, IMACs, and bedrock background values as well as a well-by-well summary of COI exceedances and characterization**.** The exceedance evaluation compares bedrock background values since it is assumed area water supply wells are installed within the bedrock, which is typical for water supply wells in the Piedmont.

The major findings from the water supply well evaluation include:

- All water supply wells are outside of the boron plume greater than background concentrations as defined on the isoconcentration contour maps for all flow zones (**Figures 6-18a/b/c**).
- All water supply wells to the south are upgradient of the AAB and ASA (**Figure 5-12**).
- All water supply wells to the southwest are upgradient of the AAB and ASA with some of the wells in a separate drainage system separated by a hydrologic divide represented by McCraw Road (**Figure 5-12)**.
- All water supply wells northeast of the AAB and ASA ash basin are side-gradient of the AAB and ASA, in a separate drainage system separated by a hydrologic divide represented by an unnamed tributary to the Broad River (**Figure 5-12)**.
- As source control (decanting) continues, groundwater flow to the northeast is expected to be reduced as the hydraulic head driving groundwater in that direction is reduced and groundwater returns to following its previous flow pattern toward the original Suck Creek channel through the downstream dam at the AAB. Therefore the water supply wells northeast of the AAB and ASA will become further isolated from the basin and ASA (**Figures 5-8b/c and 5-9b/c).**
- Eleven of 23 water supply wells sampled demonstrated exceedances to comparable standards (background values, 02L standards or IMAC, whichever is greater).

- Groundwater sample C-1005 S2 was collected from a water supply well located approximately 1,900 feet northeast of the AAB downstream dam. This well is located in a separate drainage system separated by a hydrologic divide represented by an unnamed tributary to the Broad River. Boron and sulfate were not detected at concentrations at or greater than the adjusted reporting limit in this well, and the well is outside of the boron plume as defined on the isoconcentration contour maps for all flow zones (**Figures 6-18a/b/c**). The reported vanadium concentration of 1.1 µg/L is greater than the IMAC (0.3 µg/L) and CSS bedrock background value of 1 µg/L in this well; however, the concentration falls within the range of vanadium concentrations reported in the CSS bedrock background monitoring wells (<0.3 to 1.5 µg/L). Piper diagrams of groundwater from water supply wells, background monitoring wells, wells beneath the source area, and downgradient groundwater were plotted (**Figure 6-30**). The water supply well plots in the generally unaffected category indicating that they do not have the same geochemical signature as the source area pore water within the basin. Based on these lines of evidence, groundwater in monitoring well C-1005 S2 is not impacted by the AAB or ASA.
- Groundwater sample C-1005 W2 was collected from a water supply well located approximately 1,900 feet northeast of the AAB downstream dam. This well is located in a separate drainage system separated by a hydrologic divide represented by an unnamed tributary to the Broad River. Boron and sulfate were not detected at concentrations at or greater than the adjusted reporting limit in this well, and the well is outside of the boron plume as defined on the isoconcentration contour maps for all flow zones (**Figures 6-18a/b/c**). The reported vanadium concentration of 1.1 µg/L is greater than the IMAC (0.3 µg/L) and CSS bedrock background value of 1 µg/L in this well; however, the concentration falls within the range of vanadium concentrations reported in the CSS bedrock background monitoring wells (<0.3 to 1.5 µg/L). Piper diagrams of groundwater from water supply wells, background monitoring wells, wells beneath the source area, and downgradient groundwater were plotted (**Figure 6-30**). The water supply well plots in the generally unaffected category indicating that they do not have the same geochemical signature as the source area pore water within the basin. Based on these lines of

evidence, groundwater in monitoring well C-1005 W2 is not impacted by the AAB or ASA.

- Groundwater sample C15 was collected from a water supply well located approximately 1,250 feet southeast of the AAB waste boundary. This well is located upgradient of the AAB and ASA in a separate drainage system. Boron was not detected at concentrations at or greater than the adjusted reporting limit in this well, and the well is outside of the boron plume as defined on the isoconcentration contour maps for all flow zones (**Figures 6-18a/b/c**). Sulfate was reported in the groundwater sample in this well at a concentration less than the site background value. The reported manganese and strontium results are greater than their CSS comparison criteria; however, the reported concentrations fall within the bedrock background range for other piedmont CCR sites (**Table 6-9**). Piper diagrams of groundwater from water supply wells, background monitoring wells, wells beneath the source area, and downgradient groundwater were plotted (**Figure 6-30**). The water supply well plots in the generally unaffected category indicating that they do not have the same geochemical signature as the source area pore water within the basin. Based on these lines of evidence, groundwater in monitoring well C15 is not impacted by the AAB or ASA.
- Groundwater sample C17 was collected from a water supply well located approximately 1,700 feet southwest of the AAB waste boundary. This well is located upgradient of the AAB and ASA in a separate drainage system separated by the hydraulic divide along McCraw Road. Boron was not detected at concentrations at or greater than the adjusted reporting limit in this well, and the well is outside of the boron plume as defined on the isoconcentration contour maps for all flow zones (**Figures 6-18a/b/c**). Sulfate was reported in the groundwater sample in this well at a concentration less than the site background value. The reported manganese result is greater the comparison criteria; however, the reported concentration falls within the bedrock background range for other piedmont CCR sites (**Table 6-9**). The turbidity of this sample was also greater than 10 NTU, likely causing the manganese concentration reported to be artificially greater than a sample with a turbidity of less than 10 NTU. Piper diagrams of groundwater from water supply wells, background monitoring wells, wells beneath the

source area, and downgradient groundwater were plotted (**Figure 6-30**). The water supply well plots in the generally unaffected category indicating that they do not have the same geochemical signature as the source area pore water within the basin. Based on these lines of evidence, groundwater in monitoring well C17 is not impacted by the AAB or ASA.

- Groundwater sample C23 was collected from a water supply well located approximately 1,700 feet southeast of the AAB waste boundary. This well is located upgradient of the AAB and ASA. Boron and sulfate were not detected at concentrations at or greater than the adjusted reporting limit in this well, and the well is outside of the boron plume as defined on the isoconcentration contour maps for all flow zones (**Figures 6-18a/b/c**). The reported hexavalent chromium result is greater the comparison criteria; however, the reported concentration falls within the bedrock background range for other piedmont CCR sites (**Table 6-9**). Piper diagrams of groundwater from water supply wells, background monitoring wells, wells beneath the source area, and downgradient groundwater were plotted (**Figure 6-30**). The water supply well plots in the generally unaffected category indicating that they do not have the same geochemical signature as the source area pore water within the basin. Based on these lines of evidence, groundwater in monitoring well C23 is not impacted by the AAB or ASA.
- Groundwater sample C25 was collected from a water supply well located approximately 3,500 feet southeast of the AAB waste boundary. This well is located upgradient of the AAB and ASA and in a separate drainage system. Boron was not detected at concentration at or greater than the adjusted reporting limit in this well, and the well is outside of the boron plume as defined on the isoconcentration contour maps for all flow zones (**Figures 6-18a/b/c**). Sulfate was reported in the groundwater sample in this well at a concentration less than the site background value. The reported chromium result collected during the May 2015 sampling event (14.1 μg/L) was greater the comparison criteria (10 μg/L); however, the confirmation sample collected in August 2015 had a reported concentration less than the adjusted reporting limit (<0.5 μg/L) (**Table 6-9**). Piper diagrams of groundwater from water supply wells, background monitoring wells, wells beneath the source area,

and downgradient groundwater were plotted (**Figure 6-30**). The water supply well plots in the generally unaffected category indicating that they do not have the same geochemical signature as the source area pore water within the basin. Based on these lines of evidence, groundwater in monitoring well C25 is not impacted by the AAB or ASA.

- Groundwater sample C5 was collected from a water supply well located approximately 1,000 feet east of the AAB waste boundary. This well is located upgradient of the AAB and ASA. Boron was not detected at concentration at or greater than the adjusted reporting limit in this well, and the well is outside of the boron plume as defined on the isoconcentration contour maps for all flow zones (**Figures 6-18a/b/c**). Sulfate was reported in the groundwater sample in this well at a concentration less than the site background value. The reported hexavalent chromium result is greater the comparison criteria; however, the reported concentration falls within the bedrock background range for other piedmont CCR sites (**Table 6-9**). Piper diagrams of groundwater from water supply wells, background monitoring wells, wells beneath the source area, and downgradient groundwater were plotted (**Figure 6-30**). The water supply well plots in the generally unaffected category indicating that they do not have the same geochemical signature as the source area pore water within the basin. Based on these lines of evidence, groundwater in monitoring well C5 is not impacted by the AAB or ASA.
- Groundwater sample C8 was collected from a water supply well located approximately 1,250 feet east of the AAB waste boundary. This well is located upgradient of the AAB and ASA. Boron and sulfate were not detected at concentrations at or greater than the adjusted reporting limit in this well, and the well is outside of the boron plume as defined on the isoconcentration contour maps for all flow zones (**Figures 6-18a/b/c).** The reported hexavalent chromium result is greater the comparison criteria; however, the reported concentration falls within the bedrock background range for CSS (**Table 6-9**). Piper diagrams of groundwater from water supply wells, background monitoring wells, wells beneath the source area, and downgradient groundwater were plotted (**Figure 6-30**). The water supply well plots in the generally unaffected category indicating that they do not have the same geochemical signature as

the source area pore water within the basin. Based on these lines of evidence, groundwater in monitoring well C8 is not impacted by the AAB or ASA.

- Sample C8 Spring was collected from a spring located approximately 1,700 feet east of the AAB waste boundary. This sample location is located upgradient of the AAB and ASA. Boron was not detected at concentrations at or greater than the adjusted reporting limit in this spring, and the spring is outside of the boron plume as defined on the isoconcentration contour maps for all flow zones (**Figures 6-18a/b/c**). Sulfate was reported in the water sample at this spring at a concentration less than the site background value. The reported vanadium result is greater the comparison criteria; however, the reported concentration falls within the bedrock background range for other piedmont CCR sites (**Table 6-9**). The turbidity of this sample was also greater than 10 NTU, likely causing the vanadium concentration reported to be greater than sample within the turbidity range of less than 10 NTU. Piper diagrams of groundwater from water supply wells (and springs), background monitoring wells, wells beneath the source area, and downgradient groundwater were plotted (**Figure 6-30**). The water supply well plots in the generally unaffected category indicating that they do not have the same geochemical signature as the source area pore water within the basin. Based on these lines of evidence, the water in C8 Spring is not impacted by the AAB or ASA.

6.2.3 Future Groundwater Use Areas

(CAP Content Section 6.B.c)

Duke Energy owns the land and controls the use of groundwater on the land downgradient of the AAB and ASA within and beyond the predicted area of potential groundwater COI influence. Therefore, no future groundwater use areas are anticipated downgradient of the ash basins or ASA.

It is anticipated that residences within a 0.5-mile radius of the ash basin compliance boundaries that are not connected to the municipal water system will continue to rely on groundwater resources for water supply for the foreseeable future [(**Figure 5-9** *(CAP Content Section 6.B.c.i)*].

Based on predicted groundwater flow patterns, under post ash basin closure conditions, and the location of water supply wells in the area, groundwater flow

direction from the ash basins and ASA is expected to be continue to be to the north toward the Broad River, and therefore will not flow towards any water supply wells [(**Appendix G**) *(CAP Content Section 6.B.c.ii)*].

6.3 SA1 Human and Ecological Risks

(CAP Content Section 6.C)

Updated human health and ecological risk assessments were prepared for the CSS consistent with the CAP content guidance. The updated risk assessments incorporate results from surface water, sediments, and groundwater samples collected from March 2015 through June 2019. Primary conclusions of the risk assessment include:

(1) the ash basins do not cause an increase in risks to potential human receptors located on-Site or off-Site; and

(2) the ash basins do not cause an increase in risks to ecological receptors.

These conclusions are further supported by multiple water quality and biological assessments conducted by Duke Energy as part of the NDPES monitoring program. A more detailed discussion regarding human health and ecological risk associated with the ash basin can be found in **Section 5.4**. An update to the CSS human health and ecological risk assessment is included in **Appendix E**.

6.4 SA1 Groundwater Remedial Technologies

(Supplemental Information to CAP Content Section 6.D)

This section provides supplemental information beyond the CAP content guidance to introduce groundwater remediation technologies and consider a range of individual technologies that might be used to formulate comprehensive groundwater remediation alternatives for consideration at Cliffside. The most feasible remedial options identified will form the basis, in whole or in part, for the remedial alternatives evaluated in **Section 6.6**. Groundwater remediation technologies will be evaluated based upon two primary criterion:

- Can a technology be effective when addressing one or more site-specific COIs?
- Can a technology be feasibly implemented under site-specific conditions and be effective?

The remedial alternative screening includes the criteria in the NCDEQ CAP Guidance (April 27, 2018). Technologies that are clearly not workable under Site conditions will not be carried forward. Technologies that have the potential application will be

retained for further consideration. Technologies retained for further consideration were used to formulate comprehensive groundwater remedial alternatives in **Section 6.5.**

6.4.1 Monitored Natural Attenuation

MNA is a groundwater remedy that relies on natural processes to reduce constituent concentrations in groundwater over time. The primary objective of an MNA strategy is to identify and quantify natural attenuation processes specific to a site and demonstrate that those processes would reduce constituent concentrations in groundwater to levels that are less than the regulatory standards to achieve compliance (USEPA, 1999).

MNA processes potentially applicable to inorganic constituents include:

- Dispersion
- Dilution
- Transformation
- Sorption
- Radioactive decay
- Phyto-Attenuation
- Biological stabilization
- Chemical stabilization

Dilution from recharge to groundwater, mineral precipitation, and COI adsorption would occur over time and distance from the source area, thereby, reducing COI concentrations through attenuation. MNA can be used in combination with other remediation technologies such as source control. Routine monitoring of select locations for COI concentrations is used to confirm the effectiveness of the approach.

The USEPA does not consider MNA to be a "no action" alternative. Source control and long-term monitoring are fundamental components of any MNA remedy. Furthermore, MNA is an alternative means of achieving remediation objectives that might be appropriate for specific, well-documented site circumstances where its use would satisfy applicable statutory and regulatory requirements (USEPA, 1999).

The USEPA, as shown below, considers MNA to be in-situ (USEPA, 1999):

> *The term "monitored natural attenuation", as used in this Directive, refers to the reliance on natural attenuation processes (within the context of a carefully controlled and monitored site cleanup approach) to achieve site-specific remediation objectives within a time frame that is reasonable compared to that offered by other more active methods. The "natural attenuation processes" that are at work in such a remediation approach include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity,*

mobility, volume, or concentration of contaminants in soil or groundwater. These in-situ processes include biodegradation; dispersion; dilution; sorption; volatilization…"

MNA is compared with other viable remediation methods during the remedy selection process. MNA should be selected only if it would meet site remediation objectives within a timeframe that is reasonable compared to that offered by other methods (USEPA, 1999). A contingency remedy should be proposed at the time MNA is selected to be a site remedy (NCDWM, 2000).

The NCDEQ and USEPA have guidance documents that prescribe the investigative and analytical processes required for an MNA demonstration. NCAC 02L provides additional requirements for MNA implementation (NCDEQ, 2017). USEPA developed a tiered approach to support evaluation and, if appropriate, selection of MNA as a remedial technique (USEPA, 2007). Three decision tiers require progressively greater site information and data to assess the potential effectiveness of MNA as a remedy for inorganic constituents in groundwater.

MNA will be retained for further consideration at Cliffside, as groundwater COIs do not pose an unacceptable risk to human health or the environment under conservative exposure scenarios and a source control measure will be implemented that eliminate or mitigate the source of CCR constituents in groundwater. The MNA evaluation for the technical applicability at Cliffside is provided in **Appendix I**.

6.4.2 In-Situ Technologies

Groundwater remediation technologies that are implemented in-situ, or in place, are discussed here.

Low Permeability Barriers

When used for the purpose of groundwater remediation, low permeability barriers (LPBs) are structures constructed in-situ to redirect groundwater flow. Materials used to construct LPBs are either impermeable (*e.g.,* steel sheet pile) or have a permeability that is at least two orders of magnitude lower than the permeability of the saturated media that comprises a targeted groundwater flow path. For this reason, LPBs are typically keyed into a natural barrier to groundwater flow such as a competent confining unit (*e.g.*, aquitard) or bedrock to prevent groundwater from flowing under the LPB.

LPBs can be used to redirect groundwater away from a potential receptor, redirect groundwater away from a source area, or redirect COI laden groundwater towards a groundwater extraction system or in-situ groundwater treatment system (*e.g.*, permeable reactive barrier). The design and technique used to construct a LPB typically depends upon the length of the LPB, the depth to a competent confining layer or bedrock, and cost considerations. Sheet piling, trenching, and vertical drilling are the most common means to construct a LPB. Sheet piling and trenching are typically limited to depths of approximately 50 feet whereas installation of a LPB using drilling techniques can achieve depths greater than 50 feet.

Construction of a LPB at Cliffside would involve drilling to competent bedrock and injecting bentonite or grout into fractured bedrock, the transition zone, and possibly into saprolite flow zones. Installation of an effective low permeability barrier to depths of up to 80 feet would be technically challenging and costly, therefore LPB technology will not be retained for further consideration.

Groundwater Infiltration and Flushing

In-situ groundwater flushing involves the infiltration of clean water into groundwater to accelerate removal of target constituents. Constituents mobilized by flushing would be captured by a downgradient extraction well. Flushing can enhance natural constituent transport mechanisms such as advection, dispersion, and molecular diffusion. This technology is potentially applicable to a broad range of constituents. Furthermore, in-situ flushing has potential applicability at almost any depth. However, successful implementation is site-specific. Factors affecting the effectiveness include the degree of subsurface heterogeneity, the variability of hydraulic conductivity, and the organic content of soil. Suitability testing of the clean water source and pre-design collection of data is important for most sites where this technology might be considered.

Flushing of relatively mobile and unreactive constituents like boron can be accomplished using clean water.

In-situ infiltration can also be used to enhance conventional pump and treat technology at locations with limited natural recharge or low permeability. The introduction of clean water into groundwater enhances groundwater flow by increasing the hydraulic gradient between the point of infiltration and the point of extraction or discharge. Addition of clean water can mobilize COIs, such as boron, and enhance the hydraulic gradient to improve hydraulic capture of COIs

(USEPA, 1996). Groundwater flushing can be accomplished by many methods including vertical wells, horizontal wells, and infiltration galleries. Groundwater flushing by infiltration is a technology that has possible application at Cliffside to enhance the capture of mobile constituents. Groundwater flushing will be retained for further consideration.

Encapsulation

Encapsulation technologies act to prevent waste materials and constituents from coming into contact with potential leaching agents such as water. Materials used to encapsulate a waste must be both chemically compatible with the waste and inert to common environmental conditions such as rain infiltration, groundwater flow, and freeze/thaw cycles (USEPA, 2002). Waste materials can generally be encapsulated in three ways: microencapsulation, macroencapsulation, or in-situ vitrification (ISV).

Microencapsulation involves mixing the waste together with the encasing material before solidification occurs. Macroencapsulation involves pouring the encasing material over and around a larger mass of waste, thereby enclosing it in a solidified block. Grout, sulfur polymer stabilization/solidification, chemically bonded phosphate ceramic encapsulation, and polyethylene encapsulation are examples of the techniques that have been used to improve the long-term stability of waste materials (USEPA, 2002). ISV involves the use of electrical power to heat and melt constituent laden soil and buried wastes (*e.g.*, ash). ISV uses an array of electrodes inserted into the ground. Electrical power is applied to the electrodes, which establishes an electric current through the soil. The electric current generates sufficient heat (greater than 2500°F) to melt subsurface soil and waste materials. The molten material cools to form a hard monolithic, chemically inert crystalline glass-like product with low leaching characteristics (USEPA, 1994).

Encapsulation technology is a potentially viable approach to manage a waste material or localized areas of relatively concentrated constituents. However, encapsulation will not be considered for use at Cliffside because there is no discrete volume or area of concentrated waste material that could be effectively treated using encapsulation.

Permeable Reactive Barrier

The USEPA defines a permeable reactive barrier (PRB) as being:

> *An emplacement of reactive media in the subsurface designed to intercept a contaminant plume, provide a flow path through the reactive media, and transform the contaminant(s) into environmentally acceptable forms to attain remediation concentration goals downgradient of the barrier* (USEPA, 1997).

Construction of PRBs involves emplacement of reactive media below the ground surface for the purpose of treating groundwater containing dissolved COIs. The PRB media is designed to be more hydraulically conductive than the saturated media surrounding the PRB so that groundwater would flow through the PRB media with little resistance. The depth and breadth of PRBs are oriented perpendicular to groundwater flow direction so that the PRB would intercept groundwater targeted for treatment. Design of the PRB thickness takes into account groundwater velocity and the need to provide sufficient groundwater residence and contact time for constituents to react with PRB media. PRBs can be installed as permanent or semi-permanent treatment units. The PRB reactive media in a permanent treatment unit is designed to remain emplaced over the needed timeframe whereas the reactive media in a semi-permanent treatment unit is designed to be replaced periodically once it is spent.

Two of the most common PRB designs are the continuous wall and the "funnel and gate". The continuous wall design involves the installation of a trench downgradient of a constituent plume that is oriented perpendicular to groundwater flow. The funnel and gate configuration involves construction of two LPBs that redirect groundwater flow towards the PRB. This allows for a smaller PRB design and treatment of a greater volume of groundwater. A design factor for both designs is the ability for the PRB to be keyed into a low permeability confining layer or into bedrock to minimize the potential for groundwater underflow beneath the PRB.

Media commonly used in PRBs for the treatment of inorganic COIs includes zero-valence iron (ZVI), apatite, zeolites, and materials used to affect groundwater pH. The mechanisms that take inorganic constituents out of solution include adsorption, ion exchange, oxidation-reduction, or precipitation.

ZVI (Fe^0) is an effective reducing agent as it readily donates electrons to receptor molecules or constituents ($Fe^0 \rightarrow Fe^{+2} + 2e^-$). ZVI particles can remove divalent metallic cations through reductive precipitation, surface adsorption,

complexation, or co-precipitation with iron oxyhydroxides. ZVI has been used to treat cationic metals such mercury (Hg^{+2}), nickel (Ni^{+2}), cadmium (Cd^{+2}), and lead (Pb^{+2}) (USEPA, 2009).

Apatite is a media used in PRBs to treat groundwater for the removal of certain metals in solution including lead, cadmium, and zinc. Apatite refers to a group of crystalline phosphate minerals; namely, hydroxylapatite, fluorapatite and chlorapatite. Apatite II™ is an amorphous form of a carbonated hydroxy-apatite that has random nanocrystals of apatite embedded in it. The apatite nanocrystals are capable of precipitating various phosphate phases of metals and radionuclides. Apatite II is also an efficient non-specific surface adsorber (Wright et al., 2003).

Zeolite is any of a large group of minerals consisting of hydrated aluminosilicates of sodium, potassium, calcium, and barium. Zeolites have large internal surface areas capable of treating inorganic constituents by both adsorption and cation exchange.

Limestone, and materials containing limestone such as recycled cement, can be used as a PRB media for raising the pH of acidic groundwater like that found in mine runoff (Indraratna et al., 2010).

Sulfate reduction facilitated by naturally occurring bacteria has been shown to effectively treat acidic to net alkaline groundwater containing dissolved heavy metals, including aluminum, in a variety of situations. The chemical reactions are facilitated by the bacteria *desulfovibrio*. This is a well-proven technology often used to treat acidic runoff from historic mining operations.

The ability to maintain adequate reactive reagent concentrations at depth over an extended period of time is a significant operational and performance consideration. Permeable reactive barriers are not carried forward for further evaluation for the same reasons this technology was not chosen for the following reasons:

- Detected concentrations of iron and manganese dissolved in groundwater could react with, and clog, treatment areas, diminishing the hydraulic conductivity through the PRB.
- There is recent favorable data suggesting that the technology might be effective in reducing some coal ash-related constituents, however, PRB technology is not well suited to treat boron.

6.4.3 Groundwater Extraction

Groundwater extraction is the most common design used when remediating mobile constituents in groundwater. Groundwater extraction can be used to withdraw affected groundwater from the subsurface for the purpose of reducing the mass of one or more target constituent(s) in an aquifer. Groundwater extraction can be used to hydraulically contain affected groundwater and mitigate groundwater constituent migration. Groundwater extraction can be conducted using a variety of methods that are discussed in the following sub-sections.

Vertical Extraction Wells

A vertical well is the most common design for groundwater extraction. Drilling techniques used to install vertical groundwater extraction wells range from GeoProbe® direct push, to hollow stem auger, mud rotary, air rotary, rotosonic drill rigs, and other methods. Groundwater extraction wells can be designed and screened in unconsolidated saturated media such as sand, saprolite, alluvium, transition zone, fractured bedrock, silts, and clays. Alternatively, groundwater extraction wells installed in bedrock can be completed as open-hole borings.

Low yielding aquifers can be problematic for vertical extraction wells. Relatively close spacing of vertical wells might be necessary to capture a constituent plume if the aquifer yield is low. Enhanced yield can be accomplished through injection or infiltration of water upgradient of the wells to increase the availability of water and hydraulic head, or fracking. Alternatively, low yielding wells can be effective through intermittent pumping to remove sorbed constituents with each pump cycle.

Pump options include submersible pumps and centrifugal pumps depending upon the anticipated yield, depth to water and well diameter. Jet pumps can be used in small diameter wells where the groundwater is relatively shallow (less than 25 to 30 feet below the ground surface). Submersible pumps or 'deep well jet pumps' can be used to extract groundwater from larger diameter wells with deeper groundwater levels. Deep well jet pumps have the advantage of mechanical equipment above grade and power only needs to be provided to a few pump stations rather than to every well as with submersible pump systems. All require routine maintenance of the pumps, vaults, piping and well screens to sustain desired performance (USEPA, 1992).

Groundwater modeling conducted for Cliffside indicates that vertical groundwater extraction wells can produce sufficient yield for effective

constituent mass removal without supplemental measures. The use of vertical groundwater extraction wells is retained for further consideration.

Horizontal/Angular Extraction Wells

Horizontal groundwater extraction wells offer advantages over vertical groundwater extraction wells when access is difficult or to reduce the number of system elements requiring maintenance. For example, horizontal wells can be installed below buried utilities, buildings, coal piles, and similar surface or near surface features. Also, horizontal wells can be more efficient and effective when remediating constituent plumes distributed over a large area within a relatively thin flow zone. Fewer horizontal wells would be required under this scenario compared with the number of vertical wells that might be required to achieve similar groundwater extraction rates. Furthermore, recovery efficiency might be increased relative to vertical wells due to the ability of a single horizontal well to contact a larger horizontal area, particularly where the horizontal aquifer transmissivity is greater than the vertical transmissivity.

Installation of a directionally drilled well involves the use of an auger bit that can be steered in three dimensions. The progress of direction boring installations is precisely monitored to avoid subsurface obstructions and to install the well as designed. Tracking accuracy generally decreases with increasing depth of installation. Site hydrogeologic and geologic conditions can also affect tracking accuracy.

Directionally drilled horizontal wells can be completed as blind holes (single-end completion) or surface-to-surface holes (double-end completion). Single-end holes involve one drill opening, with drilling and well installation taking place through this single opening. Borehole collapse might be more likely in single-ended drilling since the hole is left unprotected between drilling and reaming and between reaming and casing installation. An additional complication associated with single-ended completion involves the precise steering of reaming tools required to match the original borehole path. In contrast, double-end holes are typically easier to install since reaming tools and well casing can be pulled backward from the opposite opening, and the hole does not have to be left open.

Materials used for horizontal wells are typically the same or similar as those used for vertical wells. Factors to consider in the choice of the well screen and casing materials to be used with horizontal wells include axial strength, tensile strength, and flexibility (Miller, 1996).

Angle drilled wells are constructed in the same way as a vertical well with the exception that the drill rig mast is positioned at an angle that is purposely not plumb. The drilling mast angle and the targeted drilling depth would determine horizontal offset of the well screen and submersible pump from the location where drilling was initiated. Otherwise, angled wells function in the same manner as vertical wells.

Groundwater modeling conducted for Cliffside indicates that vertical groundwater extraction wells can produce sufficient yield for purposes of hydraulic containment and/or constituent mass removal. The use of horizontal or angular groundwater extraction wells is not retained for further consideration.

Extraction Trenches

Shallow horizontal groundwater extraction (collection or intercept) trenches can be installed in areas near surface waters where groundwater might discharge. These trenches can be utilized to prevent groundwater from discharging into surface waters and can be effective in lowering or managing the water table.

Trenches might be used as temporary installations to intercept and monitor subsurface flow or can be retained as a permanent installation. Trenches must be deep enough to tap and provide an outlet for ground water that is in shallow, permeable strata or in water-bearing sand. The spacing of trenches varies with soil permeability and drainage requirements.

Extraction trenches function similar to horizontal wells but are installed with excavation techniques. They can be cost-effective to construct at shallow depths (less than or equal to 35 feet bgs) using conventional equipment. Trenches can be installed to depths of approximately 50 feet bgs using specialty equipment. Horizontal collection trenches are usually not cost-effective for deeper installations or bedrock applications. Horizontal collection trenches do have the advantage of generally having lower operations and maintenance costs compared with the costs of multiple vertical wells.

Groundwater modeling conducted for Source Area 1 at Cliffside indicates that vertical groundwater extraction wells can produce sufficient yield for purposes of hydraulic containment and/or constituent mass removal. The use of extraction trenches wells is not retained for further consideration.

Hydraulic Fracturing

The effectiveness of groundwater extraction systems can sometimes be improved in low permeability formations, including bedrock, with the use of fracturing techniques.

Pneumatic fracturing involves injection of highly pressurized air into consolidated sediments to extend existing fractures and create a secondary network of fissures and channels. Similarly, hydraulic fracturing involves the use of high pressure water to extend existing fractures and create a secondary network of fissures and channels.

Hydraulic fracturing generally involves the application of high pressures to propagate existing fractures or to create fractures following fracture nucleation. When hydraulic fracturing is applied to unconsolidated materials, disk shaped notch that serves as the starting point for the fracture is created using high pressure water to cut into the formation. Pumping a slurry of water, sand, or a thick gel at high pressure into the borehole propagates the fractures. The residual gel biodegrades and the resultant fracture is a permeable sand-filled lens that might be as large as 60 feet in diameter (USEPA, 1995).

The presence of COIs in the bedrock groundwater at Cliffside is limited compared to the distribution and concentrations of COIs in saprolite and transition zone groundwater. In addition, COIs were not detected at levels greater than applicable groundwater standards in samples collected from deep dam wells. The use of hydraulic fracturing to enhance remediation of bedrock groundwater is not considered further because:

- The extent of COIs in bedrock groundwater is limited.
- COIs in bedrock groundwater might be addressed as effectively using more conventional means.

Phytoremediation

Phytoremediation involves the use of plants and trees as a means to extract groundwater. Water uptake by trees is used for plant growth and metabolism. Water uptake by plants and trees is ultimately released into the atmosphere via the pore-like structures on the leaves called stoma. Water on the leaves evaporates into the atmosphere. The loss of water by plants and trees is called transpiration. The amount of water transpired by plants, and therefore water uptake by plants, is a function of:

- **Plant type:** Plants that are native to arid regions must conserve water and therefore transpire less than plants that are native to wet regions.
- **Temperature:** Transpiration rates increase with increasing temperature and decrease with decreasing temperatures.
- **Relative humidity:** Transpired water on plant leaves evaporate at a faster rate when the relative humidity is low and that results in a correspondingly higher transpiration rate. The opposite is true when the relative humidity is high.
- **Wind and air movement:** increased movement of air around a plant will increase the rate of transpiration by plants
- **Availability of soil moisture:** Plants can sense when soil moisture is lacking and would reduce their transpiration rate.

The growth rate of selected plant species and the growing season can be limiting factors for the effectiveness of this technique. Maintenance can be long term and require, in most cases, fertilizing, regular monitoring, and harvesting.

Phytoremediation using TreeWell™ technology involves the installation of a 3 to 5 foot diameter boring to a target depth, typically a flow zone containing COIs. A Root Sleeve™ liner and aeration tubing are installed from ground surface to target depth. The boring is backfilled with soil that might include reactive media. If filled with reactive media, the TreeWell™ would serve as a PRB as well as a means to promote phytoremediation.

A tree is planted within the TreeWell™ followed by placement of plastic cover over the soil surrounding the tree. The plastic cover minimizes infiltration of precipitation into the TreeWell™. The TreeWell™ design forces the tree to draw water from the targeted depth via the Root Sleeve™ liner. Groundwater is also drawn through reactive media, if present. Consequently, the tree and the TreeWell™ are capable of uptake of some COIs and serve as a means of groundwater treatment and enhanced natural attenuation.

Ground cover plants stabilize soil/sediment and control hydraulics. In addition, densely rooted groundcover plants and grasses can also be used to remediate constituents. Phytoremediation groundcovers are one of the more widely used applications and have been applied at various bench- to full-scale remediation projects. Furthermore, in the context of this document, phytoremediation groundcovers are vegetated systems typically applied to surface soils as opposed

to TreeWells which are targeted to deep soil and/or groundwater. The typical range of effectiveness for phytoremediation groundcovers is 1–2 feet bgs; however, depths down to 5 feet have been reported as within the range of influence under some situations (ITRC, 2009)

Constructed treatment wetlands are manmade wetlands built to remove various types of pollutants that may be present in water that flows through them. They are constructed to recreate, to the extent possible, the structure and function of natural wetlands, which is to act as filters. Wetlands are ideally suited to this role. They possess wetland plants with robust root systems and a rich microbial community in the sediment to effect the biochemical transformation of pollutants. They are biologically productive, and most importantly, they are self-sustaining.

Metals are removed in constructed wetlands by a variety of mechanisms including the following. Settling and sedimentation achieve efficient removal of particulate matter and suspended solids. The chemical process that results in short-term retention or long-term immobilization of constituents is sorption. Sorption includes the combined processes of adsorption and absorption. Chemical precipitation involves the conversion of metals in the influent stream to an insoluble solid form that settles out. (ITRC, 2003)

Phytoremediation technology can be also be used as a means to treat extracted groundwater. Aquaculture treatment technologies have been applied to the treatment of water. Those using aquatic plants, have been demonstrated capable treatment of metals and other non-metal elements including boron and arsenic (USEPA, 1982).

Groundwater modeling conducted for Source Area 1 at Cliffside indicates that phytoremediation does significantly improve hydraulic containment and/or constituent mass removal. The use of phytoremediation is not retained for further consideration.

6.4.4 Groundwater Treatment

Several technologies exist for treatment of extracted groundwater to remove or immobilize constituents ex-situ, or above ground. The following technologies are used for treatment of extracted groundwater. These groundwater treatment technologies are scalable for small to large flow rates.

pH Adjustment

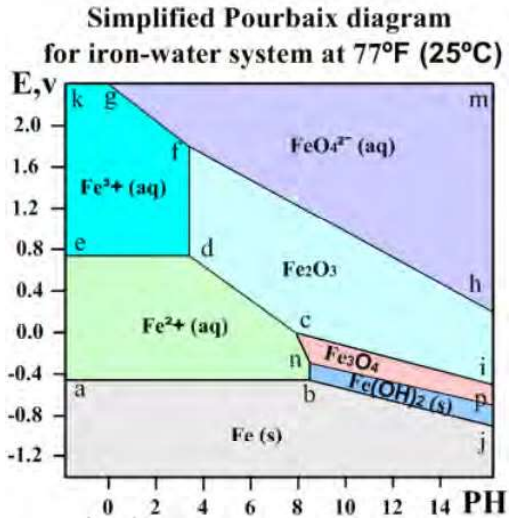
Adjustment of the pH of extracted groundwater is a proven technology. Permitted discharges would impose specific limits on the pH of discharged wastewater. The existing NPDES permitted outfalls at Cliffside maintain a pH between 6.0 and 9.0 S.U. Facilities and equipment to adjust the pH of wastewater to satisfy NPDES discharge requirements are in-place at Cliffside.

The pH adjustment of extracted groundwater is anticipated. Since 2018, a majority of background values for pH in shallow (saprolite) and intermediate (transition zone) groundwater samples at Cliffside were less than 6.0 S.U. Also, field measured pH of groundwater samples collected from 68 downgradient groundwater monitoring wells were less than 6.0 S.U. during 2018 and 2019. Among other treatment steps, Cliffside currently adjusts pH of the effluent from the Holding Basins; this treatment technology will be retained for further consideration.

Precipitation

Precipitation of metals and other inorganic constituents has been used extensively to treat extracted groundwater. The process involves the conversion of soluble (dissolved) constituents to insoluble particulates that would precipitate. The insoluble particles are subsequently removed by physical methods such as clarification or filtration. The process might involve adjustment of the wastewater pH and/or reduction-oxidation (redox) potential or E_h (volts). The stability of soluble and insoluble metals and metal complexes is commonly illustrated in Pourbaix diagrams (pH vs Eh).

FIGURE 6-31
POURBAIX DIAGRAM FOR IRON-WATER SYSTEM



https://rsteyn.wordpress.com/pourbaix-diagrams

As illustrated in the Pourbaix diagram (**Figure 6-31**), iron is soluble (aqueous or aq) at a pH of approximately 3.5 S.U. or less under aerobic conditions ($E_h > 0$ V). If the pH is increased, ferric (Fe^{+3}) iron would react to form insoluble (solid or s) complexes and precipitate out of solution, provided that the redox potential (Eh) remains between 0.75 and 1.5 V. Adjustment of groundwater pH and E_H can be used to remove other metals including cadmium, chromium, copper, nickel, and zinc.

Flocculation is another method that can be used to remove inorganic constituents from an aqueous waste stream. For example, a flocculent is being added to decanted water from the AAB at Allen Steam Station to reduce total suspended solid (TSS) concentrations in decanted water to levels that comply with NPDES discharge limits. The use of flocculation might be considered when designing the Cliffside Steam Station groundwater remediation system.

Precipitation technology might be warranted to treat, or pretreat, extracted groundwater to satisfy NPDES permitted discharge limits. The indication is that extracted groundwater will not cause violations of the NPDES permit when discharged; however, precipitation technologies are part of the Cliffside WWTP.

Ion Exchange

Ion exchange processes are reversible chemical reactions that can be used for the removal of dissolved ions from solution and replacing them with other similarly charged ions. The ion exchange medium might consist of a naturally occurring material such as zeolites or a synthetic resin with a mobile ion attached to an immobile functional acid or base group. Mobile ions held by the ion exchange resin are exchanged with solute or target ions in the waste stream having a stronger affinity to the functional group.

Ion exchange resins can be cation resins or anion resins of varying strength. Ion exchange resins are generally classified as being:

- Strong acid cation (SAC) resins.
- Weak acid cation (WAC) resins.
- Strong base anion (SBA) resins.
- Weak base anion (WBA) resins.

Over time, a resin can become saturated with the targeted or competing ions. Breakthrough might occur when a resin becomes saturated. The possibility of

breakthrough is evident when effluent concentrations of the targeted metal ion steadily increase over time and approach influent concentrations. Ion resins should be replaced or regenerated before breakthrough occurs.

Regeneration is laborious and requires safe handling of concentrated chemical reagents and waste. The first step in the co-flow regeneration process (regenerant is introduced via ion exchange bed influent) is to backwash the system with water. The regenerant solution is introduced to drive off ions and restores the resin capacity to about 60 to 80 percent of the total resin ion exchange capacity. Sodium hydroxide is a commonly used regenerant for WBA resins; weaker alkalis such as ammonia (NH3) and sodium carbonate (Na2CO3) can also be used (SAMCO, 2019).

When sufficient contact time has passed, a slow water rinse is applied to the resin bed to push the regenerant solution throughout the resin and subsequently remove the regenerant from the system. The regenerant should be retained for proper disposal. The slow rinse is followed by a fast "raw" water rinse to verify water quality requirements are being met.

A limitation of this technology is that there must be a feasible and economical method to dispose of the regeneration effluent. An additional challenge could be groundwater influent streams that might have geochemical characteristics that result in interference in the ion exchange process. Because of these challenges ion exchange is not retained for further consideration.

Membrane Filtration

There are several permeable membrane filtration technologies that can be utilized to remove metals and other constituents from extracted groundwater. The most common is reverse osmosis. Microfiltration, ultrafiltration, and nanofiltration are also permeable membrane filtration technologies that are used less frequently.

All four technologies use pressure to force influent water through a permeable membrane. Permeable membrane filtration technologies are selected and designed so that influent water can pass through the membrane while target constituents are filtered (retained) by the membrane. The permeable membrane filtration technologies discussed differ in the size of the molecules filtered and the pressures needed to allow permeate to pass through the membranes.

Permeable membrane filtration technologies can filter one or more target constituents simultaneously and achieve low effluent concentrations. However, permeable membrane filtration technologies are also susceptible to fouling and often require a pretreatment step. They can also generate a high concentration reject effluent which might require additional treatment prior to disposal. These technologies typically have high capital costs.

Membrane filtration at Cliffside is not carried forward for further evaluation for the following reasons:

- Extracted groundwater is not expected to be greater than permit discharge limits.
- Pretreatment and a high volume of reject effluent that requires additional treatment prior to disposal make this technology costly and high maintenance.

6.4.5 Groundwater Management

Extracted groundwater must be disposed of or used as supplemental process water prior to discharge. The disposition of extracted groundwater is discussed in the following sections.

National Pollutant Discharge Elimination System (NPDES) Permitted Discharge

The CSS has an NPDES permit (NC0005088) that authorizes the discharge of specific waste streams to the Broad River via NPDES Outfalls. The specific outfalls are described in **Section 1.5.3**. None of the outfalls are permitted to receive groundwater. Consequently, NPDES permit NC0005088 must be modified before extracted groundwater can be discharged to the Broad River. If extracted groundwater is ever discharged via an existing NPDES permitted outfall, Outfalls 002 and 005. Outfall 002 is located north of the AAB and Outfall 005 is located near the Holding Basins.

The CSS constructed Holding Basins and a new wastewater treatment plant (WWTP). The new WWTP discharges to NPDES outfall 005 and is a physical/chemical system. The WWTP consists of pH neutralization, coagulation and flocculation, clarification. If necessary, the wastewater polished with disk filters before being discharged to outfall 005.

Outfall 005 is the most likely outfall that might be used as it can be accessed from a sump near the WWTP that would transfer the extracted groundwater to the

Holding Basins (**Figure 1-4**). Outfall 005 and 002 effluent limitations and anticipated concentrations in the extracted groundwater are provided in **Table 6-10**.

Modifying NPDES Permit NC0005088 so that extracted groundwater can be discharged through NPDES Outfall(s) 002 and/or 005 is technically and administratively feasible. Management of extracted groundwater utilizing the NPDES discharge system will be retained for further consideration.

Publicly Owned Treatment Works (POTWs)

This groundwater management option involves the discharge of extracted groundwater to a sewer that discharges to the local POTW. The feasibility of this management option depends on a number of factors including:

- The proximity of the nearest sewer line relative to the groundwater extraction system.
- The available capacity of a POTW to accept a new waste stream.
- The suitability of a groundwater waste stream on POTW operations.
- Capital costs, pretreatment requirements, and discharge fees.

The POTWs located closest to CSS is the Town of Boiling Springs (Boiling Springs WWTP), located at 2556 Rockford Road, Shelby, NC 28152. The Boiling Springs WWTP is located approximately 4.5 miles northeast of Cliffside.

The Boiling Springs WWTP operates under NPDES Permit NC0071943. The Boiling Springs WWTP serves approximately 4,600 residential, commercial, and industrial users. The Boiling Springs WWPT has a daily capacity limit of 0.600 MGD. In 2018, the Boiling Springs WWTP collected and treated an average of 0.360 MGD. Influent wastewater undergoes the following treatment:

- Mechanical (automatic) bar screen
- Aeration and biological treatment basin
- Clarifier (microorganism recycle/solids removal)
    - Solids are pumped to a digester basin
    - Land application (WQ0018352)
- Ultra-violet disinfectant chamber
- Discharge to Sandy Run Creek of the Broad River Basin

The Boiling Springs WWTP had no compliance violations in 2018 and two incidents of sanitary sewer overflows.

It is unlikely that the Boiling Springs WWTP would allocate most of its available capacity to a single industrial user. In addition, the Town of Boiling Springs WWTP does not currently treat wastewater from any sources located in Rutherford County. Consequently, installation of significant infrastructure, including miles of sewer line and at least one lift station, would be required before groundwater could be discharged to the Boiling Springs WWTP.

Discharge of extracted groundwater to the Boiling Springs WWTP is not retained for further consideration at this time. Modifying NPDES Permit NC0005088 so that extracted groundwater can be discharged through NPDES Outfall(s) 002 and/or 005 is considered the more feasible option.

Non-Discharge Permit/Infiltration Gallery

Disposition of treated groundwater by way of infiltration into underlying groundwater involves the construction of an infiltration gallery to receive and distribute the treatment effluent or wastewater. Discharge of wastewater by way of an infiltration gallery must not result in a violation of 02L groundwater standards. Consequently, groundwater treatment must reliably produce an effluent waste stream that does not result in groundwater violation set by the 02L standard.

The construction and use of infiltration galleries are permitted under 15A NCAC 02T .0700. The effectiveness of an infiltration system depends in large part on the type of soils, or classification of soils, receiving the wastewater. Annual hydraulic loading rates shall be based on in-situ measurement of saturated hydraulic conductivity in the most restrictive horizon for each soil mapping unit. U.S. Department of Agriculture (USDA, 2019) soil map of the Site indicates that native soil at the Cliffside Plant is classified as:

- Udorthents (UdC), loamy, 0 to 15 percent slopes:
    - Capacity of the most limiting layer to transmit water (Ksat) is very low to high (0.00 to 1.98 in/hr)
    - Typical profile
        - C - 0 to 80 inches: sandy clay loam

- Pacolet-Bethlehem Complex (PbC2), 8 to 15 percent slopes, moderately eroded:
    - Capacity of the most limiting layer to transmit water (Ksat) is very low to low (0.00 to 0.01 inches/hour)
    - Typical profile
        - Ap - 0 to 7 inches: sandy clay loam
        - Bt - 7 to 28 inches: clay
        - BC - 28 to 44 inches: sandy clay loam
        - C - 44 to 80 inches: sandy loam
- Pacolet-Bethlehem Complex (PbD2), 15 to 25 percent slopes, moderately eroded:
    - Capacity of the most limiting layer to transmit water (Ksat) is moderately high to high (0.57 to 1.98 inches/hour)
    - Typical profile:
        - Ap - 0 to 7 inches: sandy clay loam
        - Bt - 7 to 28 inches: clay
        - BC - 28 to 44 inches: sandy clay loam
        - C - 44 to 80 inches: sandy loam
- Rion-Cliffside Complex (RnE), 25 to 60 percent slopes, very stony:
    - Capacity of the most limiting layer to transmit water (Ksat): Very low to low (0.00 to 0.01 in/hr)
    - Typical profile:
        - A - 0 to 7 inches: gravelly sandy loam
        - Bt - 7 to 27 inches: very cobbly sandy clay loam
        - R - 27 to 80 inches: unweathered bedrock

The use of infiltration galleries to discharge groundwater will not be retained for further consideration because most Site soils have limited capacity to transmit water.

Non-Discharge Permit/Land Application

Land application of groundwater involves the distribution of extracted groundwater onto land to irrigate the vegetative cover and supplying the vegetative cover with nutrients beneficial for growth. The vegetative cover can include grasses, TreeWells™, wetland species, native species of trees and shrubs, and ornamental trees and shrubbery.

The primary focus of groundwater remediation efforts is to reduce boron concentrations beyond the anticipated compliance boundary to acceptable levels. Consequently, extracted groundwater would be expected to contain boron. Boron is essential for plant growth. More specifically, boron in soil must be continuously delivered to growing tissues through roots and vascular tissues to maintain cell wall biosynthesis and optimal plant development (Takano, 2006). Boron is also essential for plant nitrogen assimilation, for the development of root nodules in nitrogen-fixing plants, and for the formation of polysaccharide linkages in plant cell walls (Park, 2002). If extracted groundwater is land applied, boron would be made available for plant uptake.

Extracted groundwater could be used to irrigate more than 300 acres of planted vegetative cover following the implementation of source control measures. Land application of extracted groundwater would occur within the existing and possibly future compliance boundary. A large scale irrigation system could be used to apply thousands of gallons of water onto the vegetative cover daily. Of the water applied, much of it would be lost to evaporation, particularly during sunny dry periods. Likewise, water taken up by vegetation would be lost by way of plant transpiration. All remaining water would either infiltrate into the soil or migrate downslope to wetland areas via surface water runoff.

Land application of extracted groundwater must comply with 15A NCAC 02T – *Waste Not Discharged To Surface Waters*. Duke Energy would submit an application for a non-discharge permit in accordance with 15A NCAC 02T .0105 - .0109. General permits can be effective for up to eight years. General permits issued pursuant to 15A NCAC 02T shall be considered individual permits for purposes of Compliance Boundaries established under 15A NCAC 02L .0107. Permitted facilities shall designate an Operator in Responsible Charge and a back-up operator as required by the Water Pollution Control System Operators Certification Commission.

Application of wastewater to the ground surface or surface irrigation of wastewater is governed by 15A NCAC 02L .0500 - *Wastewater Irrigation Systems*. Requirements under this subsection include:

- A soil scientist must prepare a soil report that evaluates receiving soil conditions and who makes recommendations for loading rates of liquids and wastewater constituents.
- A hydrogeologic report must be prepared by a licensed geologist, soil scientist, or professional engineer for industrial waste treatment systems with a design flow of over 25,000 gallons per day.
- The applicant must prepare a Residuals Management Plan.
- Each facility shall provide flow equalization with a capacity of 25 percent of the daily system design flow unless the facility uses lagoon treatment.
- Management areas shall be designed to maintain one-foot vertical separation between the seasonal high water table and the ground surface.
- Automatically activated irrigation systems shall be connected to a rain or moisture sensor to prevent irrigation during precipitation events or wet conditions that would cause runoff.

Setback requirements for irrigation sites (15A NCAC 02T .056) are summarized in **Table 6-11**:

The DWR might require monitoring and reporting to characterize the waste (extracted groundwater) and its effect upon surface water, ground water, or wetlands.

Land application of extracted groundwater could be used as a means to maintain the vegetative cover that would be established following implementation of source control measures. However, the designated area would have to be able to take continuous flow during both dry and wet seasons, which would not be practical. Additionally, unless the vegetation is harvested, boron uptake will be returned to the soil and aquifer upon death and decomposition of the plant matter. Therefore, land application will not be retained as an alternative means for management of extracted wastewater.

Beneficial Reuse

Beneficial reuse of extracted groundwater involves the evaluation of existing water demand and the repurposing of extracted groundwater to satisfy a need for water. Beneficial reuse of extracted groundwater can do the following:

- Provide an alternative to groundwater treatment.
- Reduce reliance on sources of non-potable water required for plant operations.
- Reduce the need and capacity for wastewater treatment.

A North Carolina Division of Water Resources (NCDWR) 2018 Annual Water Use Report for the Cliffside Steam Station indicated that water was withdrawn from the Broad River every day in 2018. The average daily withdrawal in a given month ranged from 12.7 million gallons per day (MGD) to 33.1 MGD. The average daily discharge in a given month ranged from 8.6 to 13.3 MGD (NCDWR, 2019).

Beneficial Reuse: Fire Protection

A limited amount of extracted groundwater might be used to supplement or supply water stored for fire suppression within Station operations. However, the need for fire suppression water is limited, storage is problematic and would not justify the effort and expense to substitute extracted groundwater for fire suppression water obtained from the Broad River.

Beneficial Reuse: Non-Contact Cooling Water

Extracted groundwater might be used to supplement or supply makeup water used for non-contact cooling within Station operations. The alkalinity of groundwater could pose potential scaling problems for some applications. In addition, it is possible that operation of the groundwater remediation system could extend beyond plant decommissioning. Use of extracted groundwater for non-contact cooling water is not retained.

Beneficial Reuse: Dust Suppression and Truck Wash

A limited amount of extracted groundwater can possibly be used for dust suppression during implementation of source control measures. Similarly, extracted groundwater can possibly be used for washing the tires of haul trucks leaving the ash basins during implementation of source control measures. The use of extracted groundwater for dust suppression and truck washing would be confined within ash basin limit of ash disposal. However, the need for dust

suppression and truck wash water is limited and would not justify the effort and expense to substitute extracted groundwater for dust suppression and truck wash water obtained from the Broad River. Therefore, beneficial use of the water is not retained for further consideration.

6.4.6 Technology Evaluation Summary

A summary of the remedial technologies presented above and the rationale for either retaining or rejecting a specific technology is presented in **Table 6-12**.

In conclusion, remedial technologies retained for further consideration include, MNA, in-situ technologies LRB and groundwater flushing, and several groundwater extraction technologies including vertical extraction wells, horizontal extraction wells, extraction trenches, and phytoremediation. Groundwater treatment technologies retained include pH adjustment, precipitation, ion exchange, membrane filtration, and phytoremediation. These technologies were retained to meet NPDES permit discharge limits which was the only technology retained for management of extracted groundwater. No beneficial reuse technology is retained at this time.

6.5 SA1 Evaluation of Remedial Alternatives

(CAP Content Section 6.D.a)

Technologies evaluated and retained for consideration as discussed in **Section 6.4** were used to formulate the following three groundwater remedial alternatives to remediate Site groundwater:

- Remedial Alternative 1: Monitored Natural Attenuation (MNA)
- Remedial Alternative 2: Groundwater Extraction, Clean Water Infiltration in Wells and Treatment
- Remedial Alternative 3: Groundwater Extraction, Clean Water Infiltration in Wells and Galleries and Treatment

These groundwater remedial alternatives are detailed in the following subsections.

6.5.1 Remedial Alternative 1 – Monitored Natural Attenuation

(CAP Content Section 6.D.a)

Alternative 1 is the use of MNA to address groundwater COI concentrations at or beyond the AAB compliance boundary. A comprehensive analysis of MNA is provided in **Appendix I.**

The Site has undergone the extensive hydrogeologic characterization necessary to evaluate natural attenuation processes and rates. Site-specific groundwater data including saturated media within the saprolite, transition zone, and bedrock flow zones have been collected for the MNA evaluation.

A primary component of MNA as a remedial strategy is source control. The current timeframes for implementation of the source control measures under consideration range from approximately 6 to 10 years, depending upon the selected source control remedy.

6.5.1.1 Problem Statement and Remediation Goals

(CAP Content Section 6.D.a.i)

A limited number of CCR constituents in groundwater associated with the Cliffside AAB and ASA occur at or beyond the compliance boundary to the north of the AAB within the ASA at concentrations greater than applicable 02L standards, IMAC, or background values, whichever is greater. Remediation goals are to restore groundwater quality at or beyond the compliance boundary by returning COIs to acceptable concentrations (02L standard/IMAC or background, whichever is greater), or as closely thereto as is economically and technologically feasible consistent with 15A NCAC 02L. 0106(a).

In the future, alternative standards may be proposed as allowed under 02L.0106(k). This approach is considered reasonable given the documented lack of human health or ecological risk at Cliffside.

The following groundwater COIs to be addressed by corrective action are identified (**Table 6-6**) and discussed in **Section 6.1**: arsenic, boron, cobalt, iron, lithium, manganese, sulfate, strontium, thallium, TDS, uranium, and vanadium.

The area of maximum COI distribution at or beyond the compliance boundary is the focus of corrective action. Reactive COIs are coincident with the mobile COIs. Focusing remedial action selection on addressing the mobile COIs would also address the reactive COIs as they would follow a similar flow path but with greater attenuation. The maps and cross-sections (**Figures 6-8a** through **6-11c)** show the COI-affected groundwater beyond the compliance boundary in the shallow, deep (transition zone to upper weathered bedrock).

MNA would involve the installation of six (6) saprolite, seven (7) transition zone, and five (5) bedrock groundwater monitoring wells to replace wells abandoned during implementation of source control measures. These replacement monitoring wells would be installed along geochemical transects to monitor groundwater concentration trends in the footprint of the ash basin and ASA. Long-term MNA groundwater monitoring would be conducted at the 18 replacement source area MNA monitoring wells and at 15 existing groundwater monitoring wells.

6.5.1.2 Conceptual Model

(CAP Content Section 6.D.a.ii)

Aspects of the conceptual site model (**Section 5**) would change following source control. The source of COIs in groundwater would be substantially reduced following decanting of the AAB and closure compared to existing conditions. The decanting would reduce the potentiometric head responsible for the downward vertical gradient behind the ash basin dams. A lower downward gradient would reduce COI migration downward. As a result, constituent concentrations reductions through natural attenuation processes are anticipated following decanting.

Currently, COIs in groundwater do not pose an unacceptable risk to human health or the environment under conservative exposure scenarios and, if implemented alone, MNA would not pose an unacceptable risk to human health or the environment in the future. Source control and groundwater monitoring would verify protection of human health and the environment and to confirm model predictions. The applicable technologies that would support this alternative include groundwater monitoring wells within the former source area and near the former waste boundary, along downgradient flow transects, at a potential future point of compliance, in sentinel areas prior to receptors, and near the maximum predicted extent of migration. A majority of the monitoring wells installed around the AAB and ASA have dedicated sampling equipment and an approved interim monitoring plan is in place. A subset of these monitoring wells could be immediately used for monitoring the effectiveness of Alternative 1.

6.5.1.3 Predictive Modeling

(CAP Content Section 6.D.a.iii)

Existing data and the results from the flow and transport model and the geochemical model, suggest that natural attenuation mechanisms are

applicable to the existing plumes for all COIs as described in **Appendix I.** The flow and transport and geochemical modeling reports in **Appendices G** and **H** provide detailed predictions, descriptions, and explanations of the effects of MNA after ash basin closure. The models are built and calibrated based on existing conditions consistent with observed data.

The flow and transport model predicts that concentrations of COIs would meet 02L standards at the compliance boundary in approximately 400 years after ash basin closure in the closure-in-place scenario and in approximately 200 years after ash basin closure in the closure-by-excavation scenario. The model predicts the maximum extent of the plume for any boron, at any point in time, would be 650 feet beyond the 500-foot compliance boundary (**Appendix G**).

6.5.2 Remedial Alternative 2 – Groundwater Extraction, Clean Water Infiltration in Wells and Treatment

(CAP Content Section 6.D.a)

Alternative 2 involves groundwater extraction combined with clean water infiltration in and around the ASA north of the AAB (**Figure 6-32a)**. This alternative provides an effective combination of technology for groundwater capture (*i.e.* extraction) to address Site-specific COIs. Under this alternative, compliance will be achieved in five years (for closure-in-place) to eight years (for closure-by-excavation) after system startup and operation.

6.5.2.1 Problem Statement and Remediation Goals

(CAP Content Section 6.D.a.i)

CCR constituents in groundwater associated with the Cliffside AAB and ASA occur at or beyond the compliance boundary to the north of the AAB within the ASA at concentrations greater than applicable 02L standards, IMAC, or background values, whichever is greater. Remediation goals are to restore groundwater quality at or beyond the compliance boundary by returning COIs to acceptable concentrations (02L standard/IMAC or background value, whichever is greater), or as closely thereto as is economically and technologically feasible consistent with 15A NCAC 02L. 0106(a).

In the future, alternative standards may be proposed as allowed under 02L.0106(k). This approach is considered reasonable given the documented lack of human health or ecological risk at Cliffside.

The following groundwater COIs to be addressed by corrective action are identified (**Table 6-6**) and discussed in **Section 6.1**: arsenic, boron, cobalt, iron, lithium, manganese, sulfate, strontium, thallium, TDS, uranium, and vanadium.

The area of maximum COI distribution at or beyond the compliance boundary is the focus of corrective action. Reactive COIs are coincident with the mobile COIs. Focusing remedial action selection on addressing the mobile COIs would also address the reactive COIs as they would follow a similar flow path but with greater attenuation. The maps and cross-sections (**Figures 6-8a** through **6-11c)** show the COI-affected groundwater beyond the compliance boundary in the shallow, deep (transition zone to upper weathered bedrock).

The primary remediation goals under Alternative 2 are:

- Mitigate constituent migration to the Broad River
- Achieve 02L compliance for groundwater beyond the 500-foot compliance boundary

Twenty-three (23) vertical groundwater extraction wells would be installed to depths ranging from 27 feet to 133 feet bgs and would be screened across the shallow and deep flow zones. The average groundwater extraction rate for these vertical extraction wells is estimated to be 7 gallons of groundwater per minute and the total groundwater extraction rate from the vertical groundwater extraction well network is estimated to be 160 gpm.

Forty-six (46) vertical infiltration wells would be installed to depths ranging from 13 feet to 122 feet bgs. These infiltration wells would be screened across the shallow and deep flow zones. The average groundwater infiltration rate for these vertical infiltration wells is estimated to be 3.6 gpm and the total groundwater infiltration rate from the infiltration well network is estimated to be 165 gpm.

One horizontal infiltration well would be constructed in a north to south orientation along the western boundary of the ASA. This horizontal well would be installed to a depth of 15 feet bgs and would be designed with a 240 foot screen length. The average groundwater infiltration rate for this horizontal groundwater extraction well is estimated to be 75 gallons of groundwater per minute. The total groundwater infiltration rate from the

vertical and horizontal groundwater infiltration well network is estimated to be 240 gpm.

The extracted groundwater would be piped over Suck Creek on an existing pipe rack to an existing sump near the wastewater treatment plant. The sump discharges to the Holding Basins. Holding Basin effluent is discharged to the CSS WWTP, which is a physical/chemical treatment system consisting of pH adjustment, coagulation and flocculation. Solids are removed from the wastewater using high-rate clarifiers and polishing filters, if necessary. Wastewater is discharged to the Broad River through NPDES Outfall 005.

A pilot test would be conducted wells to determine site yield and aquifer properties. Additionally, pilot infiltration testing will be completed to assess aquifer properties and to optimize potential pumping rates to return treated water back into the groundwater system. Pumping test results would be used to size pumps with the appropriate horsepower and capacity. Pumps, discharge piping, pressure gauges, flow totalizers, check valves, flow control valves, and telemetry hardware would be included in a final design package following pilot test evaluations.

6.5.2.2 Conceptual Model

(CAP Content Section 6.D.a.ii)

Groundwater Remedial Alternative 2, combined with source control, would change certain aspects of the conceptual site model in Section 5. Ash placed within the ASA would be permanently removed and would no longer be a source of COIs in underlying groundwater. Groundwater extraction wells would intercept and capture much of the groundwater flowing toward the Broad River from the AAB and the former ASA. Although constituent concentrations in Broad River surface water comply with 02B standards, mitigation of groundwater discharges to the Broad River from the AAB and the ASA would minimize the potential for a future 02B violation.

Standing water in the AAB would be decanted under any source control scenario being considered. When removed, standing water in the AAB would not be available to contribute the potentiometric head that is producing the downward vertical gradient behind the ash basin dams. A decreased gradient would reduce the rate of downward COI migration.

Alternative 2 would extract groundwater containing COIs, thereby reducing the mass of COIs in Site groundwater. The COIs most affected by groundwater extraction would be conservative COIs (boron, sulfate, lithium, and TDS) that are typically more soluble and mobile over a range of geochemical conditions when compared to non-conservative/reactive (strontium and vanadium) and variably reactive (cobalt, iron, and manganese) constituents (**Section 6.1.5**).

Alternative 2 would introduce clean water into the vadose zone and underlying groundwater via infiltration wells. This would have the effect of flushing COIs from saprolitic soils, diluting COI concentrations, and aiding groundwater extraction in the saprolite and transition flow zones.

Currently, COIs in groundwater do not pose an unacceptable risk to human health or the environment under conservative exposure scenarios. If implemented, Groundwater Remedial Alternative 2 would not pose an unacceptable risk to human health or the environment.

6.5.2.3 Predictive Modeling

(CAP Content Section 6.D.a.iii)

Sustainability analysis was completed as described in **Section 6.6**. The environmental footprint was quantified based on energy use and associated emissions, during the construction phase (e.g., material quantities and transportation), active remediation activities (e.g., groundwater pumping and treatment) and groundwater monitoring activities (e.g., transportation). The results of the environmental footprint calculations for Alternative 2 are summarized in **Table 6-14**. A summary of sustainability calculations for Alternative 2 can be found in **Appendix L**.

The environmental footprint of Alternative 2 is the second-most, energy-intensive remedial alternative being considered. Alternative 1 (MNA) requires significantly less materials and energy than Alternative 2 and is therefore characterized by a dramatically smaller environmental footprint. Alternative 2 presents lower, but generally comparable, environmental footprint metrics when measured against Alternative 3. Alternative 2 utilizes infiltration-wells rather than an infiltration gallery as used in Alternative 3, generating a lower material-related environmental footprint for the construction phase. The quantitative analysis of the environmental footprints of the remedial alternatives under consideration for this CAP indicates Alternative 2 to be the more sustainable option, although not

significantly less impactful than Alternative 3. Opportunities for system optimization and energy savings could be pursued throughout the remediation timeframe, as conditions change and component technologies possibly evolve.

6.5.3 Remedial Alternative 3 – Groundwater Extraction, Clean Water Infiltration in Wells and Galleries, and Treatment

(CAP Content Section 6.D.a)

Alternative 3 involves groundwater extraction combined with clean water infiltration in and around the ASA. The primary remediation goals under Alternative 3 are:

- Mitigate constituent migration to the Broad River
- Achieve 02L compliance for groundwater beyond the 500-foot compliance boundary

Twenty-three (23) vertical groundwater extraction wells would be installed to depths ranging from 55 feet to 155 feet bgs and would be screened across the shallow and deep flow zones. The average groundwater extraction rate for these vertical extraction wells is estimated to be 5 gpm and the total groundwater extraction rate from the vertical groundwater extraction well network is estimated to be 122 gpm or 175,680 gpd.

One 240 foot long horizontal well would be constructed in a north to south orientation along the western boundary of the ASA. This horizontal well would be installed to a depth of 5 feet below ground surface and would be designed with a 225 foot screen length. The average groundwater extraction rate for this horizontal groundwater extraction well is estimated to be 23 gpm or 33,000 gpd. The total groundwater extraction rate from the vertical and horizontal groundwater extraction well network is estimated to be 45 gpm or 64,800 gpd.

Forty-eight (48) vertical infiltration wells would be installed to depths ranging from 30 feet to 135 feet bgs. These infiltration wells would be screened across the shallow and deep flow zones. The average groundwater infiltration rate for these vertical infiltration wells is estimated to be 3 gpm and the total groundwater infiltration rate from the infiltration well network is estimated to be 140 gpm or 201,600 gpd.

An infiltration gallery approximately 6.5 acres would be constructed over the ASA following excavation of the ash. The infiltration rate is estimated to be 26

gpm or 37,000 gpd. The combined groundwater infiltration rate from infiltration wells and the infiltration gallery is estimated to be 60 gpm or 86,000 gpd.

The extracted groundwater would be piped over Suck Creek on an existing pipe rack to an existing sump near the Cliffside WWTP. The sump discharges to the Holding Basins. Holding Basin effluent is discharged to the WWTP, which is a physical/chemical treatment system consisting of pH adjustment, coagulation and flocculation. Solids are removed from the wastewater using high-rate clarifiers and polishing filters, if necessary. Wastewater is discharged to the Broad River through NPDES Outfall 005.

A pilot test would be conducted wells to determine site yield and aquifer properties. Additionally, pilot infiltration testing will be completed to assess aquifer properties and to optimize potential pumping rates to return treated water back into the groundwater system. Pumping test results would be used to size pumps with the appropriate horsepower and capacity. Pumps, discharge piping, pressure gauges, flow totalizers, check valves, flow control valves, and telemetry hardware would be included in a design package following pump test evaluations.

6.5.3.1 Problem Statement and Remediation Goals

(CAP Content Section 6.D.a.i)

CCR constituents in groundwater associated with the Cliffside AAB and ASA occur at or beyond the compliance boundary to the north of the AAB within the ASA at concentrations greater than applicable 02L standards, IMAC, or background values, whichever is greater. Remediation goals are to restore groundwater quality at or beyond the compliance boundary by returning COIs to acceptable concentrations (02L standard/IMAC or background value, whichever is greater), or as closely thereto as is economically and technologically feasible consistent with 15A NCAC 02L. 0106(a).

In the future, alternative standards may be proposed as allowed under 02L.0106(k). This approach is considered reasonable given the documented lack of human health or ecological risk at Cliffside.

The following groundwater COIs to be addressed by corrective action are identified (**Table 6-6**) and discussed in **Section 6.1**: arsenic, boron, cobalt, iron, lithium, manganese, sulfate, strontium, thallium, TDS, uranium, and vanadium.

6.5.3.2 Conceptual Model

(CAP Content Section 6.D.a.ii)

Groundwater Remedial Alternative 3, combined with source control, would change certain aspects of the conceptual site model in Section 5. Ash buried within the ASA would be permanently removed and would no longer be a source of COIs in underlying groundwater. Groundwater extraction wells would intercept and capture much of the groundwater flowing toward the Broad River from the AAB and the former ASA. Although constituent concentrations in Broad River surface water comply with 02B standards, mitigation of groundwater discharges to the Broad River from the AAB and the ASA would minimize the potential for a future 02B violation.

Standing water in the AAB would be decanted under any source control scenario being considered. When removed, standing water in the AAB would not be available to contribute to the potentiometric head responsible for the downward vertical gradient behind the ash basin dams. A lower downward gradient would reduce COI migration downward.

Alternative 3 would extract groundwater containing COIs, thereby reducing the mass of COIs in Site groundwater. The COIs most affected by groundwater extraction would be conservative COIs (boron, lithium, sulfate, and TDS) that are typically more soluble and mobile over a range of geochemical conditions when compared to non-conservative/reactive (chromium, strontium, and vanadium) and variably reactive (cobalt, iron, and manganese) constituents (**Section 6.1.5**).

Alternative 3 would introduce clean water into the vadose zone and underlying groundwater via infiltration wells and an infiltration gallery. This would have the effect of flushing COIs from saprolitic soils, diluting COI concentrations, and aiding groundwater extraction in the saprolite and transition flow zones.

Currently, COIs in groundwater do not pose an unacceptable risk to human health or the environment under conservative exposure scenarios. If implemented, Groundwater Remedial Alternative 3 would not pose an unacceptable risk to human health or the environment.

6.5.3.3 Predictive Modeling

(CAP Content Section 6.D.a.iii)

Predictive groundwater flow and transport modeling was conducted to evaluate the time frame to achieve compliance for boron because boron is the most mobile CCR constituent.

Predictive modeling predicts that the simulated boron plume would recede to within the 500-foot compliance boundary in approximately five years (for closure-in-place) to eight years (for closure-by-excavation) following complete implementation of Alternative 3. The time frame to achieve compliance for boron under Alternative 3 is approximately 400 years earlier than Alternative 1 (MNA), and about the same timeframe as Alternative 2 Groundwater Extraction and Infiltration Wells (**Sections 6.5.1 and 6.5.2**). A flow and transport modeling report is presented in **Appendix G** and a geochemical modeling report is presented in **Appendix H**.

The combined groundwater extraction rate for this extraction system is predicted to be 37 gpm or 53,000 gpd. This combined groundwater extraction rate is based on predictive flow and transport modeling which assumes a 50 percent well efficiency. Pumping tests would be conducted to determine actual groundwater extraction rates.

Predictive modeling estimates that groundwater infiltration would provide approximately 60 gpm or 86,000 gpd of clean water infiltration to vadose zone soils and underlying groundwater. This combined groundwater infiltration rate is based on predictive flow and transport modeling which assumes a 25 percent well efficiency. This water would be supplied by fire suppression water located at the FGD building. This amount of water represents less than 0.7 percent of the daily water withdrawn from the Broad River for plant operations.

6.6 SA1 Remedial Alternative Screening Criteria

(Supplemental Information for CAP Content Section 6.D.a.iv)

This section provides supplemental information beyond the CAP content guidance to describe the screening criteria used to evaluate groundwater remediation alternatives at Cliffside. These screening criteria are based on the criteria outlined in 15A NCAC 02L .0106(i) and 40 CFR 300.430. The source of the screening criteria descriptions is 40 CFR 300.430. These screening criteria will be used in evaluating remedial alternatives identified in **Section 6.4**.

- Protection of human health and the environment
- Compliance with applicable regulations
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, and volume
- Short-term effectiveness at minimizing impact on the environment and local community
- Technical and logistical feasibility
- The time required to initiate and implement corrective action alternative
- Time required to achieve remediation goals
- Community acceptance

Additional considerations for remedial alternative evaluations include:

- Adaptive site management
- Sustainability

6.6.1 Protection of Human Health and the Environment

(CAP Content Section 6.D.a.iv.1)

The Updated Human and Ecological Risk Assessments report (**Appendix E**) has determined that there are no imminent hazards to public health and safety or the environment associated with coal ash basin or coal ash constituents in Site soil and groundwater. The updated risk assessment indicates acceptable risk and no exposure to residential receptors at or near the AAB or ASA (no completed exposure pathways). The assessment did not result in an increase of risks to ecological receptors (mallard duck, great blue heron, muskrat, river otter) exposed to surface water and sediments associated with the ash basin. Regardless, potential corrective measures are being evaluated for regulatory compliance.

Technologies and remedial alternatives are evaluated to determine whether they can achieve regulatory compliance within a reasonable timeframe, without detriment to human health and the environment.

6.6.2 Compliance with Applicable Regulations

(CAP Content Section 6.D.a.iv.2)

Technologies and alternatives are herein evaluated to assess compliance with applicable federal and state environmental laws and regulations. These include:

- CAMA (NC SB 729, Subpart 2)
- Groundwater Standards (NCAC, Title 15A, Subchapter 02L)
- CCR (40 CFR § 257.96)
- Well construction and maintenance standards (NCAC Title 15A Subchapter 02C)
- NPDES (40 CFR Part 122)
- Sediment erosion and control (NCAC Title 15A Chapter 04)

Appendix I includes a detailed evaluation of the applicability of Alternative 1: MNA as a remedial alternative for the Site.

6.6.3 Long-term Effectiveness and Permanence

(CAP Content Section 6.D.a.iv.3)

Technologies and alternatives are assessed for long-term effectiveness in reducing COI concentrations and permanence in maintaining those reduced concentrations in groundwater, along with the degree of certainty that technologies will be successful. Factors considered, as appropriate, include the following:

- Magnitude of residual risk remaining from untreated material remaining at the conclusion of remedial activities. The characteristics of the residuals should be considered to the degree that they could affect long-term achievement of remediation goals, considering their volume, toxicity, and mobility. Since there is no current risk, the potential for a remedial technology to increase potential risk to a receptor is considered in the evaluation process.
- Adequacy and reliability of controls as a means of evaluating alternatives in addition to managing residual risk.

6.6.4 Reduction of Toxicity, Mobility, and Volume

(CAP Content Section 6.D.a.iv.4)

The degree to which technologies employ recycling or treatment that reduces toxicity, mobility, or volume will be assessed, including how treatment is used to address the principal risks posed at the Site. Factors considered, as appropriate, include the following:

- The treatment or recycling processes the technologies employ and constituents that will be treated

- The mass of COIs that will be destroyed, treated, or recycled
- The degree of expected reduction in toxicity, mobility, or volume
- The degree to which the treatment is irreversible
- The type and quantity of residuals that will remain after treatment, considering the persistence, toxicity, and mobility of such substances and their constituents
- The degree to which treatment reduces the inherent hazards posed by risks at the Site

6.6.5 Short-term Effectiveness

(CAP Content Section 6.D.a.iv.5)

The short-term impacts of alternatives will be assessed considering the following:

- Short-term risks that might be posed to the community during implementation
- Potential impacts on workers during implementation and the effectiveness of mitigation
- Potential environmental effects during implementation and the effectiveness of mitigation
- Time until protection is achieved

6.6.6 Technical and Logistical Feasibility

(CAP Content Section 6.D.a.iv.6)

The ease or difficulty of implementing technologies and alternatives are assessed by considering the following types of factors as appropriate:

- Technical feasibility, including technical difficulties and unknowns associated with the construction and operation of a technology, the reliability of the technology, ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of the remedy
- Administrative feasibility, including activities needed to coordinate with agencies, and the ability and time required to obtain any necessary approvals and permits
- Availability of services and materials, including the availability of adequate off-Site treatment, storage capacity, and disposal capacity and services; as well as the availability of necessary equipment and specialists, and provisions to ensure any necessary additional resources

6.6.7 Time Required to Initiate and Implement Corrective Action Alternative

(CAP Content Section 6.D.a.iv.7)

The time required to initiate and fully implement a groundwater remedial action takes into consideration the following activities, if applicable:

- Source control measures
- Bench-scale testing
- Treatability testing
- Pilot testing
- Hydraulic Conductivity Testing
- Groundwater remedial alternative system design
- Permitting
- Procurement
- System Installation
- System startup

These activities may be requisite to finalize the system design, attain regulatory approval, or initiate construction. Therefore, these activities might dictate the time it takes to initiate and fully implement a remedial alternative.

6.6.8 Time Required to Achieve Remediation Goals

(CAP Content Section 6.D.a.iv.8)

This criterion includes the estimated time necessary to achieve remedial action objectives. This includes time required for permitting, bench and pilot scale testing, design completion and approval, and implementation of approved remedies.

6.6.9 Cost

(CAP Content Section 6.D.a.iv.9)

The costs of construction and long-term costs to operate and maintain the technologies and alternatives are considered. Costs that are grossly excessive compared to overall effectiveness may be considered as one of several factors used to eliminate alternatives. Alternatives that provide effectiveness and implementability similar to that of another alternative by employing a similar method of treatment or engineering control, but at greater cost, may be eliminated.

6.6.10 Community Acceptance

(CAP Content Section 6.D.a.iv.10)

This assessment considers likely support, concerns, or opposition from community stakeholders about the alternatives. This assessment might not be fully informed until comments on the proposed plan are received. However, some general assumptions of how an alternative would be accepted by the community can be made.

6.6.11 Adaptive Site Management and Remediation Considerations

(CAP Content Section 6.D.a.iv.11)

Remediation alternatives are evaluated to determine whether an adaptive site management process would address challenges associated with meeting remedial objectives. Adaptive site management is the process of iteratively reviewing site information, remedial system performance, and current data to determine whether adjustments or changes in the remediation system are appropriate. The adaptive site management approach may be adjusted over the site's life cycle as new site information and technologies become available. This approach is particularly useful at complex sites where remediation is difficult and may require a long time, or where NCDEQ approves alternate groundwater standards for COIs, such as 4,000 µg/L for boron, pursuant to its authority under 15A NCAC 02L .0106(k). Duke Energy may request alternate standards for ash basin-related constituents, including boron, as allowed under 15A NCAC 02L .0106(k). Alternate standards are appropriate at the CSS given the lack of human health and ecological risks at the site. Factors included in this evaluation include:

- Potential to hinder use of alternative or contingency technologies later
- Suitability to later modifications or synergistic with other technologies
- Information that could be gained from technology implementation to improve the Site Conceptual Model and better inform future remediation decision-making
- Ability to adjust and optimize the technology based on performance data
- Suitability for implementation in a sequential remedial action strategy
- Flexibility to implement optimization without significant system modifications

6.6.12 Sustainability

In accordance with sustainability corporate governance documents integral to Duke Energy and guidance provided by the USEPA, analysis of the sustainability of the remedial alternatives proposed in this CAP Update was identified as an important element to be completed as part of remedy selection process described herein.

Sustainable site remediation projects maximize the environmental benefit of cleanup activities through reductions of the environmental footprint of selected remedies, while preserving the effectiveness of the cleanup measures.

The USEPA, along with ASTM International, developed the Standard Guide to Greener Cleanups – ASTM E2893, which was utilized during the evaluation process as part of the remedial alternative selection effort. ASTM E2893 describes a process to evaluate and implement cleanup activities in order to reduce the environmental footprint of remediation projects. Two primary approaches are described in the document: a qualitative Best Management Practices (BMP) process and quantitative evaluation. Quantitative evaluation was utilized for remedy selection in this CAP Update.

As stated in the ASTM standard, during the remedial selection process, "… the user considers how various remedial options may contribute to the environmental footprint. Conducting a quantitative evaluation at this phase of the remedial alternative selection process provides stakeholders with information to help identify environmental footprint reduction opportunities for all alternatives that are protective of human health and the environment, comply with applicable environmental regulations and guidance, and meet project objectives (ASTM, 2016)."

Each remedial alternative has been assessed using SiteWise™, a public domain tool for evaluating remediation projects based on the overall environmental footprint. SiteWise™ estimates collateral environmental impacts through several quantitative sustainability metrics. The output data from SiteWise™ that can be utilized for remedial alternative comparison includes greenhouse gases, energy usage, and criteria air pollutants (including sulfur oxides, oxides of nitrogen, and particulate matter), water use, and resource consumption. The assessment quantified impacts associated with activities expected to occur during the remedial alternative construction phase, system operations where applicable and long-term monitoring.

Two core elements of the USEPA's Greener Cleanup principles were not quantified through the use of the SiteWise™ tool, as part of the alternatives evaluation: water consumption and waste generation. The analysis tool is set up to quantify the footprint of municipal water use and the accompanying discharge of wastewater for treatment to a POTWs. The remediation activities proposed in the CAP Update do not use municipal water or discharge to a POTW, thereby making that input inapplicable for the calculation. Due to the difficulty of estimating reliable quantities of waste generated during construction the input was considered too uncertain to use as a criteria. These two elements were set aside as less-relevant to remedy selection for the purposes of this CAP Update than the other quantifiable data points available. For the quantitative evaluation of alternatives discussed here, the primary assessments for consideration during sustainability screening are CO2, NOx, SOx, PM10 and energy usage.

6.7 SA1 Detailed Analysis of Remedial Alternatives

Groundwater remediation Alternatives 1, 2 and 3 were formulated in **Section 6.5** using groundwater remediation technologies evaluated and retained for consideration in **Section 6.4**. The criterion for conducting detailed analysis of each groundwater remedial alternative are presented and explained in **Section 6.6**. The groundwater remediation alternatives formulated in **Section 6.5** will undergo detailed comparative analysis in the following subsections. A summary of the remediation alternative detailed analysis is also included in **Appendix M**.

6.7.1 Remedial Alternative 1 – Monitored Natural Attenuation

6.7.1.1 Protection of Human Health and the Environment

(CAP Content Section 6.D.a.iv.1)

There is no measurable difference between evaluated Site risks and risks indicated by background concentrations; therefore, no material increases in risks to human health related to the ash basin have been identified. The groundwater corrective action is being planned to address regulatory requirements. The risk assessment identified no current human health or ecological risk associated with groundwater downgradient of the AAB and ASA. Water supply wells are located upgradient of the AAB and ASA and municipal water connections have been provided to qualifying residences who selected this option. Surface water quality standards downgradient of the COI-affected groundwater are also met.

Based on the absence of receptors, it is anticipated that MNA would continue to be protective of human health and the environment because modeling results indicate COI concentrations will diminish with time. Natural attenuation mechanisms will reduce COI concentrations, and model predictions indicate that no existing water supply wells would be impacted.

6.7.1.2 Compliance with Applicable Regulations

(CAP Content Section 6.D.a.iv.2)

MNA would comply with applicable regulations assuming the conditions provided in 02L can be achieved. State and federal groundwater regulations allow for MNA as an acceptable remediation program if regulatory requirements are met. The following are the applicable 02L regulations:

(l) Any person required to implement an approved corrective action plan for a non-permitted site pursuant to this Rule may request that the Director approve such a plan based upon natural processes of degradation and attenuation of contaminants. A request submitted to the Director under this Paragraph shall include a description of site specific conditions, including written documentation of projected groundwater use in the contaminated area based on current state or local government planning efforts; the technical basis for the request; and any other information requested by the Director to thoroughly evaluate the request. In addition, the person making the request must demonstrate to the satisfaction of the Director: (1) that all sources of contamination and free product have been removed or controlled pursuant to Paragraph (f) of this Rule; (2) that the contaminant has the capacity to degrade or attenuate under the site-specific conditions; (3) that the time and direction of contaminant travel can be predicted with reasonable certainty; (4) that contaminant migration will not result in any violation of applicable groundwater standards at any existing or foreseeable receptor; (5) that contaminants have not and will not migrate onto adjacent properties, or that: (A) such properties are served by an existing public water supply system dependent on surface waters or hydraulically isolated groundwater, or (B) the owners of such properties have consented in writing to the request; (6) that, if the contaminant plume is expected to intercept surface waters, the groundwater discharge will not possess contaminant concentrations that would result in violations of standards for surface waters contained in 15A NCAC 2B .0200; (7) that the person making

the request will put in place a groundwater monitoring program sufficient to track the degradation and attenuation of contaminants and contaminant by-products within and down gradient of the plume and to detect contaminants and contaminant by-products prior to their reaching any existing or foreseeable receptor at least one year's time of travel upgradient of the receptor and no greater than the distance the groundwater at the contaminated site is predicted to travel in five years; (8) that all necessary access agreements needed to monitor groundwater quality pursuant to Subparagraph (7) of this Paragraph have been or can be obtained; (9) that public notice of the request has been provided in accordance with Rule .0114(b) of this Section; and (10) that the proposed corrective action plan would be consistent with all other environmental laws.

Appendix I includes a detailed evaluation of the applicability of Alternative 1: MNA as a remedial alternative for the Site.

6.7.1.3 Long-Term Effectiveness and Permanence

(CAP Content Section 6.D.a.iv.3)

MNA would be an effective long-term technology, assuming source control and institutional controls (such as an RS designation) for the affected area. Natural attenuation mechanisms are understood and have been documented (**Appendix I**). Once equilibrium conditions of COI concentrations less than 02L standards are achieved, it is unlikely that the concentrations would increase.

Implementation of MNA will not result in increased residual risk as current conditions and predicted conditions do not indicate unacceptable risk to human health or environment. Additionally, Duke Energy connected 70 water supply users to the municipal water supply within a half-mile of the ash basin compliance boundaries in accordance with G.S. Section 130A-309.211(c1). Furthermore, institutional controls (provided by the RS) to limit access to groundwater use are proposed.

The adequacy and reliability of this approach would be documented with the implementation and maintenance of an effectiveness monitoring program to identify variations from the expected conditions. If factors that are not known at this time were to affect the attenuation process in the future, alternative measures could be taken. Monitoring will be in place to evaluate progress and allow sufficient time to implement changes.

6.7.1.4 Reduction of Toxicity, Mobility and Volume

(CAP Content Section 6.D.a.iv.4)

While the COIs are inorganic and cannot be destroyed, they exist in the aquifer as molecules that interact with the natural components of the matrices to prevent mobility and toxicity to receptors. MNA can reduce aqueous concentrations while increasing solid phase concentrations and can therefore, under certain geochemical conditions, reduce COI plume concentrations, volume, and mass. There are no treatment or recycling processes involved with MNA as well as no residuals.

6.7.1.5 Short-Term Effectiveness

(CAP Content Section 6.D.a.iv.5)

The stability and limited areal extent of the COI plume, along with the lack of unacceptable current risk to human and ecological receptors indicates current conditions are protective. Therefore, the technology is effective in the short-term.

There are 160 monitoring wells installed associated with the AAB and ASA. Although some within the immediate area of the basin will have to be abandoned as part of closure, monitoring wells along the waste boundary and at select downgradient areas will remain to monitor natural attenuation in the short-term.

6.7.1.6 Technical and Logistical Feasibility

(CAP Content Section 6.D.a.iv.6)

There are 160 monitoring wells installed associated with the AAB and ASA. A majority of the wells have dedicated sampling equipment and an approved interim monitoring plan is in place. A subset of these monitoring wells could be immediately used for MNA purposes. Therefore, the technology could be implemented easily and immediately. Other than the abandonment of select wells within the ash basin from closure and potential installation of additional monitoring wells, no construction is required to implement this option. Implementation of an MNA program is a well-defined process, with established requirements for sampling, laboratory analysis, reporting, performance review, and communication of findings to stakeholders.

6.7.1.7 Time Required to Initiate and Implement Corrective Action Technologies and Alternatives

(CAP Content Section 6.D.a.iv.7)

The time required for implementation of an MNA program could be as immediate as approval of the approach since an extensive monitoring well network already exists. Procedures for collection, analysis, and communication of results are also established and currently in place.

6.7.1.8 Time Required to Meet Remediation Goals

(CAP Content Section 6.D.a.iv.8)

The flow and transport model predicts that the concentrations of COIs in groundwater would meet the 02L standards at the compliance boundary north of the AAB at the ASA in approximately 400 years after ash basin closure. This estimate is based on boron reaching a concentration of 700 µg/L at the compliance boundary.

6.7.1.9 Cost

(CAP Content Section 6.D.a.iv.9)

The Cliffside AAB and ASA have extensive groundwater monitoring well networks in place. MNA performance monitoring would utilize a subset of existing wells on Site with additional wells installed within the ash basin footprint, post-closure. Procedures for collection, analysis, and communication of results are also established and currently in place. Because there would be less required materials and therefore a smaller capital cost and annual cost, the costs of Alternative 1 would be comparatively less, when compared to Alternatives 2 and 3. Despite this, the significantly longer lifetime of the Alternative 1 system operating indicates that life cycle costs could be significant.

6.7.1.10 Community Acceptance

(CAP Content Section 6.D.a.iv.10)

It is expected that there will be positive and negative sentiment about implementation of an MNA program. No off-Site landowners are affected. The affected groundwater is located on property owned by Duke Energy which is anticipated to have institutional controls. However, until the final corrective action is developed and comments are received and reviewed, assessment of community acceptance will not be fully informed.

MNA as a remedial alternative would be protective of human health and the environment. Consistent with the USEPA Office of Solid Waste and

Emergency Response (OSWER) Directive 9200.4-17P (April 21, 1999) the use of MNA "does not imply that EPA or the responsible parties are 'walking away' from cleanup or financial responsibility at a site."

6.7.1.11 Adaptive Site Management and Remediation Considerations

MNA is an adaptable process and can be an effective tool in identifying the need for alternative approaches if unexpected changes in Site conditions occur. An MNA program would not hinder or preempt the use of other remedial approaches in the future if conditions change. In fact, an effectiveness monitoring program is an essential part of any future remedial strategy. An MNA effectiveness monitoring program would provide information about changing Site conditions during and after source control measures.

6.7.1.12 Sustainability

Sustainability analysis was completed as described in **Section 6.6**. The footprint was quantified based on energy use and associated emissions, during the construction phase (e.g., well installations) and groundwater monitoring activities (e.g., transportation). The results of the footprint calculations for MNA are summarized in **Table 6-14**. A summary of sustainability calculations for Alternative 1 can be found in **Appendix L**.

The footprint of the MNA alternative is the least energy-intensive of the remedial alternatives being considered, providing reduced, comparative footprint metrics in overall energy use and across all air emission parameters. The MNA alternative utilizes significantly fewer resources during construction and throughout the cleanup timeframe when compared to the other alternatives.

6.7.2 Groundwater Remedial Alternative 2: Groundwater Extraction, Clean Water Infiltration in Wells and Treatment

6.7.2.1 Protection of Human Health and the Environment

(CAP Content Section 6.D.a.iv.1)

There is no measurable difference between evaluated Site risks and risks indicated by background concentrations; therefore, no material increases in risks to human health related to the ash basin have been identified. The groundwater corrective action is being planned to address regulatory

requirements. The risk assessment identified no current human health or ecological risk associated with groundwater downgradient of the AAB and ASA. Water supply wells are located upgradient of the ash basin and municipal water connections have been provided to those who selected this option. Surface water quality standards downgradient of the COI-affected groundwater are also met.

Groundwater Remedial Alternative 2 would be used to achieve further reductions in potential risks by:

- Promptly implementing groundwater remedial measures and begin remediating groundwater underlying and downgradient of the ASA before AAB source control measures are fully implemented.
- Ultimately achieving compliance with applicable groundwater regulations including 02L standards.
- Permanently reducing the mass and overall concentrations of coal ash constituents in Site groundwater.

Predictive flow and transport modeling indicate that the 02L standard for boron could be achieved in approximately five years (for closure-in-place) to eight years (for closure-by-excavation).

6.7.2.2 Compliance with Applicable Regulations

(CAP Content Section 6.D.a.iv.2)

Alternative 2 can be implemented in compliance with applicable laws and regulations. Those regulations would include: CAMA, groundwater standards, clean water infiltration and extraction well installation and permitting.

As stated in the previous subsection, Alternative 2 would be protective of human health and the environment. Alternative 2 would satisfy groundwater protection standards (GWPS). Waste generated by Alternative 2 would include IDW (*e.g.,* soil cuttings, purge water) and extracted groundwater. IDW can be managed in compliance with applicable management standards.

Regulations pertaining to the management and disposal of extracted groundwater would have the greatest influence on the implementability of Alternative 2. No outfall listed in NPDES permit NC0005088 is currently

authorized to receive extracted groundwater. Consequently, NPDES permit NC0005088 must be modified before extracted groundwater can be discharged to the Broad River. The extracted groundwater would be piped over Suck Creek on an existing pipe rack to an existing sump near the wastewater treatment plant. The sump discharges to the Holding Basins. Holding Basin effluent is discharged to the CSS WWTP, which is a physical/chemical treatment system consisting of pH adjustment, coagulation and flocculation. Solids are removed from the wastewater using high-rate clarifiers and polishing filters, if necessary. Wastewater is discharged to the Broad River through NPDES Outfall 005.

WWTP operator certification requirements are being met for ongoing WWTP operations. Duke Energy would continue to satisfy WWTP operator certification requirements going forward.

Alternative 2 would be conducted with the goal of achieving 02L groundwater standards (15A NCAC 02L) beyond the compliance boundary. A contingency groundwater remedy would be implemented if Alternative 2 is later determined to be ineffective.

Samples of the Broad River surface water immediately downgradient of the AAB and the ASA have been sampled and the results comply with applicable 15A NCAC 02B standards (**Appendix J**). Given the amount of dilution provided by surface water in the Broad River, there is no reason to expect that 15A NCAC 02B standards would not be satisfied in the future if Alternative 2 were implemented.

Monitoring well and groundwater extraction well installations must satisfy applicable requirements of NCAC Title 15A Subchapter 2C, Well Construction Standards, including 15A NCAC 02C .0108 (*Standards of Construction*) and 15A NCAC 02C .0112 (*Well Maintenance*).

6.7.2.3 Long-Term Effectiveness and Permanence

(CAP Content Section 6.D.a.iv.3)

Flow and transport modeling indicates that implementation of Groundwater Remedial Alternative 2, in conjunction with anticipated source control measures, would achieve 02L compliance for boron within approximately five years (for closure-in-place) to eight years (for closure-by-excavation) following installation and startup of the groundwater remediation system. Furthermore, the mass of boron and other

groundwater COIs would be permanently reduced at the conclusion of groundwater extraction. Natural attenuation mechanisms would further reduce COI concentrations after the shutdown of the groundwater extraction system.

Coal ash constituents within the compliance boundary do not pose a risk to human health since there are no complete routes for potential exposure. Construction of water supply wells is prohibited within the compliance boundary of an individually permitted disposal system (15A NCAC 02L .0107 (d)). Groundwater monitoring would continue at the compliance boundary in accordance with 02L requirements.

Potential risk to human health and the environment is within acceptable levels prescribed by the USEPA. Potential risk to human health and the environment is expected to decrease over time after implementation of Alternative 2. Institutional controls, including 15A NCAC 02L .0107(d), should restrict activities that could result in exposure to groundwater COIs.

NPDES discharge requirements are protective of human health and the environment. Extracted groundwater would be pumped to the Holding Basins and discharged through NPDES Outfall 005. The discharge would comply with applicable discharge requirements and would not pose an unacceptable risk to human health and the environment.

6.7.2.4 Reduction of Toxicity, Mobility and Volume

(CAP Content Section 6.D.a.iv.4)

Cliffside Site groundwater COIs are inorganic. With the exception of radioactive constituents such as radium and uranium, elemental components of inorganic minerals and molecules cannot be destroyed, only transformed. For example, chromium in groundwater with a relatively high redox potential is predominantly trivalent chromium (Cr^{+3}). However, chromium in groundwater having a relatively low redox potential is predominantly hexavalent chromium [Cr(VI)]. Hexavalent chromium is more soluble, more mobile, and more toxic than trivalent chromium. Methods to treat chromium in groundwater may make the chromium in groundwater less concentrated, less mobile, less toxic, or may transfer chromium from groundwater to another media (e.g., surface water, sludge), but no treatment exists that can destroy chromium.

The greatest reductions in groundwater COI toxicity, mobility, and volume achieved under Alternative 2 would occur as a consequence of groundwater extraction. Consequently, constituents most amenable to groundwater extraction are those that are conservative/non-reactive (*e.g.*, boron, lithium, sulfate, and TDS) followed by variably reactive constituents (*e.g.*, cobalt, iron, and manganese). Groundwater extraction would have the least effect on non-conservative/reactive constituents (*e.g.*, chromium, strontium, and vanadium).

Groundwater extraction would permanently reduce the mass COIs in Site groundwater whereas groundwater infiltration would dilute COI concentrations in groundwater. Groundwater extracted under Alternative 2 would be discharged through NPDES permitted Outfall 005. COIs removed as consequence of treatment would be managed as a solid waste. The concentration of constituents in the NPDES discharge would be maintained at levels that do not pose an unacceptable risk to human health or the environment.

6.7.2.5 Short-Term Effectiveness

(CAP Content Section 6.D.a.iv.5)

Implementation of Groundwater Remedial Alternative 2 would be protective of private residences and communities near CSS. The installation of groundwater extraction and infiltration wells and associated infrastructure would not create dust or air emissions during implementation or system operation. Duke Energy has ample means of dust suppression in the unlikely event of dust generation.

Installation of groundwater monitoring wells, groundwater extraction wells, groundwater infiltration wells, discharge lines, collection tanks and related infrastructure are straight forward and routine tasks that can be conducted safely. Groundwater COIs do not pose an unacceptable risk to potential receptors under conservative risk assessment exposure scenarios (**Appendix E**). Regardless, remediation worker exposure to COIs in groundwater should be minimal since they would be wearing PPE if there is the potential for exposure to COIs in ash, soil, or groundwater.

Other potential environmental impacts that could occur during implementation of Groundwater Remedial Alternative 2 is accidental releases of vehicle fluids (*e.g.,* gasoline, oil, hydraulic fluid) or unearthed soils into the Broad River. Duke Energy diligently requires contractors to

prepare and adhere to erosion and sediment control plans when conducting intrusive work activities. Likewise, Duke Energy strictly enforces secondary containment be placed under stationary heavy equipment (*e.g.,* drill rig) to capture and manage an accidental release of fluids.

Extracted groundwater would be disposed via NPDES discharge. Compliance with NPDES Permit NC0005088 should make discharges of extracted groundwater protective of potential onsite and offsite receptors.

Hydraulic capture of groundwater near the groundwater extraction wells would occur soon after the groundwater extraction system is placed into service. Also, the advancement of the boron plume beyond the 500-foot compliance boundary would be mitigated as long as hydraulic capture is sustained.

6.7.2.6 Technical and Logistical Feasibility

(CAP Content Section 6.D.a.iv.6/7)

Groundwater Remediation Alternative 2 is technically feasible and readily implementable. Construction and partial implementation of Alternative 2 can be implemented before ash is excavated from the ASA. Alternative 2 cannot be fully implemented until ash is excavated from the ASA and the area of excavation is backfilled and graded. In contrast, source control measures specific to the AAB would have no bearing on the timetable for implementing Alternative 2.

Construction of Alternative 2 would include:

- Relocation of at least one transmission tower that currently exists within the ASA
- Installation of 23 vertical groundwater extraction wells
- Installation of 46 vertical groundwater infiltration wells
- Installation of one horizontal groundwater infiltration well
- Installation of groundwater extraction pumps and discharge piping
- Installation of wellhead valves and instrumentation
- Construction of groundwater extraction network discharge manifold
- Distribution of electrical service to pumps

- Modify NPDES Permit NC0005088 to include the discharge of extracted groundwater to Outfall 005
- Construction of an equalization tank with transfer pumps
- Construction of system to transfer clean infiltration water from the FGD building to the infiltration wells
- Construct discharge piping to a sump near the wastewater treatment plant which would route the extracted groundwater to the Holding Basins where it would be treated and discharged through Outfall 005
- Design and construction of groundwater extraction system telemetry

Relocation of the transmission tower is challenging and would take several months of planning and construction. Duke has the capability and support of specialty contractors to relocate the transmission tower. Otherwise, all other tasks pertaining to groundwater remediation are routine with respect to the maturity of technologies used, material requirements, material availability, and the availability of specialized services (*e.g.,* licensed drillers, electricians) and labor. Groundwater extraction wells constructed within the 500-foot compliance boundary should not pose any risk to the integrity of the AAB. However, Duke Energy and NCDEQ dam safety should be consulted before finalizing system design. Considerations for dam safety and permitting would be built within the design and construction schedule.

No permanent aboveground structures including flush mounted groundwater extraction and infiltration wells will be constructed within the transmission right-of-way. Subsurface installations must have the capacity to support mobile equipment weighing 80,000 pounds (SynTerra, 2019g).

Implementation of Groundwater Remedial Alternative 2 can be achieved administratively. However, NPDES Permit NC0005088 must first be modified because no outfall listed in the permit is currently authorized to discharge extracted groundwater. If extracted groundwater would be discharged through an existing NPDES permitted outfall, Outfall 005 is the most likely outfall that might be used. Outfall 005 is located at the Holding Basins. Other permits are not anticipated other than those associated with existing permits (*e.g.,* water withdrawal). When warranted, modifications to existing permits should be a straightforward process.

An EMP would be developed to assess the effectiveness of Alternative 2 going forward.

6.7.2.7 Time Required to Initiate and Implement Corrective Action Technologies and Alternatives

(CAP Content Section 6.D.a.iv.7)

Groundwater Remedial Alternative 2 can be implemented before AAB source control measures are initiated. However, only portions of the groundwater extraction system could be implemented before excavation and removal of ash from the ASA is completed and the final grade is constructed. The final grade following ASA excavation activities is included in **Figure 6-32a**.

Pumping tests would be conducted to validate groundwater yields predicted by flow and transport modeling. Pumping test results would be used to calibrate predictive modeling and adjustments would be made to the groundwater extraction system design, if warranted. Design of the groundwater extraction system proposed under Alternative 2 would be finalized afterwards.

Construction and operation of the full-scale groundwater remediation system could be accomplished within 36 months after NCDEQ approval of the CAP. Prerequisites that could cause significant delays before full-scale operation of Alternative 2 are relocation of the transmission tower constructed within the ASA, excavation of ash from the ASA, and final grading of the ASA.

6.7.2.8 Time Required To Meet Remediation Goals

(CAP Content Section 6.D.a.iv.8)

Groundwater extraction under Alternative 2 can be implemented before source control measures addressing the AAB are initiated. However, Alternative 2 cannot be fully implemented until a transmission tower constructed within the ASA is relocated, coal ash in the ASA is relocated, and construction of the ASA final grade is complete.

Time to achieve the remediation goal of reducing the concentration of boron beyond the compliance boundary to levels less than the 02L standard was estimated by predictive flow and transport modeling to be approximately five years (for closure-in-place) to eight years (for closure-by-excavation)

following full-scale implementation and startup of the groundwater remediation system.

6.7.2.9 Cost

(CAP Content Section 6.D.a.iv.9)

Costs to implement the Cliffside AAB groundwater extraction and infiltration well system would include capital costs for design and implementation. Implementation would include installation of groundwater monitoring wells, groundwater extraction wells, groundwater discharge piping, infiltration piping, telemetry system, and other system components. Operation and Maintenance (O&M) costs would include groundwater sampling, groundwater sample analysis, periodic reporting, redevelopment and replacement of some wells, submersible pumps and other components on an annual basis.

Cliffside AAB Groundwater Remedial Alternative 2 capital costs would be significantly higher than capital costs associated with AAB Groundwater Remedial Alternative 1, but would be comparable to capital costs associated with AAB Groundwater Remedial Alternative 3. Similarly, long term O&M costs for Groundwater Remedial Alternative 2 would be higher than long term O&M costs associated with AAB Groundwater Remedial Alternative 1, but would be comparable to long term O&M costs associated with AAB Groundwater

6.7.2.10 Community Acceptance

(CAP Content Section 6.D.a.iv.10)

It is likely that community stakeholders are sufficiently familiar with the concept of groundwater extraction that they would not have significant concerns pertaining to the installation or operation of the groundwater extraction system. Similarly, mitigating transport of untreated groundwater to the Broad River should be well received by some community stakeholders.

It is possible that some community stakeholders would have concerns with potential exposure to discharged groundwater via NPDES permit. Assurances that any means of groundwater disposal would be permitted and monitored by NCDEQ should alleviate stakeholder concerns. Stakeholder concerns should be further alleviated when they know that extracted groundwater might undergo treatment and that constituent

concentrations in the discharged groundwater would be within permitted limits.

It is anticipated that groundwater extraction and treatment would generally receive more positive community acceptance than MNA under Alternative 1 since it involves more active measures to attempt physical extraction of COI mass from groundwater. This alternative would likely be perceived as more robust than MNA in addressing groundwater impacts even if modeling predicts essentially the same effects between MNA and groundwater extraction.

6.7.2.11 Adaptive Site Management and Remediation Considerations

After full-scale implementation, it would be important to evaluate the performance of Groundwater Remedial Alternative 2. The following are potential metrics and related questions regarding the critical evaluation of Alternative 2 performance:

- Groundwater extraction rates – How do actual groundwater extraction rates compare to predicted extraction rates?
- Groundwater extraction well capture zones - How do actual capture zones compare to predicted capture zones?
- Groundwater infiltration rates – How do actual groundwater infiltration rates compare to predicted infiltration rates?
- Conservative constituent trends – Are boron concentrations and the concentrations of other conservative constituents trending downward?
- Predictive modeling – How have modeling results changed since model refinement using post-implementation data?
- Constituent mass removal – Are constituent concentrations in extracted groundwater sufficient to achieve predicted mass removal?
- Performance - How does the performance of Alternative 2 change before, during, and after AAB source control measures are implemented?
- Remediation timeframe - Has the predicted time frame for achieving groundwater remediation goals changed?

A routine program of extraction and infiltration well performance monitoring and well rehabilitation/redevelopment would be implemented during system operation to maintain and optimize performance.

Groundwater Remedial Alternative 2 is readily amenable to modifications if it is later determined that operational changes could result in greater efficiencies or shorter remediation timeframes. For example pumping tests, conducted prior to full-scale implementation of Alternative 2, might provide information that can be used to optimize extraction system design. Similarly, taking certain extraction wells out of service because they are no longer necessary could be implemented in short order without significant impact on remaining operations.

6.7.2.12 Sustainability

Sustainability analysis was completed as described in **Section 6.6**. The environmental footprint was quantified based on energy use and associated emissions, during the construction phase (e.g., material quantities and transportation), active remediation activities (e.g., groundwater pumping and treatment) and groundwater monitoring activities (e.g., transportation). The results of the environmental footprint calculations for Alternative 2 are summarized in **Table 6-14**. A summary of sustainability calculations for Alternative 2 can be found in **Appendix L**.

The environmental footprint of Alternative 2 is the most energy-intensive of the remedial alternatives being considered. Alternative 1 (MNA) requires significantly less materials and energy than Alternative 2 and is therefore characterized by a dramatically smaller environmental footprint. Alternative 2 presents higher, but generally comparable, environmental footprint metrics when measured against Alternative 3. Alternative 2 utilizes an infiltration gallery which produces more air emissions compared to Alternative 3, generating a higher material-related environmental footprint for the construction phase. The analysis indicates operating the infiltration gallery to be more energy-intensive in Alternative 2 than the infiltration well network Alternative 3.

6.7.3 Groundwater Remedial Alternative 3: Groundwater Extraction, Clean Water Infiltration Wells and Galleries and Treatment

A detailed description of groundwater remedial Alternative 3 is presented in **Section 6.5.3**. Detailed analysis of groundwater remedial Alternative 3 is presented in the following subsections.

6.7.3.1 Protection of Human Health and the Environment

(CAP Content Section 6.D.a.iv.1)

There is no measurable difference between evaluated Site risks and risks indicated by background concentrations; therefore, no material increases in risks to human health related to the AAB or ASA have been identified. The groundwater corrective action is being planned to address regulatory requirements. The risk assessment identified no current human health or ecological risk associated with groundwater downgradient of the AAB and ASA. Water supply wells are located upgradient of the ash basin and ASA and municipal water connections have been provided qualified properties who selected this option. Surface water quality standards downgradient of the COI-affected plume are also met.

Groundwater Remedial Alternative 3 would be to achieve further reductions in potential risks by:

- Promptly implementing groundwater remedial measures and begin remediating groundwater underlying and downgradient of the ASA before AAB source control measures are fully implemented.
- Ultimately achieving compliance with applicable groundwater regulations including NCAC 02L standards.
- Permanently reducing the mass and overall concentrations of coal ash constituents in Site groundwater.

Predictive flow and transport modeling indicate that the 02L standard for boron would be achieved within approximately five years (for closure-in-place) to eight years (for closure-by-excavation) following full-scale implementation and startup of the groundwater remediation system. Consequently, Groundwater Remedial Alternative 3 would achieve about the same degree of protection for human health and the environment as Groundwater Remedial Alternative 2 (**Section 6.5.2**). Alternatives 2 and 3

would achieve a slightly higher degree of protection for human health and the environment in a much shorter time frame when compared to groundwater remedial Alternative 1, MNA (**Section 6.5.1**).

6.7.3.2 Compliance with Applicable Regulations

(CAP Content Section 6.D.a.iv.2)

Alternative 3 can be fully implemented in compliance with all applicable laws and regulations. Those regulations would include: CAMA, groundwater standards, and extraction well installation and permitting**.**

As stated in the previous subsection, Alternative 3 would be protective of human health and the environment. Alternative 3 would eventually satisfy GWPS while being protective of human health and the environment going forward. Waste generated by Alternative 3 would include IDW (*e.g.,* soil cuttings, purge water) and extracted groundwater. IDW can be managed in compliance with applicable management standards.

Regulations pertaining to the management and disposal of extracted groundwater would have the greatest influence on the implementability of Alternative 3. No outfall listed in NPDES permit NC0005088 is currently authorized to receive extracted groundwater. Consequently, NPDES permit NC0005088 must be modified before extracted groundwater can be discharged to the Broad River. The extracted groundwater would be piped over Suck Creek on an existing pipe rack to an existing sump near the wastewater treatment plant. The sump discharges to the Holding Basins. Holding Basin effluent is discharged to the Cliffside WWTP, which is a physical/chemical treatment system consisting of pH adjustment, coagulation and flocculation. Solids are removed from the wastewater using high-rate clarifiers and polishing filters, if necessary. Wastewater is discharged to the Broad River through NPDES Outfall 005.

WWTP operator certification requirements are being met for ongoing wastewater treatment. Duke Energy would continue to satisfy WWTP operator certification requirements going forward.

Alternative 3 would be conducted with the goal of achieving 02L groundwater standards (15A NCAC 02L) beyond the compliance boundary. A contingency groundwater remedy would be implemented if Alternative 3 is later determined to be ineffective.

Samples of the Broad River surface water immediately downgradient of the AAB and the ASA have been sampled and analyzed and results comply with applicable 15A NCAC 02B standards (**Appendix J**). Given the amount of dilution provided by surface water in the Broad River, there is no reason to expect that 15A NCAC 02B standards would not be satisfied in the future if Alternative 3 were implemented.

Monitoring well, groundwater extraction well, and pH adjustment well installations must satisfy applicable requirements of NCAC Title 15A Subchapter 2C, Well Construction Standards, including 15A NCAC 02C .0108 (*Standards of Construction*) and 15A NCAC 02C .0112 (*Well Maintenance*).

Underground injection of water must comply with 15A NCAC 02C .0225 (*Groundwater Remediation Wells*). Addition of a chemical amendment to the injection water is not anticipated at this time.

6.7.3.3 Long-Term Effectiveness and Permanence

(CAP Content Section 6.D.a.iv.3)

Flow and transport modeling indicates that implementation of Groundwater Remedial Alternative 3, in conjunction with anticipated source control measures, would achieve 02L compliance for boron within approximately five years (for closure-in-place) to eight years (for closure-by-excavation) following installation and startup of the groundwater remediation system. Furthermore, the mass of boron and other groundwater COIs would be permanently reduced at the conclusion of groundwater extraction. Natural attenuation mechanisms would further reduce COI concentrations after the shutdown of the groundwater extraction system.

Coal ash constituents within the compliance boundary do not pose a risk to human health since there are no complete routes for potential exposure. Construction of water supply wells is prohibited within the compliance boundary of an individually permitted disposal system (15A NCAC 02L .0107 (d)). Groundwater monitoring would continue at the compliance boundary in accordance with 02L requirements.

Potential risk to human health and the environment is within acceptable levels prescribed by the USEPA. Potential risk to human health and the environment is expected to decrease over time after implementation of

Alternative 3. Institutional controls, including 15A NCAC 02L .0107(d), should restrict activities that could result in exposure to groundwater COIs.

NPDES discharge requirements are protective of human health and the environment. Extracted groundwater pumped to the Holding Basins, treated and discharged through NPDES Outfall 005. The discharge would comply with applicable discharge requirements and would not pose an unacceptable risk to human health and the environment.

NPDES discharge requirements are protective of human health and the environment. Extracted groundwater discharged via NPDES Outfall 005 would comply with applicable discharge requirements and would not pose an unacceptable risk to human health and the environment.

6.7.3.4 Reduction of Toxicity, Mobility, and Volume

(CAP Content Section 6.D.a.iv.4)

Cliffside groundwater COIs are inorganic. With the exception of radioactive constituents such as radium and uranium, elemental components of inorganic minerals and molecules cannot be destroyed, only transformed. For example, chromium in groundwater with a relatively high redox potential is predominantly trivalent chromium (Cr^{+3}). However, chromium in groundwater having a relatively low redox potential is predominantly hexavalent chromium [Cr(VI)]. Hexavalent chromium is more soluble, more mobile, and more toxic than trivalent chromium. Methods to treat chromium in groundwater may make the chromium in groundwater less concentrated, less mobile, less toxic, or may transfer chromium from groundwater to another media (e.g., surface water, sludge), but no treatment exists that can destroy chromium.

The greatest reductions in groundwater COI toxicity, mobility, and volume achieved under Alternative 3 would occur as a consequence of groundwater extraction. Consequently, constituents most amenable to groundwater extraction are those that are conservative/non-reactive (*e.g.*, boron, lithium, and sulfate) followed by variably reactive constituents (*e.g.*, cobalt, iron, and manganese). Groundwater extraction would have the least effect on non-conservative/reactive constituents (*e.g.*, chromium, strontium, and vanadium).

Groundwater extraction would permanently reduce the mass COIs in Site groundwater whereas groundwater infiltration wells and the infiltration

gallery would dilute COI concentrations in groundwater. Groundwater extracted under Alternative 3 would be transferred to the Holding Basins and discharged through NPDES Permited Outfall 005. COIs removed as consequence of treatment would be managed as a solid waste. The concentration of constituents in the NPDES discharge would be maintained at levels that do not pose an unacceptable risk to human health or the environment.

6.7.3.5 Short-Term Effectiveness

(CAP Content Section 6.D.a.iv.5)

Implementation of Groundwater Remedial Alternative 3 would be protective of private residences and communities near CSS. The installation of groundwater extraction wells and associated infrastructure should create no significant dust emissions during implementation or during system operation. Duke Energy would have ample means of dust suppression in the unlikely event that dust generation becomes an issue.

Installation of groundwater monitoring wells, groundwater extraction wells, groundwater infiltration wells, infiltration gallery, discharge lines, collection tanks and related infrastructure are straight forward and routine tasks that can be conducted safely. Groundwater COIs do not pose an unacceptable risk to potential receptors under conservative risk assessment exposure scenarios (**Appendix E**). Regardless, remediation worker exposure to COIs in groundwater should be minimal since they would be wearing PPE if there is the potential for exposure to COIs in ash, soil, or groundwater.

Other potential environmental impacts that could occur during the implementation of Groundwater Remedial Alternative 3 is accidental releases of vehicle fluids (*e.g.,* gasoline, oil, hydraulic fluid) or unearthed soils into the Broad River. Duke Energy diligently requires contractors to prepare and adhere to erosion and sediment control plans when conducting intrusive work activities. Likewise, Duke Energy strictly enforces the requirement for secondary containment to be placed under stationary heavy equipment (*e.g.,* drill rig) to capture and manage an accidental release of fluids.

Extracted groundwater would be disposed of via NPDES discharge. Compliance with NPDES Permit NC0005088 should make discharges of extracted groundwater protective of potential onsite and offsite receptors.

Hydraulic capture of groundwater would occur as soon as the groundwater extraction system is placed into service. Advancement of the boron plume beyond the compliance boundary should be mitigated near groundwater extraction wells. Similarly, the infiltration of water should promote capture of conservative non-reactive COIs.

6.7.3.6 Technical and Logistical Feasibility

(CAP Content Section 6.D.a.iv.6)

Groundwater Remediation Alternative 3 is not readily implementable. Plans for the final grade of the ASA indicate an approximate 5 to 1 slope following complete ash removal (**Figure 6-32a**). Slope stability would be a concern if an effective 6.5 acre infiltration gallery were constructed over the entirety of the ASA. In addition, construction of an effective infiltration gallery would be difficult in areas where bedrock is shallow relative to the final grade.

Another concern associated with construction of the Groundwater Remediation Alternative 3 infiltration gallery is that the northwest corner of the infiltration gallery would be within the transmission line right-of-way. Subsurface installations must have the capacity to support 80,000-pound mobile equipment (SynTerra, 2019g). Design of a sloped infiltration gallery capable of supporting 80,000 pounds would require significant armoring that would likely render that portion of the infiltration gallery within the transmission line right-of-way ineffective.

6.7.3.7 Time Required to Initiate and Implement Corrective Action Technologies and Alternatives

(CAP Content Section 6.D.a.iv.7)

Groundwater Remedial Alternative 3 can be implemented before AAB source control measures are initiated. However, only portions of the groundwater extraction system could be implemented before excavation and removal of ash from the ASA is completed and the final grade is constructed. The final grade following ASA excavation activities is included in **Figure 6-32a**.

Pumping tests would be conducted to validate groundwater yields predicted by flow and transport modeling. Pumping test results would be used to calibrate predictive modeling and adjustments would be made to the groundwater extraction system design, if warranted. Design of the

groundwater extraction system proposed under Alternative 3 would be finalized afterwards.

Construction and operation of the full-scale groundwater remediation system could be accomplished within 36 months after NCDEQ approval of the CAP. Prerequisites that could cause significant delays before full-scale operation of Alternative 3 are relocation of the transmission tower constructed within the ASA, excavation of ash from the ASA, and final grading of the ASA.

6.7.3.8 Time Required to Meet Remediation Goals

(CAP Content Section 6.D.a.iv.8)

Groundwater extraction under Alternative 3 can be implemented before source control measures addressing the AAB are initiated. However, Alternative 3 cannot be fully implemented until a transmission tower constructed within the ASA is relocated, coal ash in the ASA is relocated, and construction of the ASA final grade is complete.

Time to achieve the remediation goal of reducing the concentration of boron beyond the compliance boundary to levels less than the 02L standard was estimated by predictive flow and transport modeling to be approximately five years (for closure-in-place) to eight years (for closure-by-excavation) following full-scale implementation and startup of the groundwater remediation system.

6.7.3.9 Cost

(CAP Content Section 6.D.a.iv.9)

Costs to implement the Cliffside AAB groundwater extraction, infiltration well, and infiltration gallery systems would include capital costs for design and implementation including installation of groundwater monitoring wells, groundwater extraction wells, groundwater discharge piping, infiltration piping, telemetry system, and other system components. O&M costs include groundwater sampling, groundwater sample analysis, periodic reporting, redevelopment and replacement of some wells, submersible pumps and other components on an annual basis.

Cliffside AAB Groundwater Remedial Alternative 3 capital costs would be significantly higher than capital costs associated with AAB Groundwater Remedial Alternative 1, but would be comparable to capital costs associated with AAB Groundwater Remedial Alternative 2. Similarly, long term O&M

costs for Groundwater Remedial Alternative 3 would be higher than long term O&M costs associated with AAB Groundwater Remedial Alternative 1, but would be comparable to long term O&M costs associated with AAB Groundwater Remedial Alternative 2. A detailed cost estimate for this Alternative is provided in **Appendix K**.

6.7.3.10 Community Acceptance

(CAP Content Section 6.D.a.iv.10)

It is expected that there will be positive and negative sentiment about implementation of a clean water infiltration well, infiltration gallery, and extraction system. No off-Site landowner is anticipated to be affected by COIs in groundwater. The remaining affected property is owned by Duke Energy. It is anticipated that the extracted groundwater would be discharged through a NPDES permitted outfall that flows to the Broad River and that the discharge would be treated as necessary to meet all permit limits. Until the final Site remedy is developed and comments are received and reviewed, assessment of community acceptance will not be fully known.

It is likely that community stakeholders are sufficiently familiar with the concept of groundwater extraction wells and groundwater extraction that they would not have significant concerns pertaining to the installation or operation of the groundwater extraction system. Similarly, mitigating transport of untreated groundwater to the Broad River should be well received. Stakeholders might not be as familiar with the infiltration of water into groundwater via infiltration wells. Potential concerns of stakeholders would likely be alleviated when they know that any infiltration would be permitted by NCDEQ and that the infiltration of water would not pose an unacceptable risk to human health or the environment.

It is possible that some community stakeholders would have concerns with potential exposure to discharged groundwater via NPDES permit. Assurances that any means of groundwater disposal would be permitted and monitored by NCDEQ should alleviate the concerns of many stakeholders. Stakeholder concerns should be further alleviated when they know that extracted groundwater would undergo pretreatment and that constituent concentrations in the discharged groundwater would be well below permitted limits.

6.7.3.11 Adaptive Site Management and Remediation Considerations

After full-scale implementation, it would be important to evaluate the performance of Groundwater Remedial Alternative 3. The following are potential metrics and related questions regarding the critical evaluation of Alternative 3 performance:

- Groundwater extraction rates – How do actual groundwater extraction rates compare to predicted extraction rates?
- Groundwater extraction well capture zones - How do actual capture zones compare to predicted capture zones?
- Groundwater infiltration rates – How do actual groundwater infiltration rates compare to predicted infiltration rates?
- Infiltration rates – How well does the infiltration gallery perform compared to predicted infiltration rates?
- Conservative constituent trends – Are boron concentrations and the concentrations of other conservative constituents trending downward?
- Predictive modeling – How have modeling results changed since model refinement using post-implementation data?
- Constituent mass removal – Are constituent concentrations in extracted groundwater sufficient to achieve predicted mass removal?
- Performance - How does Alternative 3 performance change before, during, and after AAB source control measures are implemented?
- Remediation timeframe - Has the predicted time frame for achieving groundwater remediation goals changed?

A routine program of extraction and infiltration well performance monitoring and well rehabilitation/redevelopment would be implemented during system operation to maintain and optimize performance.

Groundwater Remedial Alternative 3 is readily amenable to modifications if it is later determined that operational changes could result in greater efficiencies or shorter remediation timeframes. For example pumping tests, conducted prior to full-scale implementation of Alternative 3, might provide information that can be used to optimize extraction system design.

Similarly, taking certain extraction wells out of service because they are no longer necessary could be implemented in short order without significant impact on remaining operations.

6.7.3.12 Sustainability

Sustainability analysis was completed as described in **Section 6.6**. The environmental footprint was quantified based on energy use and associated emissions, during the construction phase (e.g., material quantities and transportation), active remediation activities (e.g., groundwater pumping and treatment) and groundwater monitoring activities (e.g., transportation). The results of the environmental footprint calculations for Alternative 3 are summarized in **Table 6-14**. A summary of sustainability calculations for Alternative 3 can be found in **Appendix L**.

The environmental footprint of Alternative 3 is the most energy-intensive of the remedial alternatives being considered. Alternative 1 (MNA) requires significantly less materials and energy than Alternative 2 and is therefore characterized by a dramatically smaller environmental footprint. Alternative 3 presents higher, but generally comparable, environmental footprint metrics when measured against Alternative 2. Alternative 3 utilizes an infiltration gallery which produces more air emissions compared to Alternative 2, generating a higher material-related environmental footprint for the construction phase. The analysis indicates operating the infiltration gallery to be more energy-intensive in Alternative 3 than the infiltration well network Alternative 2.

6.8 SA1 Proposed Groundwater Remedial Alternative Selected for Source Area 1

(CAP Content Section 6.E)

Groundwater Remediation **Alternative 2, Groundwater Extraction, Clean Water Infiltration in Wells and Treatment**, is the proposed groundwater remedial alternative. Alternative 2 is detailed in **Section 6.5.2**. Rationale and details pertaining to selection of the proposed groundwater remediation alternative are presented in the following subsections.

To comply with 15A NCAC 02L .0106(h), corrective action plans must contain the following items, which are included in the following subsection:

- A description of the proposed targeted corrective action and reasons for its selection.

- Specific plans, including engineering details where applicable, for restoring groundwater quality.
- A schedule for the implementation and operation of the proposed plan.
- A monitoring plan for evaluating the effectiveness of the proposed corrective action and the movement of the COI plume.

Each of these corrective action plan components are included in the following subsections.

6.8.1 Description of Proposed Remedial Alternative and Rationale for Selection

(CAP Content Section 6.E.a)

The preferred remedy for groundwater remediation, Alternative 2, is intended to provide the remedial technology that has demonstrated to provide the most effective means for restoration of groundwater quality at or beyond the compliance boundary by returning COIs to acceptable concentrations (02L/IMAC or background, whichever is greater), or as closely thereto as is economically and technologically feasible, consistent with 15A NCAC 02L. 0106(a), and to address 15A NCAC 02L .0106(j) *(CAP Content Section 6.E.a.i).*

Groundwater Remediation Alternatives 1, 2, and 3 are all protective of human health and the environment and would comply with applicable regulations. Alternative 3 is not considered further because it is not readily implementable due to stability concerns attributed to installation of a 6.5-acre infiltration gallery on a 5 to 1 slope. In addition, a portion of the infiltration system would be constructed within the transmission right-of-way where it would require extensive armoring to support a mobile equipment weighing 80,000-pounds (SynTerra, 2019g).

Groundwater Remedial Alternative 1, was not selected because MNA would not achieve Duke Energy's objective to complete remediation in the near to mid-term. Based on modeling results, Groundwater Remediation Alternative 2 would be capable of achieving 02L compliance for boron within approximately five years (for closure-in-place) to eight years (for closure-by-excavation).

Seep Corrective Action

As stated in the SOC, decanting of the AAB is expected to substantially reduce or eliminate the seeps. After completion of decanting, remaining seeps, (constructed and non-constructed), would to be characterized post-decanting for determination of disposition. After seep characterization, an amendment to the

CAP and/or Closure Plan(s), may be required to address remaining seeps. Duke Energy is aware of other currently non-dispositioned seeps around the ash basins, ASA, and other facilities onsite that might not be dispositioned by source control measures.

Non-dispositioned seeps, where monitoring conducted has indicated the presence of CCR affects (S-4, S-6, S-7, S-14, S-15, S-16, and S-21), are evaluated for whether corrective action would be anticipated for the seep location, and if so, potential corrective action technologies that would be feasible for the location. The evaluation considers seep location, effects of decanting on seep thus far, approximate average flow rate, and predicted change in water elevations after decanting is complete from flow and transport model simulations. Potential correction action strategies for seep locations are included in **Table 6-8** and discussed herein.

Decanting has been effective in reducing flow at seep S-14, S-15, S-16, and S-21. To date, water elevation of the ash basin has decreased by 28.9 feet, and is expected to continue decreasing until decanting is completed in March 2020. AAB further decanting and basin closure might cause seeps S-14, S-15, S-16, and S-21 to become dry in the future.

No corrective action is necessary for seeps S-4 or S-6 because these seeps are permitted NPDES outfalls (Outfall #104 and Outfall #106). These locations are part of the AAB waste water treatment system and included in the NPDES permit.

As of November 2019, decanting has been effective in reducing visible standing water at seeps S-14, S-15, S-16, and S-21. Further decanting and groundwater corrective action might cause the volume of water at the toe of the AAB upstream dam to reduce more or be eliminated. If seep S-14, S-15, S-16, and S-21 continue to have low flow conditions, and are not dispositioned after decanting is complete, phytoremediation technology could be implemented to capture and extract shallow groundwater to reduce or eliminate flow at these seep locations.

As of November 2019, seep S-7 has not shown any visual reduction in flow. This seep location is partially fed by a spring to the east containing water not affected from the AAB as well as COI-affected groundwater from the AAB. As decanting continues, the portion of flow from the AAB to this seep location is expected to be reduced or eliminated. If seep S-7 sustains near its average flow rate after AAB decanting is complete, it is expected that the COI concentrations are

reduced. Under these circumstances, the current proposed action for this area is continued monitoring.

In summary, further decanting, ash basin closure, and groundwater corrective action are expected to further reduce or eliminated flow at seeps S-7, S-14, S-15, S-16, and S-21. Besides source control measures (i.e. decanting and ash basin closure), no additional corrective action for these seeps is anticipated. No corrective action is necessary for the S-4 or S-6 locations because these locations are part of the ash basin waste water treatment system and covered under the NPDES permit. Final corrective action plans for seeps that are not dispositioned after completion of decanting will be proposed in an amendment to this CAP Update and submitted based on the schedule outlined in the SOC.

6.8.2 Design Details

(CAP Content Section 6.E.b)

Design of Groundwater Remediation Alternative 2 would require a pilot test (i.e., installation of a portion of the system) to facilitate refinement of the final system design. As a part of this, the predictive groundwater flow and transport model would be refined, if necessary to determine the final number and locations of groundwater extraction wells. The design process would culminate in the preparation of a design package suitable for bidding and construction.

Basic aspects of the recommended alternative call for installation of:

- 23 groundwater extraction wells and appurtenances
- 46 groundwater infiltration wells and appurtenances
- 1 horizontal groundwater infiltration well and appurtenances
- Well vault and wellhead piping, fittings, and instrumentation
- A system to control water level within each groundwater extraction well
- Groundwater extraction system discharge piping
- Groundwater infiltration system supply piping
- Electric power supply
- Groundwater remediation telemetry system

6.8.2.1 Process Flow Diagrams and Major Design Components

(CAP Content Section 6.E.b.i)

Conceptual process flow diagrams for the groundwater extraction and infiltration systems are provided in **Figures 6-33** and **6-34.** The layout of the groundwater extraction and infiltration systems are provided in **Figure 6-32a.** A summary of select well construction details for infiltration wells is provided in **Table 6-15** and for extraction wells in **Table 6-16**. The detailed design elements may be adjusted based on a final technical review.

Site Preparation (STEP 1 – CREATE ACCESS)

Installation of the proposed groundwater extraction and infiltration systems would require significant efforts in planning, designing, and execution of site preparation. However, with effective communications between the design, implementation and project management teams, successful construction of the system would be anticipated.

A certain level of flexibility regarding well placement is expected to be required due to site conditions encountered during construction. To prevent possible delays due to vetting field changes, predetermined well-location parameters (e.g., 50-foot placement radius) that ensure remediation system effectiveness should be established and included as part of the construction drawings.

Land disturbance associated with construction of Alternative 2 includes:

- Some tree and brushy vegetation removal in areas where groundwater extraction well or groundwater infiltration well installation locations would be outside construction activities to remove ash from the ASA
- Shallow digging associated with the installation of extraction well vaults
- Trenching for the installation of buried groundwater discharge piping, infiltration water supply piping, and electrical conduit

A soil erosion and sedimentation control plan would be prepared to obtain a soil erosion and sedimentation control permit.

Pilot Tests (STEP 2 – TO FINALIZE DESIGN)

A pilot test would involve installation of a portion of the planned system to evaluate how the system performs and to make initial progress towards remediation at the same time. The results of the pilot test would be used to refine and scale up the final design thereby maximizing the likelihood of successful operation in the field. Design elements would be adapted from the existing 10-well pumping system including any lessons learned from its operation. Clean water infiltration tests would be conducted to determine the rates of clean water infiltration wells screened within or across saprolite, transition zone, and bedrock flow zones.

Extraction pilot test wells will be screened within or across a flow zone similar to model simulations to the extent feasible.

Pilot test results will be used to:

- Determine site-specific well yields for each flow zone
- Validate predictive flow and transport modeling
- Refine calibration predictive flow and transport modeling as needed
- Confirm groundwater extraction well capture zones in the saprolite and transition zone flow zones beyond available data
- If warranted, make adjustments to the groundwater extraction system design
- If warranted, make design adjustments to conveyances for extracted groundwater
- If warranted, make design adjustments to the groundwater treatment system

Clean water infiltration test wells will be screened within or across flow zones, similar to model simulations to the extent feasible. Groundwater infiltration test results will be used to:

- Determine site-specific well infiltration rates
- Validate predictive flow and transport modeling and calibrate, if necessary
- If warranted, make adjustments to the clean water infiltration system design

- If warranted, make design adjustments to conveyances for clean water for infiltration
- If warranted, make design adjustments to the clean water infiltration treatment system

The extraction and clean water infiltration wells used for testing would be included in the final groundwater remediation system design.

Vertical Groundwater Extraction Well Design (STEP 3A – INSTALL WELLS)

(CAP Content Section 6.E.b.i)

The preliminary groundwater remediation system design includes installation of 23 groundwater extraction wells (**Figure 6-32a**). The proposed extraction wells would be installed in and around the ASA. However, no groundwater extraction wells would be installed within the transmission line right-of-way. The locations are based on predicted COI plume configuration, with the intent of capturing groundwater to create groundwater flow control, COI mass removal, and reduced migration of potentially mobile COIs. The predicted effects of the wells are defined in detail in flow and transport modeling results (**Appendix G**).

Groundwater extraction wells would be completed in the saprolite and transition zones with total well depths ranging from 27 ft. bgs to 133 ft. bgs. All groundwater extraction wells would be installed by a North Carolina licensed well driller in accordance with North Carolina Administrative Code Title 15A, Subchapter 2C – Well Construction Standards, Rule 108 Standards of Construction: Wells Other Than Water Supply (15A NCAC 02C .0108).

The extraction wells might be drilled using hollow stem auger, air percussion/hammer, rotosonic methods, or a combination thereof. The drilling method would depend on Site conditions and drill rig availability. It is anticipated that the 23 groundwater extraction wells would be completed as 6 inch diameter wells to facilitate the installation of pumps and instrumentation (e.g., level control) in groundwater extraction wells. The top of the sand pack would extend a minimum of 2 feet above the top of well screens. A bentonite well seal at least 2 feet thick would be installed on top of the sand pack. Neat cement grout with 5 percent bentonite would be placed on top of the bentonite well seal and would fill the remaining well

annulus to within 3 feet of the ground surface. All materials and installations would be in accordance with 15A NCAC 02C. A typical well construction schematic for groundwater extraction wells proposed under Alternative 2 is presented in **Figure 6-32d**.

Clean Water Infiltration Vertical Well Design (STEP 3B – INSTALL WELLS)

(CAP Content Section 6.E.b.i)

The preliminary groundwater remediation system design includes installation of 46 groundwater infiltration wells (**Figure 6-32a**). The proposed infiltration wells would be installed in and around the ASA. However, no groundwater infiltration wells would be installed within the transmission line right-of-way. The locations are based on predicted COI plume configuration, with the intent of flushing clean water into vadose zone soils to flush mobile COIs into underlying groundwater. Most COIs mobilized by being flushed from unsaturated soil would be hydraulically captured by a nearby or downgradient groundwater extraction well. The predicted effects of the wells are defined in detail in flow and transport modeling results (**Appendix G**).

Groundwater infiltration wells would be completed in the saprolite and transition zones with total well depths ranging from 13 ft. bgs to 122 ft. bgs. All groundwater infiltration wells would be installed by a North Carolina licensed well driller in accordance with North Carolina Administrative Code Title 15A, Subchapter 2C – Well Construction Standards, Rule 108 Standards of Construction: Wells Other Than Water Supply (15A NCAC 02C .0108).

The infiltration wells might be drilled using hollow stem auger, air percussion/hammer, rotosonic methods, or a combination thereof. The drilling method would depend on Site conditions and drill rig availability. It is anticipated that the 46 groundwater infiltration wells would be completed as 6- inch diameter wells. The top of the sand pack would extend a minimum of 2 feet above the top of well screens. A bentonite well seal at least 2 feet thick would be installed on top of the sand pack. Neat cement grout with 5 percent bentonite would be placed on top of the bentonite well seal and would fill the remaining well annulus to within 3 feet of the ground surface. All materials and installations would be in

accordance with 15A NCAC 02C. A typical well construction schematic for a vertical infiltration well is presented in **Figure 6-32c**.

An HDPE distribution header would convey the clean water infiltration water from the FGD fire suppression water supply to each infiltration well (**Figures 6-33**). A seal at the top of the well through which the infiltration pipe and wiring would enter the well, would be designed to be leak free.

The head at the top of the well would be controlled by a pressure control valve set to produce 10-feet of water (4.34 psig) at the well head. Ten-feet of water is the infiltration pressure used in the predictive groundwater flow and transport model, but the pressure could be increased or decreased to achieve performance objectives. Operation of the infiltration wells would comply with 15A NCAC 02C.0225. Infiltration pressures and rates would be determined based on the lowest hydraulic conductivity of the strata receiving the clean water.

The amount of water flowing into the infiltration well would be measured by a flow rate and flow totalizing meter. At startup, a ball valve at the top of the well would be opened to allow water to displace the air in the well and system piping. Also, pressure transducers installed at the top of each infiltration well would monitor well head pressures.

Other appurtenances in the piping system would include a pressure gauge, ball valves to isolate piping for maintenance, and a solenoid valve that would close to stop the flow of clean infiltration water in the event a high water level occurred in the vault.

Operational parameters, such as infiltration flow rate, totalized infiltration flow, and well head pressure, as well as critical malfunctions such as accumulation of water in the well vault would be transmitted to the groundwater remediation system owner via telemetry system.

Clean Water Infiltration Horizontal Well Design (STEP 4A – INSTALL WELLS)

(CAP Content Section 6.E.b.i)

The preliminary groundwater remediation system design includes installation of 1 horizontal groundwater infiltration well (**Figure 6-32a**). This horizontal well would be a double-ended well that is 240 feet long and installed at the target depth of 15 feet (bgs) by certified North Carolina well

driller. A typical horizontal environmental well is installed at an angle approximately minus 12 degrees from horizontal (Ellington-DTD, 2004). The equipment would be set up at a distance such that the boring at an angle that is predetermined and would reach the point of beginning of the screen at the target depth of the screen. A directional pilot bore smaller than the diameter of the well would be installed using a navigational system, such as a wireline navigation system. Drilling fluid would be used for cutting the borehole and stabilizing the borehole wall until the well materials are installed. Surface seals would be installed in the annulus at both ends, and the well will be developed. One end of the well would be capped with a water-tight seal. The well head will be completed in a manner similar to the vertical injection wells. (Ellington-DTD, 2019).

The infiltration rate is estimated to be 75 gpm. A typical well construction schematic for a horizontal infiltration well is presented in **Figure 6-32c**.

Clean Water Infiltration Wells (STEP 4B)

(CAP Content Section 6.E.b.i)

An HDPE distribution header would convey groundwater infiltration water from the clean water infiltration water treatment system to each clean water infiltration well (**Figure 6-32b**). A seal at the top of the well through which the infiltration pipe and wiring would enter the well, would be designed to be leak free.

The hydraulic head at each clean water infiltration well would be controlled by a pressure control valve. Ten-feet of water (4.34 pounds per square in gauge) is the infiltration pressure used in the predictive groundwater flow and transport model, but the pressure could be increased or decreased to achieve performance objectives. Operation of the clean water infiltration wells would comply with 15A NCAC 02C.0225. Infiltration pressures and rates would be determined based on the hydraulic conductivity of the strata receiving the clean water.

The amount of water flowing into the clean water infiltration well would be measured by a flow rate and flow totalizing meter. At startup, a ball valve at the top of the well would be opened to allow water to displace the air in the well and system piping. Also, pressure transducers installed at the top of each clean water infiltration well would monitor well head pressures (**Figure 6-32b**).

Other appurtenances in the piping system would include a pressure gauge, ball valves to isolate piping for maintenance, and a solenoid valve that would close to stop the flow of infiltration water in the event high water level in the vault.

Operational parameters, such as infiltration flow rate, totalized infiltration flow, and well head pressure, as well as critical malfunctions such as accumulation of water in the well vault would be transmitted to the groundwater remediation system owner via telemetry system.

Groundwater Extraction Wells (STEP 4C)

(CAP Content Section 6.E.b.i)

A pump would be installed in each groundwater extraction well. If the water level in the well is above the top water level switch, the pump would run to pump the water to lower water level switch, which would cause the pump shut off. The flow of extracted groundwater from the submersible pump would be measured using a flow rate and flow totalizer meter before being conveyed to groundwater discharge piping for treatment and disposal. Other appurtenances in the piping system would include a check valve to prevent back flow into the well, sampling port, pressure gauge to indicate the pressure generated by the pump, ball valves to isolate piping for maintenance, and a flow control valve such as a stainless steel globe or gate valve.

Operational parameters, such as flow and water level, and critical malfunctions, such as accumulation of water in the well vault, would be transmitted via a telemetry system to inform the system operator of the status in the well and enclosure.

Well Head Configuration (STEP 4D – CONSTRUCT WELL HEADS)

(CAP Content Section 6.E.b.i)

The well head configuration is shown in **Figure 6-32d**. The proposed extraction well vaults would be precast concrete with aluminum access doors that include a drainage channel. The concrete enclosures would be finished below grade and the piping and fittings in the enclosures would be Type 304 stainless steel to reduce risk of damage during O&M. Any above ground piping would be insulated and heat traced. The piping would transition from the Type 304 stainless steel to HDPE at a flange near the

opening where the HDPE pipe leaves the enclosure. The buried sections of pipe would be fusion-welded HDPE.

The enclosures would have a 2-inch drain with a compression cap for controlled release of rainwater or condensate. A water level sensor would be mounted on the wall of the enclosure approximately 6-inches above the floor. Should water accumulate to that level, the extraction pump would be stopped and an alarm sent to the operator, who can ascertain the cause of the high water level.

Groundwater Clean Water Infiltration Water Treatment (STEP 5 - BUILD INFILTRATION TREATMENT)

(CAP Content Section 6.E.b.i)

The purpose of the proposed Infiltration Water Treatment System (IWTS) is to treat water from the existing Fire Suppression System near the CSS WWTP used at the infiltration wells. Water used for infiltration should come from the existing Fire Suppression System located near the existing WWTP. The quality of the potential infiltration water is not well determined, but it is anticipated that the water will require, at a minimum, treatment for suspended solids. The treatment process would likely be redundant to better reduce down time. For suspended solids, the treatment would possibly consist of:

- Chlorination
- Polymer addition in a rapid mix chamber
- Flocculation
- Sedimentation
- Filtration
- Storage in Tank

During the pilot testing phase, the quality of infiltration water will be assessed and the treatment system to produce acceptable infiltration water will be determined.

Groundwater Extraction Water Treatment (STEP 6 – ADDRESS GROUNDWATER TREATMENT)

(CAP Content Section 6.E.b.i)

Extracted groundwater would be directed to a collection system consisting of a gravity sewer, two duplex pump stations and a force main to pump extracted groundwater to the CSS WWTP via the pipe rack that crosses Suck Creek. One of the pump stations would be a below ground submersible pump station with duplex pumps. The other pump station would be an above ground with duplex pumps. Above ground piping, tanks, and pumps should be equipped with heating and insulation to prevent freezing in cold conditions. A process flow diagram is presented in **Figure 6-34**. The treated groundwater would discharge through permitted Outfall 005. The detailed design elements may be adjusted based on a final technical review.

Clean Water Infiltration Well Distribution System (STEP 7 – CONCEPTUAL CLEAN WATER INFILTRATION SYSTEM CONSIDERATIONS)

(CAP Content Section 6.E.b.i)

The infiltration water distribution system conveys water from the IWTS to groundwater remediation infiltration wells installed in and around the ASA. Treated water would be pumped from the IWTS to an above ground infiltration water storage tank by way of the pipe rack that crosses Suck Creek. The above ground infiltration water storage tank would be installed southwest of the ASA extraction/infiltration area. The purpose of the storage tank is to provide infiltration water to the infiltration wells via gravity feed at required infiltration pressures. The default infiltration pressure is 10-feet of water (4.34 psig); however, infiltration water pressure would be regulated to comply with 15A NCAC 02C .0255 (24)(A) and would be based on the hydraulic conductivity of the geologic material receiving the infiltration water.

The infiltration water distribution system would have blowoffs and valves incorporated throughout for operation and maintenance purposes. The distribution system would be flushed periodically to minimize buildup on the piping walls. Water used to flush the system would not be injected, but rather, it will be directed to the collection system for treatment and discharge.

Pipelines (STEP 8 – PIPELINE SPECIFICS)

(CAP Content Section 6.E.b.i)

The piping systems would be constructed in accordance with Duke Energy and Station-specific guidance. Final sizing would be based on load and head calculations. Extraction well discharge headers would connect each well to the groundwater extraction system and would discharge extracted groundwater to duplex pump stations. Underground piping would be in trenches. **Figure 6-37e** is a conceptual representation of a pipeline trench. Extracted groundwater would flow to the pump stations via gravity drain. Force mains would transfer groundwater from force mains to the Cliffside WWTP via the pipe rack that crosses Suck Creek. Aboveground piping would be insulated and heated seasonally to prevent freezing.

Electrical and Instrumentation Design (STEP 9 – SYSTEM POWER AND CONTROL SPECIFICS)

(CAP Content Section 6.E.b.i)

Existing power near the system might not be adequate for the anticipated number of wells. Additional power might need to be a component of the design. Control panels might also be necessary for each distinct area of the well systems. The control systems would be equipped with system shutdown notification.

Design Documents (STEP 10 – DETAILED DOCUMENTS)

(CAP Content Section 6.E.b.i)

The design package would provide the necessary plans and specifications for procurement of materials and construction purposes. This would include Site layout drawings, plans and profiles, well enclosure details, trench and discharge piping outlet details, well construction schematics, piping and instrumentation diagrams/drawings and complete equipment, materials and construction specifications.

System Operation and Maintenance (STEP 11 – SYSTEM POWER AND CONTROL SPECIFICS)

(CAP Content Section 6.E.b.i)

Groundwater extraction well performance would be monitored and tracked to determine if there is a loss in pumping efficiency due to mineral and/or biological fouling. If well performance monitoring indicates a decrease in flow rate, the well would be inspected for fouling and the screens would be cleaned as appropriate.

In addition to well performance monitoring and maintenance, other system elements, such as pumps controls, would receive routine maintenance in accordance with the manufacturer's recommendations.

6.8.2.2 Design Assumptions, Calculations, and Specifications

(CAP Content Section 6.E.b.ii)

Design calculations are presented in **Appendix N**.

6.8.2.3 Permits

(CAP Content Section 6.E.b.iii)

Discharge of extracted groundwater extracted under Alternative 2 would require modification of NPDES Permit NC0005088 to include discharge of groundwater. When modified, NPDES Permit NC0005088 would allow for the discharge of groundwater at Outfall 005. Extracted groundwater is not anticipated to exceed NPDES Permit NC0005088 requirements, but would likely be treated in the WWTP associated with Outfall 005.

6.8.2.4 Schedule and Cost of Implementation

(CAP Content Section 6.E.b.iv)

Since implementation of corrective action might be affected by factors that are not yet well defined, the implementation schedule will be refined as necessary as the project proceeds. Construction, startup, and monitoring schedules for the proposed groundwater remediation system will be established after a design suitable for bidding, procurement of materials and construction has been developed.

A Gantt chart (**Figure 6-35**) is provided for outlining a general timeline of implementation tasks following CAP Update submittal. The exact timeline of the schedule milestones is dependent on various factors, including NCDEQ review and approval, permitting, weather, and field conditions.

The time to construct Groundwater Alternative 2 is estimated to be approximately 8 months after contractor mobilization. Duke Energy would provide construction progress reports monthly from the beginning of construction until construction is complete.

- Reporting would include:
- Health and Safety/Man Hours.
- Tasks completed for the month prior.

- Problems affecting schedule (*e.g.,* inclement weather).
- Measures taken to achieve construction milestones (*e.g.,* increase number of drilling crews).
- Contingencies.
- Tasks to be completed by next reporting period.
- Provide updated schedule/Gantt chart.

The cost estimate for this alternative is based on capital costs for design and implementation. Implementation includes pumping tests, infiltration tests, installation of extraction wells, infiltration wells, submersible pumps, instrumentation, piping, and telemetry system. Long term O&M costs include groundwater monitoring costs, analytical costs, reporting costs, periodic redevelopment and replacement of monitoring wells, and periodic replacing of submersible pumps.

A detailed cost estimate for this Alternative is provided in **Appendix K**. The cost estimate is based on capital costs for design and implementation, and the operations, maintenance (O&M) and monitoring costs. The design costs include work plans, design documents and reports necessary for implementation of the alternative. Implementation costs include procurement and construction. O&M costs are based on annual routine labor, materials and equipment to effectively conduct monitoring, routine annual and 5-year reporting, and routine and non-routine maintenance costs

6.8.2.5 Measure to Ensure Health and Safety

(CAP Content Section 6.E.b.v)

There is no measurable difference between evaluated Site risks and risks indicated by background concentrations; therefore, no material increases in risks to human health related to the ash basin have been identified. The groundwater corrective action is being planned to address regulatory requirements. The risk assessment identified no current human health or ecological risk associated with groundwater downgradient of the ash basin. Water supply wells are located upgradient of the ash basin and water supply filtration systems have been provided to those who selected this option. Surface water quality standards downgradient of the COI-affected plume are also met. Based on the absence of receptors, it is anticipated that groundwater extraction would create conditions that continue to be

protective of human health and the environment because the COI concentrations will diminish with time.

6.8.2.6 Description of All Other Activities and Notifications Being Conducted to Ensure Compliance with 02L, CAMA, and Other Relevant Laws and Regulations

(CAP Content Section 6.E.b.vi)

The CAP provides a description of activities related to compliance with 02L, CAMA, in regard to the Ash Storage Area and the Active Ash Basin. The CAP Update addresses the requirements of G.S. Section 130A-309.211(b), complies with NCAC 15A Subchapter 02L. 0106 corrective action requirements, and follows the CAP guidance provided by NCDEQ in a letter to Duke Energy

6.8.3 Requirements for 02L .0106(l) – MNA Rule.

(CAP Content Section 6.E.c)

The requirements for implementing corrective action by MNA, under 02L .0106(l), are provided in **Section 6.7.1.** MNA is not applicable at this time for the SA 1 as described in **Section 6.8.1**, and a site-specific MNA report is included as **Appendix I.**

6.8.4 Requirements for 02L .0106(k) – Alternate Standards

(CAP Content Section 6.E.d)

Regulation 02L .0106(k), states that a request may be made for approval of a corrective action plan that uses standards other than the 02L groundwater quality standards. G.S. Section 130A, Article 9, Part 8 allows risk-based remediation as a clean-up option where the use of remedial actions and land use controls can manage properties safely for intended use. Risk-based corrective action is where constituent concentrations are remediated to an alternative standard based on the actual posed risks rather than applicable background-levels or regulatory standards. The requirements for implementing corrective action by remediating to alternate standards, under 02L .0106(k), are as follows:

- *Sources are removed or controlled;*
- *Time and direction of contaminant travel can be predicted with reasonable certainty;*

- *COIs have and will not migrate onto adjacent properties unless specific conditions are met (i.e., alternative water sources, written property owner approval, etc.);*
- *Standards specified in Rule .0202 of this Subchapter will be met at a location no closer than one year time of travel upgradient of an existing or foreseeable receptor, based on travel time and the natural attenuation capacity of subsurface materials or on a physical barrier to groundwater migration that exists or will be installed by the person making the request;*
- *If contaminant plume is expected to intercept surface waters, the groundwater discharge will not possess contaminant concentrations that would result in violations of standards for surface waters contained in 15A NCAC 02B .0200;*
- *Public notice of the request has been provided in accordance with Rule .0114(b) of this Section; and*
- *Proposed corrective action plan would be consistent with all other environmental laws*

The alternative groundwater clean-up values may be used to aid in risk management decisions at Cliffside. This approach is particularly useful at complex sites where changes in site conditions may require an extended period of time or where NCDEQ approves alternate groundwater standards for COIs, such as 4,000 µg/l for boron, pursuant to its authority under G.S. Section 15A NCAC 02L .0106(k).

6.8.5 Sampling and Reporting

(CAP Content Section 6.E.e.i)

An EMP has been developed as part of this CAP Update consistent with 02L. 0106(h)(4). The EMP is designed to monitor groundwater conditions at Cliffside and document progress towards the remedial objectives over time. This plan is designed to be adaptive over the project life cycle and can be modified as the groundwater remediation system design is prepared, completed, or evaluated for termination.

Duke Energy implemented an Interim Monitoring Plan (IMP) that was submitted to NCDEQ on December 21, 2018 and subsequent additional modifications were agreed upon between Duke Energy and NCDEQ. The IMP includes the locations of groundwater wells sampled quarterly and semiannually.

The EMP is required by G.S. Section 130A-309.211(b)(1)(e). The IMP will be replaced by the EMP upon NCDEQ approval of the CAP Update. Either submittal of the EMP, or the pilot test work plan and permit applications (as applicable), will fulfill G.S. Section 130A-309.209(b)(3).

The EMP, presented in **Appendix O**, is designed to be adaptable and would target key areas where changes to groundwater conditions are most likely to occur due to corrective action and ash basin closure activities. EMP key areas for monitoring are based on the following considerations:

- Include background locations
- Include designated flow paths
- Within areas of observed or anticipated changing Site conditions, and/or have increasing constituent concentration trends
- Will effectively monitor COI plume stability and model simulation verification
- The EMP will be used to evaluate progress towards remediation

EMP elements including well systems, locations, frequency, parameters, schedule and reporting evaluation are summarized below and outlined on **Table 6-17.** Effectiveness monitoring well locations are illustrated on **Figure 6-36**. The EMP will be implemented 30 days after CAP approval, and will continue until there is a total of three years of data confirming COIs are below applicable standards at or beyond the compliance boundary, at which time a request for completion of active remediation will be filed with NCDEQ. If applicable standards are not met, the EMP will continue and transition to post-closure monitoring, if necessary.

After ash basin closure and following ash basin closure certification, a post-closure groundwater monitoring plan (PCMP) will be implemented at the Site for a minimum of 30 years in accordance with G.S. Section 130A-309.214(a)(4)k.2. If groundwater monitoring results are below applicable standards at the compliance boundary for three years, Duke Energy may request completion of corrective action in accordance with G.S. Section 130A-309.214(a)(3)b. If groundwater monitoring results are above applicable standards, the PCMP will continue. An EMP work flow and optimization process is outlined on a flow chart on **Figure 6-37**.

Optimization of the plan to help determine the remedy's performance, appropriate number of sample locations, sampling frequency, laboratory analytes, and statistical analysis to evaluate the plume stability conditions will be conducted during EMP review periods. Optimization evaluation would be conducted using software designed to improve long-term groundwater monitoring programs such as Monitoring and Remediation Optimization System (MAROS).

6.8.5.1 Progress Reports and Schedule

(CAP Content Section 6.E.e.ii)

After groundwater remediation implementation, evaluation of Site conditions, groundwater transport rates, and COI plume stability would be based on quantitative rationale using statistical, mathematical, modeling, or empirical evidence. Existing data from historical monitoring and pilot testing would be used to provide baseline information prior to groundwater remediation implementation. Schedule and reporting of system quantitative evaluations, review and optimization would include:

- **Annual Reporting Evaluation:** The EMP will be evaluated annually for optimization and adaption for effective long-term observations, using a data-need rationale for each location. The annual evaluation would include a comparison of observed concentrations compared to model predictions and an evaluation of statistical concentration trends, such as the Mann-Kendall test.

  Results of the evaluation would be reported in annual monitoring reports and are proposed to be submitted to NCDEQ annually. The reports will include the following:

  - Laboratory reports on electronic media,
  - Tables summarizing the past year's monitoring events,
  - Historical data tables,
  - Figures showing the historical data versus time for the designated monitoring locations and parameters,
  - Figures showing sample locations,
  - Statistical analysis (Mann-Kendall test) of data to determine if trends are present, if performed,

  - Identification of exceedances of comparative values,
  - Groundwater elevation contour maps in plan view and isoconcentration contour maps in plan view for one or more of the prior year's sampling events (as mutually agreed upon by Duke Energy and NCDEQ),
  - Any notable observations related to water level fluctuations or constituent concentration trends attributable to extraction system performance or water table drawdown, and
  - Recommendations regarding modifications to the Plan

- **5-Year Review:** Similar to annual evaluation and reporting, the EMP would be re-evaluated and modified as part of each 5-year review period as adaptive or, if necessary, additional corrective actions are implemented or water quality observations warrant adjustments of the plan. The annual evaluation would include elements of the annual evaluation, plus updated background analysis, confirmation of risk assessment, evaluation of statistical concentration trends, analytical result comparison and model verification. If needed, flow and transport models could be updated as part of the 5-year review process to refine future predictions and the associated routine data needed to confirm the predictions.

  Optimization of the monitoring network could be evaluated if the remedy is determined to be effective or when conditions re-stabilize after the implementation of closure or, if necessary, additional corrective action implementation. Optimization of the monitoring network could include a lesser monitoring frequency and/or parameter list. Flow and transport model predictions indicate very slow changes in conservative (boron) concentrations will occur over time. Geochemical model predictions indicate very little or much slower changes in the remaining COI distributions will occur. Therefore, a monitoring frequency consistent with these predictions would be proposed following confirmation of the models through site data.

  If necessary, modifications to the corrective action approach would be proposed to achieve compliance within the target timeframe.

A flow diagram for effectiveness monitoring plan work and optimization is depicted on **Figure 6-37**.

6.8.5.2 Sampling and Reporting Plan During Active Remediation

(CAP Content Section 6.E.e.ii)

Groundwater Monitoring Network

EMP monitoring will provide a comprehensive monitoring strategy that (1) monitors the performance and effectiveness of the selected remedial alternative, (2) can provide adequate areal (horizontal) and vertical coverage to monitor plume status at or beyond the compliance boundary and with regard to potential receptors, and (3) confirm flow and transport and geochemical model predictions. Active groundwater remedy performance monitoring would be implemented around the AAB and ASA (**Figure 6-36**). EMP systems and objectives are outlined below:

- Compliance with 02L
- Measure and track the effectiveness of the proposed extraction system
- Monitor plume status (horizontally and vertically)
- Verify predictive model simulations
- Verify no unacceptable impact to downgradient receptors
- Verify attainment of active remedy objectives through validated model simulations
- Identify new potential releases of constituents into groundwater from changing site conditions
- Monitor approved background locations

The EMP would include existing monitoring wells for performance and effectiveness monitoring (**Table 6-17**). Several of the existing monitoring wells at the site might be abandoned from ash basin closure and related construction activities. In the event that closure activities extend to the proposed EMP well locations, the layout of wells would be modified, if necessary.

Groundwater Monitoring Flow Paths - Trend Analysis

The monitoring program will provide adequate horizontal and vertical coverage in the area of groundwater remediation to monitor:

- Changes in groundwater quality as Site conditions change (*e.g.*, groundwater remediation effects, ash basin closure commences),
- Transport rates, and
- Plume stability

Horizontal and vertical coverage would be provided by using groundwater monitoring wells located downgradient of the source areas within the corrective action area. To monitor performance, groundwater monitoring wells are located within the area of corrective action at specific intervals or as close as possible from the source area to a receptor as illustrated in **Figure 6-36.**

Multi parameters sondes would be installed in wells along the primary flow paths in the active remedy area (**Figure 6-36**). **Table 6-17** provides a detailed list of monitoring wells to be included in the EMP, along with wells proposed to have multi parameter sondes installed. Daily monitoring of changes in groundwater quality on a real-time basis using multi-parameter sondes and telemetry technology would allow continuous monitoring and evaluation of geochemical conditions. Geochemical conditions (pH, E_H, and dissolved oxygen) will be compared to geochemical modeling results to evaluate changes that could potentially affect the mobility (K_d) of reactive and variably-reactive COIs. Water levels would also be monitored by the multi-parameter sondes to verify simulated changes to groundwater flow during and after basin closure. Having groundwater quality and water level data in readily available will increase the response time to implement contingencies if field parameters significantly deviate from predicted responses. Contingency plans are included in **Section 6.8.9**.

Plume stability evaluation would be based primarily on results of trend analyses. Trend analyses will be conducted using Mann-Kendall trend test. The Mann-Kendall trend test is a non-parametric test that calculates trends based on ranked data and has the flexibility to accommodate any data distribution and is insensitive to outliers and non-detects. The test is best used when large variations in the magnitude of concentrations may be present and may otherwise influence a time-series trend analysis.

Trend analysis will be conducted using data from EMP geochemically nonreactive, conservative constituents (**Table 6-17**). These constituents include boron, sulfate, and TDS, and best depict the areal extent of the plume and plume stability and physical attenuation, either from active remedy or natural dilution and dispersion.

Trend analysis of designated groundwater monitoring flow path wells (**Figure 6-36**) would be part of the decision metrics for determining termination of the active remedy.

Sampling Frequency

Multiple years of quarterly and semiannual monitoring data are available for use in trend analysis and to establish a baseline to evaluate corrective action performance. The monitoring plan sampling frequency is based on semi-annual sampling events to be consistent with other groundwater monitoring performed at the Site.

Semi-annual monitoring following implementation of corrective action is recommended for the existing monitoring wells to be included in the EMP. Over four years of quarterly monitoring data are available for existing wells, which will be used to supplement trend analysis and to establish a baseline to evaluate corrective action performance.

Newly installed wells to be added to the EMP would be monitored by quarterly sampling events. Quarterly sampling would target locations of proposed newly installed wells with fewer than four quarters of data. Quarterly monitoring of parameters outlined on **Table 6-17** is proposed for newly installed wells.

Quantitative evaluations would also determine additional data needs (i.e., increased sampling frequency) for refining statistical and empirical model development. Additional monitoring described in the contingency plan would be implemented if significant geochemical condition changes are identified that could result in mobilization of reactive or variably-reactive COIs.

Sampling and Analysis Protocols

EMP sampling and analysis protocol will be similar to the existing IMP with some adjustment for anticipated changing site conditions. Detailed protocols are presented in **Appendix O**. Samples would be analyzed by a

North Carolina certified laboratory for the parameters listed in **Table 6-17** as summarized below. Laboratory detection limits for each constituent are targeted to be at or less than applicable regulatory values (i.e., 02L or IMAC).

- **Groundwater Quality Parameters:** Based on the constituent management approach, 12 constituents warrant corrective action at Source Area 1, and are included as groundwater quality parameters to be monitored as part of the EMP. These constituents are as follows:

  - Arsenic
  - Boron
  - Cobalt
  - Iron
  - Lithium
  - Manganese
  - Sulfate
  - Strontium
  - Thallium
  - Total Dissolved Solids (TDS)
  - Total Uranium
  - Vanadium

  Geochemically conservative, non-reactive constituents boron, lithium, sulfate, and TDS best depict the areal extent of the groundwater plume. Analyses of these constituents will be used to monitor plume stability and physical attenuation from groundwater flushing and extraction, by comparing monitoring results with flow and transport model simulations.

  Changing geochemical conditions that could cause sorption or precipitation/co-precipitation mechanisms that might affect mobility of non-conservative and variable constituents would be evaluated using multi parameter sonde data.

- **Groundwater Field Parameters:** The following six field parameters will be monitored to confirm that monitoring well conditions have stabilized prior to sample collection and to evaluate data quality: water level, pH, specific conductance, temperature, dissolved oxygen, and oxidation reduction potential. For remedy performance monitoring, these parameters will be measured daily by a multi-parameter sondes installed in each flow path monitoring well and used to evaluate geochemical conditions from remedy effectiveness.

Major cations and anions would be analyzed to evaluate monitoring data quality (electrochemical charge balance). These include alkalinity, bicarbonate alkalinity, aluminum, calcium, iron, magnesium, manganese, nitrate + nitrite, potassium and sodium. Total organic carbon (TOC), ferrous iron, and sulfate analyses are also proposed as monitoring parameters. TOC is recommended to help determine if an organic compound is contributing to TDS, and ferrous iron and sulfate to monitor potential dissolution of iron oxides and sulfide precipitates as an indicator of changing conditions related to corrective action. These parameters are indicated on **Table 6-17** as water quality parameters.

6.8.6 Sampling and Reporting Plan after Termination of Active Remediation

(CAP Content Section 6.E.e.iii)

Termination of the proposed remedial alternative for Source Area 1 will be consistent with and implemented in accordance with NCDEQ Subchapter 02L .0106(m). A flow chart of the decision metrics, request, and review timeline for termination is outlined on **Figure 6-38** *(CAP Content Section 6.E.e.iii.1)*. This process will provide stakeholders an opportunity to evaluate terminating the system, as appropriate, in the vicinity of the well or wells where groundwater restoration completion is being evaluated.

Trend analysis described in **Section 6.8.5** would be part of the decision metrics for determining termination of the active remedy *(CAP Content Section 6.E.e.iii.1.A and B).* Groundwater remediation effectiveness monitoring will transition to the attainment monitoring phase when NCDEQ determines that the remediation monitoring phase is complete at a particular well or area.

6.8.7 Proposed Interim Activities Prior to Implementation

(CAP Content Section 6.E.f)

In accordance with requirements of G.S. Section 130A-309.211(b)(3), implementation of the proposed corrective action will begin within 30 days of NCDEQ approval of the CAP Update.

Prior to pilot testing, the infiltration water will be sampled for geochemical and physical parameters for baseline conditions to evaluate the potential for biofouling and plugging of the clean water infiltration well screens. During well pumping testing, extracted groundwater will be collected and analyzed for geochemical parameters consistent with the NPDES permit.

Additional interim activities to be conducted prior to implementation of the corrective action remedy include:

- Implementation of the EMP within 30 days of CAP approval
- Submittal of permit and registration applications to NCDEQ.

6.8.8 Contingency Plan

(CAP Content Section 6.E.g)

The purpose of the Contingency Plan is to monitor changes in conditions and operations to effectively reach the remedial action objectives. The contingency plan addresses operations, groundwater conditions and performance.

The Contingency Plan will be defined in greater detail as design elements of the system are finalized. A groundwater monitoring program to measure and track the effectiveness of the proposed comprehensive clean water infiltration and extraction system is described in **Section 6.8.6**. This plan is designed to be adaptive and can be modified as the groundwater remediation system design is prepared, completed, or evaluated for termination.

6.8.8.1 Description of Contingency Plan

(CAP Content Section 6.E.g.i)

The contingency plan addresses the following areas:

- Operations (including clean water infiltration and extraction wells, pumping, piping, electrical, and controls)
- Groundwater quality
- Groundwater levels
- Groundwater treatment
- Comparison to predicted concentrations and water levels

A health and safety plan and an operations manual will be prepared. The health and safety plan will deal with management of spills and other unplanned releases and the operation manual will address operational training including backup personnel, emergency response training, and reporting to appropriate authorities.

6.8.8.2 Decision Metrics for Contingency Plan Areas

(CAP Content Section 6.E.g.ii)

This section outlines decision metrics and possible contingency actions in support of a resilient groundwater corrective action strategy.

Operations

A computer control system will be installed with the system to provide timely information to the Site Operator regarding key operational features, particularly clean water infiltration and extraction well water levels and flow rates. The control system will have remote monitoring capability to alert key personnel as to the nature and urgency of the issue. The system will be programmed with expected values for measured parameters. Alerts will be sent when actual values are outside the programmed range. Based on the alerts, the functional problem will be evaluated and repairs or replacement of faulty equipment will be completed. The expected duration of operations will exceed the life expectancy of most of the mechanical equipment that will comprise the system so ongoing replacement of equipment will be part of the operations and maintenance program.

Several aspects of the monitoring system will help ensure effective operations:

- Processes to ensure effective operation of each clean water infiltration and extraction well is maintained. Maintaining target flow rates and water levels for each well is important to minimize the potential for loss of groundwater flow control. Each well will be monitored continuously by the control system, with all data being recorded, and an alert sent if the flow rate or water level is outside the prescribed range. In addition to automated systems, each element of the system will be physically inspected and maintained as part of a routine operations and maintenance program.
- If the system detects a leak related to pumping, piping and/or wells, the respective element of the system will be shut down and a message will be immediately sent to the operator and to backup personnel. The potential leak will be inspected and repaired prior to restarting the system element.
- If pH adjustment or other water treatment technology is employed, continuous monitoring of key parameters will ensure proper operation of the system. Variances between prescribed ranges will

alert the operator and other key personnel and may result in automatic system shut down.

- The operator inspection schedule, completion, and notes for key systems will be documented.
- A system maintenance schedule will be established to ensure effective operation. System elements will be maintained in accordance with manufacturer's recommendations, which will be contained in a system Operation and Maintenance (O&M) Manual. Corrective measures, performed by appropriately skilled personnel, will be taken if mechanical issues are identified during routine maintenance monitoring.

Groundwater Quality

The EMP includes a primary network of wells that will provide focused monitoring in critical areas following corrective action implementation.

After each sampling event, data will be entered into a comprehensive data base system. Trend analyses will be conducted, spatially and temporally, to evaluate COI plume changes. If groundwater quality field parameters or constituent concentrations significantly deviate from predicted responses, a focused investigation will be conducted to determine if the variation is due to system performance or other factors. Based on this analysis, possible responses could include adding or deleting clean water infiltration or extraction wells, or changing flow rates or target water levels.

To assess the effectiveness of changes, or to determine if the unexpected data trends are temporary, increased monitoring frequency or additional monitoring locations may be conducted.

If subsequent results continue to show non-conformance, a more comprehensive assessment and corrective action plan for the specific non-conformance may be completed and implemented.

Groundwater Levels

Water levels in selected EMP monitoring wells will be monitored using downhole instrumentation until Site conditions have stabilized. Water level data will be evaluated as part of the ongoing monitoring. Technical evaluations will include spatial and temporal trend analyses, drawdown calculations, and flow and transport model refinement to reflect current

conditions, as needed. If results conclude that water levels are not similar to predicted patterns a focused investigation will be conducted that could include adjusting system pumping rates, refining the flow and transport model for clean water infiltration and extraction rates, adding monitoring wells to the EMP monitoring network for greater resolution, installation of monitoring wells in key areas, and/or other activities.

If subsequent results from ongoing investigation continue to show non-conformance, a corrective action response with suggested approaches to determine possible reasons for the non-conformance would be implemented until resolution is achieved.

Groundwater Treatment

If extracted groundwater treatment is required prior to discharge through a permitted outfall, evaluation of that system will be part of the routine monitoring program.

If a treatment system is not meeting performance standards or if trends suggest performance is not optimal, an analysis of the trends and an assessment of the system will be completed and corrective measures implemented. Changes could be the result of changing influent characteristics.

Comparison to Predicted Concentrations and Water Levels

Many aspects of the proposed remediation approach are based on modeling and predicted groundwater conditions. As remedial efforts begin, hydraulic conditions change, and additional groundwater data are collected, the models will be updated. However, as conditions change, especially at the beginning of the process there maybe deviations from existing data trends and model predictions. The models will be updated to reflect changing conditions, as necessary, and changes in predicted results will be analyzed to determine if the remedial approach needs to be modified to effectively address the changes.

Given that groundwater infiltration is an element of the system, there is a potential that soil might become saturated near the ground surface, with the potential to create surface discharges. If this occurs, reducing infiltration rates by adjusting water-level controllers at wells near the area or increasing the extraction system would be used to control surficial saturation.

6.9 SA1 Summary and Conclusions

This CAP Update meets the corrective action requirements under G.S. and Subchapter 02L.0106 and to addresses Subchapter 02L.0106 (j). This CAP Update proposes a remedy for COIs in groundwater associated with the Cliffside AAB and ASA that are at or beyond the compliance boundary to the north of the AAB within the ASA.

Remedial **Alternative 2, groundwater extraction combined with clean water infiltration and treatment**, is selected as the preferred groundwater corrective action option for the AAB and ASA. This alternative meets the correction action objectives described in **Section 1.0** of this CAP in the expeditious timeframe through groundwater extraction combined with flushing effect of clean water infiltration. Although there are no significant risks to human or ecological receptors, the alternative will meet the regulatory requirements most effectively and provide further protection for downgradient surface water. This alternative is readily implementable, although it is the most costly alternative due to the addition of the clean water infiltration wells. The system would be adaptable based on effectiveness monitoring field data results.

In addition to the selection and description of the preferred corrective action groundwater remedy, this CAP Update also provides:

- A groundwater remediation approach that can be implemented under either closure scenario (closure-in-place or closure-by-excavation).
- A screening process of multiple potential groundwater corrective action alternatives that would address areas requiring corrective action.
- Specific plans, including engineering design details, for restoring groundwater quality.
- A schedule for the implementation and operation of the corrective action strategy.
- A monitoring plan for evaluating the performance and effectiveness of corrective action groundwater remedy, and its effect on the restoration of groundwater quality.
- Planned activities prior to full-scale implementation including pilot testing in selected areas and water treatment testing. Pilot test work plan(s) will be submitted to NCDEQ within 30 days of CAP approval to fulfill G.S. Section 130A-309.211(b)(3).

SOURCE AREA 2 (SA2) – FORMER UNITS 1-4 ASH BASIN (U1-4 AB)

Groundwater contains varying concentrations of naturally occurring inorganic constituents. Constituents in groundwater with sporadic and low concentrations greater than the corresponding standard (02L/IMAC/background value, as applicable) do not necessarily demonstrate horizontal or vertical distribution of COI-affected groundwater migration from the source area. Constituents with concentrations above corresponding standards were evaluated to determine if the level of concentration is present due to the source area. COIs are those constituents identified from the "constituent management process" described below and are specific to the source area, not the Site. This evaluation assists in identifying constituents and areas that warrant corrective action under G.S. Section 130A-309.211 and 15A NCAC 02L .0106.

A constituent management process was developed by Duke Energy at the request and acceptance of NCDEQ (NCDEQ letter dated October 24, 2019, **Appendix A**), to gain a thorough understanding of constituent behavior and distribution in site groundwater and to aid in identifying COIs that warrant corrective action. The constituent management process consists of three steps:

1. Perform a detailed review of the applicable regulatory requirements under NCAC, Title 15A, Subchapter 02L
2. Understand the potential mobility of source-related constituents in groundwater based on Site hydrogeology and geochemical conditions
3. Determine the constituent distribution at the source area under current and predicted future conditions

This constituent management process is supported by multiple lines of evidence including empirical data collected at the site, geochemical modeling, and groundwater flow and transport modeling. The management process uses a matrix evaluation to identify those constituents that have migrated downgradient of the source unit, in the direction of groundwater flow at concentrations greater than 02L standards/IMAC/background value with a discernable plume. The matrix evaluation considers the following per constituent:

- Regulatory criteria,
- Site and Piedmont background values,
- Maximum mean constituent concentrations,
- Exceedance ratios,

- Number and distribution of wells at or beyond the compliance boundary with constituent concentrations greater than criterion,
- constituent presence in ash pore water at concentrations greater than criterion, and
- constituent geochemical mobility

This approach has been used to identify specific COIs that have migrated from the U1-4 AB that require corrective action. The results of the constituent management process (described in detail in **Section 6.10.3**) identify 11 groundwater COIs for the Cliffside U1-4 AB: arsenic, boron, cobalt, iron, lithium, manganese, radium (total), strontium, sulfate, TDS, and vanadium.

Data indicate unsaturated soil COI concentrations are generally consistent with background concentrations or are less than regulatory screening values. In the few instances where unsaturated soil COI concentrations are greater than PSRG POG standards or background values, COI concentrations are within range of background dataset concentrations or there are no mechanisms by which the COI could have been transported from the U1-4 AB to the unsaturated soils, therefore, no soil COIs were identified for the Cliffside U1-4 AB.

6.10 Source Area 2 (SA2) Extent of Constituent Distribution

This section provides an in-depth review of constituent characteristics associated with source area 2 (former Units 1-4 ash basin) and the mobility, distribution and extent of constituent migration within, at, and beyond the point of compliance.

6.10.1 Source Material within the Waste Boundary

(CAP Content Section 6.A.a)

The U1-4 AB waste boundary is shown in **Figure 1-2**. An overview of the material within the U1-4 AB is presented in the following subsections.

6.10.1.1 Description of Waste Material and History of Placement

(CAP Content Section 6.A.a.i)

The U1-4 AB (**Figure 1-2**), constructed in 1957, began receiving fly ash and bottom ash from Units 1-4. The U1-4 AB consisted of a single impoundment created with the construction of an earth fill embankment dam (State ID CLEVE-047) located on the north and northeast sides of the basin between the U1-4 AB and the Broad River. The basin encompassed approximately 14.5 acres. Sending fly ash and bottom ash to the U1-4 AB

ceased in 1977 when the basin reached capacity and the impounded ash material was capped with a soil cover approximately 2 feet thick. The western portions of the ash basin were formerly converted into holding cells for storm and plant process water. Water from those holding cells was pumped to the AAB to the east.

Excavation of the CCR historically deposited in the basin began in October 2015 and concluded in February 2018. Approximately 450,000 tons of ash were excavated from the U1-4 AB and placed in the lined CSS CCP Landfill. An LRB and wastewater treatment plant were constructed within the U1-4 AB footprint and began operating on March 31, 2019.

6.10.1.2 Specific Waste Characteristics of Source Material

(CAP Content Section 6.A.a.ii)

Source characterization was performed through the completion of soil borings, installation of monitoring wells, and collection and analysis of associated solid matrix and aqueous samples. Source characterization was performed to identify the physical and chemical properties of the ash in the source areas. The source characterization involved determining physical properties of ash, identifying the constituents present in ash, measuring concentrations of constituents in the ash pore water, and performing laboratory analyses to estimate constituent concentrations from leaching of ash.

Five ash samples were collected from borings at three well cluster locations (IB-2, IB-3, and IB-4) within the U1-4 AB waste boundary prior to excavation for chemical analyses (**Figure 1-2**). Ash was encountered in borings IB-1, IB-2, IB-3, and IB-4 at varying intervals. Ash was not observed in borings outside the U1-4 AB (prior to excavation) with the exception of the AAB, ASA, and the U5 AB.

The deposits of ash consisted of interbedded fine- to coarse-grained fly ash and bottom ash materials. Ash was generally described as gray to dark gray, non-plastic, loose to medium density, dry to wet, fine- to coarse-grained sandy silt texture. Physical properties analyses (grain size, specific gravity, and moisture content) were performed on three ash samples from the U1-4 AB using ASTM methods. Fly ash is generally characterized as a moderately dense silty fine sand or silt. Bottom ash, while not sampled from

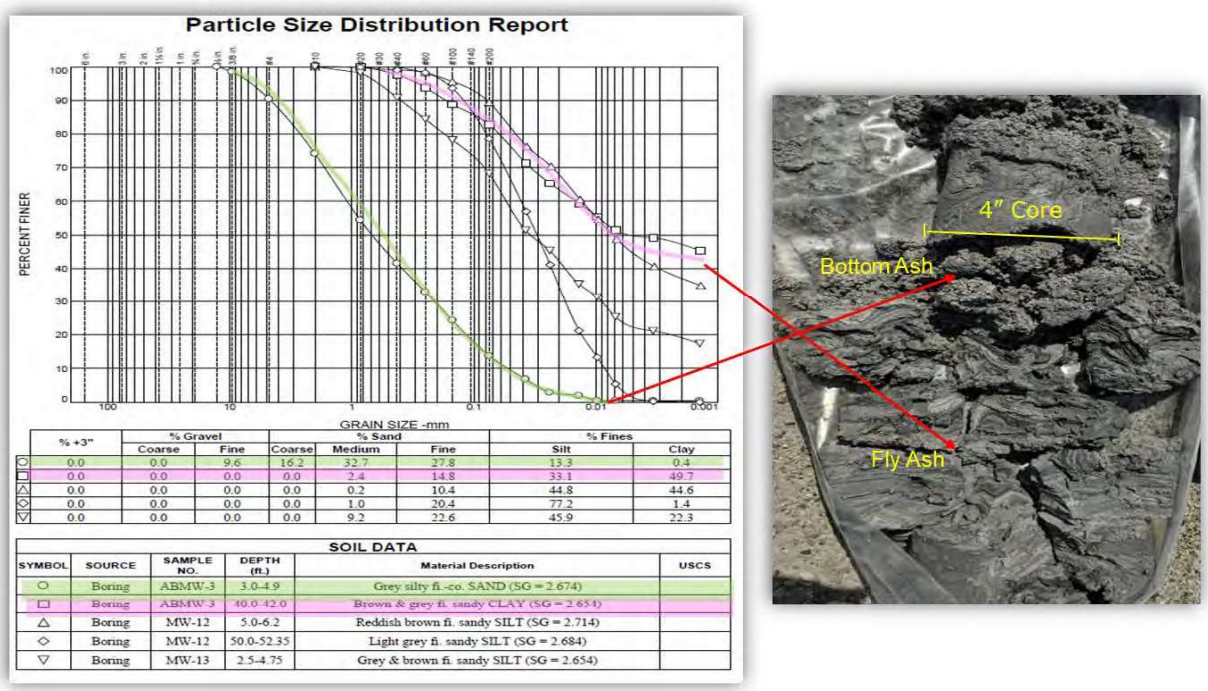
the Site, is generally characterized as loose, poorly graded (fine- to course-grained) sand.

Based on published literature not specific to the CSS site, the specific gravity of fly ash typically ranges from 2.1 to 2.9, and the specific gravity of bottom ash typically ranges from 2.3 to 3.0. The permeability of fly ash and bottom ash vary based on material density but would be within the range of sand gravel with similar gradation, grain size distribution, and density (EPRI, 1995).

Within an ash basin, ash typically contains interbedded layers of fly ash and bottom ash as a result of the varying rates and pathways of bottom ash and fly ash settlement. A depiction of the typical interbedded nature of fly ash and bottom ash within an ash basin, as seen from an ash boring photograph can be found below (**Figure 6-39**). Layers of bottom ash are typically more permeable than layers of fly ash due to the coarser grain size of bottom ash.

FIGURE 6-39

FLY ASH AND BOTTOM ASH INTERBEDDED DEPICTION



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	9.6	16.2	32.7	27.8	13.3	0.4
□	0.0	0.0	0.0	0.0	2.4	14.8	33.1	49.7
△	0.0	0.0	0.0	0.0	0.2	10.4	44.8	44.6
◇	0.0	0.0	0.0	0.0	1.0	20.4	77.2	1.4
▽	0.0	0.0	0.0	0.0	9.2	22.6	45.9	22.3

SOIL DATA

SYMBOL	SOURCE	SAMPLE NO.	DEPTH (ft.)	Material Description	USCS
○	Boring	ABMW-3	3.0-4.9	Grey silty fi.-co. SAND (SG = 2.674)	
□	Boring	ABMW-3	40.0-42.0	Brown & grey fi. sandy CLAY (SG = 2.654)	
△	Boring	MW-12	5.0-6.2	Reddish brown fi. sandy SILT (SG = 2.714)	
◇	Boring	MW-12	50.0-52.35	Light grey fi. sandy SILT (SG = 2.684)	
▽	Boring	MW-13	2.5-4.75	Grey & brown fi. sandy SILT (SG = 2.654)	

6.10.1.3 Volume and Physical Horizontal and Vertical Extent of Source Material

(CAP Content Section 6.A.a.iii)

Duke Energy decided to excavate the U1-4 AB fully. Excavation of the basin began in October 2015 and concluded in February 2018, with the exception of minor ash removal that continued at the interior slopes of the dam. Approximately 450,000 tons of ash and comingled soil material were removed from the basin and relocated in the existing lined CSS CCP Landfill. Based on topographic surveys, the maximum depth of CCRs within the U1-4 AB is estimated to have been approximately 35 feet. Volume and physical horizontal and vertical extent of ash material historically contained within the basin (prior to excavation) are presented in plan view on **Figures 1-2** and on cross-sections in **Figures 6-40** and **6-41**.

6.10.1.4 Volume and Physical Horizontal and Vertical Extent of Anticipated Saturated Source Material

(CAP Content Section 6.A.a.iv)

Excavation of the basin began in October 2015 and concluded in February 2018 with the exception of minor ash removal that occurred later at the interior slopes of the dam. There is no ash currently within the basin.

6.10.1.5 Saturated Ash and Groundwater

(CAP Content Section 6.A.a.v)

Layered ash within the U1-4 AB resulted in relatively low vertical hydraulic conductivity, reducing the potential for downward flow of pore water into underlying residual material. The CSM indicates that the flow-through ash basin system should result in low to non-detectable COI concentrations in groundwater underlying previously saturated ash within the basin except near the dam where downward vertical hydraulic gradients would have occurred. Boron is the CCR constituent most indicative of groundwater migration from the source area with a discernable COI plume pattern. Using boron data to indicate COI distribution potentially related to the U1-4 AB, the generalized flow-through system is consistent with Site-specific data as summarized in **Table 6-18**.

Of the six well locations within the U1-4 AB, all demonstrate minimal (<700 µg/l) to non-detectable boron concentrations consistent with the flow-through system, which suggests there is no correlation between the thickness of saturated ash and the underlying groundwater quality. Exceptions to the stream valley flow-through system exist at the U1-4 AB;

however, boron concentrations below the basin are still low. The U1-4 AB was not constructed in a former stream valley, rather in a low area along the Broad River. The well location with the highest boron concentrations detected below the basin is IB-2AL, a shallow well screened in coarse alluvial material acting as a preferential pathway for groundwater flow. The U1-4 AB has been excavated, therefore source removal has already occurred and overlying ash no longer exists.

A technical memorandum, titled *Saturated Ash Thickness and Underlying Groundwater Boron Concentrations – Allen, Belews Creek, Cliffside, Marshall, Mayo, and Roxboro Sites* (Arcadis, 2019), conducted linear regression analyses to evaluate the relationships between saturated ash thickness and concentrations of boron in ash pore water and underlying groundwater. The linear regression analysis was conducted using analytical data from Piedmont ash basins, including data from Cliffside.

The statistical evaluation was performed using a dataset which included 89 monitoring wells completed in shallow, transition, and bedrock groundwater zones directly beneath ash basins and 54 ash pore water monitoring wells completed in saturated ash. Linear regression results indicated that 87% of the groundwater monitoring locations below the saturated ash locations had boron groundwater concentrations less than the 02L standard. Exceptions to this relationship occur for select groundwater wells located near ash basin dikes and dams. This is due to the downward vertical hydraulic gradient in these areas, which enhances migration of COIs.

The analysis demonstrates saturated ash and ash pore water are not significantly contributing COI concentrations to underlying groundwater except near dikes and dams, where downward vertical gradients exist. The U1-4 AB has previously been excavated and therefore there is no thickness of saturated ash remaining in place have limited to no adverse effect on future groundwater quality.

6.10.1.6 Chemistry within Waste Boundary

(CAP Content Section 6.A.a.vi)

Analytical sampling results associated with material from within the U1-4 AB waste boundaries are included in the following appendix tables or appendices:

- Ash solid phase: **Appendix C**, Table 4 *(CAP Content Section 6.A.a.vi.1.1)*
- Ash synthetic precipitation leaching procedures (SPLP): **Appendix C**, Table 6 *(CAP Content Section 6.A.a.vi.1.2)*
- Ash Leaching Environmental Assessment Framework: **Appendix H,** Attachment C *(CAP Content Section 6.A.a.vi.1.3)*
- Soil: **Appendix C**, Table 4 (*CAP Content Section 6.A.a.vi 1.4*)
- Ash pore water: **Appendix C**, Table 1 *(CAP Content Section 6.A.a.vi.1.6)*

Ash Solid Phase and Synthetic Precipitation Leaching Potential

(CAP Content Section 6.A.a.vi.1.1 and 6.A.a.vi.1.2)

Ash samples collected inside the U1-4 AB waste boundary were analyzed for total extractable inorganic constituents using USEPA Methods 6010/6020. For information purposes, ash samples were compared with soil background values and PSRG POG. The ash analytical data do not represent soil conditions outside of or beneath the ash basin. Concentrations of arsenic, barium, boron, and selenium in ash samples were greater than background soil concentrations and PSRG POGs (**Appendix C**, Table 4).

In addition, two ash samples from the U1-4 AB were collected and analyzed for leachable inorganic constituents. The samples were processed using SPLP and Method 1312 (**Appendix C,** Table 6). The purpose of SPLP testing is to evaluate the potential for leaching of constituents that might result in concentrations greater than 02L standards or IMACs. SPLP analytical results are compared with the 02L or IMAC comparative values to evaluate potential source contribution; the data do not represent groundwater conditions. The results of the SPLP analysis indicated that concentrations of cobalt and manganese were greater than the 02L or IMAC comparative value in one of the two samples.

Ash Leaching Environmental Assessment Framework

(CAP Content Section 6.A.a.vi.1.3)

Ash samples were analyzed for extractable inorganics, including HFO/HAO, using the CBD method. Leaching studies of consolidated ash samples from the CSS ash basins were conducted using two LEAF tests,

EPA methods 1313 and 1316 (USEPA, 2012a, b). The data are presented and discussed in the Geochemical Modeling Report in **Appendix H,** Attachment C.

Leaching test results, using USEPA LEAF method 1316, indicate that, even for conservative COIs such as boron, the leachable concentration of boron present in ash from Cliffside is considerably lower than the total boron concentration (**Appendix H,** Attachment C). Cliffside data indicate that there is a process by which the COIs might become stable within the ash and would make the COI unavailable for leaching. The exact mechanisms of this process are unknown, however, literature suggests that incorporating COIs, such as boron, into the silicate mineral phases is a potential mechanism (Boyd, 2002). The leaching behavior of several COIs as a function of pH, examined using USEPA LEAF method 1313, demonstrated that for anionic COIs, the leaching increased with increasing pH and the cationic constituents showed the opposite trend (**Appendix H,** Attachment C).

Soil beneath Ash

(CAP Content Section 6.A.a.vi 1.4 and 6.A.a.vi 1.5)

Samples from soil collected within the the U1-4 AB waste boundary pre and post-excavation were analyzed to understand and vertically delineate COI concentrations in soil. Soil samples include samples collected from beneath the U1-4 AB and samples collected from the fill material within the U1-4 AB dam.

Constituents considered for soil evaluation were limited to constituents identified as COIs for the U1-4 AB since soil impacts would be related to the source areas interactions to the underlying soils and groundwater, which may migrate beyond the source area. The range of constituent concentrations in soils within the waste boundary, along with a comparison to soil background values and PSRG POG standards (NCDEQ May 2019), whichever is greater, is provided in **Appendix C**, Table 4.

For constituents lacking an established target concentration for soil remediation (*i.e.* sulfate), the following equation was used in general accordance with the references in 15A NCAC 02L.0202 to calculate a POG value.

$$C_{soil} = C_{gw}\,[k_d + (\theta_w + \theta_a H')/P_b]df$$

Where necessary, the PSRG POG values were calculated using laboratory testing and physical soil data for effective porosity (0.3) and dry bulk density (1.6 kg/L) prepared in part for flow and transport modeling for the Site. Soil water K_d were obtained from the *Groundwater Quality Signatures for Assessing Potential Impacts from Coal Combustion Product Leachate* (EPRI, 2012). Soil PSRG POG standard equation parameters and values used in the equation above are outlined on **Table 6-2**. The resulting PSRG POG calculated value for sulfate was 1,438 mg/kg (**Appendix C**, Table 4).

Soil samples were also collected from residual soils after the ash had been removed from the basin in general accordance with the *Excavation Soil Sampling Plan, Rogers Energy Complex, Units 1-4 Inactive Ash Basin for Ash Basin Excavation, North Carolina Ash Basin Closure* (Duke Energy, 2017). This soil sampling excavation plan was developed to satisfy the requirements presented in *CCR Surface Impoundment Closure Guidelines for Protection of Groundwater* (Zimmerman, 2016). Those samples have "S" prefixes, and their depth bgs (post ash excavation) is in the sample identification in parentheses. The samples were collected on a grid system from beneath the excavated basin. Two lined retention basins were planned and constructed in a portion of the footprint of the basin, so Scenario 1 soil sampling criteria from the referenced guidelines was applied for the S-100 series of samples located in those areas (discrete surface samples collected from the first 6 inches of soil only). The range of constituent concentrations in soils beneath the ash basin with a comparison to soil PSRG POG and BTVs is provided in **Appendix C**, Table 4.

Saturated soil and rock is considered a component of the groundwater flow system and can serve as a source for groundwater COIs at the Site. The potential leaching and sorption of constituents in the saturated zone is included in the flow and transport and geochemical model evaluations (**Appendix G** and **H**) by continuously tracking the COI concentrations over time in the saprolite, transition zone, and bedrock materials throughout the models. Historical transport models simulate the migration of COIs through the soil and rock from the ash basin, and these results are used as the starting concentrations for the predictive simulations.

Saturated soil samples with values reported greater than the PSRG for POG or background values are vertically delineated by groundwater constituent concentrations in the corresponding flow layer of the soil sample depth.

Unsaturated soil and rock is considered a potential secondary source to groundwater. Constituents present in unsaturated soil or partially saturated soil (vadose zone) have the potential to leach into the groundwater system if exposed to favorable geochemical conditions for chemical dissolution to occur. Constituent levels from unsaturated soil samples within the waste boundary were compared to PSRG for POG standards. Concentrations of arsenic, chromium, cobalt, iron, molybdenum, selenium, and thallium were greater than the PSRG for POG or BTV, whichever is greater. Analytical results for unsaturated soil data within the waste boundary can be found on **Table 6-19.** These soils have been partially capped in the locations of the lined retention basins.

The range of constituent concentrations in soils within the waste boundary, along with a comparison with soil background values, is provided in **Appendix C,** Table 4. Soil SPLP constituent concentrations within the waste boundary, along with a comparison to 02L standards/IMAC is provided in **Appendix C,** Table 6.

Ash Pore Water

(CAP Content Section 6.A.a.vi.1.6 and 6.A.a.vi.3)

The ash basins are wastewater treatment systems. Water within the ash basins is not groundwater; therefore, ash pore water isoconcentration maps are not prepared and comparison to 02L standards/IMAC/background values is for general information only. In ash pore water samples collected from wills within the U1-4 AB, arsenic, iron, manganese, sulfate, thallium, vanadium, and TDS were historically reported at concentrations greater than the 02L standard, IMAC, and/or background values in ash pore water collected from wells within the U1-4 AB prior to ash excavation.

Figures in previous CSS reports included ash pore water concentrations on isoconcentrations maps and cross-sections. Ash pore water concentrations are not included on updated cross-sections, as the source material has been removed. For further discussion of geochemical trends within the ash pore water see **Appendix H,** Section 2. All ash pore water sample locations are shown on **Figure 1-2,** and analytical results are provided in **Appendix C**, Table 1.

Ash Pore Water Piper Diagrams

(CAP Content Section 6.A.a.vi.2)

Piper diagrams can be used to differentiate water sources in hydrogeology (Domenico and Schwartz 1998). Piper diagrams of ash pore water monitoring data (**Figure 6-45**) are used to assess the relative abundance of major cations (*i.e.*, calcium, magnesium, potassium, and sodium) and major anions (*i.e.*, chloride, sulfate, bicarbonate, and carbonate) in groundwater. Data used for the piper diagrams include groundwater data between January 2018 and June 2019 and historical ash pore water data with a charge balance between -10 and 10%.

Ash pore water results tend to plot with higher proportions of sulfate, chloride, calcium, and magnesium, which is generally characteristic of ash pore water (EPRI, 2006). The area where ash pore water tends to plot on the piper diagram is identified as "affected" on **Figure 6-45.** One ash pore water sample (AB-4S-SL) plots in the "generally unaffected" area, which indicates that only general conclusions regarding impact to groundwater from the ash basin based on relative abundance of major cations and anions can be made. The ash pore water distribution results on the piper diagrams indicates that only general conclusions can be made regarding impact to groundwater from the ash basin based on relative abundance of major cations and anions can be made.

6.10.1.7 Other Potential Source Material

(CAP Content Section 6.A.a.vii)

No additional CCR source areas near the U1-4 AB are known with the exception of constituent contributions from the AAB flowing under Suck Creek and migrating towards the U1-4 AB. Potential non-ash source areas near the U1-4 AB include the coal pile, gypsum stack-out area, and of groundwater criteria exceedances reported in some of the monitoring wells east of Unit 6 and west of Suck Creek. These areas are being assessed on a separate timeline from the U1-4 AB, and a CSA report presenting the assessment results of these areas will be submitted under separate cover.

6.10.1.8 Interim Response Actions

(CAP Content Section 6.A.a.viii)

Duke Energy decided to fully excavate the U1-4 AB. Excavation of the basin began in October 2015 and concluded in February 2018, with the exception of minor ash quantities that were later removed from the interior slopes of the dam. Approximately 450,000 tons of ash and comingled soil

material was removed from the basin and relocated in the existing lined CSS CCP Landfill.

A LRB and WWTP were constructed within the U1-4 AB footprint and are operational. These structures act as a partial cover of the soil beneath the excavated U1-4 AB footprint. The LRB was lined with a dual liner system comprised of a textured HDPE geomembrane liner over a GCL. With the U1-4 AB source material removed and a partial cover within the former basin footprint, it is expected that groundwater constituent concentrations will decrease over time.

Pressure transducers were placed in select shallow flow zone monitoring wells (GWA-10S, GWA-11S, GWA-12S, GWA-14S, GWA-33S, and IB-3S) in the vicinity of the U1-4 AB to monitor water levels at 6-hour intervals during the excavation process. The transducers began monitoring water levels in November 2015, approximately one month after excavation began, and continued until August 2017. Water level data collected from the transducers demonstrated a general downward trend in water levels over time (during the excavation process) in most of the monitoring wells. More short-term water level fluctuations were observed in individual monitoring wells in response to fluctuating rainfall infiltration within the U1-4 AB during excavation. Also, samples were collected for field parameters analyses from GWA-11S and GWA-11BRU every 2 weeks during the excavation process. Additionally, quarterly sampling and analysis for a larger suite of parameters was also completed for BG-1BR, BG-1D, BG-1S, BG-2D, GWA-10D, GWA-10S, GWA-11BRU, GWA-11S, IB-1D, IB-1S, IB-3D, and IB-3S until excavation was completed. Results from the transducer monitoring and groundwater sampling were regularly submitted to NCDEQ. All of the information above was compiled into a summary spreadsheet for a final submittal to NCDEQ on August 21, 2017. The data showed no substantial change in geochemical conditions and COI concentrations during the excavation activities.

6.10.2 Extent of Constituent Migration beyond the Compliance Boundary

(CAP Content Section 6.A.b)

This section is an overview of constituent occurrences at or beyond the point of compliance. The point of compliance at the U1-4 AB is the ash basin compliance boundary. The compliance boundary for groundwater quality at the U1-4 AB is

defined in accordance with Subchapter 02L .0107(a) as being established at either 500 feet from the waste boundary or at the property boundary, whichever is closer to the waste (**Figure 1-2**).

Analytical sampling results associated with the source area: U1-4 AB for each media are included in the following tables and appendix tables:

- Soil: **Appendix C**, Table 4 and **Table 6-19** *(CAP Content Section 6.A.b.ii.1)*
- Groundwater: **Appendix C**, Table 1 and **Table 6-20** *(CAP Content Section 6.A.b.ii.2)*
- Seeps: **Appendix C**, Table 3 *(CAP Content Section 6.A.b.ii.3)*
- Surface water: **Appendix C**, Table 2 and **Appendix J** *(CAP Content Section 6.A.b.ii.4)*
- Sediment: **Appendix C**, Table 5 *(CAP Content Section 6.A.b.ii.5)*

Soil Constituent Extent

Data indicate unsaturated soil constituent concentrations at or beyond the compliance boundary are generally consistent with background concentrations or are less than regulatory screening values (**Table 6-19**). Horizontal and vertical extent of constituent concentrations in soil is discussed further in **Section 6.10.4**.

Groundwater Constituent Extent

The U1-4 AB compliance boundary extends 500 feet beyond the ash basin waste boundary, or to the property boundary, whichever is closer. Groundwater concentrations greater than 02L standard/IMAC/applicable background concentration values occur locally at or beyond the compliance boundary northeast of the U1-4 AB adjacent to the Broad River.

The maximum extent of COI-affected groundwater migration for all flow zones is represented by boron concentration greater than background values. The boron extent greater than background extends to the northeast of the U1-4 AB dam near the compliance boundary. Boron has not migrated to the southeast of the U1-4 AB. The Broad River downgradient of the basin is a groundwater discharge zone that limits the horizontal transport of constituents downgradient of the basin. Due to the limited presence and mobility of most constituents in the groundwater system, COI concentrations in groundwater have not caused, and will not cause, current surface water quality standards to be exceeded (**Appendix J**).

Arsenic, cobalt, iron, lithium, manganese, radium (total), sulfate, strontium, TDS, and vanadium, have concentrations greater than their respective groundwater regulatory standards at or near the compliance boundary. Of these constituents, all concentrations greater than regulatory standards are generally at locations where boron concentrations are greater than background values. The distribution of these constituents is confined within the extent of the boron plume greater than background concentrations, but not as widespread.

Section 6.10.3 includes a constituent management process for determining which groundwater constituents warrant corrective action, and **Section 6.10.4** provides isoconcentration maps and cross-sections depicting groundwater flow and constituent distribution and extent in groundwater *(CAP Content Section 6.A.b.i)*.

Seep Constituent Extent

Seeps at Cliffside are subject to the monitoring and evaluation requirements contained in the SOC. The SOC states that the effects from non-constructed seeps should be monitored. Attachment A to the SOC identifies the following seeps:

- Non-constructed seeps to be monitored — S-2, S-3, S-7, S-14, S-15, S-16, S-18, S-19, S-19A, S-21, S-23, S-27, S-28, S-29, S-30, S-31, S-32 and S-36.
- Non-constructed seeps dispositioned — S-1, S-5, S-8, S-9, S-10, S-11, S-12, S-13, S-17, S-20, S-22, S-24, S-25, S-26, S-33, S-34, and S-35.

The SOC defines dispositioned:

1. The seep is dry for at least three consecutive quarters;
2. The seep does not flow to waters of the State;
3. The coal ash basin no longer impacts the seep for all COIs over four consecutive sampling events;
4. An engineering solution has eliminated the seep.

Non-dispositioned seeps at the U1-4 AB, where monitoring conducted has indicated the presence of CCR affects, include: S-3 (**Figure 1-2**). **Table 6-23** provides a summary of seep general location and approximate flow rate. Analytical results for these seep samples are included in **Appendix C**, Table 3.

Surface water sampling conducted downstream of non-dispositioned seep S-3 from the Broad River, demonstrate that flow from this seep has not caused constituent concentrations greater than 02B standards in the river. Surface water

samples collected from the Broad River are shown on **Figure 1-2**. Surface water samples collected from the Broad River downstream of seep S-3 include SW-BRU14-1 and SW-BRU14-2. Analytical results for these surface water samples are included in **Appendix C**, Table 2.

Surface Water Constituent Extent

(CAP Content Section 6.A.b.ii.4)

Surface water samples have been collected from the Broad River and Suck Creek to confirm groundwater downgradient of the U1-4 AB has not resulted in surface water concentrations greater than 02B water quality standards. Surface water samples were collected to evaluate acute and chronic water quality values. Surface water samples were also collected at background locations (upgradient of potential migration areas) within the Broad River and Suck Creek. Analytical results were evaluated with respect to 02B water quality standards and background data. Surface water conditions is further discussed in **Section 6.11.1** and the full report for CSS surface water current conditions can be found in **Appendix J**.

Additionally, environmental assessments of the Broad River have all demonstrated that the river has been an environmentally healthy and functioning ecosystem, and ongoing sampling programs have been established to ensure the health of this system will continue. Furthermore, these data indicate that there have been no significant effects to the local aquatic systems related to coal ash constituents over the last 30 years. More information related environmental health assessments conducted for the Broad River, including sampling programs, water quality and fish community assessments, and fish tissue analysis, can be found in **Appendix E.**

Sediment Constituent Extent

(CAP Content Section 6.A.b.ii.5)

Most sediment sample locations are co-located with surface water or tributary stream seep sample locations (**Figure 1-2**). Similar to saturated soils and groundwater, sediment is considered a component of the surface water system, and the potential leaching and sorption of constituents in the saturated zone is related to water quality. Because no regulatory standards are established for sediment inorganic constituents, background sediment constituent concentration ranges are considered in this sediment evaluation. **Table 4-5** presents constituent ranges of background sediment data. Analytical results for all sediment samples are provided in **Appendix C,** Table 5**.**

Assessment of constituents in sediment in the vicinity of the U1-4 AB was conducted through evaluation of data from 12 one-time grab samples at Cliffside. Analytical results for sediment samples is provided in **Appendix C,** Table 5 (CAP Content Section 6.A.b.ii.5). Sample locations shown on **Figure 1-2** include:

- Three background locations along the bank of Suck Creek, the Broad River, and the Second Broad River
- Three locations along the banks of the Broad River downgradient of the U1-4 AB
- Six seeps downgradient of the U1-4 AB

Sediment results from samples collected at locations upstream of the ash basins (background data) were compared to results from samples collected at locations downstream of the U1-4 AB.

CLFSP-51, S-10, and S-11 have the greatest arsenic concentrations reported. These sample locations are likely showing influence from sediemtn deposition along the bank of the Broad River.

Chromium concentrations were above the detected background range in sediment from locations CLFSP-51, CLFTD-52, and S-10, however these concentrations are similar to levels detected in background sediment.

Cobalt concentrations were above the detected background range in sediment from locations CLFSP-51, CLFTD-52, S-3, and S-11, however these concentrations are similar to levels detected in background sediment.

Iron concentrations were above the detected background range in sediment from locations CLFSP-51, CLFTD-52, S-10, S-11, and SED-7, however these concentrations are similar to levels detected in background sediment.

Manganese concentrations were above the detected background range in sediment from locations CLFSP-51, S-10, and SED-7, however these concentrations are similar to levels detected in background sediment. Manganese in sediment collected at location S-11 was approximately 18 times the highest detected background value. These sample locations are likely showing influence from deposition along the river bank.

Molybdenum sediment concentrations exceeded the PSRG POG at four downgradient locations, CLFSP-51, CLFTD-52, S-10, and S-11. These sample locations are likely showing influence from deposition along the river bank.

The selenium sediment concentration at S-3 exceeded the background range for selenium, but selenium is not a groundwater COI at the U1-4 AB.

The thallium concentration in a sample from location SED-7 was above the detected background range, but is well within an order of magnitude. The presence of these COIs in sediment at concentrations greater than background values appears to be a condition of influence from deposition along the river bank or natural variability and do not require remediation.

A human health and ecological risk assessment pertaining to CSS was prepared and is included in **Appendix E**. The risk assessment focuses on the potential effects of CCR constituents from the Cliffside ash basins and ASA on groundwater, surface water, and sediment. The human health and ecological risk assessments demonstrated no measurable difference in modeled risks to potential human or ecological receptors compared with background concentrations. Based on this information, no COIs require remediation in sediments at the U1-4 AB.

6.10.2.1 Piper Diagrams

(CAP Content Section 6.A.b.iii)

Piper diagrams can be used to differentiate water sources in hydrogeology by assessing the relative abundance of major cations (*i.e.*, calcium, magnesium, potassium, and sodium) and major anions (*i.e.*, chloride, sulfate, bicarbonate, and carbonate) in water.

Groundwater Piper Diagrams

(CAP Content Section 6.A.a.vi.2)

Piper diagrams of groundwater monitoring data from shallow, deep and bedrock background locations and downgradient of the U1-4 AB are shown in **Figure 6-45.** Data used for the piper diagrams include groundwater data between January 2018 and June 2019 and historical ash pore water data with a charge balance between -10 and 10 percent.

- Background groundwater from each flow zone tends to plot central to the diagram indicating water quality is more balanced between major anions and cations. The area where background groundwater

(or native groundwater) tends to plot on the piper diagram is identified as "generally unaffected" on **Figure 6-45.**

- Shallow groundwater monitoring wells GWA-10S, GWA-11S, and CCR-IB-3S plot within the "affected (by ash pore water)" zone identified in the literature (EPRI, 2006) (**Figure 6-45**). Mean boron concentrations of samples from each will is greater than background values but less than the 02L standard, which supports that groundwater in these areas is affected by the source area (**Table 6-20**).
- Deep groundwater monitoring well CCR-IB-1D plots within the "generally affected" zone indicating water quality more similar to ash pore water than background groundwater (**Figure 6-45**). However, the mean concentration of boron is less than background in CCR-IB-1D (**Table 6-20**). Deep groundwater monitoring well GWA-11BRU plots in the region between the "generally affected" and "generally unaffected" zones of the piper diagram. This area is identified as a zone of "potential mixing" on **Figure 6-45.** The mean boron concentrations for GWA-11BRU is greater than background but less than the 02L standard, which supports that groundwater in these locations are affected by a source area.
- Bedrock groundwater monitoring well CCR-IB-3BR plots within the "affected" zone indicating water quality more similar to ash pore water than background groundwater (**Figure 6-45**). However, the mean concentration of boron is less than background in CCR-IB-3BR (**Table 6-20**). Bedrock groundwater monitoring well GWA-11BR plots in the region between the "generally affected" and "generally unaffected" zones of the piper diagram. This area is identified as a zone of "potential mixing" on **Figure 6-45.** The mean boron concentrations for GWA-11BR is greater than background but less than the 02L standard, which supports that groundwater in these locations are affected by a source area.
- The distribution results of ash pore water results on the piper diagrams in **Figure 6-45** indicate only general conclusions can be made regarding impact to groundwater from the ash basin based on relative abundance of major cations and anions.

Seep and Surface Water Piper Diagrams

Piper diagrams of seep, Broad River and Suck Creek surface water monitoring data are included on **Figure 6-57.** Data are used to assess the relative abundance of major cations (*i.e.*, calcium, magnesium, potassium, and sodium) and major anions (*i.e.*, chloride, sulfate, bicarbonate, and carbonate) in surface water. Data used for the piper diagrams include most recent available seep and surface water data (**Appendix C**, Table 2) with a charge balance between -10 and 10 percent. As discussed in **Section 6.10.**2, the distribution of ash pore water from the U1-4 AB on piper diagrams suggests that only general conclusions regarding potential impact to surface water from the U1-4 AB at Cliffside can be made (**Figure 6-57**). General observations from the seep and surface water piper diagrams include:

- All surface water sample locations plot together in a cluster in the "generally unaffected" zone (**Figure 6-57**). The background, upgradient, and downgradient samples are not distinguishable in their location on the piper diagram.
- Seep S-3 plots on the piper diagram in the "generally affected" zone. Seep S-10 plots in the "potential mixing" zone (**Figure 6-57**). Both of these seeps are immediately downgradient of the U1-4 AB. S-3 is covered by the SOC and S-10 has been dispositioned.

6.10.3 Constituents of Interest (COIs)

(CAP Content Section 6.A.c)

This CAP Update evaluates the extent of, and remedies for constituents associated with the U1-4 AB are at or beyond the compliance boundary to the northeast of the U1-4 AB detected at concentrations greater than 02L standards, IMACs, or background values, whichever is greater.

Site-specific COIs were developed by evaluating groundwater sampling results with respect at concentrations greater than regulatory criteria or background values, whichever is greater. The distribution of constituents in relation to the source area, co-occurrence with CCR indicator constituents, such as boron, and migration directions based on groundwater flow direction are considered in determination of COIs.

The following list of COIs was developed as part of the CSA Update for Cliffside (SynTerra, 2018):

- Arsenic
- Boron
- Chromium (Total)
- Chromium (Hexavalent)
- Cobalt
- Iron
- Manganese
- pH
- Total Uranium
- Total Radium
- Strontium
- Sulfate
- Total Dissolved Solids
- Thallium
- Vanadium

Soil

(CAP Content Section 6.A.c.i.1)

Unsaturated soil at or near the compliance boundary is considered a potential secondary source to groundwater. Constituents present in unsaturated soil or partially saturated soil (vadose zone) have the potential to leach into the groundwater system if exposed to favorable geochemical conditions for chemical dissolution to occur. Constituents considered for unsaturated soil evaluation were limited to constituents identified as COIs for the U1-4 AB since soil impacts would be related to past ash pore water interaction to the underlying soils within the basin and groundwater migration beyond the ash basin.

Data indicate unsaturated soil COI concentrations are generally consistent with background concentrations or are less than regulatory screening values (**Table 6-20**). In the few instances where unsaturated soil COI concentrations are greater than PSRG POG standards or background values, COI concentrations are within range of background dataset concentrations or there are no mechanisms by which the COI could have been transported from the ash basin to the unsaturated soils. Horizontal and vertical extent of COI concentrations in soil, and reasons why no necessary corrective action for soils is identified at the Site, is discussed further in **Section 6.10.4**.

Groundwater

(CAP Content Section 6.A.c.i.2)

A measure of central tendency analysis of groundwater COI data (January 2018 to June 2019) was conducted and means were calculated to support the analysis of groundwater conditions to provide a basis for defining the extent of the COI migration at or beyond the compliance boundary. A measure of central tendency analysis was completed to capture the appropriate measure of central tendency (arithmetic mean, geometric mean, or median) for each dataset of constituent concentrations. Constituent concentrations in a single well might vary over

orders of magnitude; therefore, a single sample result might not be an accurate representation of the concentrations observed over several months to years of groundwater monitoring. Evaluating COI plume geometries with central tendency data minimizes the potential for incorporating occasions where COIs are reported at concentrations outside of the typical concentration range, and potentially greater than enforceable groundwater standards. Previous Site assessments might have overrepresented areas affected by the ash basin by posting a single data set on maps and cross-sections that might have included isolated data anomalies.

NCDEQ (October 24, 2019; **Appendix A**) recommended use of a lower confidence limit (LCL95) rather than the central tendency value. LCL95 concentration were calculated for each COI. The LCL95 concentration for the sample with the highest COI LCL95 concentration is provided for comparison to the COI mean concentration in Table 1 of the technical memorandum titled *COI Management Plan Approach – Cliffside Steam Station* (Arcadis, 2019) included within **Appendix H**. The mean is typically higher than the LCL95 value, and therefore, is a more conservative approach for evaluation and comparison to applicable criteria.

The mean of up to six quarters of valid data was calculated for each identified COI to analyze groundwater conditions and define the extent of COI migration at or beyond the compliance boundary. At a minimum, four quarters of valid data were used for calculating means, however, if fewer than four quarters of valid data were available, the most recent valid sample result was reported. Less than four quarters of valid data were not available either because the well was recently installed or sample results from one or more quarters were excluded. For use in calculating means, non-detect values were assigned the laboratory reporting limit and estimated (J-flag) values were treated as the reported value. Procedures for excluding data from calculating means are based on USEPA's National Functional Guidelines (USEPA, 2017a, 2017b), published research about leaching of elements from coal combustion fly ash (Izquierdo, and others 2012), and professional judgement.

The following steps outline the approach followed in calculating central tendency values for constituent concentrations in groundwater:

1. If the maximum analytical value divided by the minimum value for each constituent was greater or equal to 10 (*i.e.* the data set ranges over an

order of magnitude), the geometric mean of the analytical values was used.

2. If the maximum analytical value divided by the minimum value for each constituent was less than 10 (*i.e.* the data set range is within an order of magnitude), the arithmetic mean is used.
3. The median of the data was used for records that contain zeros (e.g., total radium).
4. If the dataset mode (most common) is equal to the RL, and the geomean or mean value is less than or equal to the dataset's mode, the value is reported as "<RL" (e.g. the reporting limit for boron is 50 µg/L; for wells with geomean or mean analysis results less than 50 µg/L the mean analysis result would be shown as "<50").

Sample results were excluded from calculations for the following conditions:

- Duplicate sampling events for a given location and date. The parent (CAMA) sample was retained.
- Turbidity was greater than 10 NTUs
- Records where pH was greater than 10 S.U. Data with pH greater than 10 S.U. might be related to grout from well construction
- Data flagged as unusable (R0 qualified)
- Data reported as non-detect with a RL greater than the normal laboratory reporting limit
- Negative values for total radium were set equal to 0.

Table 6-20 presents the mean analysis results of the COI data using groundwater monitoring sampling results from January 2018 to June 2019. Where means could not be calculated, the most recent valid sample was evaluated to determine whether the sample result is an appropriate representation of the historical dataset. Data from **Table 6-20** are used in evaluating COI plume geometry in the vicinity of the U1-4 AB.

Constituent Management Approach

As discussed at the beginning of **Section 6**, a 'COI management process' was developed by Duke Energy at the request and acceptance of NCDEQ to gain understanding of the COI behavior and distribution in groundwater and to aid in selection of the appropriate remedial approach. Details of the COI

management approach are provided in **Appendix H.** In general, the COI management process consists of three steps:

1. Performing a detailed review of the applicable regulatory requirements under NCAC, Title 15A, Subchapter 02L,
2. Understand the potential mobility of site-related COIs in groundwater based on site hydrogeology and geochemical conditions,
3. Determine the constituent distribution at the U1-4 AB under current or predicted future conditions.

The management process uses a matrix evaluation [(**Table 6-21**) (CAP Content Section 6.A.c.i.2)].

The COI management process is supported by multiple lines of evidence including empirical data collected at the site, geochemical modeling, and groundwater flow and transport modeling. This approach has been used to understand and predict constituent behavior in the subsurface related to the U1-4 AB or constituents that are naturally occurring. Constituents that have migrated beyond the compliance boundary at concentrations greater than 02L, IMAC or background, and that are related to the source area would be subject to corrective action. Constituents that are naturally occurring at concentrations greater than the 02L standard or IMAC do not warrant corrective action.

Using the constituent management process, four of 14 inorganic groundwater COIs (not including pH) identified in the CSA Update (CSA Update, 2018), exhibit mean concentrations that are currently less than background values, 02L standard, or IMAC at or beyond the compliance boundary, or have few concentrations greater than comparison criteria but with no discernable plume characteristics. These four constituents include:

- Chromium (total)
- Hexavalent chromium
- Thallium
- Uranium (total)

These constituents are not expected to migrate distances at or beyond the compliance boundary or migrate distances that would present risk to potential receptors, and are predicted, based on geochemical modeling, to remain at stable concentrations, typically less than background values, 02L standard, or IMAC (**Appendix H**).

The remaining 10 inorganic groundwater COIs exhibit mean concentrations greater than background values, 02L standard, or IMAC downgradient of the U1-4 AB at or beyond the compliance boundary. These constituents are as follows:

- Arsenic
- Boron
- Cobalt
- Iron
- Manganese
- Strontium
- Sulfate
- Total Dissolved Solids (TDS)
- Total Radium
- Vanadium

Lithium has been added to the constituent list for the CSS U1-4 AB. Lithium was not previously analyzed for in collected groundwater samples until the second quarterly sampling event in 2018 (April 2018). This was after the submission of the CSA (CSA Update, 2018) and therefore lithium was not evaluated in that submittal.

As discussed in the CSA Update (SynTerra, 2018), not all constituents with results greater than background values can be attributed to the U1-4 AB. Naturally occurring groundwater contains varying concentrations of inorganic constituents. Sporadic and low-concentration occurrences of these constituents in the groundwater data do not necessarily demonstrate horizontal or vertical distribution of affected groundwater migration from the ash basin.

6.10.4 Horizontal and Vertical Extent of COIs

(CAP Content Section 6.A.d)

The COIs at the CSS have been delineated horizontally and vertically in groundwater based on sampling and analysis data collected from 292 monitoring wells present at the site. The majority of COIs are either present below their applicable standards, do not exhibit discernable plumes, or have migrated a limited distance from the ash basins in groundwater. Furthermore, an evaluation of site data indicates that COI presence in groundwater decreases with depth. Supporting information for these findings are presented in the COI management evaluation presented in **Section 6.10.3** and in **Appendix H**.

Boron, a conservative (non-reactive) constituent, is a key indicator of COI migration (COI-affected by the ash basin pore water) and COI plume characteristics associated with the ash basin. Boron typically has greater

concentrations in CCR than in native soil and is relatively soluble and mobile in groundwater (Chu et al., 2017). Additional constituent concentrations identified as being greater than their respective groundwater regulatory standards or background values, and are associated with COI-affected groundwater migration from the ash basin, are confined within the extent of the boron plume greater than background values at the Site. Non-conservative and variable constituents have smaller, and generally isolated, plume geometries relative to boron because of their high K_d values and reactivity, which reduce their mobility. Therefore, the maximum extent of the boron plume greater than its background value (50 µg/L) was used to determine the maximum extent of COI-affected groundwater migration.

Since naturally occurring COIs might be present at concentrations greater than Site-specific background values, isoconcentration maps of primary CCR indicator COIs (i.e., boron) are most representative of the groundwater COI plume extent in three-dimensional space. The horizontal extent of COI-affected groundwater migration in each flow layer is depicted on the boron isoconcentration maps (**Figures 6-47a/b/c**). The background boron plume generally represents the maximum extent of COI-affected groundwater migration in each flow layer.

Isoconcentration maps and cross-sections use groundwater analytical data to spatially and visually define areas where groundwater COI concentrations are greater than the respective constituent background values and/or 02L standard/IMAC. Geometric means of groundwater COI monitoring sampling results from January 2018 to June 2019 provide an understanding of groundwater flow dynamics and direction to define the current horizontal and vertical extent of the COI plume.

Horizontal extent of the COI plume is depicted on isoconcentration maps (**Figures 6-47a/b/c**). Non-conservative constituents, boron, sulfate and TDS, are mapped with empirical Site data and supplemented with flow and transport model simulated plume depictions where no data is available. For monitoring wells that were abandoned prior to 2018 (IB-1, IB-2, IB-3, and IB-4 well clusters), the data from the most recent valid sample event was considered when contouring a constituent's distribution.

Vertical extent of the COI plume at the U1-4 AB is depicted on two generalized cross-sectional depictions of the Site. Four cross-sections (B-B', C-C', G-G', and

H-H′) were prepared near the U1-4 AB for previous CSA and CAP reports. One of the cross-sections (B-B′) is oriented perpendicular to the flow direction through the U1-4 AB, and one cross-section (C-C′) provides similar information through the U1-4 AB as cross-section H-H′. Therefore, these cross-sections have limited use in depicting flow and COI transport and are not used in this CAP.

Two cross-sections (G-G′ and H-H′) are included in this CAP Update:

- Cross-section G-G′ (**Figure 6-40**) is oriented northwest to southeast and displays the U1-4 AB footprint, topography, and historical depth of saturated ash in the U1-4 AB (prior to excavation).
- Cross-section H-H′ (**Figure 6-41**) is oriented generally southwest to northeast from the southwestern end of the U1-4 AB, through the central portion of the basin, and to the Broad River to the northeast. Cross-section H-H′ displays the U1-4 AB footprint, topography, and historical depth of saturated ash in the U1-4 AB (prior to excavation).

At or beyond the compliance boundary, the maximum extent of COI-groundwater affected by the ash basin occurs northeast of the U1-4 AB dam, near the Broad River.

6.10.4.1 COIs in Unsaturated Soil

(CAP Content Section 6.A.d.i)

Unsaturated soil at or near the compliance boundary is considered a potential secondary source to groundwater. Constituents present in unsaturated soil or partially saturated soil (vadose zone) have the potential to leach into the groundwater system if exposed to favorable geochemical conditions for chemical dissolution to occur. Therefore, constituents considered for unsaturated soil evaluation as related to the U1-4 AB were the same constituents identified as COIs for the U1-4 AB.

Cliffside samples of background soil and rock media indicate that some naturally occurring constituents that are also typically related to CCR material and likely effect the chemistry of groundwater at the Site, are present at concentrations greater than the PSRGs POG values (**Table 4-2**). Constituents with background values greater than PSRGs POG values include arsenic, cobalt, iron, manganese, and thallium.

Unsaturated soil samples from locations at or beyond the U1-4 AB compliance boundary were collected during well installation activities from

wells GWA-10D, GWA-12BRU, GWA-13BR, and GWA-29D [**Figure 6-42** (*CAP Content Section 6.A.d.i*)]. COIs in saturated soil are considered and evaluted as part of the groundwater flow system, separate from this evaluation. An evaluation of the potential nature and extent of COIs in unsaturated soil at or beyond the U1-4 AB compliance boundary was conducted by comparing unstaurated soil concentrations with background values or PSRG POG standards, whichever is greater [**Table 6-19** (*CAP Content Section 6.A.d.i*)]. The PSRG POG standard for sulfate (1,438 mg/kg) was calculated (**Table 6-2**).

Constituents detected at concentrations greater than either background values or the PSRG POG standard, whichever is greater, in unsaturated soil samples (depth), upgradient or downgradient of the U1-4 AB, at or beyond the compliance boundary include:

- pH: GWA-10D (13.5-15)
- Arsenic: GWA-10D (13.5-15)

No necessary corrective action for soils is identified at the Site because there is no potential secondary source to groundwater from leaching of unsaturated soil constituent concentrations that are greater than either background values or the PSRG POG standard. Groundwater from the U1-4 AB primarily flows northeast towards the Broad River (**Figures 5-4a/b/c)**. While GWA-10D is downgradient of the U1-4 AB, it is unlikely the exceedances observed are derived from the basin due to a lack of transport mechanism. Arsenic concentrations observed at an approved background location upgradient of the U1-4 AB (BGSB- MW-32) are greater than concentrations observed at GWA-10D (**Table 6-19**).

6.10.4.2 Horizontal and Vertical Extent of Groundwater in Need of Restoration

(CAP Content Section 6.A.d.ii)

This section discusses the horizontal and vertical extent of groundwater in need of restoration northeast of the U1-4 AB. Groundwater is not in need of restoration adjacent to the U1-4 AB to the south, east, and west due to the lack of COIs above applicable standards in these areas. A limited number of COIs in groundwater are present near or at the compliance boundary to the northeast of the U1-4 AB. Additional detail for this area is provided below.

Northeastern Extent of COI-Affected Groundwater

Northeast of the U1-4 AB the COI plume at or beyond the compliance boundary is defined by arsenic, iron, lithium, manganese, strontium, and radium at concentrations greater than their comparison criteria. The COIs generally are located within the boron plume greater than background concentrations, which is used to describe the extent of COIs at or beyond the compliance boundary.

Mean analysis of boron in groundwater shows that the shallow flow layer extent of boron greater than the background value is greater than in the deep or bedrock, which is to be expected based on the CSM ash basin flow-through system. Boron greater than background values in the shallow flow layer extends the length of the U1-4 AB between the waste boundary and the Broad River. The deep and bedrock boron extents are limited in area and not present beneath the U1-4 AB with the exception of IB-4BR which had a historical boron result reported at 57 μg/L, slightly greater than the background value (50 μg/L). The boron extents greater than background values are presented on **Figures 6-47a/b/c**.

Mean concentrations near the compliance boundary support the following observations regarding the northeastern extent COI-affected by the ash basin groundwater:

- Cobalt, sulfate, TDS, and vanadium are reported at concentrations greater than their comparison criteria near the U1-4 AB compliance boundary in various flow layers. These are isolated exceedances and not part of a discernable plume from the U1-4 AB.
- Arsenic is reported at concentrations greater than the 02L standard at the U1-4 AB complaince boundary in the shallow flow layer at monitoring wells CCR-IB-3S and IB-7S. These exceedances appear to be from discernable plume from the basin (**Figure 6-46**). Arsenic is not reported at concentrations greater than the 02L standard in the deep or bedrock flow layers near the U1-4 AB compliance boundary.
- Iron has an exceedance of comparison criteria (background value) in an isolated location at the compliance boundary in the shallow flow layer at CCR-IB-3S. Iron exceedances of comparison criteria in the deep flow layer are reported at the U1-4 AB compliance boundary. These exceedances appear to be part of a discernable plume from the U1-4 AB (**Figures 6-49a/b/c**). Iron has an exceedance of comparison

criteria in an isolated location at the compliance boundary in the bedrock flow layer at CCR-IB-3BR.

- Lithium has exceedances of comparison criteria (background value) in the shallow and deep flow layers at the U1-4 AB compliance boundary. An isolated lithium exceedance is reported at the compliance boundary in the bedrock flow layer at monitoring well CCR-IB-3BR (**Figures 6-50a/b/c**).
- Manganese exceedances of the comparison criteria (background value) in the shallow and deep flow layers are reported at the U1-4 AB compliance boundary. These exceedances appear to be part of a discernable plume from the U1-4 AB (**Figures 6-51a/b/c**). An isolated manganese exceedance is reported near the compliance boundary in the bedrock flow layer at monitoring well CCR-IB-3BR.
- Strontium is reported greater than its comparison criteria at the compliance boundary in the shallow, deep, and bedrock flow layers northeast of the U1-4 AB (**Figures 6-52a/b/c**). Strontium concentrations greater than the statistically derived background values are common at the Site and often are not located in flow paths reflective of migration from the ash basins or ASA. Therefore, the natural variability of strontium may not be accurately reflected by the current background dataset. As part of the EMP, a five year review process is proposed which would include routine re-evaluation of background concentrations as additional data becomes available.
- Radium concentrations greater than the comparison criteria (background values) standard are reported in the shallow flow layer at the U1-4 AB beyond the compliance boundary. Radium is not reported greater than comparison criteria at the U1-4 AB compliance boundary in the deep flow layer to the northeast of the basin. An isolated radium exceedance of the comparison criteria is reported near the compliance boundary in the bedrock flow layer at monitoring well CCR-IB-3BR (**Figures 6-55a/b**).

6.10.5 COI Distribution in Groundwater

(CAP Content Section 6.A.e)

As part of the COI management process and geochemical modeling (**Appendix H**) constituents with concentrations greater than the 02L standard, IMAC, or

background values beyond the compliance boundary were grouped by geochemical behavior and mobility. A comprehensive evaluation (*i.e.* mean analysis and groupings) of available data was used to demonstrate constituent distribution in groundwater to evaluate the spatial occurrence with a discernable plume in the direction of groundwater flow downgradient of the U1-4 AB. The groupings of constituents that were mapped and are considered for corrective action are as follows:

- **Conservative, non-reactive constituents:** boron, lithium, sulfate, and TDS. Geochemical model simulations support that these constituents would transport conservatively (K_d values <1 L/kg) as soluble species under most conditions, and that the mobility of these COIs will not change significantly due to current geochemical conditions or potential geochemical changes related to remedial actions.
- **Non-conservative, reactive constituents:** arsenic, strontium, and vanadium. Geochemical model simulations support that these constituents are subject to significant attenuation in most cases and have high K_d values indicating the mobility of these COIs is unlikely to be geochemically affected by current geochemical conditions or potential geochemical changes related to remedial actions.
- **Variably reactive constituents:** cobalt, iron, manganese, and radium (total). Geochemical model simulations, and resulting K_d values, support these constituents may be non-reactive or reactive in relation to geochemical changes and are dependent on the pH and Eh of the system. The sensitivity of these COI to the groundwater pH and Eh indicates that these constituents could respond to natural changes under current conditions, such as water level fluctuations imposed by seasonality, and decanting or source control activities that have the potential to change the groundwater pH or E_h.

COIs identified in the CSA that are not mapped in this CAP Update generally not only have limited spatial occurrences within the compliance boundary, but are further spatially limited to isolated areas within the compliance boundary that do not have a discernable plume geometry.

6.10.5.1 Conservative Constituents

(CAP Content Section 6.A.e.i)

Boron, lithium, sulfate, and TDS mean isoconcentration maps (**Figures 6-47a/b/c, 6-50a/b/c, 6-53a/b, and 6-54**) and cross-sections (**Figures 6-43a** and

6-44a) support the following observations regarding the extent of COI-affected groundwater represented by these conservative constituents:

- Boron is not reported in the shallow, deep, or bedrock flow layers greater than the 02L standard at or beyond the U1-4 AB compliance boundary.
- Lithium is reported at the compliance boundary at concentrations greater than the comparison criteria (background values) in the shallow flow layer at CCR-IB-3S, IB-7S, and IB-6S, in the deep flow layer at CCR-IB-3D, GWA-11BRU, and IB-6D, and in the bedrock flow layer at CCR-IB-3BR. Lithium exceedances do not extend beyond the U1-4 AB compliance boundary due to the compliance boundary intersecting the Broad River northeast of the U1-4 AB.
- Sulfate is reported at the compliance boundary at a concentration greater than the 02L standard in the shallow flow layer at IB-6S. Sulfate exceedances of the 02L standard were not reported near or at the compliance boundary in the deep flow layer. Sulfate is reported at the compliance boundary at a concentration greater than the 02L standard in the bedrock flow layer at CCR-IB-3BR.
- TDS exceedances of the 02L standard were not reported near or at the compliance boundary in the shallow or deep flow layers. TDS is reported at the compliance boundary at a concentration greater than the 02L standard in the bedrock flow layer at CCR-IB-3BR.

The maximum extent of COI-affected groundwater migration for all flow zones is represented by boron greater than the background value. Arsenic, iron, lithium, manganese, strontium, and radium concentrations identified as being greater than their respective groundwater regulatory standards are associated with COI-affected groundwater migration from the ash basin but are generally confined within the extent of the boron background plume.

Plume Behavior and Stability

(CAP Content Section 6.A.e.i.1)

Mann-Kendall trend analysis was performed using conservative constituent datasets for ash pore water and groundwater wells within the waste boundary, between the waste boundary and compliance boundary, and downgradient the source area, at or beyond the compliance boundary (**Table 6-22**). Trend analysis and results are prepared by Arcadis U.S. Inc.

and included in a technical memorandum titled *Plume Stability Evaluation – Cliffside Steam Station* (Arcadis, 2019). The technical memorandum is included in **Appendix I** as Attachment A.

The analysis was performed using analytical results for samples collected from 2011 through 2019. Trend analysis results are presented where at least four samples were available and frequency of detection was greater than 50%. Statistically significant trends are reported at the 95% confidence level. The analysis of constituent concentrations through time produced six possible results:

1. Statistically significant, decreasing concentration trend (D)
2. Statistically significant, increasing concentration trend (I)
3. Greater than 50% of concentrations were non-detect (ND)
4. Insufficient number of samples to evaluate trend (n <4) (NE)
5. No significant trend, and variability is high (NT)
6. Stable. No significant trend, and variability is low (S)

Results of the Mann-Kendall trend analysis indicate the following:

Groundwater COI concentration trends with time were evaluated for 17 constituents for 20 wells for a total number of 340 trends. Trends that were not increasing accounted for 315 of the 340 trends evaluated (93% of total). Excluding trends that had greater than 50% non-detect values or insufficient number of valid samples to run a trend (n<4), 143 of 168 trends (85% of total) had statistically decreasing trends, stable trends, or no trends. These results demonstrate an overall decreasing to stable plume for constituents in groundwater at the U1-4 AB.

Statistically increasing trends account for 25 of 168 trends (15%) total. Most constituents with increasing constituent concentration trends also have decreasing constituent concentration trends (9 of 12 constituents with any increasing trend). Wells with increasing constituent concentrations and maximum concentrations >50% COI criterion are located within the planned area of corrective action for the U1-4 AB.

6.10.5.2 Non-Conservative Constituents

(CAP Content Section 6.A.e.ii)

Arsenic, strontium, and vandium isoconcentration maps (**Figures 6-46, 6-52a/b/c, and 6-55a/b**) and cross-sections (**Figures 6-43b** and **6-44b**) support the following observations regarding the extent of COI-affected groundwater represented by this non-conservative constituent:

- Arsenic exceedances of the 02L standard are reported in the shallow flow layer at the northern end of the U1-4 AB at and near the compliance boundary. Arsenic is not reported at the compliance boundary at a concentration greater than the 02L standard in the deep or bedrock flow layers.
- Strontium is reported at concentrations greater than comparison criteria (background value) at or beyond the compliance boundary in the shallow, deep, and bedrock flow layers. Strontium concentrations greater than the statistically derived background values are common at the Site and often are not located in flow paths reflective of migration from the ash basins or ASA. Therefore, the natural variability of strontium may not be accurately reflected by the current background dataset. As part of the EMP, a five year review process is proposed which would include routine re-evaluation of background concentrations as additional data becomes available.
- Vanadium is reported at concentrations greater than comparison criteria (background value) as an isolated exceedance near the compliance boundary in the shallow flow layer at monitoring well GWA-11S. Vanadium is reported at concentrations greater than comparison criteria as an isolated exceedance near the compliance boundary in the bedrock flow layer at monitoring well GWA-29BRA. Vanadium is not reported near the compliance boundary at a concentration greater than the comparison criteria the deep flow layer.

6.10.5.3 Variably Conservative Constituents

Cobalt, iron, manganese, and radium (total), isoconcentration maps (**Figures 6-48, 6-49a/b/c, 6-51a/b/c** and **6-66a/b**) and cross-sections (**Figures 6-43c** and **6-44c**) support the following observations regarding the extent of COI-affected groundwater represented by these variable constituents:

- Cobalt is reported at concentrations greater than comparison criteria (background value) at the compliance boundary in the bedrock flow layer at monitoring well CCR-IB-3BR. Cobalt is not reported at the compliance boundary at a concentration greater than the comparison criteria in the shallow or deep flow layers.
- Iron is reported at concentrations greater than comparison criteria (background value) at the compliance boundary in the shallow and bedrock flow layers at monitoring well cluster CCR-IB-3. Iron is reported greater than comparison criteria at or beyond the compliance boundary in the deep flow layer at IB-6D and CCR-IB-1D.
- Manganese is reported at concentrations greater than comparison criteria (background value) at the compliance boundary in the shallow flow layer along the length of the U1-4 AB, between the dam and the Broad River. Manganese is reported at concentrations greater than comparison criteria at the compliance boundary in the deep flow layer at monitoring wells GWA-11BRU and IB-6D. Manganese is reported at concentrations greater than comparison criteria at the compliance boundary in the bedrock flow layer at monitoring well CCR-IB-3BR.
- Radium (total) is not reported in the shallow flow layer at the U1-4 AB compliance boundary at a concentration greater than the comparison criteria (background value). Radium (total) is reported at concentrations greater than comparison criteria at the compliance boundary in the deep flow layer at monitoring wells GWA-11BRU and IB-6D. Radium (total) is reported at concentrations greater than comparison criteria at the compliance boundary in the bedrock flow layer at monitoring well CCR-IB-3BR.

6.11 SA2 Potential Receptors Associated with Source Area

(CAP Content Section 6.B)

CSA and ongoing monitoring data confirm that affected groundwater is located immediately downgradient of the U1-4 AB. COI-affected groundwater is limited to Duke Energy property. COI-affected groundwater from the U1-4 AB does not reach any water supply wells, and modeling indicates this will remain the case in the future. Therefore, potential receptors are limited to Suck Creek and the Broad River.

6.11.1 Surface Waters – Downgradient Within a 0.5-Mile Radius of Waste Boundary

(CAP Content Section 6.B.a)

A depiction of surface water features — including wetlands, ponds, unnamed tributaries, seeps, streams, lakes, and rivers — within a 0.5-mile radius of the ash basin compliance boundary, along with permitted outfalls under the NPDES and the SOC locations are shown on **Figure 5-10** (*CAP Content Section 6.B.a.i and6.B.a.ii*). The 0.5-mile radius from the ash basin compliance boundary, for which data is evaluated and depicted on figures, includes surface water features within 0.5-mile radius of the waste boundary. The U1-4 AB is located adjacent to the Broad River. Suck Creek is located to the east of the U1-4 AB. Associated North Carolina surface water classifications for the Broad River and Suck Creek are summarized in **Section 5.3.1** and **Table 5-3** (*CAP Content Section 6.B.a.iii*).

For groundwater corrective action to be implemented under 15A NCAC .02L .0106(k), groundwater discharge to surface water cannot result in exceedances of standards for surface waters contained in 15A NCAC 02B .0200 (02B). Surface water samples were collected from the Broad River and Suck Creek to confirm groundwater downgradient of the U1-4 AB has not resulted in surface water concentrations greater than 02B water quality standards. A map of surface water sample locations for groundwater discharge to surface water evaluation is included in **Appendix J** (*CAP Content Section 6.B.a.iv*). Surface water samples were collected, using division approved protocols, to evaluate acute and chronic water quality values. Surface water samples were also collected at background locations (upgradient of potential migration areas) within the Broad River and Suck Creek. Analytical results were evaluated with respect to 02B water quality standards and background data.

Comparisons of surface water data with the applicable USEPA National Recommended Water Quality Criteria for Protection of Aquatic Life, Human Health and/or Water Supply (USEPA, 2015; 2018a; 2018b) was conducted on surface water samples from the Broad River and Suck Creek. As stated by the USEPA, these criteria are not a regulation, nor do they impose a legally-binding requirement. Therefore, comparisons with these criteria are only for situational context. The constituents that have corresponding USEPA criteria but do not have 02B criteria are alkalinity, aluminum, antimony, iron and manganese. The background ranges reported in Suck Creek and the Broad River were greater than the USEPA criteria with the exception of antimony which was non-detect in surface water background location samples. Alkalinity had one result reported

greater than the background range at SW-8 during the June 2016 sampling event. The other nine sampling events at this location have had alkalinity results within the range of surface water background concentrations. Manganese was reported in Broad River sample locations SW-BRAB-1, SW-BRAB-2, and SW-BRAB-3 at concentration greater than the range of background values during the January 2017 sampling event and less than the range of background values during the June 2019 sampling event.

The surface water samples were collected in accordance with NCDEQ DWR Internal Technical Guidance: Evaluating Impacts to Surface Water from Discharging Groundwater Plumes - October 31, 2017. The full report for CSS groundwater discharge to surface water and the evaluation of surface waters to evaluate compliance with 15A NCAC 02B .0200 was submitted to NCDEQ in March 2017. A copy of the report is provided in **Appendix J**.

General findings of the evaluation of current surface water quality conditions at CSS include:

- Groundwater migration from the ash basin source area has not resulted in violations of the 15 NCAC 02B surface water quality standards in the Broad River.
- Groundwater migration from the ash basin source area has not resulted in violations of the 15 NCAC 02B surface water quality standards in the Suck Creek.
- Previously identified seeps are deemed covered by Special Order by Consent EMC SOC WQ S18-009 (SOC).

Surface Water - Future Conditions Evaluation

An evaluation of potential future groundwater migration to surface water was conducted to identify areas where further evaluation might be warranted. For areas of potential future groundwater migration to surface water, a mixing model approach was used for the evaluation of future surface water quality conditions. Flow and transport modeling results were used to determine where groundwater migration from the U1-4 AB might intersect surface water in the future. Predictive groundwater modeling using boron as a proxy for COI plume migration demonstrated the Broad River to the north of the U1-4 AB could potentially be influenced by future groundwater migration. A groundwater to surface water mixing model approach was used to determine the potential surface water quality in the future groundwater discharge zones. The full report

for CSS groundwater discharge to surface water under future conditions can be found in **Appendix J**.

General findings of the evaluation of future surface water conditions in potential groundwater discharge areas include:

- The surface water mixing model evaluation demonstrates that predicted constituent concentrations in surface waters are less than 02B surface water standards. Therefore, the criteria for compliance with 02B is met, allowing further evaluation of potential corrective action under 15A NCAC 02L.0106 (k), (l), or (m).
- Review of Site data and results from the flow and transport model indicate that affected groundwater migration would not reach Stream 12 on the west side of the Site.

Seeps currently governed by the SOC that remain and are not dispositioned 90 days after completion of decanting would be characterized for determination of corrective action applicability. Where applicable, and accounting for seep jurisdictional status, corrective action planning at that time would occur.

6.11.2 Water Supply Wells

(CAP Content Section 6.B.b)

A total of 71 private water supply wells were identified within the 0.5-mile radius of the pre-2018 ash basin compliance boundaries. Most of these water supply wells were located south, southeast, east, and northeast of the AAB off of McCraw Road, Prospect Church Road, Fox Place, and Riverfront Drive, west and southwest of the U5 AB along Duke Power Road, US-221A, and Old US-221A; and north of the Broad River (**Figure 5-12**). The 0.5-mile radius from the ash basin compliance boundary, for which data is evaluated and depicted on figures, is greater than the required 0.5-mile radius from the waste boundary and is consistent with the drinking water well and receptor surveys.

No public or private drinking water wells or wellhead protection areas were found to be located downgradient of the U1-4 AB as discussed in **Section 5.3**. This finding has been supported by field observations, a review of public records, historical groundwater flow direction data and groundwater flow and transport modeling (**Appendix G**). The location and information pertaining to water wells located upgradient or side-gradient of the facility, within 0.5-miles of the compliance boundary, were included in the survey reports.

6.11.2.1 Provision of Alternative Water Supply

(CAP Content Section 6.B.b.i)

Although results from local water supply well testing do not indicate effects from the source areas at CSS, owners of private water supply wells identified within the 0.5-mile radius of the pre-2018 compliance boundaries have been offered to be connected to an alternative water supply, per G.S. Section 130A-309.211(c1) requirements.

Duke Energy identified a total of 70 private residential properties eligible for connections to the public water supply near CSS. Eligibility was contingent that the property did not include:

- A business
- A church
- A school
- Connection to the public water supplier
- An empty lot

Of the 70 eligible connections, one opted out of the option to connect to the public water system and two did not respond to the offer. Duke Energy connected 65 occupied residences to the public water system, and two will be connected in the future in accordance with G.S. 130A-309.211(c1).

On September 5, 2018, Duke Energy provided completion documentation to NCDEQ to fulfill the requirements of House Bill 630. NCDEQ provided correspondence, dated October 12, 2018, to confirm that Duke Energy satisfactorily completed the alternative water supply provisions under CAMA G.S. 130A-3099.211(c1) at CSS. Both documents are provided in **Appendix D**.

Figure 5-12 shows the private water supply well locations with reference to properties connected to the public water supply, along with vacant parcels and residential properties whose owners have either decided to opt-out of the water treatment system program or did not respond to the offer. As discussed in **Section 5.0**, all of the private water supply wells are located either upgradient or side-gradient of the ash basins and all water supply wells are outside of the area of groundwater affected by ash basin.

6.11.2.2 Findings of Drinking Water Supply Well Surveys

(CAP Content Section 6.B.b.ii)

The location and information pertaining to water supply wells located upgradient or side-gradient of the facility, within 0.5 miles of the ash basin compliance boundaries, were included in drinking water supply well survey reports. Results from surveys conducted to identify potential receptors for groundwater, including public and private water supply wells and surface water features within a 0.5-mile radius of the pre-2018 ash basin compliance boundaries, have been reported to NCDEQ:

- *Drinking Water Well and Receptor Survey – Cliffside Steam Station* (HDR, 2014a)
- *Supplement to Drinking Water Well and Receptor Survey – Cliffside Steam Station* (HDR, 2014b)
- *Comprehensive Site Assessment Report – Cliffside Steam Station Ash Basin* (HDR, 2015a)
- *Draft Drinking Water Well and Receptor Survey – Cliffside Steam Station* (HDR, 2016b)
- Comprehensive Site Assessment Update Report – Cliffside Steam Station Ash Basins (SynTerra 2018a)

As documented in the 2018 CSA Update, NCDEQ arranged for independent analytical laboratories to collect and analyze water samples in 2014 and 2015 from private wells identified during the well survey, if the owner agreed to have their well sampled. NCDEQ collected and analyzed 32 groundwater samples from 23 private water supply wells within a 0.5 mile radius of the CSS pre-2018 ash basin compliance boundaries.

Duke Energy collected samples from private water supply wells in 2016 and 2017 after the NCDEQ sampling effort. For many of the wells sampled in this program, as with standard practice, samples were split for analysis by Duke Energy's certified (North Carolina Laboratory Certification #248) laboratory.

Table 6-9 (*CAP Content Section 6.B.b.ii*) provides tabulated results for the NCDENR and Duke Energy sampling results as well as identified exceedances of 02L standards, IMACs, and bedrock background values as well as a well-by-well summary of COI exceedances and characterization.

The exceedance evaluation compares bedrock background values since it is assumed area water supply wells are installed within the bedrock, which is typical for water supply wells in the Piedmont.

The major findings from the water supply well evaluation include:

- The nearest water supply wells to the U1-4 AB are northeast and northwest of the basin on the north side of the Broad River, not hydrologically connected to the basin (**Figure 5-12**).

6.11.3 Future Groundwater Use Areas

(CAP Content Section 6.B.c)

Duke Energy owns the land and controls the use of groundwater on the land downgradient of the U1-4 AB within and beyond the predicted area of potential groundwater COI influence. Therefore, no future groundwater use areas are anticipated downgradient of the ash basin.

It is anticipated that residences within a 0.5-mile radius of the ash basin compliance boundaries that are not connected to the municipal water system will continue to rely on groundwater resources for water supply for the foreseeable future [(**Figure 5-9** *(CAP Content Section 6.B.c.i)*].

Based on predicted groundwater flow patterns, under post ash basin closure conditions, and the location of water supply wells in the area, groundwater flow direction from the ash basin is expected to be continue to be to the northeast toward the Broad River, and therefore will not flow towards any water supply wells [(**Appendix G**) *(CAP Content Section 6.B.c.ii)*].

6.12 SA2 Human and Ecological Risks

(CAP Content Section 6.C)

Updated human health and ecological risk assessments were prepared for the CSS consistent with the CAP content guidance. The updated risk assessments incorporate results from surface water, sediments, and groundwater samples collected from March 2015 through June 2019. Primary conclusions of the risk assessment include:

(1) the ash basins do not cause an increase in risks to potential human receptors located on-Site or off-Site; and

(2) the ash basins do not cause an increase in risks to ecological receptors.

These conclusions are further supported by multiple water quality and biological assessments conducted by Duke Energy as part of the NDPES monitoring program. A more detailed discussion regarding human health and ecological risk associated with the ash basin can be found in **Section 5.4**. An update to the CSS human health and ecological risk assessment is included in **Appendix E**.

6.13 SA2 Groundwater Remedial Technologies

(Supplemental Information to CAP Content Section 6.D)

This section provides supplemental information beyond the CAP content guidance to introduce groundwater remediation technologies and consider a range of individual technologies that might be used to formulate comprehensive groundwater remediation alternatives for consideration at Cliffside. Groundwater remedial technologies are described in detail in **Section 6.4**.

6.13.1 Monitored Natural Attenuation

MNA will be retained for further consideration for source area 2 at Cliffside. Groundwater COIs do not pose an unacceptable risk to human health or the environment under conservative exposure scenarios. Furthermore, the U1-4 AB has been closed by excavating the ash. The concentration of COIs appear to be stable.

6.13.2 In-Situ Technologies

Groundwater remediation technologies that are implemented in-situ, or in place, are discussed here.

Low Permeability Barriers

The depth to bedrock is varies at downgradient of U1-4 AB from approximately 20 to 60 feet bgs. Therefore, construction of an effective LPB is potentially feasible. However, the source of COIs has been excavated and the concentrations of COIs appears to be stable. LPB technology will not be retained for further consideration.

Groundwater Flushing

The source of COIs has been excavated and the concentrations of COIs appear to be stable. Groundwater flushing will not be retained for further consideration.

Encapsulation

The source of COIs has been excavated and there is no concentration of COIs that would be treated effectively by encapsulation. Encapsulation will not be retained for further consideration.

Permeable Reactive Barrier

The source of COIs has been excavated and the concentrations of COIs appear to be stable. PRB technology will not be retained for further consideration.

6.13.3 Groundwater Extraction

Groundwater extraction is a technology often used when remediating mobile constituents in groundwater. Groundwater extraction can be used to withdraw affected groundwater from the subsurface for the purpose of reducing the mass of one or more target constituent(s) in an aquifer. Groundwater extraction can be used to hydraulically contain affected groundwater and mitigate groundwater constituent migration. Groundwater extraction can be conducted using a variety of methods that are discussed in the following sub-sections.

Vertical Extraction Wells

The source of COIs has been excavated and the concentrations of COIs appear to be stable. Vertical extraction wells are not retained for further consideration.

Horizontal/Angular Extraction Wells

The source of COIs has been excavated and the concentrations of COIs appear to be stable. Horizontal/angular extraction wells are not retained for further consideration.

Extraction Trenches

The source of COIs has been excavated and the concentrations of COIs appear to be stable. Extraction trenches are not retained for further consideration.

Hydraulic Fracturing

The use of hydraulic fracturing to enhance remediation of bedrock groundwater is not considered further because:

- The extent of COIs in bedrock groundwater is limited.
- COIs in bedrock groundwater might be addressed as effectively using more conventional means.

Phytoremediation

The source of COIs has been excavated and the concentrations of COIs appear to be stable. Groundwater extraction by TreeWells™ could act as a barrier to mitigate COIs to the Broad River. TreeWells™ are retained for further consideration.

6.13.4 Groundwater Treatment

The source of COIs has been excavated and the concentrations of COIs appear to be stable. No extraction of groundwater is anticipated in source area 2; therefore, no groundwater treatment will be retained for further evaluation.

6.13.5 Groundwater Management

The source of COIs has been excavated and the concentrations of COIs appear to be stable. Horizontal/angular extraction wells are not retained for further consideration. No groundwater extraction is anticipated in source area 2; therefore, no extracted groundwater management alternatives will be retained for further consideration.

6.14 SA2 Groundwater Remediation Alternatives

Technologies evaluated and retained for consideration as discussed in **Section 6.13** were used to formulate the following two groundwater remedial alternatives to remediate Site groundwater:

- Remedial Alternative 1: Monitored Natural Attenuation
- Remedial Alternative 2: Continued Monitoring with Phytoremediation and TreeWell™ Technology

These groundwater remedial alternatives are detailed in the following subsections.

6.14.1 Remedial Alternative 1 – Monitored Natural Attenuation

(CAP Content Section 6.D.a)

Alternative 1 is the use of MNA as a remedial alternative to address groundwater COIs. Excavation of the U1-4 AB began in October 2015 and was completed in February 2018.

The compliance boundary for the U1-4 AB is 500 feet beyond the boundary of the unit. However, the compliance boundary northeast of the U1-4 AB extends to the near bank of the Broad River. The Broad River acts as a hydrologic barrier and groundwater from the U1-4 AB discharges into the Broad River. Surface water samples collected from the near bank of the Broad River have been analyzed and found to comply with 02B standards. The Site has undergone the extensive hydrogeologic characterization necessary to evaluate natural attenuation processes and rates. Site-specific groundwater data including saturated media within the saprolite, transition zone, and bedrock flow zones have been collected for the MNA evaluation. A comprehensive analysis of MNA is provided in **Appendix I.**

6.14.1.1 Problem Statement and Remediation Goals

(CAP Content Section 6.D.a.i)

CCR constituents in groundwater associated with the Cliffside U1-4 AB occur near the compliance boundary at concentrations detected greater than applicable 02L standards, IMAC, or background values, whichever is greater. Remediation goals are to restore groundwater quality near the compliance boundary by returning COIs to acceptable concentrations (02L/IMAC or background, whichever is greater), or as closely thereto as is economically and technologically feasible consistent with 15A NCAC 02L. 0106(a).

In the future, alternative standards may be proposed as allowed under 02L.0106(k). This approach is considered reasonable given the documented lack of human health or ecological risk at Cliffside.

The Broad River acts as a hydrologic barrier to groundwater flow. Groundwater from U1-4 AB discharges into the Broad River. Surface water samples collected from the near bank of the Broad River have been analyzed and have been found to comply with 02B standards. Natural attenuation of constituents in groundwater has been protective of Broad River surface water and sediments.

The following groundwater COIs to be addressed by corrective action are identified and discussed in Section **6.10**: arsenic, boron, cobalt, iron, lithium, manganese, radium, strontium, sulfate, thallium, TDS, and vanadium.

The conceptual model and predictive modeling discussions summarize the foundations for development of Alternative 1. More extensive discussion of the CSM can be found in **Section 5.0**, discussion of flow and transport modeling in **Appendix G**, and discussion of geochemical modeling in **Appendix H.**

6.14.1.2 Conceptual Model

(CAP Content Section 6.D.a.ii)

Implementation of MNA at U1-4 AB would not change the conceptual site model (**Section 5**) because source control measures have been fully implemented and, with the exception of new MNA monitoring well installations, there would be no material changes proposed under Alternative 1.

A primary component of MNA as a remedial strategy is source control. Coal ash that was once buried at U1-4 AB has been excavated and placed in the onsite CCP Landfill. Consequently, U1-4 AB source control measures have been completed.

The following three chemical natural attenuation mechanisms are also an effective corrective action approach north and northwest of the Site because they aid in stabilizing control of reactive and variable reactive COI's in groundwater by the following processes:

- **Sorption**: Chemical attachment of electrochemically charged ions to charged receptors in the subsurface media
- **Precipitation:** Removal of a COI from a dissolved state in groundwater by incorporation into the matrix of a solid such as a mineral or an amorphous mass
- **Ion Exchange**: Incorporation of an ion into the crystal structure of a matrix mineral or amorphous solid

The following five physical natural attenuation mechanisms are an effective corrective action approach northeast of the U1-4 AB because they control the migration and distribution of all or some COIs, particularly boron, lithium, sulfate and TDS, in groundwater by the following processes:

- **Dilution**: Reduce COI concentrations through mixing with unaffected groundwater
- **Dispersion**: Reduce COI concentrations through variability of the flow velocity and concentration gradients
- **Transfer to surface water**: Reduce COI concentrations through mixing and flushing with surface water without exceeding 02B standards
- **Groundwater flow control within the stream valley system**: Control COI migration within hydraulic divide boundaries south, east and west of the ash basin
- **Phyto-attenuation:** Uptake of the COI by plants or organisms

More information on one or more effective natural attenuation mechanism for reducing the concentration of the COIs in groundwater can be found in **Appendix I**.

COIs in groundwater do not pose an unacceptable risk to human health or the environment under conservative exposure scenarios. If implemented, Groundwater Remedial Alternative 1 would not pose an unacceptable risk to human health or the environment in the future. Source control and groundwater monitoring would verify protection of human health and the environment and to confirm model predictions. The applicable technologies that would support this alternative include groundwater monitoring wells within the former source area and near the former waste boundary, along downgradient flow transects, at the point of compliance, in sentinel areas prior to receptors, and near the maximum predicted extent of migration.

MNA would involve the construction of one saprolite, one transition zone, and one bedrock groundwater monitoring well. Long-term MNA groundwater monitoring would be conducted at new MNA monitoring wells and at existing groundwater monitoring wells. The existing monitoring wells could be immediately used for monitoring the effectiveness of Alternative 1.

6.14.1.3 Predictive Modeling

(CAP Content Section 6.D.a.iii)

Predictive modeling has been conducted at locations where boron, a conservative and non-reactive constituent, is encroaching upon, or is beyond, the 500-foot compliance boundary. Specifically, flow and transport modeling to date has been calibrated to predict boron concentrations under future groundwater remediation scenarios. However, predictive modeling has not been conducted for the U1-4 AB area because boron concentrations in this area are less than the 02L standard. A flow and transport modeling report prepared for the Cliffside Site is presented in **Appendix G.** Similarly, a geochemical modeling report specific to Cliffside is presented in **Appendix H**.

According to the Technical Memorandum for the U1-4 AB (**Appendix G**), arsenic, boron, cobalt, iron, lithium, manganese, strontium, sulfate, TDS, and total radium have been detected in groundwater at concentrations greater than their applicable comparison criteria; however, not all COIs have a discernible plume and currently are not outside the compliance

boundary. According to the MNA Report for Cliffside (**Appendix I**), COIs that exhibit plume like characteristics associated with U1-4 AB are boron, strontium, sulfate, and TDS.

The MNA Report (**Appendix I**) for the U1-4 AB concluded the following:

- Arsenic concentrations in groundwater are greater than 02L standard beyond the waste boundary of the U1-4 AB (shallow). Geochemical modeling indicates that arsenic concentrations in groundwater would likely be less than 02L standard at the compliance boundary because the source has been excavated.
- Boron concentrations in groundwater are less than the 02L standard near the compliance boundary of U1-4 AB.
- Cobalt concentrations are greater than background values near the compliance boundary of the U1-4 AB (one location). Geochemical models predict that influent waters containing unaffected concentrations of cobalt will result in decreased downgradient cobalt concentrations over time after source removal.
- Iron concentrations greater than background values near the compliance boundary of the U1-4 AB. Physical attenuation (*i.e.,* dilution and dispersion) and persistence of oxidized conditions over a period of time would ultimately return the concentration of iron in groundwater to background conditions.
- Lithium concentrations are greater than background values. Geochemical models predict that influent waters containing unaffected concentrations of lithium will result in decreased downgradient lithium concentrations over time after source control.
- Manganese concentrations greater than the background values were identified near the compliance boundary. Geochemical models predict that influent waters containing unaffected concentrations of manganese will result in decreased downgradient manganese concentrations over time after source control.
- There are no 02L or IMAC constituent concentration standards for strontium. However, strontium concentrations are greater than the background values at wells located both upgradient and downgradient of U1-4 AB in all flow zones.

- Sulfate concentrations greater than the 02L standard were identified near the compliance boundary of the U1-4 AB. The geochemical model indicates that sulfate would decrease to less than 02L without the excavation of the ash. The model indicates that influent waters containing unaffected concentrations of sulfate will promote the dilution mechanism and decrease the sulfate concentration.
- Total radium concentrations greater than background values are identified near the compliance boundary of the U1-4 AB in shallow, deep or bedrock flow zone in four of fifteen monitoring wells.
- TDS are the total mass of material dissolved in a volume of water. Any attenuation mechanism that reduces the concentration of another COI will reduce TDS. TDS is not addressed beyond this point in the analysis.

6.14.2 Remedial Alternative 2 – Continued Monitoring With Phytoremediation and TreeWell™ Technology

(CAP Content Section 6.E.a)

Alternative 2 involves the use continued monitoring and phytoremediation and TreeWell™ technology downgradient of the former U1-4 AB for the purpose of extracting and treating underlying groundwater. Alternative 2 also includes the use of continued monitoring of groundwater in the vicinity of the U1-4 AB. Groundwater downgradient of the former U1-4 AB is compliant with North Carolina groundwater standards since the compliance boundary northeast of U1-4 AB extends to the near bank of the Broad River. Regardless, Groundwater Remedial Alternative 2 is considered for the continued protection of nearby Broad River surface water and sediment.

6.14.2.1 Problem Statement and Remediation Goals

(CAP Content Section 6.D.a.i)

CCR constituents in groundwater associated with the Cliffside U1-4 AB occur near the compliance boundary at concentrations detected greater than applicable 02L standards, IMAC, or background values, whichever is greater. Remediation goals are to restore groundwater quality near the compliance boundary by returning COIs to acceptable concentrations (02L/IMAC or background, whichever is greater), or as closely thereto as is economically and technologically feasible consistent with 15A NCAC 02L. 0106(a).

In the future, alternative standards may be proposed as allowed under 02L.0106(k). This approach is considered reasonable given the documented lack of human health or ecological risk at Cliffside.

The Broad River acts as a hydrologic barrier to groundwater flow. Groundwater from U1-4 AB discharges into the Broad River. Surface water and sediment samples collected from the near bank of the Broad River have been analyzed and have been found to comply with 02B standards. Natural attenuation of constituents in groundwater has been protective of Broad River surface water and sediments. Regardless, Groundwater Remedial Alternative 2 would supplement MNA and would be more protective of Broad River surface water and sediment adjacent to the U1-4 AB.

The following groundwater COIs to be addressed by corrective action are discussed in **Section 6.10**: arsenic, boron, cobalt, iron, lithium, manganese, radium, strontium, sulfate, thallium, TDS, and vanadium. Of these COIs which will be addressed by corrective action, sulfate and TDS are distributed in a plume-like geometry. Additionally, the concentrations of the COIs are stable; which indicates that natural attenuation combined with source removal maintains compliance. Groundwater extraction through TreeWell™ technology will provide protection of surface water when combined with MNA.

The conceptual model and predictive modeling discussions summarize the foundations for development of Alternative 1. More extensive discussion of the CSM can be found in **Section 5.0**, discussion of flow and transport modeling in **Appendix G**, and discussion of geochemical modeling in **Appendix H.**

6.14.2.2 Conceptual Model

(CAP Content Section 6.D.a.ii)

The applicable technologies that comprise Alternative 2 include:

- Approximately 280 trees and TreeWells™ spaced 20 ft. apart installed on approximately 2.5 acres of land situated between the U1-4 dam and the slope to the Broad River.

Remedial Alternative 2 would change certain aspects of the CSM (**Section 5**). Alternative 2 would extract groundwater and metabolize certain U1-4 AB COIs. Consequently, less groundwater from the U1-4 AB would

discharge to the Broad River and the mass of COIs in U1-4 AB groundwater would be reduced. The COIs most affected by groundwater extraction would be conservative COIs (boron, lithium, sulfate, and TDS) that are typically more soluble and mobile over a range of geochemical conditions when compared to non-conservative/reactive (arsenic and strontium) and variably reactive constituents (cobalt, iron, and manganese) (**Section 6.10.5**).

Currently, COIs in groundwater do not pose an unacceptable risk to human health or the environment under conservative exposure scenarios. If implemented, Groundwater Remedial Alternative 2 would not pose an unacceptable risk to human health or the environment.

6.14.2.3 Predictive Modeling

(CAP Content Section 6.D.a.iii)

The phytoremediation conceptual design by Geosyntec (2019) (**Figure 6-58a**), was applied to a numerical simulation under current conditions and a TreeWell™ unit is shown in **Figure 6-58b**. The area available for installation, northeast of the U1-4 AB, is approximately 2.56 acres and can accommodate approximately 285 TreeWell™ units. The entire TreeWell™ system would extract approximately 3.1 million gallons of groundwater per year upon maturity. The phytoremediation design was simulated by removing 3.1 million gallons of water per year from the treatment area. In the model, this water was removed from model layers representing the saprolite and the transition zone at a depth of 30-40 feet below ground surface. The computed heads with the TreeWells™ is shown in **Figure 6-58c**. The TreeWells™ reduce groundwater flow towards the River in this area by several million gallons per year. This removal of groundwater, coupled with the source removal that has already occurred, is expected to achieve compliance regulatory standards in the treatment area.

The combined groundwater extraction rate for this phytoremediation TreeWell™ system would vary based on seasonal variations and climatic circumstances such as humidity and availability of sunlight. By the third growing season, the rate of water uptake by the trees could be approximately 30 gallons per day per tree or approximately 3.1 million gallons per year (Geosyntec, 2019). The flow and transport report (**Appendix G**) and geochemical modeling report (**Appendix H)** provide detailed predictions, descriptions, and explanations of the effects of groundwater extraction.

Predictive modeling has been conducted at locations where boron, a conservative and non-reactive constituent, is encroaching upon, or is beyond, the 500-foot compliance boundary. Specifically, flow and transport modeling to date has been calibrated to predict boron concentrations under future groundwater remediation scenarios. However, predictive modeling of this remedial alternative has not been conducted in the U1-4 AB area because conservative constituent concentrations in this area are less than the 02L standard near the compliance boundary. Modeling of the hydraulic heads and particle tracking were done on this area (**Appendix G**).

Maximum mass removal from tree wells was also calculated for the conservative COIs that are mobilized geochemically. The COI concentration geometric means were calculated from model evaluation of TreeWells™ wells within the U1-4 AB and between the waste boundary and the compliance boundary. The COI geometric mean was then multiplied by the TreeWells™ removal rate of 3.1 million gallons of water per year to determine the maximum mass removal rate. The maximum mass removal rate for COIs ranges from 0.01 lbs/yr to 12 lbs/yr (**Appendix G).**

6.15 SA2 Remedial Alternative Screening Criteria

(Supplemental Information for CAP Content Section 6.D.a.iv)

This section provides supplemental information beyond the CAP content guidance to describe the screening criteria used to evaluate groundwater remediation alternatives at Cliffside.

As described further in this section, each groundwater remedial alternative formulated and discussed in **Section 6.14** has undergone detailed comparative analysis using the screening criterion described below. These screening criteria are based upon the criteria outlined in 15A NCAC 02L .0106(i), 40 CFR 300.430, and *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (USEPA, 1988). The screening criteria are as follows:

- Protection of human health and the environment
- Compliance with applicable regulations
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, and volume
- Short-term effectiveness at minimizing impact on the environment and local community

- Technical and logistical feasibility
- The time required to initiate and implement corrective action alternative
- Time required to achieve remediation goals
- Community acceptance

Additional considerations for remedial alternative evaluations include:

- Adaptive site management
- Sustainability

These screening criteria are discussed in detail in **Section 6.6**.

6.16 SA2 Detailed Analysis of Remedial Alternatives

Groundwater remedial Alternatives 1 and 2 formulated in **Section 6.14** will undergo detailed comparative analysis in the following subsections.

6.16.1 Groundwater Remedial Alternative 1 – MNA

A detailed description of groundwater remedial Alternative 1 (MNA) is presented in **Section 6.14.1**. Detailed analysis of groundwater remedial Alternative 1 is presented in the following subsections.

The ash was removed from U1-4 AB beginning in October 2015, and the excavation was completed in February 2018; therefore, the source of COIs in groundwater is gone. Concentrations of the COIs will be reduced as the COIs in the groundwater are attenuated.

The concentrations of COIs in monitoring wells near the compliance boundary appear stable. Sulfate, arsenic, cobalt, TDS, radium and vanadium have been detected in fewer than four of the fifteen wells near the compliance boundary for the U1-4 AB. Lithium, manganese, and strontium are detected in monitoring wells both upgradient and downgradient of the former ash basin. Only iron was found near the compliance boundary and not upgradient.

6.16.1.1 Protection of Human Health and the Environment

(CAP Content Section 6.D.a.iv.1)

Groundwater Remedial Alternative 1, MNA, is protective of human health and the environment. Groundwater COIs do not pose an unacceptable risk to potential receptors under conservative risk assessment exposure

scenarios (**Appendix E**). Alternative exposure scenarios are not anticipated as long as Duke Energy owns and controls the property where groundwater COIs exist and institutional controls (*e.g.*, 15A NCAC 02L) remain in place. Furthermore, the Broad River surface water immediately downgradient of U1-4 AB have been sampled and analyzed and found to comply with applicable 15A NCAC 02B standards (**Appendix J**). Consequently, MNA would be protective of human health and the environment.

6.16.1.2 Compliance with Applicable Regulations

(CAP Content Section 6.D.a.iv.2)

Alternative 1 can be fully implemented in compliance with all applicable laws and regulations. As it pertains to the selection of a groundwater remedy, the North Carolina Coal Ash Management Act 15A NCAC 13B .1636 states that the selected remedy will:

- Be protective of human health and the environment.
- Attain approved GWPS.
- Comply with standards for management of wastes as specified in Rule .1637(d).

As stated previously in the previous subsection MNA would be protective of human health and the environment. MNA would eventually satisfy GWPS while being protective of human health and the environment going forward. The only waste generated by MNA would be IDW such as soil cuttings during the installation of monitoring wells and purge water generated during groundwater sampling. IDW can be managed in compliance with applicable management standards.

Samples of the Broad River surface water downgradient of U1-4 AB have been sampled and analyzed and found to comply with applicable 15A NCAC 02B standards (**Appendix J**). Given the amount of dilution provided by surface water in the Broad River, there is no reason to expect that 15A NCAC 02B standards would not be satisfied in the future if MNA were implemented.

New MNA monitoring well installations must satisfy applicable requirements of NCAC Title 15A Subchapter 02C, Well Construction Standards, including 15A NCAC 02C .0108 (*Standards of Construction*) and 15A NCAC 02C .0112 (*Well Maintenance*).

Compliance with applicable regulations should not affect the implementability, effectiveness, or cost of Alternative 1.

6.16.1.3 Long-Term Effectiveness and Permanence

(CAP Content Section 6.D.a.iv.3)

Groundwater northeast of the U1-4 AB that is within the compliance boundary complies with the 02L standard. Regardless, the concentrations of groundwater COIs would decrease over time as a result of MNA mechanisms.

Groundwater monitoring wells might require repair or replacement following decades of groundwater monitoring. Repair or installation of a new replacement groundwater monitoring well should be a routine task

Coal ash constituents within the compliance boundary would not pose an unacceptable risk to human health since there would be no complete routes for potential exposure. Construction of water supply wells are prohibited within the compliance boundary of an individually permitted disposal system (15A NCAC 02L .0107 (d)). Groundwater monitoring would continue at the compliance boundary in accordance with 02L and at the waste boundary in accordance with the CCR Rule post-closure care requirements.

The magnitude of residual risk to human health and the environment is within acceptable levels prescribed by the USEPA. Institutional controls, including 15A NCAC 02L .0107(d), should restrict activities that could result in exposure to groundwater COIs.

6.16.1.4 Reduction of Toxicity, Mobility and Volume

(CAP Content Section 6.D.a.iv.4)

Any reductions in groundwater COI toxicity, mobility, and volume achieved under Groundwater Remedial Alternative 1 would occur as a consequence of natural occurring attenuation mechanisms. The mechanisms that naturally attenuate the concentrations of COIs are dilution, dispersion, advection, sorption (including ion exchange and precipitation) and phyto-attenuation, the uptake of COIs by plants.

These natural attenuation mechanisms would address some soluble COIs in groundwater. Reduction of conservative/non-reactive COI concentrations would most likely be achieved by way of non-reactive attenuation

mechanisms such as dispersion and dilution whereas reductions in non-conservative/reactive COIs would most likely be achieved by way of reactive attenuation mechanisms such as sorption, transformation, biological stabilization and chemical stabilization.

Natural attenuation of COIs would occur throughout the groundwater underlying the U1-4 AB. However, natural attenuation would be most effective at the leading edge of a constituent plume where sites for reactive natural attenuation mechanisms would be most plentiful. Reductions in COI concentrations would occur slowly relative to more aggressive groundwater remediation treatment technologies.

6.16.1.5 Short-Term Effectiveness

(CAP Content Section 6.D.a.iv.5)

Installation and sampling of the MNA monitoring network would not result in community exposure to groundwater. Therefore, implementation of MNA would be protective of private residences and communities near Cliffside. The installation of groundwater monitoring wells should not generate airborne dust emissions because all ash has been removed and a vegetative cover has since been established to stabilize U1-4 AB soils. Regardless, Duke Energy would have ample means of dust suppression in the unlikely event that dust generation becomes an issue.

Installation and sampling of groundwater monitoring wells are straight forward and routine tasks that can be conducted safely. Groundwater COIs do not pose an unacceptable risk to potential receptors under conservative risk assessment exposure scenarios (**Appendix E**). Regardless, remediation worker exposure to COIs in groundwater should be minimal since they would be wearing personal protective equipment (PPE) if there is the potential for exposure to COIs in U1-4 AB soil or groundwater.

6.16.1.6 Technical and Logistical Feasibility

(CAP Content Section 6.D.a.iv.6)

Groundwater Remediation Alternative 1 is technically feasible and readily implementable. Construction of Alternative 1 would involve the installation of 3 MNA groundwater monitoring wells; one MNA monitoring well would be screened in the shallow flow zone, one MNA monitoring well would be screened in the deep flow zone, and one MNA monitoring well would be screened in the bedrock flow zone. The wells would be installed to monitor constituent concentration trends. Installation of

groundwater monitoring wells is a routine task. It would involve a utility clearance of the area where monitoring wells would be installed. All groundwater monitoring wells would be installed by a licensed driller. Afterwards, each well installation would be surveyed for location and elevation. Material requirements, material availability, and the availability of specialized services (*e.g.,* licensed drillers, licensed surveyors) and labor are readily available. Implementation of MNA would not involve direct permitting. Once implemented, MNA would involve long-term groundwater monitoring and reporting. Otherwise, there are no "operations" associated with MNA.

MNA relies on natural attenuation processes which would provide reliable results as long as the geochemistry within U1-4 AB remains stable. For example, natural attenuation processes would reliably work once geochemistry equilibrium is achieved (*e.g.,* pH and ORP remain within a stable range). An MNA EMP would be developed to assess the effectiveness of Alternative 1 going forward.

6.16.1.7 Time Required to Initiate and Implement Corrective Action Alternatives

(CAP Content Section 6.D.a.iv.7)

The time required for implementation of an MNA program could be as immediate as approval of the approach since a monitoring well network already exists. MNA can be fully initiated because source control measures are completed.

6.16.1.8 Time Required to Achieve Remediation Goals

(CAP Content Section 6.D.a.iv.8)

Predictive modeling has been conducted at locations such as the AAB were boron, a conservative and non-reactive constituent, is encroaching upon, or is beyond, the 500-foot compliance boundary. Flow and transport modeling is calibrated to predict boron concentrations at locations within and beyond the 500-foot compliance boundary. However, predictive modeling has not been conducted at the U1-4 AB area because boron concentrations in this area are less than the 02L standard. A flow and transport modeling report prepared for the Site is presented in **Appendix G.** Similarly, a geochemical modeling report specific to the Site is presented in **Appendix H**.

6.16.1.9 Cost

(CAP Content Section 6.D.a.iv.9)

Estimated costs for the Cliffside U1-4 AB MNA program is based on capital costs for design and implementation including installation of groundwater monitoring wells. O&M costs include groundwater sampling, groundwater sample analysis, periodic reporting, redevelopment and replacement of some wells on an annual basis.

MNA capital costs would be significantly lower than capital costs associated with U1-4 AB Groundwater Remedial Alternative 2. Long term O&M costs for MNA can be significant but would generally be less than U1-4 AB Groundwater Remedial Alternative 2.

6.16.1.10 Community Acceptance

(CAP Content Section 6.D.a.iv.10)

Groundwater COIs do not pose an unacceptable risk to potential human or ecological receptors under conservative risk assessment exposure scenarios (**Appendix E**). These community stakeholders would take into account that the capital and near-term O&M costs associated with Groundwater Remediation Alternative 1 would be lower than the capital and O&M costs of Groundwater Remediation Alternative 2 when compared over identical time periods (*e.g.,* 30 years of operation).

6.16.1.11 Adaptive Site Management

Following full-scale implementation MNA, it would be important to evaluate Groundwater Remedial Alternative 1 performance. Following are potential metrics for critical evaluation of Alternative 1 performance:

- **Reevaluation of Tier 1:** Is actual COI removal meeting or exceeding predicted COI removal? Is actual COI removal changing as a consequence coal ash removal?
- **Reevaluation of Tiers 2 and 3:** Is the performance of predominant attenuation mechanisms meeting or exceeding predicted attenuation rates? Has the performance of predominant attenuation mechanisms changed since coal ash removal?
- **Reevaluation of Tier 3 – Is attenuation capacity is stable, over the long term:** Tier 3 should answer the question, "will current attenuation rates continue indefinitely?"
- Are COI plumes stable or declining?

- Would the mass flux of COIs cause exceedances of 15A NCAC 02L (2L) groundwater standards beyond the compliance boundaries?
- Would the mass flux of COIs cause exceedances of 15A NCAC 02B (2B) surface water standards?
- Has the predicted time frame to achieve groundwater remediation goals changed?

Groundwater Remedial Alternative 1 is readily amenable to modifications if it is later determined that MNA is an inadequate remedy or that supplemental initiatives, such as the addition of TreeWells™ could enhance MNA performance.

Groundwater Remedial Alternative 1 is readily amenable to contingencies. There is little that would preclude implementation of a completely different remedial approach following implementation of source control measures. For example, Groundwater Remedial Alternative 2 is a potential contingency if Groundwater Remedial Alternative 1 is determined to be inadequate.

6.16.1.12 Sustainability

Sustainability analysis was completed as described in **Section 6.6**. The environmental footprint was quantified based on energy use and associated emissions, during the construction phase (e.g., HDPE pipe length quantities and material transportation) and groundwater monitoring activities (e.g., transportation). The results of the environmental footprint calculations for MNA are summarized in **Table 6-26**. A summary of sustainability calculations for Alternative 1 can be found in **Appendix L**.

The environmental footprint of the MNA alternative is less energy-intensive but generally comparable to the required energy of Alternative 2. The MNA alternative provides more air emissions compared to Alternative 2. This occurs as a result of the carbon capture provided through photosynthetic activities of TreeWells™. The quantitative analysis of the environmental footprints of the remedial alternatives under consideration for this CAP indicates Alternative 1 to be the least sustainable option.

6.16.2 Groundwater Remedial Alternative 2: Continued Monitoring With Phytoremediation and TreeWell™ Technology

A detailed description of groundwater remedial Alternative 2 (Continued Monitoring with Phytoremediation and TreeWells™) is presented in **Section 6.14.2**. Detailed analysis of groundwater remedial Alternative 2 is presented in the following subsections.

6.16.2.1 Protection of Human Health and the Environment

(CAP Content Section 6.D.a.iv.1)

Groundwater Remedial Alternative 2 is protective of human health and the environment. Groundwater COIs do not pose an unacceptable risk to potential receptors under conservative risk assessment exposure scenarios (**Appendix E**). Alternative exposure scenarios are not anticipated as long as Duke Energy owns and controls the property where groundwater COIs exist and institutional controls (*e.g.*, 15A NCAC 02L) remain in place. Furthermore, the Broad River surface water immediately downgradient of the ash basins have been sampled and analyzed and comply with applicable 15A NCAC 02B standards (**Appendix J**). Additional provisions relating to the disposal of tree material would be provided in order to properly mitigate additional human or environmental contact with COIs stored in the trees. If implemented, Alternative 2 would be protective of human health and the environment.

The risk assessment (**Appendix E**) has determined that there are no imminent hazards to public health and safety or the environment associated with coal ash or coal ash constituents in Site soil and groundwater. Potential risks to human health and the environment are within acceptable levels prescribed by the USEPA. The effect of Groundwater Remedial Alternative 2 would be to achieve regulatory compliance in a shorter timeframe than MNA by reducing the mass and concentrations of COIs in U1-4 AB groundwater in a shorter timeframe.

6.16.2.2 Compliance with Applicable Regulations

(CAP Content Section 6.D.a.iv.2)

Alternative 2 can be implemented in compliance with applicable laws and regulations. Those regulations would include: CAMA, groundwater standards, clean water infiltration and extraction well installation and permitting.

As stated in the previous subsection, Alternative 2 would be protective of human health and the environment. Alternative 2 would satisfy GWPS. Waste generated by Alternative 2 would include IDW (*e.g.*, soil cuttings, purge water). IDW can be managed in compliance with applicable management standards.

A portion of the proposed active remediation area may be located within the 100-year floodplain. Installation of the TreeWells™ may require additional permitting. Receiving permit approval is likely due to the minimally invasive nature of the system.

Otherwise, compliance with applicable regulations should not affect the implementability, effectiveness, or cost of Alternative 2.

6.16.2.3 Long-Term Effectiveness and Permanence

(CAP Content Section 6.D.a.iv.3)

Flow and transport modeling indicates that implementation of Groundwater Remedial Alternative 2 and ongoing natural attenuation mechanisms, would permanently reduce the mass and concentrations of COIs as long as phytoremediation and the TreeWells™ are maintained and remain operational. Natural attenuation mechanisms would reduce COI mass and concentrations in the aquifer beyond the gains attributed to phytoremedation and TreeWell™ technology.

Coal ash constituents do not pose a risk to human health since there are no complete routes for potential exposure. Groundwater monitoring would continue in accordance with 02L.

The risk to human health and the environment is within acceptable levels prescribed by the USEPA. The risk to human health and the environment is also expected to decrease over time following implementation of Alternative 2. Performance monitoring would be conducted in accordance with 02L standard or the CCR rule post-closure care requirements. Institutional controls, including 15A NCAC 02L .0107(d), restrict activities that could result in exposure to groundwater COIs.

6.16.2.4 Reduction of Toxicity, Mobility and Volume

(CAP Content Section 6.D.a.iv.4)

Significant reductions in groundwater COI toxicity, mobility, and volume would be achieved through phytoremediation under Groundwater

Remedial Alternative 2. This would occur as a result of the removal of water and constituents by biological uptake through the tree roots. The effect of this would be a constituent mass and volume reduction as well as some hydraulic control exhibited by the uptake of groundwater that would reduce the mobility of aqueous constituents.

The constituents most amenable to extraction through phytoremediation are those that are conservative/non-reactive (*e.g.*, boron, lithium, sulfate, and TDS). The treatment via interactions with reactive media would have an effect on non-conservative/reactive constituents (*e.g.*, arsenic, chromium, cobalt, iron, and manganese).

In addition to the reductions of toxicity, mobility, and volume as a result of phytoremediation, natural attenuation would lead to reduction in toxicity and mobility through mechanisms in the subsurface impounding the constituents and converting them chemically to more benign forms.

Phytoremediation and TreeWell™ technology would be implemented downgradient of the U1-4 AB. Dissolved constituents within the uptake zone of TreeWell™ would be drawn toward a TreeWell™ and could be extracted. Consequently, the mass of constituents in groundwater would be reduced as a consequence of groundwater extraction.

TreeWells™ installed near the Broad River shoreline, might draw the Broad River surface water into the saprolite aquifer. This would have the effect of diluting the concentrations of soluble constituents in groundwater between the river shoreline and the phytoremediation system.

Groundwater underlying the ash basin footprint and beyond the capture zone of the TreeWells™ would be subject to the influences of natural attenuation. The mechanisms that naturally attenuate the concentrations of COIs are dilution, dispersion, advection, sorption (including ion exchange and precipitation) and phyto-attenuation, the uptake of COIs by plants.

However, natural attenuation mechanisms would be least effective where constituent concentrations are highest. For example, sites for adsorption of non-conservative/reactive and variably reactive constituents might be saturated. This would result in elevated concentrations of these constituents in groundwater until adsorption sites become available.

The volume of groundwater containing COIs at concentrations greater than standards would be reduced over a measurable timeframe. The system is assumed to continue to operate for the duration of the lifetime of the trees. Natural regenerative propagation processes in the vegetative area would produce additional trees which would allow the uptake of groundwater and constituents to continue indefinitely or until constituent mass has become effectively negligible.

Groundwater Remedial Alternative 2 would reduce the aerial extent of the COI plume in groundwater.

6.16.2.5 Short-Term Effectiveness

(CAP Content Section 6.D.a.iv.5)

Implementation of Groundwater Remedial Alternative 2 would be protective of private residences and communities adjacent to and near the CSS. The installation of TreeWells™ should not create dust or air emissions during implementation or system operation. Regardless, Duke Energy has ample means of dust suppression in the unlikely event of dust generation.

Installation of groundwater monitoring wells and TreeWells™ are straight forward tasks that can be conducted safely. Groundwater COIs do not pose an unacceptable risk to potential receptors under conservative risk assessment exposure scenarios (**Appendix E**). Regardless, remediation worker exposure to COIs in groundwater should be minimal since they would be wearing PPE if there is the potential for exposure to COIs in ash, soil, or groundwater.

Other potential environmental impacts that could occur during implementation of Groundwater Remedial Alternative 2 is accidental releases of vehicle fluids (*e.g.,* gasoline, oil, hydraulic fluid) or unearthed soils into the Broad River. Duke Energy diligently requires contractors to prepare and adhere to erosion and sediment control plans when conducting intrusive work activities. Likewise, Duke Energy strictly enforces secondary containment be placed under stationary heavy equipment (*e.g.,* drill rig) to capture and manage an accidental release of fluids.

Some effect of hydraulic capture of groundwater as a result of tree uptake of water would occur in the vicinity of the TreeWells™ shortly after the system is placed into service. The length of time between installation of the TreeWells™ and when measurable groundwater extraction would occur is

contingent upon uncontrollable environmental factors such as temperature, hours of sunlight each day, weather, humidity, tree growth, and tree maturity. When the extraction of groundwater begins, the advancement of a constituent plume would be slowed while biological groundwater extraction is sustained.

A pilot test would be performed prior to full scale implementation to evaluate technology effectiveness and predict phytoremediation and TreeWells™ technology performance going forward.

6.16.2.6 Technical and Logistical Feasibility

(CAP Content Section 6.D.a.iv.6)

Groundwater Remediation Alternative 2 is technically feasible and readily implementable. Construction of Alternative 2 would include:

- Boring of approximately 140 saprolite and 140 transition zone TreeWells™ 3 to 5 ft. in diameter.
- Installation of Root Sleeve™ liner
- Installation of aeration tubing
- Backfilling well borings with reactive media and soil
- Planting trees
- Placement of plastic cover over soil surrounding trees

All of these tasks are routine with respect to the maturity of technologies used, material requirements, material availability, and the availability of specialized services (*e.g.,* licensed drillers, phytoremediation consultants) and labor. Similarly, Alternative 2 is technically implementable with respect to the suitability and availability of TreeWell™ installation locations. The potential presence of threatened and endangered species in the vicinity of the proposed installation location represents a challenge to the feasibility of Alternative 2. Likewise, a portion of the proposed active remediation area lies within the 100-year floodplain. A survey of the area would confirm if the dwarf-flowered heartleaf, a known threatened and endangered plant species identified on the Site, is present. This survey combined with a detailed analysis of the 100-year floodplain would provide necessary information to appropriately adapt the layout to avoid these. If the layout cannot be adapted to avoid threatened and endangered species or the floodplain, the project may require additional permitting through the

United States Army Corp of Engineers in order to complete the necessary installation.

Considerations for dam safety and permitting would be built within the design and construction schedule. Installation of TreeWells™ is not proposed within the emergency spillway.

Other permits are not anticipated other than those associated with existing permits. When warranted, modifications to existing permits should be a straightforward process.

Implementation of Groundwater Remedial Alternative 2 can be achieved administratively. No administrative impediments to the alternative can be identified, largely as a result of the minimally invasive nature of this groundwater remedy.

An EMP would be developed to assess the effectiveness of Alternative 2 going forward.

6.16.2.7 Time Required to Initiate and Implement Corrective Action Alternative

(CAP Content Section 6.D.a.iv.7)

Groundwater extraction and treatment through phytoremediation and TreeWell™ technologies can be implemented following development of a design for phytoremediation and TreeWell™ technology. There are intervals of approximately 2 to 2.5 months in the spring and fall when planting of phytoremediation trees is optimal. Planting of phytoremediation trees during these intervals is recommended.

Preparation of the final design, preparation of bid documents, and submission of bid documents to prospective bidders could be accomplished in approximately 42 months following NCDEQ approval of the CAP. Full-scale operation of this groundwater remedial alternative could be accomplished within 42 months following the selection of a contractor.

6.16.2.8 Time Required To Achieve Remediation Goals

(CAP Content Section 6.D.a.iv.8)

Groundwater extraction treatment proposed under Alternative 2 can be implemented following bench scale and pilot testing different tree species being considered under site conditions.

The remedial goal of improving U1-4 AB groundwater quality would be achieved as soon as phytoremediation trees become established and begin withdrawing groundwater.

6.16.2.9 Cost

(CAP Content Section 6.D.a.iv.9)

Costs to implement the Cliffside U1-4 AB phytoremediation and TreeWell™ technology would include capital costs for design and implementation. Implementation would include bench scale testing, pilot testing, and installation of the phytoremediation and TreeWell™ system. O&M costs would include groundwater sampling, groundwater sample analysis, periodic reporting, redevelopment and replacement of some monitoring wells, tree fertilization, pruning, and replacement on an annual basis.

Cliffside U1-4 AB Groundwater Remedial Alternative 2 capital costs would be significantly higher than capital costs associated with U1-4 AB Groundwater Remedial Alternative 1. Long term O&M costs for Groundwater Remedial Alternative 2 would also be higher than long term O&M costs associated with U1-4 AB Groundwater Remedial Alternative 1.

6.16.2.10 Community Acceptance

(CAP Content Section 6.D.a.iv.10)

It is likely that community stakeholders are sufficiently familiar with the concept of trees extracting water from the ground. It is expected that the community stakeholders would not have significant concerns pertaining to the installation or operation of the phytoremediation system. Similarly, mitigating transport of untreated groundwater to the Broad River should be well received by some community stakeholders.

It is possible that some community stakeholders would have concerns regarding potential migration as a result of seasonal variability in vegetative uptake by the TreeWell™ system. Assurances would be made as to the natural attenuation processes occurring constantly regardless of any uptake of groundwater taking place, and that effectiveness monitoring would be in place to determine compliance and constituent migration. In addition, stakeholders concerns might be alleviated when they understand that groundwater underlying U1-4 AB currently do not pose an unnecessary risk to human health or the environment, do not result in 02B violations in receiving surface waters, and that remedial actions proposed under Alternative 2 would reduce potential risks further.

6.16.2.11 Adaptive Site Management and Remediation Considerations

Following full-scale implementation, it would be important to evaluate Groundwater Remedial Alternative 2 performance. The following are potential metrics and related questions regarding the critical evaluation of Alternative 2 performance:

- Conservative constituent trends – Are COI concentrations and the concentrations of other conservative constituents trending downward?
- Predictive modeling – How have modeling results changed since model refinement using post-implementation data?
- Constituent mass removal – Are constituent concentrations in extracted groundwater sufficient to achieve predicted mass removal?
- Remediation timeframe - Has the predicted time frame for achieving groundwater remediation goals changed?

Groundwater Remedial Alternative 2 is marginally amenable to modifications if it is later determined that operational changes could result in greater efficiencies or shorter remediation timeframes. For example, additional TreeWells™ could be installed to change the configuration and increase the phytoremediative groundwater extraction rate. Similarly, replacing one species of tree for a different species having greater potential for remedial benefits could be implemented in relatively short order without significant impact on remaining operations.

6.16.2.12 Sustainability

Sustainability analysis was completed as described in **Section 6.6.12**. The environmental footprint was quantified based on energy use and associated emissions, during the construction phase (e.g., material quantities and transportation), active remediation activities (e.g., groundwater pumping and treatment) and groundwater monitoring activities (e.g., transportation). The results of the environmental footprint calculations for Alternative 2 are summarized in **Table 6-26**. A summary of sustainability calculations for Alternative 2 can be found in **Appendix L**.

The environmental footprint of Alternative 2 is the more energy-intensive remedial alternative being considered. Alternative 1 (MNA) requires less materials and energy than Alternative 2 and is therefore characterized by a

smaller energy footprint. Alternative 2 presents lower air emissions footprint metrics when measured against Alternative 1 as a result of carbon capture by TreeWells™. The quantitative analysis of the environmental footprints of the remedial alternatives under consideration for this CAP indicates Alternative 2 to be the more sustainable option. Opportunities for system optimization and energy savings could be pursued throughout the remediation timeframe, as conditions change and component technologies possibly evolve.

6.17 SA2 Proposed Remedial Alternative Selected for Source Area

(CAP Content Section 6.E)

Groundwater Remediation Alternative 2, Continued Monitoring with Phytoremediation and TreeWell™ Technology, is the proposed groundwater remedial alternative. Alternative 2 is detailed in **Sections 6.14.2** and **6.16.2**. Rationale and details pertaining to selection of the proposed groundwater remediation alternative are presented in the following subsections.

6.17.1 Description of Proposed Remedial Alternative and Rationale for Selection

(CAP Content Section 6.E.a)

Groundwater Remediation Alternatives 1 and 2 are both protective of human health and the environment, would comply with applicable regulations, and are readily implementable. Groundwater Remediation Alternative 1, MNA, was not selected because COI concentrations would migrate with groundwater flow towards the Broad River and likely be discharged into the river. In contrast, Groundwater Remediation Alternative 2 is capable of extracting groundwater and removing certain constituents from groundwater. Groundwater extracted by phytoremediation trees and constituents metabolized by phytoremediation trees would not be able to discharge into the Broad River. While groundwater constituent concentrations at the U1-4 AB are within the compliance boundary and constituents in Broad River surface water and sediments are within 02B regulatory limits, efforts are being made to provide additional protections for the purpose of maintaining surface water quality in the Broad River.

The numerical model was recently updated using flow and transport models MODFLOW and MT3DMS for boron, sulfate, and TDS. Within the U1-4 AB arsenic, boron, cobalt, iron, lithium, manganese, strontium, sulfate, TDS, and total radium have been detected in groundwater at concentrations greater than their applicable comparison criteria; however, not all COIs have a discernible

plume and currently are not outside the compliance boundary. Boron is typically the COI selected to estimate the time to achieve compliance because it is mobile in groundwater and tends to have the largest extent of migration; however, the boron simulation predicts concentrations less than the 02L standard by 2021. Sulfate and TDS were also modeled because they are conservative COIs migrating from the basin footprint; however, simulations also predict that sulfate and TDS concentrations will be less than 02L standards by within two years. The less mobile, more geochemically controlled constituents (i.e., arsenic, cobalt, iron, manganese, and strontium) will follow the same flow path as that of boron, but to a lesser extent (**Appendix G**).

The full-scale implementation of Alternative 2 is recommended because phytoremediation and TreeWell™ technology would be more protective of Broad River surface water. Alternative 2 would address COIs between the U1-4 AB and the Broad River by extracting groundwater and constituents.

Predictive modeling has been conducted at locations where boron, a conservative and non-reactive constituent, is encroaching upon, or is beyond, the 500-foot compliance boundary. Specifically, flow and transport modeling to date has been calibrated to predict boron concentrations under future groundwater remediation scenarios. However, predictive modeling has not been conducted in the U1-4 AB area because boron concentrations in this area are less than the 02L standard. Modeling of hydraulic heads was completed for this area (**Appendix G**).

Maximum mass removal from tree wells was also calculated for the conservative COIs that are mobilized geochemically. The COI concentration means were calculated from monitoring Model Evaluation of TreeWells™ wells within the U1-4 AB and between the waste boundary and the compliance boundary. The COI means were then multiplied by the TreeWells™ removal rate of 3.1 million gallons of water per year to determine the maximum mass removal rate. The maximum mass removal rate for COIs ranges from 0.01 lbs/yr to 12 lbs/yr (**Appendix G**).

Proposed Alternative 2 is evaluated to be the most effective and cost efficient means to improve the quality of groundwater underlying former U1-4 AB. Proposed Groundwater Remediation Alternative 2 would mitigate the migration of groundwater COIs.

Seep Corrective Action

Non-dispositioned seeps, where monitoring conducted has indicated the presence of CCR affects (S-3), are evaluated for whether corrective action would be anticipated for the seep location, and if so, potential corrective action technologies that would be feasible for the location. The evaluation considers seep location, effects of decanting on seep thus far, approximate average flow rate, and predicted change in water elevations after decanting is complete from flow and transport model simulations. Potential correction action strategies for seep locations are included in **Table 6-23** and discussed herein.

As of November 2019, seep S-3 has not shown any visual reduction in flow and is not anticipated to, based on its location relative to AAB where decanting is occurring (**Figure 1-2**). This seep location is located north of the U1-4 AB in the area of the former outfall from the basin to the Broad River. Corrective action at this location may consist of capturing and treating the seep or other remedial actions. Final corrective action plans for seeps that are not dispositioned after completion of decanting will be proposed in an amendment to this CAP Update and submitted based on the schedule outlined in the SOC.

6.17.2 Design Details

(CAP Content Section 6.E.b)

Design of Groundwater Remediation Alternative 2 would require no predesign efforts. The design process would culminate in the preparation of a design package suitable for bidding and construction.

Basic aspects of the recommended alternative call for installation of design of the phytoremediation system and TreeWells™ consisting of 285 TreeWell™ units on the 2.65 acres near the Broad River downgradient of the U1-4 ash basins.

6.17.2.1 Process Flow Diagram and Major Design Components

(CAP Content Section 6.E.b.i)

The preliminary layout of TreeWellsTM is shown in **Figure 6-58a** and typical construction and implementation of phytoremediation and TreeWell™ technology is depicted in **Figure 6-58b**.

Site Preparation (STEP 1 – CREATE ACCESS)

(CAP Content Section 6.E.b.i)

Installation of the proposed groundwater extraction and infiltration systems would require significant efforts in planning, designing, and execution of

site preparation. However, with effective communications between the design, implementation and project management teams, successful construction of the system would be anticipated.

Land disturbance associated with construction of Alternative 2 includes:

- Some tree and brushy vegetation removal in areas where TreeWells™ would be installed.
- Borings for installation of the TreeWells™

A soil erosion and sedimentation control plan would be prepared to obtain a soil erosion and sedimentation control permit.

Finalize TreeWell™ System Design (STEP 2)

(CAP Content Section 6.E.b.i)
Review and revise layout of TreeWells ™.

Install TreeWell™ System (STEP 3)

(CAP Content Section 6.E.b.i)
Installation of the proposed TreeWells™.

Design Documents (STEP 4 – DETAILED DOCUMENTS)

(CAP Content Section 6.E.b.i)
The design package would provide the necessary plans and specifications for procurement of materials and construction purposes. This would include Site layout drawings, plans and profiles, materials and construction specifications.

System Operation and Maintenance

(CAP Content Section 6.E.b.i)
Phytoremediation and TreeWell™ performance would be monitored to determine performance and general health of the trees. Evapotranspiration rates would be tested using collection techniques and scaled appropriately to estimate the biological pumping rates of the phytoremediation system.

In addition to well performance monitoring, the system would receive routine maintenance in accordance with phytoremediation consultant and arborist recommendations.

6.17.2.2 Design Assumptions, Calculations, and Specifications

(CAP Content Section 6.E.b.ii)

Groundwater will not be treated during dormant periods. The dormant period associated with central North Carolina is assumed to last up to four-months. At the calculated groundwater velocity, the untreated "front" of the groundwater would move approximately 16 feet into the treatment zone and will not likely move through the zone untreated (Geosyntec Consultants, 2019).

TreeWell™ Design

TreeWells™ would be installed using a large diameter auger. The exact drilling method would depend on drill rig availability and Site conditions. All TreeWells™ would be 3 to 5 feet in diameter.

TreeWells™ would be constructed to a depth that corresponds to the target flow zone. Root Sleeve™ liners and aeration tubing would be installed. Backfill soil mixed with natural humic substances would be placed in the well in which a tree would be planted. Typical phytoremediation and TreeWell™ construction is presented in **Figure 6-58b**.

Additional design calculations are presented in Appendix N.

6.17.2.3 Permits for Remedy and Schedule

(CAP Content Section 6.E.b.iii)

Land disturbance permitting would likely be required. Other permits are not anticipated. The schedule for obtaining permits is based on the project implementation schedule discussed in **Section 6.17.7** and presented on **Figure 6-59**.

6.17.2.4 Schedule and Cost of Implementation

(CAP Content Section 6.E.e.iv)

The time to construct Groundwater Alternative 2 is estimated to be 42 months from CAP approval. Duke Energy would provide NCDEQ construction progress reports monthly from the beginning of construction until construction is complete.

Reporting would include:

- Health and Safety/Man Hours.

- Tasks completed for the month prior.
- Problems affecting schedule (*e.g.,* inclement weather).
- Measures taken to achieve construction milestones (*e.g.*, increase number of drilling crews).
- Contingencies.
- Tasks to be completed by next reporting period.
- Provide updated schedule/Gantt chart.

The cost estimate for this alternative is based on capital costs for design and implementation that includes bench scale testing, pilot testing and installation of tree wells. Long term O&M costs include groundwater monitoring costs, analytical costs, reporting costs, periodic redevelopment and replacement of monitoring wells, and periodic replacing of phytoremediation trees, tree fertilization, and pruning.

A detailed cost estimate for this Alternative is provided in **Appendix K**. The cost estimate is based on capital costs for design and implementation, and the operations, maintenance (O&M) and monitoring costs. The design costs include work plans, design documents and reports necessary for implementation of the alternative. Implementation costs include procurement and construction. O&M costs are based on annual routine labor, materials and equipment to effectively conduct monitoring, routine annual and 5-year reporting, and routine and non-routine maintenance costs.

6.17.2.5 Measure to Ensure Health and Safety

(CAP Content Section 6.E.b.v)

There is no measurable difference between evaluated Site risks and risks indicated by background concentrations; therefore, no material increases in risks to human health related to the ash basin have been identified. The groundwater corrective action is being planned to address regulatory requirements. The risk assessment identified no current human health or ecological risk associated with groundwater downgradient of the ash basin. Water supply wells are located upgradient of the ash basins and municipal water connections have been provided to those who selected this option. Surface water quality standards downgradient of the constituent affected groundwater are also met. Based on the absence of receptors, it is

anticipated that groundwater extraction would create conditions that continue to be protective of human health and the environment because the COI concentrations will diminish with time.

6.17.3 Requirements for Monitored Natural Attenuation

A stand-alone MNA report addressing this requirement for Cliffside is included as **Appendix I.**

6.17.4 Requirements for 02L .0106(k) – Alternate Standards

(CAP Content Section 6.E.d)

Regulation 02L .0106(k), states that a request may be made for approval of a corrective action plan that uses standards other than the 02L groundwater quality standards. G.S. Section 130A, Article 9, Part 8 allows risk-based remediation as a clean-up option where the use of remedial actions and land use controls can manage properties safely for intended use. Risk-based corrective action is where constituent concentrations are remediated to an alternative standard based on the actual posed risks rather than applicable background-levels or regulatory standards. The requirements for implementing corrective action by remediating to alternate standards, under 02L .0106(k), are as follows:

- *Sources are removed or controlled;*
- *Time and direction of contaminant travel can be predicted with reasonable certainty;*
- *COIs have and will not migrate onto adjacent properties unless specific conditions are met (i.e., alternative water sources, written property owner approval, etc.);*
- *Standards specified in Rule .0202 of this Subchapter will be met at a location no closer than one year time of travel upgradient of an existing or foreseeable receptor, based on travel time and the natural attenuation capacity of subsurface materials or on a physical barrier to groundwater migration that exists or will be installed by the person making the request;*
- *If contaminant plume is expected to intercept surface waters, the groundwater discharge will not possess contaminant concentrations that would result in violations of standards for surface waters contained in 15A NCAC 02B .0200;*
- *Public notice of the request has been provided in accordance with Rule .0114(b) of this Section; and*

- *Proposed corrective action plan would be consistent with all other environmental laws*

The alternative groundwater clean-up values may be used to aid in risk management decisions at Cliffside. This approach is particularly useful at complex sites where changes in site conditions may require an extended period of time or where NCDEQ approves alternate groundwater standards for COIs, such as 4,000 µg/l for boron, pursuant to its authority under G.S. Section 15A NCAC 02L .0106(k).

6.17.5 Sampling and Reporting

(CAP Content Section 6.E.e)

An EMP has been developed as part of this CAP Update consistent with 02L. 0106(h)(4). The EMP is designed to monitor groundwater conditions at Cliffside and document progress towards the remedial objectives over time. This plan is designed to be adaptive over the project life cycle and can be modified as the groundwater remediation system design is prepared, completed, or evaluated for termination.

Duke Energy implemented an IMP that was submitted to NCDEQ on December 21, 2018 and subsequent additional modifications were agreed upon between Duke Energy and NCDEQ. The IMP includes the locations of groundwater wells sampled quarterly and semiannually.

The EMP is required by G.S. Section 130A-309.211(b)(1)(e). The IMP will be replaced by the EMP upon NCDEQ approval of the CAP Update. Either submittal of the EMP and permit applications (as applicable), will fulfill G.S. Section 130A-309.209(b)(3).

The EMP, presented in **Appendix O**, is designed to be adaptable and would target key areas where changes to groundwater conditions are most likely to occur due to corrective action and ash basin closure activities. EMP key areas for monitoring are based on the following considerations:

- Include background locations
- Include designated flow paths,
- Within areas of observed or anticipated changing Site conditions, and/or have increasing constituent concentration trends

- Will effectively monitor COI plume stability and model simulation verification

EMP elements including well systems, locations, frequency, parameters, schedule and reporting evaluation are summarized below and outlined on **Table 6-27.** Effectiveness monitoring well locations are illustrated on **Figure 6-60**. The EMP will be implemented 30 days after CAP approval, and will continue until there is a total of three years of data confirming COIs are below applicable standards at or beyond the compliance boundary, at which time a request for completion of active remediation will be filed with NCDEQ. If applicable standards are not met, the EMP will continue and transition to post-closure monitoring, if necessary.

After ash basin closure and following ash basin closure certification, a post-closure groundwater monitoring plan (PCMP) will be implemented at the Site for a minimum of 30 years in accordance with G.S. Section 130A-309.214(a)(4)k.2. If groundwater monitoring results are below applicable standards at the compliance boundary for three years, Duke Energy may request completion of corrective action in accordance with G.S. Section 130A-309.214(a)(3)b. If groundwater monitoring results are above applicable standards, the PCMP will continue. An EMP work flow and optimization process is outlined on a flow chart on **Figure 6-61**.

Optimization of the plan to help determine the remedy's performance, appropriate number of sample locations, sampling frequency, laboratory analytes, and statistical analysis to evaluate the plume stability conditions will be conducted during EMP review periods. Optimization evaluation would be conducted using software designed to improve long-term groundwater monitoring programs such as Monitoring and Remediation Optimization System (MAROS).

6.17.5.1 Progress Reports and Schedule

(CAP Content Section 6.E.e.i)

The effectiveness monitoring plan for Source Area 2 will be consistent with the EMP presented in **Section 6.8.5.1** and provided in **Appendix O.**

6.17.5.2 Sampling and Reporting Plan During Active Remediation

(CAP Content Section 6.E.e.ii)

See **Section 6.17.4.2** regarding sampling and reporting during active remediation for Source Area 2.

6.17.6 Sampling and Reporting Plan after Termination of Active Remediation

(CAP Content Section 6.E.e.iii)

Termination of the proposed remedial alternative for Source Area 2 will be consistent with and implemented in accordance with NCDEQ Subchapter 02L .0106(m). A flow chart of the decision metrics, request, and review timeline for termination is outlined on **Figure 6-62** *(CAP Content Section 6.E.e.iii.1)*. This process will provide stakeholders an opportunity to evaluate terminating the system, as appropriate, in the vicinity of the well or wells where groundwater restoration completion is being evaluated.

Trend analysis described in **Section 6.8.6** would be part of the decision metrics for determining termination of the active remedy *(CAP Content Section 6.E.e.iii.1.A and B).* Groundwater remediation effectiveness monitoring will transition to the attainment monitoring phase when NCDEQ determines that the remediation monitoring phase is complete at a particular well or area.

6.17.7 Interim Activities

(CAP Content Section 6.E.a.iv; 6.E.a.v; 6.E.f)

No pilot testing is anticipated.

6.17.8 Implementation Schedule

NCDEQ would require an approved basis of design report prior to installation of the groundwater extraction system. Interim actions must be initiated and completed prior to preparing design documents suitable for bidding and construction. Implementation of corrective action might be affected by factors that are not yet well defined.

A preliminary implementation schedule for the proposed corrective action is provided below. The exact timeline of these schedule milestones is highly dependent on various factors including: NCDEQ direction and approvals, permitting, weather, and field conditions.

6.17.9 Contingency Plan

(CAP Content Section 6.E.g)

The purpose of the Contingency Plan is to monitor changes in conditions and operations to effectively reach the remedial action objectives. The contingency plan addresses operations, groundwater conditions and performance.

The Contingency Plan would be defined in greater detail as design elements of the system are finalized. A groundwater monitoring program to measure and track the effectiveness of the proposed phytoremediaton system is described in **Section 6.17.4**. This plan is adaptive and can be modified as the final design is prepared.

Elements within the Contingency Plan

(CAP Content Section 6.E.g.i)

The contingency plan addresses the following areas:

- Operations (including extraction wells, pumping, piping, electrical, and controls).
- Groundwater quality.
- Groundwater levels.
- Groundwater rates.
- Comparison to predicted concentrations and water levels.

Operations

(CAP Content Section 6.E.g.i)

Several aspects of the monitoring system would help ensure effective operations:

- Processes to ensure effective operation of each phytoremediation TreeWell™ is maintained. Maintaining target tree growth rates and groundwater uptake rates for each TreeWell™ is important to optimize remedial benefit. Each phytoremediation TreeWell™ would be monitored and inspected approximately monthly.
- When humic substances are employed, continuous monitoring of key parameters would ensure proper operation of the system and the reduction of constituent concentrations. Variances between prescribed ranges would alert the operator and other key personnel and might result in amendments to encourage the phytoextraction process.

- The operator inspection schedule, completion, and notes for key systems would be documented.
- A system maintenance schedule as determined under the guidance of an arborist or forester would be established to ensure effective operation.
- The maintenance schedule would include the prescribed annual applications of fertilizers and pruning techniques as well as frequency.
- Additional guidance would be given so that trunk protection, tree preplacement, pest removal, and TreeWell™ fouling can be mitigated when issues arise.

Groundwater Quality

(CAP Content Section 6.E.g.i)

The EMP includes a network of wells that would provide focused monitoring in critical areas following implementation of corrective actions.

Data would be entered into a comprehensive data base system following each sampling event. Trend analyses would be conducted, spatially and temporally, to evaluate COI plume changes. If groundwater quality field parameters or constituent concentrations significantly deviate from predicted responses, a focused investigation would be conducted to determine if the variation is due to system performance or other factors. Possible responses could include adding or removing extraction wells, or changing flow rates or target water levels.

To assess the effectiveness of changes, or to determine if the unexpected data trends are temporary, increased monitoring frequency or additional monitoring locations might be conducted.

If subsequent results continue to show non-conformance, a more comprehensive assessment and corrective action plan for the specific non-conformance might be completed and implemented.

Groundwater Levels

(CAP Content Section 6.E.g.i)

Water levels in selected EMP monitoring wells would be monitored until Site conditions have stabilized. Water level data would be measured and recorded as part of the ongoing IMP. Technical evaluations would include spatial and temporal trend analyses, drawdown calculations, and flow and transport model refinement to reflect current conditions, as needed. If results conclude that water levels are not similar to predicted patterns a focused investigation would be

conducted that could include adjusting system pumping rates, refining the flow and transport model for extraction rates, adding monitoring wells to the EMP monitoring network for greater resolution, installation of monitoring wells in key areas, and/or other activities.

If subsequent results from ongoing investigation continue to show non-conformance, a corrective action response with suggested approaches to determine possible reasons for the non-conformance would be implemented until resolution is achieved.

Groundwater Treatment

(CAP Content Section 6.E.g.i)

Ex-situ treatment of U1-4 AB groundwater is not anticipated.

Comparison to Predicted Concentrations and Water Levels

(CAP Content Section 6.E.g.ii)

Boron and other modeled conservative constituents (sulfate and TDS) do not have modeled concentrations exceeding comparison criteria near the compliance boundary at the U1-4 AB (**Appendix G**). The predicted modeled concentrations of these constituents do not reach the compliance boundary in the future with or without active remediation at the U1-4 AB, therefore model predictions of water levels have not been conducted for comparison. The U1-4 AB has previously been excavated and changes in water levels and geochemical conditions were monitored and reported during the excavation process. A comparison of predicted concentrations and water levels will not be conducted at the U1-4 AB during implementation of the remedial alternative; however water levels will be gauged as outlined in the EMP (**Appendix O**).

6.18 SA2 Corrective Action Approach Summary

This CAP Update proposes a groundwater remedial alternative that addresses COIs in U1-4 AB groundwater. This CAP Update provides:

- A screening and ranking process of two potential groundwater corrective action alternatives, MNA and phytoremediation using TreeWell™ technology.
- A selection and description of the proposed targeted corrective action: Groundwater Remedial Alternative 2 – Continued Monitoring with Phytoremediation and TreeWell™ Technology.
- Specific plans, including engineering details where applicable, for improving U1-4 AB groundwater quality.

- An EMP for evaluating the performance and effectiveness of the proposed targeted corrective action and its effect on the movement of the affected groundwater plume. The EMP uses an optimized groundwater monitoring system with multiple groundwater flow paths in the area of corrective action that would monitor geochemical and physical conditions.
- A schedule for the implementation and operation of the proposed groundwater corrective action strategy.

SOURCE AREA 3 (SA3) – UNIT 5 INACTIVE ASH BASIN (U5 AB)

This section provides an in-depth review of constituent characteristics associated with source area 3 (Unit 5 inactive ash basin) and the mobility, distribution and extent of constituent migration within, at, and beyond the point of compliance.

6.19 SA3 Extent of Constituent Distribution

6.19.1 Source Material within the Waste Boundary

(CAP Content Section 6.A.a)

The U5 AB waste boundary is shown on **Figure 1-2**. An overview of the material within the U5 AB is presented in the following subsections.

6.19.1.1 Description of Waste Material and History of Placement

(CAP Content Section 6.A.a.i)

The U5 AB (**Figure 1-2**) was constructed from 1969 to 1970, in advance of Unit 5 operation. CCR materials, composed primarily of fly ash and bottom ash, were initially deposited in the unlined U5 AB via sluice lines. A water/ash slurry was discharged from sluice lines in the eastern portion of the U5 AB south of the saddle dam. The U5 AB received inflows from Unit 5 operations from 1972 to 1980, when the basin reached capacity and was retired from service, covered with soil, and established with vegetation. The eastern portion of the U5 AB footprint has been used as a laydown area for CSS, and the northwestern portion of the U5 AB footprint has served as a storm water retention pond. Spoil material including soil and rock as well as some concrete from the grading and construction of Unit 6 was placed on top of the southwestern portion of the U5 AB from 2007 to 2011. The U5 AB currently receives storm water from a localized drainage area. Ponded water remains in small areas of the inactive basin footprint to the southeast and northwest.

6.19.1.2 Specific Waste Characteristics of Source Material

(CAP Content Section 6.A.a.ii)

Source characterization was performed through the completion of soil borings, installation of monitoring wells, and collection and analysis of associated solid matrix and aqueous samples. Source characterization was performed to identify the physical and chemical properties of the ash in the source areas. The source characterization involved determining physical

properties of ash, identifying the constituents present in ash, measuring concentrations of constituents in the ash pore water, and performing laboratory analyses to estimate constituent concentrations from leaching of ash.

Six ash samples were collected from borings at two well cluster locations (U5-2 and U5-7) within the U5 AB waste boundary for chemical analyses (**Figure 1-2**). Borings at the U5-3, U5-4, U5-5, and U5-6 locations were advanced through the earthen dams without encountering ash. Ash was encountered in borings U5-2 and U5-7 at varying intervals. Ash was not observed in borings outside the U5 AB with the exception of with the AAB, ASA and U1-4 AB (prior to excavation).

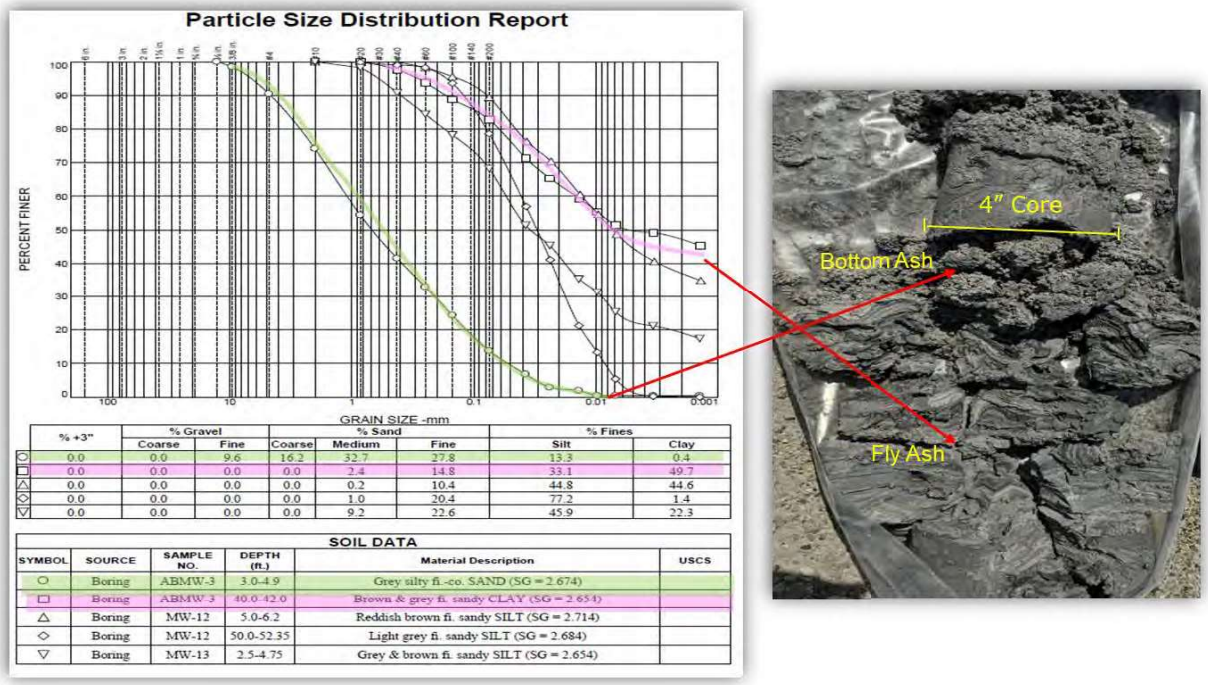
The hydraulically sluiced deposits of ash consisted of interbedded fine- to coarse-grained fly ash and bottom ash materials. Ash was generally described as gray to dark gray, non-plastic, loose to medium density, dry to wet, fine- to coarse-grained sandy silt texture. Physical properties analyses (grain size, specific gravity, and moisture content) were performed on two ash samples from the U5 AB using ASTM methods. Fly ash is generally characterized as a moderately dense silty fine sand or silt. Bottom ash, while not sampled from the Site, is generally characterized as loose, poorly graded (fine- to course-grained) sand.

Based on published literature not specific to the CSS site, the specific gravity of fly ash typically ranges from 2.1 to 2.9, and the specific gravity of bottom ash typically ranges from 2.3 to 3.0. The permeability of fly ash and bottom ash vary based on material density but would be within the range of sand gravel with similar gradation, grain size distribution, and density (EPRI, 1995).

Within an ash basin, ash typically contains interbedded layers of fly ash and bottom ash as a result of the varying rates and pathways of bottom ash and fly ash settlement. A depiction of the typical interbedded nature of fly ash and bottom ash within an ash basin, as seen from an ash boring photograph can be found below (**Figure 6-63**). Layers of bottom ash are typically more permeable than layers of fly ash due to the coarser grain size of bottom ash.

FIGURE 6-63

FLY ASH AND BOTTOM ASH INTERBEDDED DEPICTION



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	9.6	16.2	32.7	27.8	13.3	0.4
□	0.0	0.0	0.0	0.0	2.4	14.8	33.1	49.7
△	0.0	0.0	0.0	0.0	0.2	10.4	44.8	44.6
◇	0.0	0.0	0.0	0.0	1.0	20.4	77.2	1.4
▽	0.0	0.0	0.0	0.0	9.2	22.6	45.9	22.3

SOIL DATA

SYMBOL	SOURCE	SAMPLE NO.	DEPTH (ft.)	Material Description	USCS
○	Boring	ABMW-3	3.0-4.9	Grey silty fi.-co. SAND (SG = 2.674)	
□	Boring	ABMW-3	40.0-42.0	Brown & grey fi. sandy CLAY (SG = 2.654)	
△	Boring	MW-12	5.0-6.2	Reddish brown fi. sandy SILT (SG = 2.714)	
◇	Boring	MW-12	50.0-52.35	Light grey fi. sandy SILT (SG = 2.684)	
▽	Boring	MW-13	2.5-4.75	Grey & brown fi. sandy SILT (SG = 2.654)	

6.19.1.3 Volume and Physical Horizontal and Vertical Extent of Source Material

(CAP Content Section 6.A.a.iii)

Based on historical and current topographic surveys, the U5 AB is estimated to contain approximately 1,960,000 cy of ash (AECOM, 2018b). The maximum depth of CCR within the U5 AB is estimated to be approximately 70 feet. The volume, horizontal extent, and vertical extent of ash material within the U5 AB are presented in plan view on **Figure 1-2** and on cross-sections in **Figures 6-64, 6-65,** and **6-66.**

6.19.1.4 Volume and Physical Horizontal and Vertical Extent of Anticipated Saturated Source Material

(CAP Content Section 6.A.a.iv)

Based on information from field measurements and model outputs, the maximum depth of saturated ash within the U5 AB is approximately 55 feet. The volume, horizontal extent, and vertical extent of saturated ash material under current conditions within the U5 AB are presented in plan view (**Figure 6-67**) and on cross-sections in **Figures 6-64, 6-65,** and **6-66.**

The anticipated range of saturated ash thickness after closure by closure-in-place is between a few feet to 50 feet with the greatest volume of anticipated saturated ash in the eastern portion of the U5 AB and lesser volumes in the southern and western portions of the basin. The estimate is based on the approximated bottom of ash from the flow and transport model simulation (**Appendix G**) and simulated hydraulic heads.

Under the closure-by-excavation option, all of the ash in the ash basin would be excavated, and therefore, no saturated ash would remain in the ash basin footprint.

6.19.1.5 Saturated Ash and Groundwater

(CAP Content Section 6.A.a.v)

Based on the trend analysis results, the thickness of saturated ash remaining in place following closure (closure-in-place only) will have limited to no adverse effect on future groundwater quality. Layered ash within the U5 AB has resulted in relatively low vertical hydraulic conductivity, reducing the potential for downward flow of pore water into underlying residual material. The CSM indicates that the flow-through ash basin system should result in low to non-detectable constituent concentrations in groundwater underlying saturated ash within the basin except near the dams where downward vertical hydraulic gradients are observed. The horizontal flow-through system is consistent with Site-specific data, as observed with boron concentration data from groundwater below the source area (**Table 6-28**).

In summary, the data from the three well cluster locations within the ash basin demonstrate low (less than 470 µg/L and below the 02L groundwater standard) consistent with the flow-through system and suggests there is no correlation between the thickness of saturated ash and the underlying groundwater quality (**Table 6-28**).

A technical memorandum, titled *Saturated Ash Thickness and Underlying Groundwater Boron Concentrations – Allen, Belews Creek, Cliffside, Marshall, Mayo, and Roxboro Sites* (Arcadis, 2019), conducted linear regression analyses to evaluate the relationships between saturated ash thickness and concentrations of boron in ash pore water and underlying groundwater. The linear regression analysis was conducted using analytical data from Piedmont ash basins, including data from Cliffside.

The statistical evaluation was performed using a dataset which included 89 monitoring wells completed in shallow, transition, and bedrock groundwater zones directly beneath ash basins and 54 ash pore water monitoring wells completed in saturated ash. Linear regression results indicated that 87% of the groundwater monitoring locations below the saturated ash locations had boron groundwater concentrations less than the 02L standard. Exceptions to this relationship occur for select groundwater wells located near ash basin dikes and dams. This is due to the downward vertical hydraulic gradient in these areas, which enhances migration of constituents.

The analysis demonstrates saturated ash and ash pore water are not significantly contributing constituent concentrations to underlying groundwater except near dikes and dams, where downward vertical gradients exist.

Two statistical methods (Mann-Kendall and linear regression trend analysis) methods were used to evaluate correlations between groundwater boron concentrations and saturated ash thickness, and between groundwater boron concentrations and ash pore water boron concentrations. Bedrock groundwater boron concentrations were negatively correlated with saturated ash thickness and ash pore water concentrations (groundwater boron concentrations decreased with increasing saturated ash thickness and with increasing ash pore water boron concentrations). For all groundwater zones, boron concentrations were negatively correlated with ash pore water concentrations (groundwater boron concentrations decreased with increasing ash pore water boron concentrations).

The maximum boron concentration in groundwater below the U5 AB is 286 µg/L. Given the low concentrations of boron beneath these ash basins, the negative correlations between groundwater boron concentrations and saturated ash thickness/pore water concentrations suggest that boron concentrations in groundwater are not expected to increase based on corrective actions for groundwater at U5 AB. Data demonstrate that concentrations for other, less mobile, constituents are also low below saturated ash.

6.19.1.6 Chemistry within Waste Boundary

(CAP Content Section 6.A.a.vi)

Analytical sampling results associated with material from within the U5 AB waste boundary are included in the following appendix tables or appendices:

1. Ash solid phase: **Appendix C**, Table 4 *(CAP Content Section 6.A.a.vi.1.1)*
2. Ash synthetic precipitation leaching procedures (SPLP): **Appendix C**, Table 6 *(CAP Content Section 6.A.a.vi.1.2)*
3. Ash Leaching Environmental Assessment Framework: **Appendix H,** Attachment C *(CAP Content Section 6.A.a.vi.1.3)*
4. Soil: **Appendix C**, Table 4 *(CAP Content Section 6.A.a.vi 1.4)*
5. Ash pore water: **Appendix C**, Table 1 *(CAP Content Section 6.A.a.vi.1.6)*

Ash Solid Phase and Synthetic Precipitation Leaching Potential

(CAP Content Section 6.A.a.vi.1.1 and 6.A.a.vi.1.2)

Ash samples collected inside the U5 AB waste boundary were analyzed for total extractable inorganic constituents using USEPA Methods 6010/6020. For information purposes, ash samples were compared to soil background values and PSRG POG. The ash analytical data do not represent soil conditions outside of or beneath the ash basin. Ash samples were compared to soil background values and the PSRG POG. The ash analytical data do not represent soil conditions outside of or beneath the ash basin. Concentrations of arsenic, barium, and selenium were greater than soil background concentrations and the POG PSRG (**Appendix C,** Table 4).

In addition, one ash sample collected from borings completed within the U5 AB was analyzed for leachable inorganic constituents using SPLP and Method 1312 (**Appendix C,** Table 6**)**. The purpose of the SPLP testing is to evaluate the potential for leaching of constituents that might result in concentrations greater than the 02L standards or IMACs. SPLP analytical results are compared with the 02L or IMAC comparative values to evaluate potential source contribution; the data do not represent groundwater conditions. The results of the SPLP analysis indicated that concentrations of

all analyzed constituents were less than the 02L standard or IMAC comparative value.

Ash Leaching Environmental Assessment Framework

(CAP Content Section 6.A.a.vi.1.3)

Ash samples were analyzed for extractable metals analysis, including HFO and HAO, using the CBD method. Leaching studies of consolidated ash samples from the Cliffside ash basins were conducted using two LEAF tests, EPA methods 1313 and 1316 (USEPA, 2012a, b). The data are presented and discussed in the geochemical modeling report in **Appendix H,** Attachment C.

Leaching test results, using USEPA LEAF method 1316, indicate that, even for conservative constituents such as boron, the leachable concentration of boron present in ash from Cliffside is considerably lower than the total boron concentration (**Appendix H,** Attachment C). Cliffside data indicate that there is a process by which the constituents might become stable within the ash and would make the constituent unavailable for leaching. The exact mechanisms of this process are unknown, however, literature suggests that incorporating COIs, such as boron, into the silicate mineral phases is a potential mechanism (Boyd, 2002). The leaching behavior of several constituents as a function of pH, examined using USEPA LEAF method 1313, demonstrated that for anionic constituents, the leaching increased with increasing pH and the cationic constituents showed the opposite trend (**Appendix H,** Attachment C).

Soil beneath Ash

(CAP Content Section 6.A.a.vi 1.4 and 6.A.a.vi 1.5)

Samples from soil collected beneath the U5 AB were analyzed to understand and vertically delineate COI concentrations in soil.

Constituents consisidered for soil evaluation were limited to consituents identified as COIs from the Cliffside CSA Update (SynTerra, 2018), since soil impacts would be related to source area interactions to the underlying soils and groundwater, which may migrate beyond the source area. The range of constituent concentrations in saturated soils within the waste boundary, along with a comparison with soil background values and North Carolina PSRG POG standards (NCDEQ May 2019), whichever is greater, is provided in **Appendix C**, Table 4. For constituents lacking an established target concentration for soil remediation (*i.e.* sulfate), the following equation

was used in general accordance with the references in 15A NCAC 02L.0202 to calculate a POG value.

$$Csoil = Cgw\ [k_d + (\theta w + \theta aH')/Pb]df$$

Where necessary, the PSRG POG values were calculated using laboratory testing and physical soil data for effective porosity (0.3) and dry bulk density (1.6 kg/L) prepared in part for flow and transport modeling for the Site. Soil water partition coefficients (K_d) were obtained from the *Groundwater Quality Signatures for Assessing Potential Impacts from Coal Combustion Product Leachate* (EPRI, 2012). Soil PSRG POG standard equation parameters and values used in the equation above are outlined on **Table 6-2.** The resulting PSRG POG calculated value for sulfate was 1,438 mg/kg (**Appendix C**, Table 4).

Saturated soil is considered a component of the groundwater flow system and can serve as a source for constituents in groundwater at the Site. The potential leaching and sorption of constituents in the saturated zone is included in the flow and transport and geochemical model evaluations (**Appendix G** and **H**) by continuously tracking the constituent concentrations over time in the saprolite, transition zone, and bedrock materials throughout the models. Historical transport models simulate the migration of constituents through the soil and rock from the ash basin, and these results are used as the starting concentrations for the predictive simulations.

Unsaturated soil and rock is considered a potential secondary source to groundwater. Constituents present in unsaturated soil or partially saturated soil (vadose zone) have the potential to leach into the groundwater system if exposed to favorable geochemical conditions for chemical dissolution to occur. No unsaturated soil samples were collected from within the U5 AB waste boundary due to saturated soil conditions beneath the ash in the basin, and no samples being analyzed from soil in the dams. Soil SPLP constituent concentrations within the waste boundary, along with a comparison to 02L standards/IMAC is provided in **Appendix C,** Table 6.

Ash Pore Water

(CAP Content Section 6.A.a.vi.1.6 and 6.A.a.vi.3)

The ash basins are wastewater treatment systems. Water within the ash basins is not groundwater; therefore, ash pore water isoconcentration maps

are not prepared. Ash pore water data is provided for general information purposes only in **Appendix C**, Table 1. **Figures 6-64, 6-65, and 6-66** represent ash pore water distribution in cross-section. For further discussion of geochemical trends within the ash pore water, see **Appendix H,** Section 2. All ash pore water sample locations are shown on **Figure 1-2,** and analytical results are provided in **Appendix C,** Table 1.

Ash Pore Water Piper Diagrams

(CAP Content Section 6.A.a.vi.2)

Piper diagrams can be used to differentiate water sources in hydrogeology (Domenico and Schwartz 1998). Piper diagrams of ash pore water monitoring data (**Figure 6-72**) are used to assess the relative abundance of major cations (*i.e.*, calcium, magnesium, potassium, and sodium) and major anions (*i.e.*, chloride, sulfate, bicarbonate, and carbonate) in water. Data used for the piper diagrams include ash pore water data between January 2018 and June 2019 with a charge balance between -10 and 10%.

Ash pore water results tend to plot with higher proportions of sulfate, chloride, calcium, and magnesium, which is generally characteristic of ash pore water (EPRI, 2006). The area where ash pore water tends to plot on the piper diagram is identified as "affected" on **Figure 6-72**. Ash pore water results from the U5 AB plot in the "affected," "generally unaffected," and the area in between identified as "potential mixing" (**Figure 6-72**). The ash pore water distribution on the piper diagrams indicates that only general conclusions regarding impact to groundwater from the ash basin based on relative abundance of major cations and anions can be made.

6.19.1.7 Other Potential Source Material

(CAP Content Section 6.A.a.vii)

Low pH in water occurs downgradient of the U5 AB Saddle Dam, in the ditch surrounding the southern Unit 5 cooling tower (Cooling Tower B), and in groundwater monitoring wells located downgradient of the U5 AB saddle dam. The pH in the water in the area is inconsistent with pH values in ash pore water and groundwater wells measured in wells elsewhere across the Site. The measured pH values from the water within the ditch surrounding Cooling Tower B as well as groundwater measurements collected near the ditch using a hand auger to intersect the water table are presented as **Figure 6-73**. Based on borings installed and pH readings collected on the cooling tower side and the U5 AB side of the ditch, low pH is emanating from the U5 AB side of the ditch. Historical aerial photographs

depict the sluice line discharging into the basin on the south end of the U5 AB saddle dam with a delta of ash behind the dam (**Figure 6-74)**.

It is suspected that near the former sluice line outfall "mill rejects" or "clinkers" may have been deposited with the ash. "Clinkers" or "mill rejects" are rocks mixed-in with coal that were not combusted as part of the power generation process. Clinkers are typically pyrite-rich and can cause low pH conditions in the subsurface.

The low pH conditions are suspected to be the cause of constituents to solubilize and be transported with seep water and shallow and deep groundwater at concentrations greater than other areas at the Site. Those constituents include strontium, iron, and manganese. Several of these constituents would be less mobile under pH conditions observed elsewhere on the Site. Lesser effects are noted in the deep and bedrock flow zones. This source of low pH is contained within and is addressed as part of the U5 AB source area.

6.19.1.8 Interim Response Actions

(CAP Content Section 6.A.a.viii)

Interim response actions to date include source area stabilization. A summary of each interim action and the intended remedy are described in **Table 6-30**.

Source Area Stabilization

(CAP Content Section, 6.A.a.viii.2)

In an August 22, 2016 correspondence, NCDEQ provided a notice of deficiencies related to the U5 AB dams including the installation of a new spillway at the main dam. In response, Duke Energy undertook activities to correct the deficiencies.

Pursuant to G.S. Section 130A-309.213(d)(1) and based upon determinations in a letter dated November 13, 2018, NCDEQ has classified the CCR surface impoundments at CSS as low-risk (**Appendix A**). The relevant closure requirements for low-risk impoundments are in G.S. Section 130A-309.214(a)(3), which states low-risk impoundments shall be closed as soon as practicable, but no later than December 31, 2029.

6.19.2 Extent of Constituent Migration beyond the Compliance Boundary

(CAP Content Section 6.A.b)

This section is an overview of COI occurrences at or beyond the point of compliance. The point of compliance at the U5 AB is the ash basin compliance boundary. The compliance boundary for groundwater quality at the U5 AB is defined in accordance with Subchapter 02L .0107(a) as being established at either 500 feet from the waste boundary or at the property boundary, whichever is closer to the waste (**Figure 1-2**).

Analytical sampling results associated with the U5 AB source area for each media are included in the following tables and appendix tables:

1. Soil: **Appendix C**, Table 4 and **Table 6-2** *(CAP Content Section 6.A.b.ii.1)*
2. Groundwater: **Appendix C**, Table 1 and **Table 6-5** *(CAP Content Section 6.A.b.ii.2)*
3. Seeps: **Appendix C**, Table 3 *(CAP Content Section 6.A.b.ii.3)*
4. Surface water: **Appendix C**, Table 2 and **Appendix K** *(CAP Content Section 6.A.b.ii.4)*
5. Sediment: **Appendix C**, Table 5 *(CAP Content Section 6.A.b.ii.5)*

Soil Constituent Extent

(CAP Content Section 6.A.b.ii.1)

Data indicate unsaturated soil COI concentrations at or beyond the compliance boundary are generally consistent with background concentrations or are less than regulatory screening values (**Table 6-29**). Horizontal and vertical extent of COI concentrations in soil is discussed further in **Section 6.19.4**.

Groundwater Constituent Extent

(CAP Content Section 6.A.b.ii.2)

The U5 AB compliance boundary extends 500 feet beyond the ash basin waste boundary, or to the property boundary, whichever is closer. Groundwater concentrations greater than 02L standard/IMAC/background values occur locally at or beyond the compliance boundary in one area:

1. Northeast of the U5 AB saddle dam

Groundwater concentrations greater than applicable 02L standard/IMAC/background values also occur locally near the compliance boundary:

1. North of the U5 AB main dam

The maximum extent of affected groundwater migration for all flow zones is represented by boron concentrations greater than background values. Boron concentrations greater than background values have migrated from the U5 AB to areas north and northeast, at or beyond the compliance boundary. Boron concentrations greater than the 02L standards have not migrated at or beyond the compliance boundary in any areas at the U5 AB. Due to the limited presence and mobility of constituents in the groundwater system, coinstituent concentrations in groundwater have not caused, and are not predicted to cause, current surface water quality standards to be exceeded (**Appendix K**).

Chromium, cobalt, hexavalent chromium, iron, lithium, manganese, strontium, sulfate, and TDS have concentrations greater than their respective groundwater regulatory standards at or beyond the compliance boundary. Of these constituents, all concentrations greater than regulatory standards are at locations where boron concentrations are greater than background values. The constituent concentrations of chromium, hexavalent chromium, and total radium do not exhibit a discernable plume from the U5 AB greater than comparison criteria. These exceedances appear as isolated instances that do not exhibit a discernable plume within the flow zone in which they appear.

Section 6.19.3 includes a detailed matrix evaluation and rationale of groundwater constituents requiring corrective action, and **Section 6.19.4** provides isoconcentration maps and cross-sections depicting groundwater flow and constituent distribution in groundwater *(CAP Content Section 6.A.b.i)*.

Seep Constituent Extent

(CAP Content Section 6.A.b.ii.3)

Seeps at Cliffside are subject to the monitoring and evaluation requirements contained in the SOC. The SOC states that the effects from non-constructed seeps should be monitored. Attachment A to the SOC identifies the following seeps:

- Non-constructed seeps to be monitored — S-2, S-3, S-7, S-14, S-15, S-16, S-18, S-19, S-19A, S-21, S-23, S-27, S-28, S-29, S-30, S-31, S-32 and S-36.

- Non-constructed seeps dispositioned — S-1, S-5, S-8, S-9, S-10, S-11, S-12, S-13, S-17, S-20, S-22, S-24, S-25, S-26, S-33, S-34, and S-35.

The SOC defines dispositioned:

1. The seep is dry for at least three consecutive quarters;
2. The seep does not flow to waters of the State;
3. The coal ash basin no longer impacts the seep for all constituents over four consecutive sampling events;
4. An engineering solution has eliminated the seep.

Non-dispositioned seeps, where monitoring conducted has indicated the presence of CCR affects near the U5 AB, include: S-2 (**Figure 5-10**). **Table 6-34** provides a summary of seep general location and approximate flow rate. Analytical results for these seep samples are included in **Appendix C,** Table 3.

Surface water sampling conducted downstream of non-dispositioned seep S-2 from the Broad River, demonstrate that flow from this seep has not caused constituent concentrations greater than 02B standards in the river. Surface water samples collected from the Broad River are shown on **Figure 5-10**. Surface water samples collected from the Broad River downstream of seep S-2 include SW-BRU5-1. Analytical results for this surface water sample are included in **Appendix C**, Table 2.

Surface Water Constituent Extent

(CAP Content Section 6.A.b.ii.4)

Surface water samples have been collected from the Broad River to confirm groundwater downgradient of the U5 AB has not resulted in surface water concentrations greater than 02B water quality standards. Surface water samples were collected to evaluate acute and chronic water quality values. Surface water samples were also collected at background locations (upgradient of potential migration areas) within the Broad River. Analytical results were evaluated with respect to 02B water quality standards and background data. Surface water conditions is further discussed in **Section 6.20.1** and the full report for CSS surface water current conditions can be found in **Appendix J**.

Additionally, environmental assessments of the Broad River have all demonstrated that the river has been an environmentally healthy and functioning ecosystem, and ongoing sampling programs have been established

to ensure the health of this system will continue. Furthermore, these data indicate that there have been no significant effects to the local aquatic systems related to coal ash constituents over the last 30 years. More information related environmental health assessments conducted for the Broad River, including sampling programs, water quality and fish community assessments, and fish tissue analysis, can be found in **Appendix E.**

Sediment Constituent Extent

(CAP Content Section 6.A.a.ii.5)

Sediment sample locations are generally co-located with surface water or seep sample locations (**Figure 1-2**). Similar to saturated soils and groundwater, sediment is considered a component of the surface water system, and the potential leaching and sorption of constituents in the saturated zone is related to water quality. Because no regulatory standards are established for seidment inorganic constituents, background sediment constituent concentration ranges and are considered in this sediment evaluation. **Table 4-5** presents constituent ranges of background sediment datasets per water body. Analytical results for all sediment samples are provided in **Appendix C,** Table 5**.**

Assessment of constituents in sediment in the vicinity of the U5 AB was conducted through evaluation of data from 15 one-time grab samples at Cliffside. Sample locations shown on (**Figure 1-2**) include:

- Three background locations along the bank of Suck Creek, the Broad River, and the Second Broad River
- Two locations along the southern bank of the Broad River downgradient of the U5 AB
- One location in the unnamed tributary west of the U5 AB that flows to the Broad River
- Nine seeps downgradient of the U5 AB

Sediment results from samples collected at locations upstream of the ash basins (background data) were compared to results from samples collected at locations downstream of the U5 AB.

Boron sediment concentration exceeded the the background sediment range for boron at CLFTD-005. This location could be impacted by the seepage at the toe of the U5 AB.

Chromium concentrations were reported greater than the background range in sediment from locations CLFTD-004, S-1, S-2, S-17, S-19, S-20, SED-2, and SED-3, however these concentrations are similar to levels detected in background sediment.

Cobalt concentrations were greater than the background range for cobalt in sediment from locations S-1, S-2, S-17, S-18, and S-19, however these concentrations are within an order of magnitude compared to levels detected in background sediment. Cobalt in sediment from CLFTD-004 was detected significantly greater than the range of background concentrations. This location could be impacted by the seepage at the toe of the U5 AB.

Iron concentrations were greater than the iron background range in sediment from locations S-1, S-2, S-17, S-20, SED-2, and SED-3, however these concentrations are similar to levels detected in background sediment. Iron in sediment samples collected from CLFTD-004, CLFTD-005, and S-18 was detected significantly higher than the range of background concentrations. This location could be impacted by the seepage at the toe of the U5 AB.

Manganese concentrations were greater than the manganese background range in sediment from locations S-2, S-20, SED-2, and SED-3, however these concentrations are similar to levels detected in background sediment. Manganese in sediment collected from CLFTD-004 was detected at a concentration significantly higher than the range of background concentrations. This location could be impacted by the seepage at the toe of the U5 AB.

The thallium concentration in sediment collected from SED-2 was greater than the thallium background range, but well within an order of magnitude.

After completion of AAB decanting, all seeps, constructed and non-constructed and if not dispositioned in accordance with the SOC, are to be characterized post-decanting for determination of seep disposition by the decanting process. If a seep is dispositioned, no corrective action for the location would be proposed. After seep characterization, an amendment to this CAP Update and submitted based on the schedule outlined in the SOC, may be required to address non-dispositioned seeps. Corrective action strategies for seeps, including seeps are discussed in **Section 6.26.1**. Seep corrective action measures target reducing flow and the saturated zone at seeps and therefore reduces the potential for additional leaching and sorption of constituents to occur with sediment.

6.19.2.1 Piper Diagrams

(CAP Content Section 6.A.b.iii)

Piper diagrams can be used to differentiate water sources in hydrogeology by assessing the relative abundance of major cations (*i.e.*, calcium, magnesium, potassium, and sodium) and major anions (*i.e.*, chloride, sulfate, bicarbonate, and carbonate) in water.

Groundwater Piper Diagrams

(CAP Content Section 6.A.a.vi.2)

Piper diagrams of groundwater monitoring data from shallow, deep and bedrock background locations and downgradient of the U5-AB are shown in **Figure 6-72**. Data used for the piper diagrams include ash pore water data and groundwater data between January 2018 and April 2019 with a charge balance between -10 and 10%.

- Background groundwater from each flow zone tends to plot central to the diagram indicating water quality is more balanced between major anions and cations. The area where background groundwater (or native groundwater) tends to plot on the piper diagram is identified as "generally unaffected" on **Figure 6-72.** However, samples from two (U5-2S-SLA and U5-7S) of the three ash pore water wells from the U5 AB plot in this area **Figure 6-72.**
- Shallow groundwater monitoring wells GWA-2S, U5-3SA, and GWA-37S plot within the "potential mixing" zone (**Figure 6-72**). Shallow groundwater monitoring wells GWA-4S and U5-6S both plot in the "affected" zone. (**Figure 6-**72). Mean boron concentrations of samples from the two wells in the "affected" zone (GWA-4S and U5-6S) range from 139 to 159 µg/L, indicating influence from ash pore water. These wells are located within the ash basin (U5-6S) or downgradient of the ash basin (GWA-4S).
- Deep groundwater monitoring wells U5-2D and U5-3D plot in the "potential mixing" or "generally unaffected" zones (**Figure 6-**72). Deep groundwater monitoring wells GWA-37D and GWA-4D plot within the "affected" zone indicating water quality more similar to ash pore water than background groundwater (**Figure 6-72**). Boron is detected at each of these deep monitoring well locations.
- No samples from bedrock groundwater monitoring wells plot in the "affected" zone of the piper diagram (**Figure 6-72**). Bedrock

groundwater monitoring wells GWA-2BRA, GWA-2BRU, and U5-2BR plot in the "generally unaffected" zone (**Figure 6-72).** Monitoring well MW-38BR plots in the "potential mixing" zone (**Figure 6-72**). Boron is detected at MW-38BR, but at a concentration less than the 02L standard.

- The distribution results on the piper diagrams in **Figure 6-72** indicate no conclusion can be made regarding impact to groundwater from the ash basin based on relative abundance of major cations and anions.

Seep and Surface Water Piper Diagrams

Piper diagrams of seep, Broad River and Suck Creek surface water monitoring data (**Figure 6-86**) are used to assess the relative abundance of major cations (*i.e.*, calcium, magnesium, potassium, and sodium) and major anions (*i.e.*, chloride, sulfate, bicarbonate, and carbonate) in surface water. Data used for the piper diagrams include most recent available seep and surface water data (**Appendix C**, Table 2) with a charge balance between -10 and 10%. As discussed in **Section 6.19.**2, ash pore water from the U5 ash basin does not plot on piper diagrams in an area that is distinguishable from background and "unaffected" groundwater locations (**Figure 6-72**). Therefore, the data shown on **Figure 6-86** cannot be used to make inferences regarding potential impact to surface water from the U5 ash basin at Cliffside. General observations from the seep and surface water piper diagrams include:

- Surface water samples from locations SW-1 and SW-WCU5-1(4) plot within the "potential mixing" zone of the piper diagrams (**Figure 6-86**). The other six surface water sample locations plot together in a cluster in the "generally unaffected" zone (**Figure 6-86**). The background, upgradient, and downgradient samples are not distinguishable in their location on the piper diagram.
- Seep S-18 plots on the piper diagram in the "affected" zone (**Figure 6-86**). Seeps CLFTD-004, S-1, and S-2 plot in the "potential mixing" zone (**Figure 6-86**). Each of these seeps are immediately downgradient of the U5 AB (except S-1) and are covered by the SOC. Remaining seep and plot with water quality in the region of generally unaffected (**Figure 6-86**).

6.19.3 Constituents of Interest (COIs)

(CAP Content Section 6.A.c)

This CAP Update evaluates the extent of, and remedies for constituents associated with the CSS U5 AB that are at or beyond the compliance boundary to the northeast of the U5 AB saddle dam and near the compliance boundary to the north of the U5 AB main dam, detected at concentrations greater than 02L standards, IMACs, or background values, whichever is greater.

Site-specific COIs were developed by evaluating groundwater sampling results with respect at concentrations greater than regulatory criteria or background values, whichever is greater. The distribution of constituents in relation to the source area, co-occurrence with CCR indicator constituents, such as boron, and migration directions based on groundwater flow direction are considered in determination of COIs.

The following list of COIs was developed as part of the CSA Update for Cliffside (SynTerra, 2018):

- Arsenic
- Boron
- Chromium (Total)
- Chromium (Hexavalent)
- Cobalt
- Iron
- Manganese
- pH
- Total Uranium
- Total Radium
- Strontium
- Sulfate
- Total Dissolved Solids
- Thallium
- Vanadium

Soil

(CAP Content Section 6.A.c.i.1)

Unsaturated soil at or near the compliance boundary is considered a potential secondary source to groundwater. Constituents present in unsaturated soil or partially saturated soil (vadose zone) have the potential to leach into the groundwater system if exposed to favorable geochemical conditions for chemical dissolution to occur. Constituents considered for unsaturated soil evaluation were limited to constituents identified as COIs for the U5 AB since soil impacts would be related to past ash pore water interaction to the underlying soils within the basin and groundwater migration beyond the ash basin.

Data indicate unsaturated soil COI concentrations are generally consistent with background concentrations or are less than regulatory screening values (**Table 6-29**). In the few instances where unsaturated soil COI concentrations are greater than PSRGs for POG standards or background values, COI concentrations are within range of background dataset concentrations or there are no mechanisms by which the COI could have been transported from the ash basin to the unsaturated soils. Horizontal and vertical extent of COI concentrations in soil, and reasons why no necessary corrective action for soils is identified at the Site, is discussed further in **Section 6.19.4**.

Groundwater

(CAP Content Section 6.A.c.i.2)

A measure of central tendency analysis of groundwater COI data (January 2018 to June 2019) was conducted and means were calculated to support the analysis of groundwater conditions to provide a basis for defining the extent of the COI migration at or beyond the compliance boundary. A measure of central tendency analysis was completed to capture the appropriate measure of central tendency (arithmetic mean, geometric mean, or median) for each dataset of constituent concentrations. Constituent concentrations in a single well might vary over orders of magnitude; therefore, a single sample result might not be an accurate representation of the concentrations observed over several months to years of groundwater monitoring. Evaluating COI plume geometries with central tendency data minimizes the potential for incorporating occasions where COIs are reported at concentrations outside of the typical concentration range, and potentially greater than enforceable groundwater standards. Previous Site assessments might have overrepresented areas affected by the ash basin by posting a single data set on maps and cross-sections that might have included isolated data anomalies.

NCDEQ (October 24, 2019; **Appendix A**) recommended the use of a lower confidence limit (LCL95) rather than the central tendency value. LCL95 concentrations were calculated for each COI. The LCL95 concentration for the sample with the highest COI LCL95 concentration is provided for comparison to the COI mean concentration in Table 1 of the technical memorandum titled *COI Management Plan Approach – Cliffside Steam Station* (Arcadis, 2019) included within **Appendix H**. The mean is typically higher than the LCL95 value, and therefore, is a more conservative approach for evaluation and comparison to applicable criteria.

The mean of up to six quarters of valid data was calculated for each identified COI to analyze groundwater conditions and define the extent of COI migration at or beyond the compliance boundary. At a minimum, four quarters of valid data were used for calculating means, however, if fewer than four quarters of valid data were available, the most recent valid sample result was reported. Less than four quarters of valid data were not available either because the well was recently installed or sample results from one or more quarters were excluded. For use in calculating means, non-detect values were assigned the laboratory reporting limit and estimated (J-flag) values were treated as the reported value. Procedures for excluding data from calculating means are based on USEPA's National Functional Guidelines (USEPA, 2017a, 2017b), published research about leaching of elements from coal combustion fly ash (Izquierdo, and others 2012), and professional judgement.

The following steps outline the approach followed in calculating central tendency values for constituent concentrations in groundwater:

1. If the maximum analytical value divided by the minimum value for each constituent was greater or equal to 10 (*i.e.* the data set ranges over an order of magnitude), the geometric mean of the analytical values was used.
2. If the maximum analytical value divided by the minimum value for each constituent was less than 10 (*i.e.* the data set range is within an order of magnitude), the arithmetic mean is used.
3. The median of the data was used for records that contain zeros or negative values (e.g., total radium). Negative values were set to zero prior to calculating the median concentration.
4. If the dataset mode (most common) is equal to the RL, and the geometric mean or mean value is less than or equal to the dataset's mode, the value is reported as "<RL" (e.g. the reporting limit for boron is 50 µg/L; for wells with geomean or mean analysis results less than 50 µg/L the mean analysis result would be shown as "<50").

Sample results were excluded from calculations for the following conditions:

- Duplicate sampling events for a given location and date. The parent (CAMA) sample was retained.
- Turbidity was greater than 10 NTUs

- Records where pH was greater than 10 S.U. Data with pH greater than 10 S.U. might be related to grout from well construction
- Data flagged as unusable (R0 qualified)
- Data reported as non-detect with a RL greater than the normal laboratory reporting limit
- Negative values for total radium were set equal to 0

Table 6-31 presents the mean analysis results of the COI data using groundwater monitoring sampling results from January 2018 to June 2019. Where means could not be calculated, the most recent valid sample was evaluated to determine whether the sample result is an appropriate representation of the historical dataset. Data from **Table 6-31** are used in evaluating COI plume geometry in the vicinity of the U5 AB.

Constituent Management Approach

As discussed at the beginning of **Section 6**, a 'COI management process' was developed by Duke Energy at the request and acceptance of NCDEQ to gain understanding of the COI behavior and distribution in groundwater and to aid in selection of the appropriate remedial approach. Details of the COI management approach are provided in **Appendix H.** In general, the COI management process consists of three steps:

1. Performing a detailed review of the applicable regulatory requirements under NCAC, Title 15A, Subchapter 02L

2. Understand the potential mobility of site-related COIs in groundwater based on site hydrogeology and geochemical conditions

3. Determine the COI distribution at the U5 AB under current or predicted future conditions.

The management process uses a matrix evaluation [(**Table 6-32**) (*CAP Content Section 6.A.c.i.2)].*

This COI management process is supported by multiple lines of evidence including empirical data collected at the site, geochemical modeling, and groundwater flow and transport modeling. This approach has been used to understand and predict constituent behavior in the subsurface related to the U5 AB or constituents that are naturally occurring. Constituents that have migrated

beyond the compliance boundary at concentrations greater than 02L standard, IMAC or background value, and that are related to the source area would be subject to corrective action. Constituents that are naturally occurring at concentrations greater than the 02L standard or IMAC do not warrant corrective action.

Using the constituent management process, four of 14 inorganic groundwater COIs (not including pH) identified in the CSA Update (CSA Update, 2018), exhibit mean concentrations that are currently less than background values, 02L standard, or IMAC at or beyond the compliance boundary, or have few concentrations greater than comparison criteria but with no discernable plume characteristics. These four constituents include:

- Arsenic
- Thallium
- Vanadium
- Uranium (total)

These constituents are not expected to migrate distances at or beyond the compliance boundary or migrate distances that would present risk to potential receptors, and are predicted, based on geochemical modeling, to remain at stable concentrations, typically less than background values, 02L standard, or IMAC (**Appendix H**).

The remaining 10 COIs exhibit mean concentrations greater than background values, 02L standard, or IMAC downgradient of the ash basin at or beyond the compliance boundary. These constituents are as follows:

- Boron
- Chromium (hexavalent)
- Chromium (total)
- Cobalt
- Iron
- Manganese
- Strontium
- Sulfate
- Total Dissolved Solids (TDS)
- Total Radium

Lithium has been added to the conservative list for the CSS U5 AB. Lithium was not previously analyzed for in collected groundwater samples until the second quarterly sampling event in 2018 (April 2018). This was after the submission of the CSA (CSA Update, 2018) and therefore lithium was not evaluated in that submittal.

As discussed in the CSA Update (SynTerra, 2018), not all constituents with results greater than background values can be attributed to the U5 AB. Naturally occurring groundwater contains varying concentrations of inorganic constituents. Sporadic and low-concentration occurrences of these constituents in the groundwater data do not necessarily demonstrate horizontal or vertical distribution of COI-affected groundwater migration from the U5 AB.

6.19.4 Horizontal and Vertical Extent of COIs

(CAP Content Section 6.A.d)

The COIs at the CSS have been delineated horizontally and vertically in groundwater based on sampling and analysis data collected from 292 monitoring wells present at the site. The majority of COIs are either present below their applicable standards, do not exhibit discernable plumes, or have migrated a limited distance from the ash basins in groundwater. Furthermore, an evaluation of site data indicates that COI presence in groundwater decreases with depth. Supporting information for these findings are presented in the COI management evaluation presented in **Section 6.19.3** and in **Appendix H.**

Boron, a conservative (non-reactive) constituent, is the main COI that is present in Site groundwater in a discernable plume associated with the U5 AB. Boron typically has greater concentrations in CCR than in native soil and is relatively soluble and mobile in groundwater (Chu et al., 2017). Sulfate and TDS are also conservative constituents and represent discernable COI plume geometries, but smaller in extent and plum footprint than boron. Additional constituent concentrations identified as being greater than their respective groundwater regulatory standards or background values, and are associated with COI-affected groundwater migration from the ash basin, are confined within the extent of the boron plume at the Site. Therefore, the maximum extent of the boron plume greater than its background value (50 μg/L) was used to determine the maximum extent of COI-affected groundwater migration.

Since naturally occurring COIs might be present at concentrations greater than Site-specific background values, isoconcentration maps of primary CCR indicator COIs (*i.e.*, boron, lithium, sulfate, and TDS) are most representative of the groundwater COI plume extent in three-dimensional space.

For monitoring wells that were abandoned prior to 2018 (U5-3 and U5-7 well clusters), the data from the most recent valid sample event was considered when contouring a constituent's distribution.

Isoconcentration maps and cross-sections use groundwater analytical data to spatially and visually define areas where groundwater COI concentrations are greater than background values and/or 02L standards/IMAC. Geometric means of groundwater COI monitoring sampling results from January 2018 to June 2019 provide an understanding of groundwater flow dynamics and direction to define the horizontal and vertical extent of the COI plume. Horizontal extent of the COI plume is depicted on isoconcentration maps (**Figures 6-75a** through **6-85**). Non-conservative constituents, boron, sulfate, and TDS, are mapped with empirical Site data and supplemented with flow and transport model simulated plume depictions where no data is available.

The flow and transport model calibration targets are boron, sulfate, and TDS concentrations measured in monitoring wells in the second quarter of 2019. All sampled wells are included in the calibration. Data that has been collected since that timeframe were not included in the updated model calibration process. Fall 2019 data from relatively newly installed wells suggest the model predictions are accurate, or conservative; the model over-predicts the actual groundwater concentrations in some areas.

Vertical extent of the COI plume at the U5 AB is depicted on three generalized cross-sectional depictions of the Site. Four cross-sections (D-D′, E-E′, L-L′, and M-M′) were prepared near the U5 AB for previous CSA and CAP reports. One of the cross-sections (M-M′) provides similar information related to the U5 AB as provided by cross-section E-E′. Therefore, cross-section M-M′ has limited use in depicting flow and COI transport, and is not used in this CAP.

Three cross-sections (L-L′, D-D′, and E-E′) are included in this CAP Update:

- Cross-section L-L′ (**Figure 6-66)** is oriented generally north to south in the eastern edge of the U5 AB waste boundary and displays the eastern side of the basin and location downgradient of the saddle dam toward the Broad River to the north.
- Cross-section D-D′ (**Figure 6-64**) is oriented southwest to northeast through the basin and displays the U5 AB footprint, topography, and depth of saturated ash.
- Cross-section E-E′ (**Figure 6-65**) is oriented generally south to north in the western portion of the U5 AB, through the central portion of the basin, and to the Broad River to the north. Cross-section E-E′ displays the U5 AB footprint, topography, and depth of saturated ash in the U5 AB.

At or beyond the compliance boundary, the maximum extent of COI-groundwater affected by the ash basin occurs northeast of the U5 AB, downgradient of the U5 AB saddle dam. Near the compliance boundary, the maximum extent of groundwater affected by the ash basin occurs north of the U5 AB main dam.

Northern Extent of Constituent Affected Groundwater

The groundwater analytical results north of the U5 AB main dam near the compliance boundary were reviewed. Constituents reported with greater than their comparison criteria near the compliance boundary include iron, manganese, and strontium.

Groundwater Data Comparison to Criteria

Iron is an isolated exceedance of groundwater comparison criteria (background value) near the compliance boundary at GWA-35S and GWA-35D, in the shallow and deep flow layers. Iron exceedances are not reported greater than the groundwater comparison criteria in the bedrock flow layer near the compliance boundary. These iron exceedances at GWA-35D do not exhibit a discernable plume from the U5 AB to this well cluster.

Manganese in the shallow flow zone has an isolated exceedance of groundwater comparison criteria (background value) near the compliance boundary at GWA-35S. Manganese does not have reported exceedances of comparison criteria in the deep flow layer near the compliance boundary. Manganese in the bedrock flow zone has an exceedance of groundwater comparison criteria at GWA-2BR which is approximately 250 feet from the compliance boundary. Manganese in the shallow flow layer does show evidence of a discernable plume from the U5 AB, but not in the deep or bedrock flow layers.

Strontium is reported greater than its comparison criteria (background value) near the compliance boundary in the shallow, deep, and bedrock flow layers. Strontium concentrations greater than comparison criteria are reported widespread across the CSS site. The background value for strontium should be re-evaluated as more data become available as the concentrations currently established may be not representative of the actual background conditions on the site.

Discussion

Twenty-seven monitoring wells are downgradient of the U5 AB, an area that is not influenced by other parts of the Site. Comparing the number of exceedances to the groundwater comparison criteria yields the following: chromium (VI), total radium and total uranium, arsenic, boron, chromium and thallium have two or less exceedances; while manganese and strontium have 18 and 25 exceedances. The monitoring wells with the greatest number of exceedance are associated with the CCR-U5-4 well cluster. The exceedances are generally spread throughout the area downgradient of the U5 AB.

Boron: Boron has one exceedance of the 02L standard at monitoring well CCR-U5-04D. The remaining monitoring wells generally have mean values which are less than 300 μg/L; with many of them less than 100 μg/L. The boron results do not follow a trend with regards to their concentrations relative to their distance from the basin.

Cobalt: Cobalt has six of 27 values exceeding the background values; two are associated with the CCR-U5-04 well cluster and the others are spread with no apparent pattern. There is no evidence of a plume of cobalt coming from the U5 AB.

Iron: Iron was not detected above the groundwater comparison criterion (background value) other than isolated detections at GWA-35S and GWA-35D, in the shallow and deep flow layers. There are no iron exceedances in the bedrock flow layer in this area. The iron exceedances at GWA-35S and GWA-35D appear to be a localized condition and not reflective of groundwater conditions in the remainder of the area north of the U5 AB main dam.

Manganese: Manganese does not have reported exceedances of groundwater comparison criterion (background value) in this area other than an isolated detection above the comparison criteria at GWA-35S and at bedrock flow zone monitoring well GWA-2BR, which is approximately 250 feet from the compliance boundary. There are no reported exceedances in the deep flow layer in this area. Manganese in the shallow flow layer does show evidence of a discernible plume from the U5 AB, but not in the deep or bedrock flow layers.

Strontium: Strontium is reported greater than its groundwater comparison criterion (background value) near the compliance boundary in the shallow, deep, and bedrock flow layers. Strontium concentrations greater than the comparison

criteria are reported widespread across the CSS site. The background value for strontium should be re-evaluated as more data become available as the current BTV is not representative of the actual background conditions at the site.

Vanadium: Vanadium has seven of 27 values exceeding the background value; but five of these results are reported at monitoring wells with the least boron values reported. There is no evidence of a vanadium plume coming from the U5 AB. The vanadium data suggest that the geometric mean concentrations are largely the result of localized mineralogical and chemical factors as opposed to the ash basin.

Key findings for this area include:

- Boron, which acts as the key indicator of impacts on groundwater quality resulting from an ash basin is nominally impacted. Groundwater concentrations from only one monitoring well exceeds the 02L standard There does not appear to be a plume at the U5 AB.
- Strontium and manganese have a large number of exceedances in this area. In the case of strontium this may be attributed to transport from the basin, it is that the background values for both COIs should be re-evaluated due to their prevalence in groundwater throughout the area. To the extent that these values are from the basin their concentrations are projected to diminish once basin closure occurs based on findings from the Geochemical Model Report (**Appendix H**) and the MNA Evaluation (**Appendix I**).

Mann-Kendall trend analysis was performed using conservative constituent datasets for ash pore water and groundwater wells within the waste boundary, between the waste boundary and compliance boundary, and downgradient the source area, at or beyond the compliance boundary. Trend analysis and results are prepared by Arcadis U.S. Inc. and included in a technical memorandum titled *Plume Stability Evaluation – Cliffside Steam Station* (Arcadis, 2019). The technical memorandum is included as in **Appendix I** as Attachment A.

The analysis was performed using analytical results for samples collected from 2011 through 2019. Results of the Mann-Kendall trend analysis at the U5 AB include:

- Groundwater COI concentration trends with time were evaluated for 17 constituents for 61 wells for a total number of 1,037 trends. Trends that

were not increasing accounted for 978 of the 1,037 trends evaluated (94% of total). Excluding trends that had greater than 50% non-detect values or insufficient number of valid samples to run a trend (n<4), 613 of 672 trends (91% of total) had statistically decreasing trends, stable trends, or no trends. These results demonstrate an overall decreasing to stable plume for constituents in groundwater at the U5 AB.

- Statistically increasing trends account for 59 of 1,037 total trends (6%) and 59 of 672 trends (9%) excluding non-detects and data sets with too few data points. Five of six wells with increasing constituent concentration trends and maximum concentrations >50% COI criterion are located within or upgradient from the planned area of corrective action for the U5 AB. The other well, GWA-1BRU, is located on the far side of a hydrologic divide from the U5 AB and increasing iron concentrations at this location are likely associated with natural background conditions.
- North of the U5 AB main dam, increasing constituent concentrations trends are limited to three constituents at three wells (one constituent per well) located between the waste boundary and the compliance boundary. There are no constituents with increasing concentration trends (>50% COI criterion) at or beyond the compliance boundary. Decreasing constituent concentration trends are prevalent. Concentration of constituents with increasing trends (>50% COI criterion) are below their respective COI criterion.
- These results support proposed continued monitoring of groundwater north of the U5 AB main dam through closure.

Summary

Results of the Mann-Kendall trend analysis indicate that the limited occurrence of increasing constituent concentrations trends at the U5 AB downstream dam supports continuing to monitor groundwater concentrations at this location during the decanting process and through basin closure. Therefore, near term corrective action for groundwater north of the U5 AB main dam is not warranted, and continued monitoring of groundwater in this area is recommended. The continued monitoring network and analytical parameters are presented on **Table 6-40** and **Figure 6-91**. Given the seepage velocities for the CCR constituents, ample time is available to implement an alternate approach without increasing the risk of affecting receptors should the monitored

groundwater wells show results which are in contrast to the predicted concentration trends for this area of the site.

6.19.4.1 COIs in Unsaturated Soil

(CAP Content Section 6.A.d.i)

Unsaturated soil at or beyond the compliance boundary is considered a potential secondary source to groundwater. Constituents present in unsaturated soil or partially saturated soil (vadose zone) have the potential to leach into the groundwater system if exposed to favorable geochemical conditions for chemical dissolution to occur. Therefore, constituents considered for unsaturated soil evaluation as related to the U5 AB were the same constituents identified as COIs for the U5 AB.

Cliffside samples of background soil and rock media indicate that some naturally occurring constituents that are also typically related to CCR material and likely effect the chemistry of groundwater at the Site, are present at concentrations greater than the PSRGs POG values (**Table 4-2**). Constituents with background values greater than PSRGs POG values include arsenic, cobalt, iron, manganese, and thallium.

Unsaturated soil samples from locations at or beyond the U5 AB compliance boundary were collected during soil boring installation activities from wells BG-2D, BGSB-MW-30, BGSB-MW-32, MW-30D, MW-32D, MW-32S, MW-42S, GWA-3D, GWA-5BRU, GWA-5S, GWA-6D, GWA-31BR, GWA-31D, GWA-32D, MW-38D, MW-38S, and MW-40BRU [**Figure 6-68** (*CAP Content Section 6.A.d.i*)]. COIs in saturated soil are considered and evaluted as part of the groundwater flow system, separate from this evaluation. An evaluation of the potential nature and extent of COIs in unsaturated soil at or beyond the U5 AB compliance boundary was conducted by comparing unstaurated soil concentrations with background values or PSRG POG standards, whichever is greater [**Table 6-68** (*CAP Content Section 6.A.b.ii.1, 6.A.c.i.1, and 6.A.d.i*)]. The PSRG POG standard for sulfate (1,438 mg/kg) was calculated (**Table 6-2**)

Constituents detected at concentrations greater than either background values or the PSRG POG standards in unsaturated soil samples (depth), upgradient or downgradient of the U5 AB, at or beyond the compliance boundary include:

- pH: GWA-31BR (4-4), GWA-31D (7-7), GWA-31D (8.7-8.7), MW-40BRU (3.5-5)
- Arsenic: BGSB-MW-32 (2-3), MW-32S (22.5-24)
- Chromium: GWA-3D (48.5-50)
- Manganese: MW-30D (28.5-30), MW-32S (22.5-24)

The arsenic and manganese exceedances listed above are reported at approved background sampling locations. These exceedances are not derived from the U5 AB. The chromium exceedance listed above is within the compliance boundary. There is no transport mechanism from the ash basin to the unsaturated soil exceedance reported at GWA-3D.

6.19.4.2 Horizontal and Vertical Extent of Groundwater in Need of Restoration

(CAP Content Section 6.A.d.ii)

This section discusses the horizontal and vertical extent of groundwater in need of restoration associated with the U5 AB. Groundwater is not in need of restoration adjacent to the U5 AB to the south, east, and west due to the lack of COIs above applicable standards in these areas. A limited number of COIs in groundwater are present at or beyond the compliance boundary to the northeast of the U5 AB. Additional detail for this area is provided below.

Northeastern Extent of COI-Affected Groundwater

Northeast of the U5 AB saddle dam downgradient of the U5 AB, the COI plume at or beyond the compliance boundary is defined by cobalt, iron, lithium, manganese, sulfate, strontium, and TDS at concentrations greater than their comparison criteria. The COIs generally are located within the boron plume with concentrations greater than the boron background values which are used to describe the extent of COIs at or beyond the compliance boundary.

Cobalt, iron, lithium, manganese, strontium, sulfate, and TDS concentrations at or beyond the compliance boundary support the following observations regarding the northeastern extent of COI-affected groundwater by the ash basin (**Figures 6-76** through **6-84c**):

Chromium and hexavalent chromium are reported beyond the U5 AB compliance boundary in the deep flow layer at monitoring well GWA-37D.

Total radium is reported at the compliance boundary at the U5 AB in the bedrock flow layer at MW-38BR. These exceedances are slightly greater than their comparison criteria and are not part of a discernable plume from the U5 AB. These constituents are not considered COIs associated with the U5 AB northeast of the basin.

Cobalt is reported at concentration greater than comparison criteria (background values) at or beyond the U5 AB compliance boundary in the shallow flow layer at monitoring wells GWA-36S and GWA-37S. These exceedances appear to be part of a discernable plume from the U5 AB. Cobalt is not reported at concentrations greater than comparison criteria in the deep or bedrock flow layers at or beyond the U5 AB compliance boundary northeast of the U5 AB saddle dam.

Iron has an exceedance of comparison criteria (background value) at or beyond the compliance boundary in the shallow flow layer at GWA-36S and GWA-37S. These exceedances appear to be part of a discernable plume from the U5 AB. Iron concentrations greater than the comparison criteria are not reported in the deep or bedrock flow layers northeast of the U5 AB at or beyond the compliance boundary.

Lithium has exceedances of comparison criteria (background value) in the shallow flow layer near the U5 AB compliance boundary at GWA-36S. This exceedance appears to be part of a discernable plume from the U5 AB. Lithium is not reported at concentrations greater than the comparison criteria at or beyond the compliance boundary in the deep flow layer at the U5 AB. An isolated lithium exceedance is reported at the compliance boundary in the bedrock flow layer northeast of the U5 AB at monitoring well MW-38BR.

Manganese exceedances of the comparison criteria (background value) in the shallow and deep flow layers are reported at and beyond the U5 AB compliance boundary to the northeast of the basin. This exceedance appear to be part of a discernable plume from the U5 AB. An isolated manganese exceedance is reported at the compliance boundary in the bedrock flow layer northeast of the U5 AB at monitoring well MW-38BR.

Strontium is reported greater than its comparison criteria at or beyond the compliance boundary in the shallow, deep, and bedrock flow layers northeast of the U5 AB. Strontium concentrations greater than the

statistically derived background values are common at the Site and often are not located in flow paths reflective of migration from the ash basins or ASA. Therefore, the natural variability of strontium may not be accurately reflected by the current background dataset. As part of the EMP, a five year review process is proposed which would include routine re-evaluation of background concentrations as additional data becomes available.

Sulfate concentrations greater than the 02L standard are not reported in the shallow flow layer northeast of the U5 AB at or beyond the compliance boundary. Sulfate is reported greater than the 02L standard at or beyond the U5 AB compliance boundary in the deep flow layer to the northeast of the U5 AB. These exceedances appear to be reflective of migration from the U5 AB. An isolated sulfate exceedance of the 02L standard is reported at the compliance boundary in the bedrock flow layer northeast of the U5 AB at monitoring well MW-38BR.

TDS concentrations greater than the 02L standard are not reported in the shallow flow layer northeast of the U5 AB at or beyond the compliance boundary. TDS is reported greater than the 02L standard at or beyond the U5 AB compliance boundary in the deep flow layer to the northeast of the U5 AB. These exceedances appear to be reflective of migration from the U5 AB. An isolated TDS exceedance of the 02L standard is reported at the compliance boundary in the bedrock flow layer northeast of the U5 AB at monitoring well MW-38BR.

6.19.5 COI Distribution in Groundwater

(CAP Content Section 6.A.e)

As part of the COI management process and geochemical modeling (**Appendix H**) constituents with concentrations greater than the 02L standard, IMAC, or background values beyond the compliance boundary were grouped by geochemical behavior and mobility. A comprehensive evaluation (*i.e.* mean analysis and groupings) of available data was used to demonstrate constituent distribution in groundwater to evaluate the spatial occurrence with a discernable plume in the direction of groundwater flow downgradient of the U5 AB. The groupings of constituents that were mapped and are considered for corrective action are as follows:

- **Conservative, non-reactive constituents:** boron, lithium, sulfate, and TDS. Geochemical model simulations support that these constituents would transport conservatively (K_d values <1 L/kg) as soluble species under most

conditions, and that the mobility of these COIs will not change significantly due to current geochemical conditions or potential geochemical changes related to remedial actions.

- **Non-conservative, reactive constituents:** chromium and strontium. Geochemical model simulations support that these constituents are subject to significant attenuation in most cases and have high K_d values indicating the mobility of these COIs is unlikely to be geochemically affected by current geochemical conditions or potential geochemical changes related to remedial actions.
- **Variably reactive constituents:** cobalt, hexavalent chromium, iron, manganese, and radium (total). Geochemical model simulations, and resulting K_d values, support these constituents may be non-reactive or reactive in relation to geochemical changes and are dependent on the pH and E_h of the system. The sensitivity of these COI to the groundwater pH and E_h indicates that these constituents could respond to natural changes under current conditions, such as water level fluctuations imposed by seasonality, and decanting or source control activities that have the potential to change the groundwater pH or Eh.

COIs identified in the CSA that are not mapped in this CAP Update generally not only have limited spatial occurrences within the compliance boundary, but are further spatially limited to isolated areas within the compliance boundary that do not have a discernable plume geometry.

6.19.5.1 Conservative Constituents

(CAP Content Section 6.A.e.i)

Boron, lithium, sulfate, and TDS mean isoconcentration maps (**Figures 6-75a/b/c, 6-80a/b/c, 6-83a/b/c,** and **6-84a/b/c**) and cross-sections (**Figures 6-69a, 6-70a,** and **6-70a**) support the following observations regarding the extent of COI-affected groundwater represented by these conservative constituents:

- Boron is not reported in the shallow, deep, or bedrock flow layers greater than the 02L standard at or beyond the U5 AB compliance boundary.
- Lithium is reported near the compliance boundary at concentrations greater than the comparison criteria (background values) in the shallow flow layer northeast of the U5 AB at GWA-36S. Lithium is

reported at or beyond the compliance boundary at concentrations greater than the comparison criteria in the deep flow layer at GWA-56D and in the bedrock flow layer at MW-38BR.

- Sulfate and TDS concentrations in the shallow flow layer do not extend beyond the U5 AB compliance boundary at concentrations greater than their 02L standards. Sulfate and TDS are reported at concentrations greater than their 02L standards in the deep flow layer near the compliance boundary at GWA-36D, and at or beyond the compliance boundary at GWA-37D. Sulfate and TDS are reported at concentrations greater than their 02L standards at the compliance boundary in the bedrock flow layer at GWA-38BR.

The maximum extent of COI-affected groundwater migration for all flow zones is represented by boron. Lithium, sulfate, and TDS concentrations identified as being greater than their respective groundwater regulatory standards are associated with COI-affected groundwater migration from the ash basin but are generally confined within the extent of the boron background plume.

Plume Behavior and Stability

(CAP Content Section 6.A.e.i.1)

Mann-Kendall trend analysis was performed using conservative constituent datasets for ash pore water and groundwater wells within the waste boundary, between the waste boundary and compliance boundary, and downgradient the source area, at or beyond the compliance boundary (**Table 6-33**). Trend analysis and results are prepared by Arcadis U.S. Inc. and included in a technical memorandum titled *Plume Stability Evaluation – Cliffside Steam Station* (Arcadis, 2019). The technical memorandum is included as in **Appendix I** as Attachment A.

The analysis was performed using analytical results for samples collected from 2011 through 2019. Trend analysis results are presented where at least four samples were available and frequency of detection was greater than 50%. Statistically significant trends are reported at the 95% confidence level. The analysis of constituent concentrations through time produced six possible results:

1. Statistically significant, decreasing concentration trend (D)
2. Statistically significant, increasing concentration trend (I)

3. Greater than 50% of concentrations were non-detect (ND)
4. Insufficient number of samples to evaluate trend (n <4) (NE)
5. No significant trend, and variability is high (NT)
6. Stable. No significant trend, and variability is low (S)

Results of the Mann-Kendall trend analysis indicate the following:

- Groundwater COI concentration trends with time were evaluated for 17 constituents for 61 wells for a total number of 1,037 trends. Trends that were not increasing accounted for 978 of the 1,037 trends evaluated (94% of total). Excluding trends that had greater than 50% non-detect values or insufficient number of valid samples to run a trend (n<4), 613 of 672 trends (91% of total) had statistically decreasing trends, stable trends, or no trends. These results demonstrate an overall decreasing to stable plume for constituents in groundwater at the U5 AB.
- Statistically increasing trends account for 59 of 1,037 total trends (6%) and 59 of 672 trends (9%) excluding non-detects and data sets with too few data points. Five of six wells with increasing constituent concentration trends and maximum concentrations >50% COI criterion are located within or upgradient from the planned area of corrective action for the U5 AB. The other well, GWA-1BRU, is located on the far side of a hydrologic divide from the U5 AB and increasing iron concentrations at this location are likely associated with natural background conditions.
- North of the dam, increasing constituent concentrations trends are limited to three constituents at three wells (one constituent per well) located between the waste boundary and the compliance boundary. There are no constituents with increasing concentration trends (>50% COI criterion) at or beyond the compliance boundary. Decreasing constituent concentration trends are prevalent. Concentration of constituents with increasing trends (>50% COI criterion) are below their respective COI criterion. These results support proposed continued monitoring of groundwater north of the dam through closure.

6.19.5.2 Non-Conservative Constituents

(CAP Content Section 6.A.e.ii)

Chromium and strontium isoconcentration maps (**Figures 6-76** and **6-82a/b/c**) and cross-sections (**Figures 6-69b, 6-70b,** and **6-71b**) support the following observations regarding the extent of COI-affected groundwater represented by these non-conservative constituents:

- Chromium exceedances of the 02L standard are not reported at or beyond the compliance boundary at the U5 AB in the shallow or bedrock flow layers. Chromium is reported as an isolated 02L standard exceedance northeast of the U5 AB compliance boundary in the deep flow layer at monitoring well GWA-37D. This 02L exceedance is not part of a discernable plume originating from the U5 AB.
- Strontium is reported at concentrations greater than comparison criteria (background value) at or beyond the compliance boundary in shallow and deep well clusters at MW-40, GWA-56, GWA-37, MW-38, and MW-36. Strontium is reported at or beyond the compliance boundary at concentrations greater than the comparison criteria in the bedrock flow layer at GWA-38BR. Strontium concentrations greater than the statistically derived background values are common at the Site and often are not located in flow paths reflective of migration from the ash basins or ASA. Therefore, the natural variability of strontium may not be accurately reflected by the current background dataset. As part of the EMP, a five year review process is proposed which would include routine re-evaluation of background concentrations as additional data becomes available.

6.19.5.3 Variably Conservative Constituents

Cobalt, hexavalent chromium, iron, manganese, and radium (total) isoconcentration maps (**Figures 6-78, 6-77, 6-79a/b, 6-81a/b/c**, and **6-85**) and cross-sections (**Figures 6-69c, 6-70c,** and **6-71c**) support the following observations regarding the extent of COI-affected groundwater represented by these variable constituents:

- Cobalt is reported at concentrations greater than the comparison criteria (background values) at or beyond the compliance boundary in the shallow flow layer. The cobalt exceedances in the shallow flow layer appear to be the result of a discernable plume originating from

the U5 AB. Cobalt is not reported at concentrations greater than its comparison criteria at or beyond the compliance boundary in the deep or bedrock flow layers.

- Hexavalent chromium has an isolated exceedance of its comparison criteria (background values) in the deep flow layer at or beyond the compliance boundary at monitoring well GWA-37D. Hexavalent chromium is not reported at concentrations greater than its comparison criteria at or beyond the compliance boundary in the shallow or bedrock flow layers.
- Iron is reported at concentrations greater than comparison criteria (background value) at or beyond the compliance boundary in shallow monitoring well GWA-37S. The iron exceedances in the shallow flow layer appear to be the result of a discernable plume originating from the U5 AB. Iron is not reported in the deep or bedrock flow layers at concentrations which exceed the comparison criteria at or beyond the compliance boundary.
- Manganese is reported at concentrations greater than comparison criteria (background value) at or beyond the compliance boundary in shallow monitoring well GWA-37S. Manganese is reported at concentrations greater than comparison criteria at or beyond the compliance boundary in the deep and bedrock flow layers at the monitoring well GWA-38 cluster. The manganese exceedances in the shallow and deep flow layers appear to be the result of a discernable plume originating from the U5 AB.
- Radium (total) is not reported in the shallow or deep flow layers at concentrations which exceed the comparison criteria (background value) at or beyond the compliance boundary. Radium (total) has an isolated exceedance of its comparison criteria in the bedrock flow layer at or beyond the compliance boundary at monitoring well GWA-38BR.

6.20 SA3 Potential Receptors Associated with Source Area

(CAP Content Section 6.B)

CSA and ongoing monitoring data confirm that affected groundwater is located immediately downgradient of the U5 AB. COI-affected groundwater is limited to Duke Energy property. COI-affected groundwater from the U5 AB does not reach any water

supply wells, and modeling indicates this will remain the case in the future. Therefore, potential receptors are limited to Suck Creek and the Broad River.

6.20.1 Surface Waters – Downgradient Within a 0.5-Mile Radius of Waste Boundary

(CAP Content Section 6.B.a)

A depiction of surface water features — including wetlands, ponds, unnamed tributaries, seeps, streams, lakes, and rivers — within a 0.5-mile radius of the ash basin compliance boundary, along with permitted outfalls under the NPDES and the SOC locations are shown on **Figure 5-10** (*CAP Content Section 6.B.a.i and6.B.a.ii*). The 0.5-mile radius from the ash basin compliance boundary, for which data is evaluated and depicted on figures, includes surface water features within 0.5-mile radius of the waste boundary. The U5 AB is located south of the Broad River to the north. Suck Creek is located to the east of the U5 AB. Associated North Carolina surface water classifications for the Broad River and Suck Creek are summarized in **Section 5.3.1** and **Table 5-3** (*CAP Content Section 6.B.a.iii*).

For groundwater corrective action to be implemented under 15A NCAC .02L .0106(k), groundwater discharge to surface water cannot result in exceedances of standards for surface waters contained in 15A NCAC 02B .0200 (02B). Surface water samples were collected from the Broad River and Suck Creek to confirm groundwater downgradient of the U5 AB has not resulted in surface water concentrations greater than 02B water quality standards. A map of surface water sample locations for groundwater discharge to surface water evaluation is included in **Appendix J** (*CAP Content Section 6.B.a.iv*). Surface water samples were collected, using division approved protocols, to evaluate acute and chronic water quality values. Surface water samples were also collected at background locations (upgradient of potential migration areas) within the Broad River and Suck Creek. Analytical results were evaluated with respect to 02B water quality standards and background data.

Comparisons of surface water data with the applicable USEPA National Recommended Water Quality Criteria for Protection of Aquatic Life, Human Health and/or Water Supply (USEPA, 2015; 2018a; 2018b) was conducted on surface water samples from the Broad River and Suck Creek. As stated by the USEPA, these criteria are not a regulation, nor do they impose a legally-binding requirement. Therefore, comparisons with these criteria are only for situational context. The constituents that have corresponding USEPA criteria but do not

have 02B criteria are alkalinity, aluminum, antimony, iron and manganese. The background ranges reported in Suck Creek and the Broad River were greater than the USEPA criteria with the exception of antimony which was non-detect in surface water background location samples. Alkalinity had one result reported greater than the background range at SW-8 during the June 2016 sampling event. The other nine sampling events at this location have had alkalinity results within the range of surface water background concentrations. Manganese was reported in Broad River sample locations SW-BRAB-1, SW-BRAB-2, and SW-BRAB-3 at concentration greater than the range of background values during the January 2017 sampling event and less than the range of background values during the June 2019 sampling event.

The surface water samples were collected in accordance with NCDEQ DWR Internal Technical Guidance: Evaluating Impacts to Surface Water from Discharging Groundwater Plumes - October 31, 2017. The full report for CSS groundwater discharge to surface water and the evaluation of surface waters to evaluate compliance with 15A NCAC 02B .0200 was submitted to NCDEQ in March 2017 (**Appendix J)**.

General findings of the evaluation of current surface water quality conditions at CSS include:

- Groundwater migration from the ash basin source area has not resulted in violations of the 15 NCAC 02B surface water quality standards in the Broad River.
- Groundwater migration from the ash basin source area has not resulted in violations of the 15 NCAC 02B surface water quality standards in the Suck Creek.

An addendum to the current conditions surface water evaluation was completed to assess surface water at sample location SW-SC-6A (**Figure 1-2**). The result of the surface water quality standards addendum found that groundwater migration from the U5 AB has not resulted in violations of the 15 NCAC 02B surface water quality standards in Suck Creek (**Appendix J**).

Surface Water - Future Conditions Evaluation

An evaluation of potential future groundwater migration to surface water was conducted to identify areas where further evaluation might be warranted. For areas of potential future groundwater migration to surface water, a mixing

model approach was used for the evaluation of future surface water quality conditions. Flow and transport modeling results were used to determine where groundwater migration from the U5 AB might intersect surface water in the future. Predictive groundwater modeling using boron as a proxy for COI plume migration demonstrated the Broad River to the north of the U5 AB could potentially be influenced by future groundwater migration. A groundwater to surface water mixing model approach was used to determine the potential surface water quality in the future groundwater discharge zones. The full report for CSS groundwater discharge to surface water under future conditions can be found in **Appendix J**.

General findings of the evaluation of future surface water conditions in potential groundwater discharge areas include:

- The surface water mixing model evaluation demonstrates that predicted constituent concentrations in surface waters are less than 02B surface water standards. Therefore, the criteria for compliance with 02B is met, allowing further evaluation of potential corrective action under 15A NCAC 02L.0106 (k), (l), or (m).
- Review of Site data and results from the flow and transport model indicate that affected groundwater migration would not reach Stream 12 on the west side of the Site.

Seeps currently governed by the SOC that remain and are not dispositioned 90 days after completion of decanting would be characterized for determination of corrective action applicability. Where applicable, and accounting for seep jurisdictional status, corrective action planning at that time would occur.

6.20.2 Water Supply Wells

(CAP Content Section 6.B.b)

A total of 71 private water supply wells were identified within the 0.5-mile radius of the pre-2018 ash basin compliance boundaries. Most of these water supply wells were located south, southeast, east, and northeast of the AAB off of McCraw Road, Prospect Church Road, Fox Place, and Riverfront Drive, west and southwest of the U5 AB along Duke Power Road, US-221A, and Old US-221A; and north of the Broad River (**Figure 5-12**). The 0.5-mile radius from the ash basin compliance boundary, for which data is evaluated and depicted on figures, is greater than the required 0.5-mile radius from the waste boundary and is consistent with the drinking water well and receptor surveys.

No public or private drinking water wells or wellhead protection areas were found to be located downgradient of the U5 AB as discussed in **Section 5.3**. This finding has been supported by field observations, a review of public records, historical groundwater flow direction data and groundwater flow and transport modeling (**Appendix G**). The location and relevant information pertaining to water wells located upgradient or side-gradient of the facility, within 0.5-miles of the compliance boundary, were included in the survey reports.

6.20.2.1 Provision of Alternative Water Supply

(CAP Content Section 6.B.b.i)

Although results from local water supply well testing do not indicate effects from the source areas at CSS, private water supply wells identified within the 0.5-mile radius of the pre-2018 compliance boundaries have been offered to be connected to an alternative water supply, per G.S. Section 130A-309.211(c1) requirements.

Duke Energy identified a total of 70 private residential properties eligible for connections for a public water supply connection near CSS. Eligibility was contingent that the property did not include:

- A business
- A church
- A school
- Connection to the public water supplier
- An empty lot

Of the 70 eligible connections, one opted out of the option to connect to the public water system and two did not respond to the offer. Duke Energy connected 65 properties to the public water system, and two will be connected in the future in accordance with G.S. Section 130A-309.211(c1).

On September 5, 2018, Duke Energy provided completion documentation to NCDEQ to fulfill the requirements of House Bill 630. NCDEQ provided correspondence, dated October 12, 2018, to confirm that Duke Energy satisfactorily completed the alternative water supply provisions under CAMA G.S. 130A-3099.211(c1) at CSS. Both documents are provided in **Appendix D**.

Figure 5-12 shows the public and private water supply well locations with reference to properties connected to the public water supply, along with vacant parcels and residential properties whose owners have either decided to opt-out of the water treatment system program or did not respond to the offer. As discussed in **Section 5.3**, all of the private water supply wells are located either upgradient or side-gradient of the ash basins and all water supply wells are outside of the area of groundwater affected by the U5 AB.

6.20.2.2 Findings of Drinking Water Supply Well Surveys

(CAP Content Section 6.B.b.ii)

The location and information pertaining to water supply wells located upgradient or side-gradient of the facility, within 0.5 miles of the ash basin compliance boundaries, were included in drinking water supply well survey reports. Results from surveys conducted to identify potential receptors for groundwater, including public and private water supply wells and surface water features within a 0.5-mile radius of the pre-2018 ash basin compliance boundaries, have been reported to NCDEQ:

- *Drinking Water Well and Receptor Survey – Cliffside Steam Station* (HDR, 2014a)
- *Supplement to Drinking Water Well and Receptor Survey – Cliffside Steam Station* (HDR, 2014b)
- *Comprehensive Site Assessment Report – Cliffside Steam Station Ash Basin* (HDR, 2015a)
- *Draft Drinking Water Well and Receptor Survey – Cliffside Steam Station* (HDR, 2016b)
- *Comprehensive Site Assessment Update Report – Cliffside Steam Station Ash Basins* (SynTerra 2018a)

As documented in the 2018 CSA Update, NCDEQ arranged for independent analytical laboratories to collect and analyze water samples in 2014 and 2015 from private wells identified during the well survey, if the owner agreed to have their well sampled. NCDEQ collected and analyzed 32 groundwater samples from 23 private water supply wells within a 0.5 mile radius of the CSS pre-2018 ash basin compliance boundaries.

Duke Energy collected samples from private water supply wells in 2016 and 2017 after the NCDEQ sampling effort. For many of the wells sampled in

this program, as with standard practice, samples were split for analysis by Duke Energy's certified (North Carolina Laboratory Certification #248) laboratory.

Table 6-9 provides tabulated results for the NCDENR and Duke Energy sampling results as well as identified exceedances of 02L standards, IMACs, and bedrock background values as well as a well-by-well summary of COI exceedances and characterization**.** The exceedance evaluation compares bedrock background values since it is assumed area water supply wells are installed within the bedrock, which is typical for water supply wells in the Piedmont.

The major findings from the water supply well evaluation include:

- All water supply wells are outside of the boron plume as defined on the isoconcentration contour maps for all flow zones (**Figure 6-75a/b/c**).
- All water supply wells to the southwest are upgradient of the U5 AB (**Figure 5-12**).
- Eleven of 23 water supply wells sampled demonstrated exceedances to comparable standards (background values, 02L standards or IMAC, whichever is greater).
- Groundwater sample C-1007: 433 Dysart Place was collected from a water supply well located approximately one-mile southwest of the U5 AB waste boundary. This well is located in a separate drainage system separated by a hydrologic divide represented by an unnamed tributary to the Broad River. Boron was not detected at concentrations at or greater than the adjusted reporting limit in this well, and the well is outside of the boron plume as defined on the isoconcentration contour maps for all flow zones (**Figure 6-75a/b/c**). Sulfate was reported in the groundwater sample in this well at a concentration less than the site background value. The reported manganese results are greater the comparison criteria; however, the reported concentrations fall within the bedrock background range for other piedmont CCR sites (**Table 6-9**). The water supply well plots in the generally unaffected category indicating that they do not have the same geochemical signature as the source area pore water within the basin. Based on these lines of evidence, groundwater in

monitoring well C-1007: 433 Dysart Place is not impacted by the U5 AB.

- Groundwater sample C4 Well 3 was collected from a water supply well located approximately 1,250 feet southwest of the U5 AB waste boundary. This well is upgradient of the U5 AB. Boron and sulfate were reported in the groundwater sample from this well at concentration less than their respective site background values. The well is located outside of the boron plume as defined on the isoconcentration contour maps for all flow zones (**Figures 6-79a/b/c**). The reported vandium result is greater the comparison criteria; however, the reported concentration falls within the bedrock background range for other piedmont CCR sites (**Table 6-9**). The water supply well plots in the generally unaffected category indicating that they do not have the same geochemical signature as the source area pore water within the basin.Based on these lines of evidence, groundwater in monitoring well C4 Well 2 is not impacted by the U5 AB.

6.20.3 Future Groundwater Use Areas

(CAP Content Section 6.B.c)

Duke Energy owns the land and controls the use of groundwater on the land downgradient of the U5 AB within and beyond the predicted area of potential groundwater COI influence. Therefore, no future groundwater use areas are anticipated downgradient of the ash basins or ASA.

It is anticipated that private and public properties within a 0.5-mile radius of the ash basin compliance boundaries that are not connected to the municipal water system will continue to rely on groundwater resources for water supply for the foreseeable future [(**Figure 5-9**) *(CAP Content Section 6.B.c.i)*].

Based on predicted groundwater flow patterns, under post ash basin closure conditions, and the location of water supply wells in the area, groundwater flow direction from the ash basins and ASA is expected to be continue to be to the north toward the Broad River, and therefore will not flow towards any water supply wells [(**Appendix G**) *(CAP Content Section 6.B.c.ii)*].

6.21 SA3 Human and Ecological Risks

(CAP Content Section 6.C)

Updated human health and ecological risk assessments were prepared for the CSS consistent with the CAP content guidance. The updated risk assessments incorporate results from surface water, sediments, and groundwater samples collected from March 2015 through June 2019. Primary conclusions of the risk assessment include:

(1) the ash basins do not cause an increase in risks to potential human receptors located on-Site or off-Site; and

(2) the ash basins do not cause an increase in risks to ecological receptors.

These conclusions are further supported by multiple water quality and biological assessments conducted by Duke Energy as part of the NDPES monitoring program. A more detailed discussion regarding human health and ecological risk associated with the ash basin can be found in **Section 5.4**. An update to the CSS human health and ecological risk assessment is included in **Appendix E**.

6.22 SA3 Groundwater Remedial Technologies

(Supplemental Information to CAP Content Section 6.D)

This section provides supplemental information beyond the CAP content guidance to introduce groundwater remediation technologies and consider a range of individual technologies that might be used to formulate comprehensive groundwater remediation alternatives for consideration at Cliffside. Groundwater remedial technologies are discussed in detail in **Section 6.4**.

6.22.1 Monitored Natural Attenuation

MNA will be retained for further consideration for source area 3 at Cliffside, as groundwater COIs do not pose an unacceptable risk to human health or the environment under conservative exposure scenarios and a source control measure will be implemented that eliminate or mitigate the source of CCR constituents in groundwater. The MNA evaluation for the technical applicability at Cliffside is provided in **Appendix I**.

6.22.2 In-Situ Technologies

Groundwater remediation technologies that are implemented in-situ, or in place.

Low Permeability Barriers

Construction of a LPB in Source Area 3 would involve drilling to competent bedrock and injecting bentonite or grout into fractured bedrock, the transition zone, and possibly into saprolite flow zones. Installation of an effective low

permeability barrier to depths approaching 100 feet would be technically challenging and costly; therefore LPB technology will not be retained for further consideration.

Groundwater Flushing

Because the primary COIs in Source Area 3 at Cliffside are reactive (non-conservative), groundwater flushing is not an appropriate technology for this application.

Encapsulation

COIs are not concentrated in any discrete areas making encapsulation impractical. Encapsulation technologies are not carried forward for further evaluation.

Permeable Reactive Barrier

Because low pH is a concern in Source Area 3, permeable reactive barriers are carried forward of further consideration.

6.22.3 Groundwater Extraction

Groundwater extraction is potentially applicable to control the migration of COIs in Source Area 3.

Vertical Extraction Wells

The use of vertical groundwater extraction wells is retained for further consideration.

Horizontal/Angular Well Extraction Wells

Groundwater modeling conducted for Source Area 3 at Cliffside indicates that vertical groundwater extraction wells can produce sufficient yield for purposes of hydraulic containment and/or constituent mass removal and are more cost effective. The use of horizontal or angular groundwater extraction wells is not retained for further consideration.

Extraction Trenches

Acidic groundwater in the area of the U5 AB saddle dam is thought to mobilize COIs in Source Area 3. A shallow trench for capture and control of the acidic groundwater near the saddle dam is retained for further consideration. Following closure of the U5 AB the acidic groundwater should be eliminated.

Hydraulic Fracturing

The use of hydraulic fracturing to enhance remediation of bedrock groundwater is not considered further because the extent of COIs in bedrock groundwater is limited.

Phytoremediation

Phytoremediation technology can be used to extract groundwater; however, phytoremediation is not capable of achieving extraction rates necessary to achieve groundwater remediation in Source Area 3 within reasonable timeframes. The use of phytoremediation is not retained for further consideration.

6.22.4 Groundwater Treatment

The facility has treatment in place at the Holding Basins for their NPDES discharge.

pH Adjustment

Low pH is an issue in Source Area 3; therefore, this treatment technology will be retained for further consideration.

Precipitation

Precipitation is one of the processes used in the Cliffside WWTP associated with Outfall 005.

Ion Exchange

A limitation of this technology is that there must be a feasible and economical method to dispose of the regeneration effluent. An additional challenge could be groundwater influent streams that might have geochemical characteristics that result in interference in the ion exchange process. Because of these challenges ion exchange is not retained for further consideration.

Membrane Filtration

Membrane filtration for Source Area 3 is not carried forward for further evaluation for the following reasons:

- Extracted groundwater is not expected to be greater than permit discharge limits.
- Pretreatment and a high volume of reject effluent that requires additional treatment prior to disposal make this technology costly and high maintenance.

6.22.5 Groundwater Management

Extracted groundwater must be disposed of or used as supplemental process water prior to discharge. The disposition of extracted groundwater is discussed in the following sections.

National Pollutant Discharge Elimination System (NPDES) Permitted Discharge

Anticipated groundwater remediation parameter levels are within NPDES permit limits on **Table 6-35**. Therefore, discharge of extracted groundwater through the NPDES discharge system will be retained for further consideration.

Publicly Owned Treatment Works (POTWs)

Discharge of extracted groundwater to a POTW is not retained for further consideration at this time because of the extensive distance required to pipe extracted groundwater to the POTW.

Non-Discharge Permit/Infiltration Gallery

Treatment of conservative and variably conservative constituents could result in a complicated system with significant operation and maintenance efforts. Therefore, the use of infiltration galleries to dispose of treated groundwater is not retained for further consideration.

Non-Discharge Permit/Land Application

Land application of extracted groundwater must not result in concentrations greater than 02L groundwater standards or affect the model predictions. Therefore, land application will not be retained as an alternative means for disposal of extracted groundwater because the treatment to achieve adequate water quality is excessive.

Beneficial Reuse

Beneficial reuse of extracted groundwater involves the evaluation of existing Station water demand and the repurposing of extracted groundwater to satisfy a need for water. Beneficial reuse of extracted groundwater can do the following:

- Provide an alternative to groundwater treatment.
- Reduce reliance on sources of non-potable water required for plant operations.
- Reduce the need and capacity for wastewater treatment.

Beneficial reuse for non-contact cooling water or for dust suppression or truck washing is not carried forward for further consideration at this time.

6.22.6 Technology Evaluation Summary

A summary of the remedial technologies presented above and the rationale for either retaining or rejecting a specific technology is presented in **Table 6-35**.

In conclusion, remedial technologies retained for further consideration include, MNA, a permeable reactive barrier, and groundwater extraction using vertical extraction wells and a source control trench. Discharge of the extracted groundwater is anticipated to be through the existing NPDES outfall.

6.23 SA3 Groundwater Remediation Alternatives

(CAP Content Section 6.D.a)

Technologies evaluated and retained for consideration as discussed in **Section 6-36** were used to formulate the following three groundwater remedial alternatives to remediate Site groundwater:

- Remedial Alternative 1: Monitored Natural Attenuation
- Remedial Alternative 2: pH Adjustment Gallery
- Remedial Alternative 3: Groundwater Extraction and Source Control

These groundwater remedial alternatives are detailed in the following subsections.

6.23.1 Remedial Alternative 1 – Monitored Natural Attenuation

(CAP Content Section 6.D.a)

Alternative 1 is the use of MNA to address groundwater COI concentrations outside of the U5 AB compliance boundary. Under this alternative the groundwater plume could continue to migrate beyond the current compliance boundary northeast of the ash basin; compliance is will eventually be achieved after ash basin closure completed (**Appendix G**). A detailed comprehensive analysis of MNA is provided in **Appendix I.**

6.23.1.1 Problem Statement and Remediation Goals

(CAP Content Section 6.D.a.i)

CCR constituents in groundwater associated with the Cliffside U5 AB occur at or beyond the compliance boundary to the northeast of the ash basin at concentrations detected greater than applicable 02L standards, IMAC, or background values, whichever is greater. Remediation goals are to restore groundwater quality at or beyond the compliance boundary by returning

COIs to acceptable concentrations (02L standard/IMAC or background values, whichever is greater), or as closely thereto as is economically and technologically feasible consistent with 15A NCAC 02L. 0106(a).

The conceptual model and predictive modeling discussions summarize the foundations for development of the groundwater treatment alternative. More extensive discussion of the CSM can be found in **Section 5.0**, discussion of flow and transport modeling in **Appendix G**, and discussion of geochemical modeling in **Appendix H**.

6.23.1.2 Conceptual Model

(CAP Content Section 6.D.a.ii)

Based on the CSM (**Section 5**) and flow and transport modeling results (**Appendix G**), the groundwater COIs are hydraulically controlled within the topographic drainage basin downgradient of the ash basin, with the exception of the area to the northeast of the U5 AB saddle dam.

In the future, alternative standards may be proposed as allowed under 02L.0106(k). This approach is considered reasonable given the documented lack of human health or ecological risk at Cliffside.

Source control is a primary component of MNA as a remedial strategy. The current timeframes for implementation of the source control measures under consideration range from approximately 6 to 10 years, depending upon the selected source control remedy. Active source control is considered a critical component of reducing constituent migration from the ash basin. The closure will reduce the potentiometric head responsible for the downward vertical gradient upstream of the U5 AB basin saddle dam. A lower downward gradient would reduce downward COI migration. As a result, constituent concentration reductions through natural attenuation processes are anticipated following closure.

The following three chemical natural attenuation mechanisms are also an effective corrective action approach northeast of the U5 AB because they aid in stabilizing control of reactive and variable reactive COIs in groundwater by the following processes:

- **Sorption**: Chemical attachment of electrochemically charged ions to charged receptors in the subsurface media

- **Precipitation:** Removal of a COI from a dissolved state in groundwater by incorporation into the matrix of a solid such as a mineral or an amorphous mass
- **Ion Exchange**: Incorporation of an ion into the crystal structure of a matrix mineral or amorphous solid

The following five physical natural attenuation mechanisms are an effective corrective action approach northeast of the U5 AB because they control the migration and distribution of all or some COIs in groundwater by the following processes:

- **Dilution**: Reduce COI concentrations through mixing with unaffected groundwater
- **Dispersion**: Reduce COI concentrations through variability of the flow velocity and concentration gradients
- **Transfer to surface water**: Reduce COI concentrations through mixing and flushing with surface water without exceeding 02B standards
- **Groundwater flow control within the stream valley system**: Control COI migration within hydraulic divide boundaries near of the ash basin
- **Phyto-attenuation:** Uptake of the COI by plants or organisms

Currently, COIs in groundwater do not pose an unacceptable risk to human health or the environment under conservative exposure scenarios and, if implemented alone, MNA would not pose an unacceptable risk to human health or the environment in the future. Source control and groundwater monitoring would verify protection of human health and the environment and to confirm model predictions. The applicable technologies that would support this alternative include groundwater monitoring wells within the former source area and near the former waste boundary, along downgradient flow transects, at the point of compliance, in sentinel areas prior to receptors, and near the maximum predicted extent of migration. A majority of the wells have dedicated sampling equipment and an approved interim monitoring plan is in place. A subset of these monitoring wells could be immediately used for monitoring the effectiveness of Alternative 1.

6.23.1.3 Predictive Modeling

(CAP Content Section 6.D.a.ii)

At most ash basin locations, such as the AAB, predictive modeling has been conducted at locations such as the AAB were to mitigate the concentration of a conservative non-reactive constituent, primarily boron, that is encroaching upon, or is beyond, the 500-foot compliance boundary. Therefore, the flow and transport modeling is calibrated to predict concentrations of a conservative constituent at locations within and beyond the 500-foot compliance boundary.

For the U5 AB, non-conservative constituents are the primary issue at and beyond the 500-foot compliance boundary. However, predictive modeling has not been conducted in the area northeast of the U5 AB because boron concentrations in this area are less than the 02L standard. Similar simulations conducted on conservative constituents other than boron predict that they would naturally attenuate to less than the groundwater comparison criteria. For the U5 AB, particle tracking and modeled hydraulic head contours were used rather than flow and transport modeling to assess the effectiveness of the alternatives (**Figures 88e** and **88f**). A flow and transport modeling report prepared for Cliffside is presented in **Appendix G**. Similarly, a geochemical modeling report specific to Cliffside is presented in **Appendix H**.

6.23.2 Remedial Alternative 2 – pH Adjustment Gallery

(CAP Content Section 6.E.a)

Alternative 2 involves the installation of a pH adjustment gallery constructed south and west of Cooling Tower B. The proposed design has been applied successfully to treat acid mine drainage. This alternative provides technology for in-situ groundwater treatment to address Site-specific COIs.

6.23.2.1 Problem Statement and Remediation Goals

(CAP Content Section 6.D.a.i)

CCR constituents in groundwater associated with the Cliffside U5 AB occur near the compliance boundary to the northeast of the U5 AB saddle dam at concentrations detected greater than applicable 02L standards, IMAC, or background values, whichever is greater. Remediation goals are to restore groundwater quality near d the compliance boundary by returning COIs to acceptable concentrations (02L standard/IMAC or background value,

whichever is greater), or as closely thereto as is economically and technologically feasible consistent with 15A NCAC 02L. 0106(a).

In the future, alternative standards may be proposed as allowed under 02L.0106(k). This approach is considered reasonable given the documented lack of human health or ecological risk at Cliffside.

The conceptual model and predictive modeling discussions summarize the foundations for development of the in-situ groundwater treatment alternative. More extensive discussion of the CSM can be found in **Section 5**, discussion of flow and transport modeling in **Appendix G**, and discussion of geochemical modeling in **Appendix H**.

6.23.2.2 Conceptual Model

(CAP Content Section 6.D.a.ii)

The applicable technology that comprises Alternative 2 includes a pH adjustment gallery.

The pH adjustment gallery would be constructed using a conventional back hoe. The dimensions and design would be based on bench-scale testing but would range from 6 to 10 ft. deep and 5 ft. wide. The length of the pH adjustment gallery trench would be determined by the residence time needed to neutralize water flowing through the trench. Bench scale testing would be conducted on the low pH surface water flowing west of Cooling Tower B.

The bottom of the trench would be native soil lined with approximately 6 inches of limestone. Subsequent materials placed in the pH adjustment gallery trench would not inhibit infiltration of treated surface water below the limestone bedding to underlying groundwater. Bailed hay, typically 48-inches long, 24-inches wide, and 16-inches tall and 4-inch layers of composted horse or cow manure, would be placed below and over the limestone lining the bottom of the trench (Johnson, 2005). A geosynthetic liner would be placed over and along the sides of the hay bales to minimize silt intrusion. Limestone would be applied over the top of the geosynthetic liner to a height of approximately 4-inches above the ground surface.

Treated effluent from the pH adjustment gallery trench would gravity drain to a storm water sewer line that directs storm water to the Basement Basin (Holding Cell). Storm water and other waste streams accumulate in the

Holding Cell. The Basement Basin is discharged to the Cliffside WWTP, which is a physical/chemical treatment system consisting of pH adjustment, coagulation and flocculation. Solids are removed from the wastewater using high-rate clarifiers and polishing filters, if necessary. Wastewater is discharged to the Broad River through NPDES Outfall 005.

Treated effluent from the pH adjustment gallery that is not collected by the storm water drain would be allowed to infiltrate into underlying groundwater. Neutralized surface water infiltrating to underlying groundwater would tend to neutralize acidic groundwater downgradient of the pH adjustment gallery. Certain groundwater constituents that are more soluble under acidic conditions might fall out of solution (precipitate or adsorb) at higher or more neutral pH levels (e.g., iron).

The following groundwater COIs subject to corrective action are identified and discussed in **Section 6.19**: boron, chromium, cobalt, hexavalent chromium, iron, lithium, manganese, radium, strontium, sulfate, and TDS.

Groundwater Remedial Alternative 2, coupled with the selected U5 AB closure, would change certain aspects of the conceptual site model (Section 5). When closed, the U5 AB would not contribute as much to the potentiometric head responsible for the downward vertical gradient behind the ash basin dams due to lowering of groundwater levels in the basin. A lower downward gradient would reduce COI migration to groundwater.

The pH of acidic surface water entering the pH adjustment gallery would be neutralized. Some constituents like ferric iron (Fe^{+3}) that are soluble under acidic conditions would become insoluble at higher pH levels and would precipitate. For example, ferric iron ($Fe^{+3}{}_{[aq]}$) would hydrolyze in water to form ferric hydroxide ($Fe(OH)_{3[s]}$). Constituents that precipitate within the pH adjustment gallery would precipitate onto the reactive media. Over time, the precipitant can completely cover the reactive media and render the reactive media ineffective. This is referred to as "armoring". Treatment to de-armor the reactive media or replacement of the reactive media would be warranted if armoring renders the pH adjustment gallery ineffective.

Alternative 2 would immobilize or decrease the mobility of some groundwater COIs, thereby reducing the mass of soluble COIs in Site groundwater. The COIs most affected by pH neutralization of groundwater

would be non-conservative/reactive and variably reactive constituents, as discussed in **Section 6.19.5**.

Currently, COIs in groundwater do not pose an unacceptable risk to human health or the environment under conservative exposure scenarios. If implemented, Groundwater Remedial Alternative 2 would not pose an unacceptable risk to human health or the environment.

6.23.2.3 Predictive Modeling

(CAP Content Section 6.D.a.iii)

At most ash locations, such as the AAB, Predictive modeling has been conducted at locations such as the AAB were to mitigate the concentration of a conservative non-reactive constituent, primarily boron, a conservative and non-reactive constituent, that is encroaching upon, or is beyond, the 500-foot compliance boundary. Therefore, the flow and transport modeling is calibrated to predict concentrations of a conservative constituent at locations within and beyond the 500-foot compliance boundary.

For the U5 AB, non-conservative constituents are the primary issue near the 500-foot compliance boundary. However, predictive modeling has not been conducted in the area northeast of the U5 AB because boron concentrations in this area are less than the 02L standard. Similar simulations conducted on conservative constituents other than boron predict that they would naturally attenuate to less than the 02L standard. For the U5 AB, particle tracking and hydraulic head contours were used rather than flow and transport modeling to assess the effectiveness of the alternatives (**Figures 88e** and **88f**). A flow and transport modeling report prepared for Cliffside is presented in **Appendix G.** Similarly, a geochemical modeling report specific to Cliffside is presented in **Appendix H.**

6.23.3 Remedial Alternative 3 – Groundwater Extraction and Source Control

(CAP Content Section 6.E.a)

Alternative 3 consists of groundwater extraction for remediation of the groundwater northeast of the U5 AB at or beyond the compliance boundary. This alternative provides an effective combination of technology for groundwater remediation at or beyond the compliance boundary.

Under this alternative, active remediation would likely achieve compliance faster than Alternative 1 or Alternative 2.

6.23.3.1 Problem Statement and Remediation Goals

(CAP Content Section 6.D.a.i)

CCR constituents in groundwater associated with the Cliffside U5 AB occur near the compliance boundary to the northeast of the ash basin's saddle dam at concentrations detected greater than applicable 02L standards, IMAC, or background values, whichever is greater. Remediation goals are to restore groundwater quality at or beyond the compliance boundary by returning COIs to acceptable concentrations (02L standard/IMAC or background value, whichever is greater), or as closely thereto as is economically and technologically feasible consistent with 15A NCAC 02L. 0106(a).

In the future, alternative standards may be proposed as allowed under 02L.0106(k). This approach is considered reasonable given the documented lack of human health or ecological risk at Cliffside.

The conceptual model and predictive modeling discussions summarize the foundations for development of the groundwater extraction treatment alternative. More extensive discussion of the CSM can be found in **Section 5.0**, discussion of flow and transport modeling in **Appendix G**, and discussion of geochemical modeling in **Appendix H**.

6.23.3.2 Conceptual Model

(CAP Content Section 6.D.a.ii)

The applicable technologies that comprise this alternative include:

- 12 new extraction wells to the northeast of the ash basin
- 380 foot source control trench
- Pumps, associated piping, and control systems
- pH adjustment or other treatment systems, if necessary

The proposed design and well locations are shown on **Figure 6-88a**. The flow and transport model predicts a total groundwater extraction system flow rate of approximately 29 gpm. The number of extraction wells is estimated based on flow and transport modeling results (**Appendix G**). A general summary of the systems anticipated number of groundwater extraction wells per flow zone with corresponding depth ranges, and system flow rate and operation assumptions is included in **Table 6-37.**

Based on the CSM (**Section 5**) and flow and transport modeling results (**Appendix G**), the groundwater COIs are hydraulically controlled within the topographic drainage basin downgradient of the ash basin.

Alternative 3 involves groundwater extraction and source control. Groundwater is extracted for hydraulic control within the low pH area south of Unit 5 Cooling Tower A and west of Cooling Tower B and north of Cooling Tower A (**Figure 6-88a**). Also, a source control trench near the saddle dam would mitigate the low pH groundwater that mobilizes COIs in the area. The primary remediation goals under Alternative 3 are:

- Control the discharge of acidic water into storm water and groundwater
- Mitigate constituent migration to the Broad River
- Achieve 02L compliance for groundwater beyond the 500-foot compliance boundary

Extracted groundwater would be routed to the Basement Basin and the new CSS WWTP. The extracted groundwater would be treated along with other wastewater to comply with the NPDES discharge requirements. The WWTP at Cliffside, which discharges to NPDES outfall 005, is a physical/chemical system consisting of pH neutralization, coagulation and flocculation. The treated wastewater is sent to high-rate clarifiers and then, if necessary, to polishing filters before being discharged.

Seven vertical groundwater extraction wells would be installed to the south of Cooling Tower A and five vertical groundwater extraction wells would be installed to the north of Cooling Tower A. The wells would be installed to a depth corresponding to the top of bedrock. The primary purposes of these vertical groundwater extraction wells are to hydraulically capture groundwater beyond the 500 ft. compliance boundary. The extraction wells would discharge to a new sump between

A source control trench would be constructed along a ditch that carries acidic water from the southern end of Cooling Tower B to the west and then north, parallel to and beyond Cooling Tower B as depicted in **Figure 6-88a**. The source control trench would be approximately 380 feet long, 20 feet deep, and 2 to 6 feet wide. The trench would be lined with a geo-fabric followed by a bed of stone. Captured groundwater from the area near the

saddle dam would be collected and flow through the stone to a collection sump.

The primary purpose of the source control trench is to prevent the acidic groundwater from discharging to the ditch where it becomes more acidic. The collection sump would be installed to a depth approximately 25 to 30 feet bgs. A pump at the bottom of the sump would pump water from the sump to a new manhole located between Cooling Towers A and B.

The new manhole that collects the extracted groundwater from the extraction wells and the source control trench would be tied into existing piping that is routed along with storm water to the Holding Cell. There it mixes with process water and is conveyed to the Cliffside WWTP. The WWTP, which is a physical/chemical treatment system consisting of pH adjustment, coagulation and flocculation. Solids are removed from the wastewater using high-rate clarifiers and polishing filters, if necessary. Wastewater is discharged to the Broad River through NPDES Outfall 005.

Alternative 3 would extract groundwater containing COIs, thereby reducing the mass of COIs in Site groundwater. The COIs most affected by groundwater extraction would be conservative COIs that are typically more soluble and mobile over a range of geochemical conditions when compared to non-conservative/reactive and variably reactive constituents (**Section 6.19.9**).

Currently, COIs in groundwater do not pose an unacceptable risk to human health or the environment under conservative exposure scenarios. If implemented, Groundwater Remedial Alternative 3 would not pose an unacceptable risk to human health or the environment.

6.23.3.3 Predictive Modeling

(CAP Content Section 6.D.a.iii)

At most ash locations, such as the AAB, predictive modeling has been conducted at locations such as the AAB were to mitigate the concentration of a conservative non-reactive constituent, primarily boron, a conservative and non-reactive constituent, that is encroaching upon, or is beyond, the 500-foot compliance boundary. Therefore, the flow and transport modeling is calibrated to predict concentrations of a conservative constituent at locations within and beyond the 500-foot compliance boundary.

For the U5 AB, non-conservative constituents are the primary issue at and beyond the 500-foot compliance boundary. Similar simulations conducted on conservative constituents other than boron predict that they would naturally attenuate to less than the 02L standard. For the U5 AB, particle tracking and hydraulic head contours were used rather than flow and transport modeling to assess the effectiveness of the alternatives (**Figures 88e** and **88f**). A flow and transport modeling report prepared for Cliffside is presented in **Appendix G**. Similarly, a geochemical modeling report specific to Cliffside is presented in **Appendix H**.

6.24 SA3 Remedial Alternative Screening Criteria

(Supplemental Information for CAP Content Section 6.D.a.iv)

This section provides supplemental information beyond the CAP content guidance to describe the screening criteria used to evaluate groundwater remediation alternatives at Cliffside.

These screening criteria are based upon the criteria outlined in 15A NCAC 02L .0106(i), 40 CFR 300.430, and *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (USEPA, 1988). The screening criteria, which are described in detail in **Section 6.4**, are as follows:

- Protection of human health and the environment
- Compliance with applicable regulations
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, and volume
- Short-term effectiveness at minimizing impact on the environment and local community.
- Technical and logistical feasibility
- The time required to initiate and implement corrective action alternative
- Time required to achieve remediation goals
- Community acceptance

Additional considerations for remedial alternative evaluations include:

- Adaptive site management
- Sustainability

6.25 SA3 Detailed Analysis of Remedial Alternatives

Groundwater remedial Alternatives 1, 2 and 3 formulated in **Section 6.23** will undergo detailed comparative analysis in the following subsections.

6.25.1 Groundwater Remedial Alternative 1 – MNA

A detailed description of groundwater remedial Alternative 1 (MNA) is presented in **Section 6.23.1**. Detailed analysis of groundwater remedial Alternative 1 is presented in the following subsections.

6.25.1.1 Protection of Human Health and the Environment

(CAP Content Section 6.D.a.iv.1)

Alternative 1, MNA, is protective of human health and the environment. Groundwater COIs do not pose an unacceptable risk to potential receptors under conservative risk assessment exposure scenarios (**Appendix E**). Alternative exposure scenarios are not anticipated as long as Duke Energy owns and controls the property where groundwater COIs exist and institutional controls (*e.g.,* 15A NCAC 02L) remain in place. Furthermore, the Broad River surface water immediately downgradient of the U5 AB has been sampled and analyzed and comply with applicable 15A NCAC 02B standards (**Appendix J**). Consequently, MNA would be protective of human health and the environment.

6.25.1.2 Compliance with Applicable Regulations

(CAP Content Section 6.D.a.iv.2)

Alternative 1 can be fully implemented in compliance with all applicable laws and regulations. As it pertains to the selection of a groundwater remedy, the North Carolina Coal Ash Management Act 15A NCAC 13B .1636 states that the selected remedy will:

- Be protective of human health and the environment.
- Attain approved GWPS.
- Comply with standards for management of wastes as specified in Rule .1637(d).

As stated in the previous subsection, MNA would be protective of human health and the environment. MNA would eventually satisfy groundwater protection standards while being protective of human health and the environment going forward. The only waste generated by MNA would be

IDW such as soil cuttings during the installation of monitoring wells and purge water generated during groundwater sampling. IDW can be managed in compliance with applicable management standards.

MNA would be conducted with the goal of achieving the 02L standards (15A NCAC 02L) beyond the compliance boundary. A contingency groundwater remedy would be implemented if MNA is later determined to be ineffective.

Samples of the Broad River surface water immediately downgradient of the U5 AB have been sampled and analyzed and comply with applicable 15A NCAC 02B standards (**Appendix J**). Given the amount of dilution provided by surface water in the Broad River, there is no reason to expect that 15A NCAC 02B standards would not be satisfied in the future if MNA were implemented.

New MNA monitoring well installations must satisfy applicable requirements of NCAC Title 15A Subchapter 02C, Well Construction Standards, including 15A NCAC 02C .0108 (*Standards of Construction*) and 15A NCAC 02C .0112 (*Well Maintenance*).

Compliance with applicable regulations should not affect the implementability, effectiveness, or cost of Alternative 1.

6.25.1.3 Long-Term Effectiveness and Permanence

(CAP Content Section 6.D.a.iv.3)

The area of groundwater containing COIs greater than comparison criteria would be reduced over time as a result of U5 AB closure and MNA mechanisms. Furthermore, the mass COIs in groundwater would be permanently reduced. Natural attenuation mechanisms would continue to reduce COI concentrations in groundwater after regulatory standards have been attained.

Groundwater monitoring wells might require repair or replacement following decades of groundwater monitoring. Repair or installation of a new replacement groundwater monitoring well should be a routine task.

Coal ash constituents within the compliance boundary would not pose an unacceptable risk to human health since there would be no complete routes for potential exposure. Construction of water supply wells are prohibited

within the compliance boundary of an individually permitted disposal system (15A NCAC 02L .0107 (d)). Groundwater monitoring would continue at the compliance boundary in accordance with 02L requirements.

The magnitude of residual risk to human health and the environment is within acceptable levels prescribed by the USEPA. Institutional controls, including 15A NCAC 02L .0107(d), should restrict activities that could result in exposure to groundwater COIs.

6.25.1.4 Reduction of Toxicity, Mobility and Volume

(CAP Content Section 6.D.a.iv.4)

Cliffside groundwater COIs are inorganic. Any reductions in groundwater COI toxicity, mobility, and volume achieved under Groundwater Remedial Alternative 1 would occur as a consequence of natural occurring attenuation mechanisms. The mechanisms that naturally attenuate the concentrations of COIs are dilution, dispersion, advection, sorption (including ion exchange and precipitation) and phyto-attenuation, the uptake of COIs by plants.

Non-reactive natural attenuation mechanisms like dispersion and dilution are almost always irreversible in natural settings whereas most reactive natural attenuation mechanisms, such as sorption, transformation, and stabilization are reversible.

Reduction of conservative/non-reactive COI concentrations would most likely be achieved by way of non-reactive attenuation mechanisms such as dispersion and dilution whereas reductions in non-conservative/reactive COIs would most likely be achieved by way of reactive attenuation mechanisms such as sorption, transformation, biological stabilization and chemical stabilization.

Natural attenuation of COIs would occur throughout the groundwater underlying the U5 AB. However, natural attenuation would be most effective at the leading edge of a constituent plume where sites for reactive natural attenuation mechanisms would be most plentiful. Reductions in COI concentrations would occur slowly relative to more aggressive means of groundwater remediation.

6.25.1.5 Short-Term Effectiveness

(CAP Content Section 6.D.a.iv.5)

Installation and sampling of the MNA monitoring network would not result in community exposure to groundwater. Therefore, implementation of MNA would be protective of communities near Cliffside. The installation of groundwater monitoring wells should not generate airborne dust emissions because a vegetative cover would be established to stabilize soil following implementation of source control measures. Regardless, Duke Energy would have ample means of dust suppression in the unlikely event that dust generation becomes an issue.

Installation and sampling of groundwater monitoring wells are straight forward and routine tasks that can be conducted safely. Groundwater COIs do not pose an unacceptable risk to potential receptors under conservative risk assessment exposure scenarios (**Appendix E**). Regardless, remediation worker exposure to COIs in groundwater should be minimal since they would be wearing PPE if there is the potential for exposure to COIs in ash, soil, or groundwater.

6.25.1.6 Technical and Logistical Feasibility

(CAP Content Section 6.D.a.iv.6)

Groundwater Remediation Alternative 1 is technically feasible and readily implementable. Construction of Alternative 1 would involve the installation of MNA replacement groundwater monitoring wells following completion of source control measures. The wells would be installed along a geochemical transect to monitor constituent concentration trends within the U5 AB. Installation of groundwater monitoring wells is a routine task. It would involve a utility clearance of the area where monitoring wells would be installed. All groundwater monitoring wells would be installed by a licensed driller. Afterwards, each well installation would be surveyed for location and elevation. Material requirements, material availability, and the availability of specialized services (*e.g.,* licensed drillers, licensed surveyors) and labor are readily available. Implementation of MNA would not involve direct permitting. Once implemented, MNA would involve long-term groundwater monitoring and reporting. Otherwise, there are no "operations" associated with MNA.

MNA relies on natural attenuation processes which would provide reliable results as long as the geochemistry within the footprint of the ash basin

remains stable. For example, natural attenuation processes would reliably work once geochemistry equilibrium is achieved (*e.g.,* pH and ORP remain within a stable range). An EMP would be developed to assess the effectiveness of Alternative 1 going forward.

6.25.1.7 Time Required to Initiate and Implement Corrective Action Alternatives

(CAP Content Section 6.D.a.iv.7)

The time required for implementation of an MNA program could be as immediate as approval of this remedial approach since an extensive monitoring well network already exists. However, MNA cannot be fully initiated until source control measures are completed and replacement monitoring wells are installed along geochemical transects within the footprint of the U5 AB.

6.25.1.8 Time Required to Achieve Remediation Goals

(CAP Content Section 6.D.a.iv.8)

The flow and transport model is calibrated to predict concentrations of conservative constituents. For U5 AB, non-conservative constituents are the primary issue at and beyond the 500-foot compliance boundary. Simulations conducted on conservative constituents other than boron predict that they would naturally attenuate to less than the 02L standard. For the U5 AB, particle tracking and hydraulic head contours were used rather than flow and transport modeling to assess the effectiveness of the alternatives (**Figures 88e** and **88f**). A flow and transport modeling report prepared for Cliffside is presented in **Appendix G**. Similarly, a geochemical modeling report specific to Cliffside is presented in **Appendix H**.

6.25.1.9 Cost

CAP Content Section 6.D.a.iv.9)

Estimated costs for the Cliffside U5 AB MNA program is based on capital costs for design and implementation including installation of groundwater monitoring wells. O&M costs include groundwater sampling, groundwater sample analysis, periodic reporting, redevelopment and replacement of some wells on an annual basis.

MNA capital costs would be significantly lower than capital costs associated with U5 AB Groundwater Remedial Alternatives 2 and 3. Long term O&M costs for MNA can be significant but would generally be less than U5 AB Groundwater Remedial Alternatives 2 and 3.

6.25.1.10 Community Acceptance

(CAP Content Section 6.D.a.iv.10)

Groundwater COIs do not pose an unacceptable risk to potential human or ecological receptors under conservative risk assessment exposure scenarios (**Appendix E**). These community stakeholders would take into account that the capital and near-term O&M costs associated with Groundwater Remediation Alternative 1 would be lower than the capital and O&M costs of Groundwater Remediation Alternatives 2 and 3 when compared over identical time periods (*e.g.,* 30 years of operation).

6.25.1.11 Adaptive Site Management

Following full-scale implementation of MNA, it would be important to evaluate Groundwater Remedial Alternative 1 performance. Following are potential metrics for critical evaluation of Alternative 1 performance:

- **Reevaluation of Tier 1:** Is actual COI removal meeting or exceeding predicted COI removal? Is actual COI removal changing as a consequence coal ash removal?
- **Reevaluation of Tiers 2 and 3:** Is the performance of predominant attenuation mechanisms meeting or exceeding predicted attenuation rates? Has the performance of predominant attenuation mechanisms changed since coal ash removal?
- **Reevaluation of Tier 3 – Is attenuation capacity is stable, over the long term:** Tier 3 should answer the question, "will current attenuation rates continue indefinitely?"
- Are COI plumes stable or declining?
- Is available attenuation capacity going to be sufficient to handle the mass of COIs expected following ash removal?
- Would the mass flux of COIs cause exceedances of 15A NCAC 02L (2L) groundwater standards beyond the compliance boundaries?
- Would the mass flux of COIs cause exceedances of 15A NCAC 02B (2B) surface water standards?
- Has the predicted time frame to achieve groundwater remediation goals changed?

Groundwater Remedial Alternative 1 is readily amenable to modifications if it is later determined that MNA is an inadequate remedy or that

supplemental initiatives, such as the construction a groundwater extraction system.

Groundwater Remedial Alternative 1 is readily amenable to contingencies. There is little that would preclude implementation of a completely different remedial approach following implementation of source control measures. For example, Groundwater Remedial Alternatives 2 and 3 are potential contingencies if Groundwater Remedial Alternative 1 is determined to be inadequate.

6.25.1.12 Sustainability

Sustainability analysis was completed as described in **Section 6.6**. The environmental footprint was quantified based on energy use and associated emissions, during the construction phase (e.g., HDPE pipe length quantities and material transportation) and groundwater monitoring activities (e.g., transportation). The results of the environmental footprint calculations for MNA are summarized in **Table 6-38**. A summary of sustainability calculations for Alternative 1 can be found in **Appendix L**.

The environmental footprint of the MNA alternative is the least energy-intensive of the remedial alternatives being considered, providing reduced, comparative environmental footprint metrics in overall energy use and across all air emission parameters. The MNA alternative utilizes significantly fewer resources during construction and throughout the cleanup timeframe when compared to the other alternatives.

6.25.2 Groundwater Remedial Alternative 2: pH Adjustment Gallery

A detailed description of groundwater remedial Alternative 2 is presented in **Section 6.23.2**. Detailed analysis of groundwater remedial Alternative 2 is presented in the following subsections.

6.25.2.1 Protection of Human Health and the Environment

(CAP Content Section 6.D.a.iv.1)

Groundwater Remedial Alternative 2 is protective of human health and the environment. Groundwater COIs do not pose an unacceptable risk to potential receptors under conservative risk assessment exposure scenarios (**Appendix E**). Alternative exposure scenarios are not anticipated as long as Duke Energy owns and controls the property where groundwater COIs

exist and institutional controls (*e.g.*, 15A NCAC 02L) remain in place. Furthermore, the Broad River surface water immediately downgradient of the ash basins has been sampled and analyzed and complies with applicable 15A NCAC 02B standards (**Appendix J**). Consequently, Alternative 2 is protective of human health and the environment would continue to be protective of human health and the environment going forward.

The risk assessment (**Appendix E**) has determined that there are no imminent hazards to public health and safety or the environment associated with coal ash or coal ash constituents in soil and groundwater at the Site. Potential risks to human health and the environment are very low and are within acceptable levels prescribed by the USEPA. The effect of Groundwater Remedial Alternative 2 would be to achieve further reductions in potential risks by:

- Promptly implementing groundwater remedial measures and begin remediating Site groundwater before source control measures are fully implemented.
- Ultimately achieving compliance with applicable groundwater regulations including NCAC 02L standards.
- Permanently reducing the mass and overall concentrations of coal ash constituents in Site groundwater.

6.25.2.2 Compliance with Applicable Regulations

(CAP Content Section 6.D.a.iv.2)

Alternative 2 can be fully implemented in compliance with all applicable laws and regulations. As it pertains to the selection of a groundwater remedy, CAMA regulation 15A NCAC 13B .1636 states that the selected remedy will:

- Be protective of human health and the environment.
- Attain approved GWPS.
- Comply with standards for management of wastes as specified in Rule .1637(d).

As stated in **Section 6.23.2**, Alternative 2 would be protective of human health and the environment. Alternative 2 would eventually satisfy GWPS

while being protective of human health and the environment going forward. Waste generated by Alternative 2 would include IDW (*e.g.,* soil excavated during construction of the source control trench and vertical wells) and extracted groundwater. IDW can be managed in compliance with applicable management standards.

Acidic surface water in the vicinity of the Cooling Towers A and B northeast of the U5 AB is currently enters a gravity pipe near Cooling Tower A and is being routed to the Basement Basin with other storm water. The Basement Basin effluent is treated discharged through NPDES Outfall 005. If Alternative 2 is implemented, effluent from the pH adjustment gallery would continue to be routed through existing piping to the through the storm water system. Surface water treated by the pH adjustment gallery should not have any material effect on treatment operations currently being conducted at the Cliffside WWTP.

WWTP operator certification requirements are being met for ongoing pretreatment of influent to Outfall 005. Duke Energy would continue to satisfy WWTP operator certification requirements necessary to operate the pH adjustment gallery going forward.

Alternative 2 would be conducted with the goal of achieving 02L groundwater standards beyond the compliance boundary. A contingency groundwater remedy would be implemented if Alternative 2 is later determined to be ineffective.

Samples of the Broad River surface water immediately downgradient of the U5 AB have been analyzed and found to comply with applicable 15A NCAC 02B standards (**Appendix J**). Given the amount of dilution provided by surface water in the Broad River, there is no reason to expect that 15A NCAC 02B standards would not be satisfied in the future if Alternative 2 were implemented.

6.25.2.3 Long-Term Effectiveness and Permanence

(CAP Content Section 6.D.a.iv.3)

Coal ash constituents within the compliance boundary should not pose unacceptable risk to human health since there should be no complete routes for potential exposure (**Appendix E**). Construction of water supply wells is prohibited within the compliance boundary of an individually permitted disposal system (15A NCAC 02L .0107 (d)). Groundwater monitoring

would continue at the compliance boundary as long as groundwater within the waste boundary contains constituents at concentrations greater than regulatory standards.

The magnitude of residual risk to human health and the environment is within acceptable levels prescribed by the USEPA. The magnitude of residual risk to human health and the environment is expected to decrease over time following implementation of Alternative 2. Performance monitoring would be conducted as long as any COI concentration beyond the compliance boundary is greater than the 02L standard or applicable GWPS. Institutional controls, including 15A NCAC 02L .0107(d), should restrict activities that could result in exposure to groundwater COIs.

NPDES discharge requirements are protective of human health and the environment. Extracted groundwater would be treated as necessary to comply with applicable NPDES discharge requirements. Treated water discharged via NPDES Outfall 005 and would not pose an unacceptable risk to human health and the environment.

6.25.2.4 Reduction of Toxicity, Mobility, and Volume

(CAP Content Section 6.D.a.iv.4)

The greatest reductions in groundwater COI toxicity, mobility, and volume achieved under Groundwater Remedial Alternative 2 would occur as a consequence of altering the chemistry of groundwater underlying the pH adjustment gallery.

Constituents most amenable to adjustment of groundwater pH are those that are non-conservative/reactive constituents (*e.g.,* strontium) followed by variably reactive constituents (*e.g.,* cobalt, iron, and manganese). Adjustment of groundwater pH would have little influence on conservative/non-reactive (*e.g.,* sulfate and TDS). Some soluble conservative/reactive and variably reactive constituents might be subject to adsorption or precipitation at elevated pH levels. The concentrations of these constituents in groundwater would decrease. However, it is possible that some insoluble conservative/reactive and variably reactive constituents might become more soluble at increased pH levels (*e.g.,* amphoteric metals). If this were to occur, the concentrations of these constituents in groundwater would increase.

Groundwater underlying the pH adjustment gallery and beyond would be subject to the influences of natural attenuation. The mechanisms that naturally attenuate the concentrations of COIs are dilution, dispersion, advection, sorption (including ion exchange and precipitation) and phyto-attenuation, the uptake of COIs by plants.

However, natural attenuation mechanisms would be least effective where constituent concentrations are highest. For example, sites for adsorption of non-conservative/reactive and variably reactive constituents might be saturated. This would result in elevated concentrations of these constituents in groundwater until adsorption sites start becoming available.

Surface water treated under Alternative 2 would be disposed of via NPDES discharge. COIs contained in surface water treated by the pH adjustment gallery and discharged to the Basement Basin would undergo treatment before being directed to the Broad River via NPDES Outfall 005. COIs removed as consequence of pretreatment would not be available to Site groundwater and would be taken offsite and managed as a solid waste. Otherwise, the concentration of constituents in the NPDES discharge would be at levels that do not pose an unacceptable risk to human health or the environment.

6.25.2.5 Short-Term Effectiveness

(CAP Content Section 6.D.a.iv.5)

Implementation of Groundwater Remedial Alternative 2 would be protective of private residences and communities near CSS. Installation of the pH adjustment gallery should create no significant dust emissions during implementation or during system operation. Duke Energy would have ample means of dust suppression in the unlikely event that dust generation becomes an issue.

Installation of the pH adjustment gallery and related infrastructure are straight forward and routine tasks that can be conducted safely. Groundwater COIs do not pose an unacceptable risk to potential receptors under conservative risk assessment exposure scenarios (**Appendix E**). Regardless, remediation worker exposure to COIs should be minimal since they would be wearing PPE to minimize potential for exposure to ash, soil, or groundwater.

Other potential environmental impacts that could occur during the implementation of Groundwater Remedial Alternative 2 is accidental releases of vehicle fluids (*e.g.,* gasoline, oil, hydraulic fluid) or unearthed soils into the Broad River. Duke Energy diligently requires contractors to prepare and adhere to erosion and sediment control plans when conducting intrusive work activities. Likewise, Duke Energy strictly enforces the requirement for secondary containment to be placed under stationary heavy equipment (*e.g.,* drill rig) to capture and manage an accidental release of fluids.

Effluent from the pH adjustment gallery be carried through existing storm water conveyances to the Basement Basin. The Basement Basin effluent is treated and discharged to the Broad River through NPDES Outfall 005. Compliance with NPDES Permit NC0005088 should make discharges of extracted groundwater protective of potential onsite and offsite receptors.

The pH of near-surface groundwater would trend towards a neutral pH range as soon as the pH adjustment gallery is placed into service and infiltration of treated surface water begins. Neutralized groundwater would migrate towards the Broad River and would neutralize groundwater within the migration flow path.

6.25.2.6 Technical and Logistical Feasibility

(CAP Content Section 6.D.a.iv.6)

Groundwater Remediation Alternative 2 is technically feasible and readily implementable. Alternative 2 can be implemented before implementation of source control measures.

Construction of Alternative 2 would include:

- Bench scale testing of reactive media used to neutralize acidic surface water
- Design the pH adjustment gallery based upon results of bench scale testing
- Construct, install and operate pH adjustment gallery

Design, construction and use of a pH adjustment gallery are not routine occurrences for Duke Energy. However, the technology necessary to treat of low pH groundwater and surface water associated with acid mine

drainage is mature and readily implementable. All tasks required to implement Alternative 2 are routine with respect the maturity of technologies used, material requirements, material availability, and the availability of specialized services (*e.g.,* licensed electricians) and labor. Similarly, Alternative 2 appears to be technically implementable with respect to the location of the pH adjustment gallery. The pH adjustment trench would be located south and west of the cooling towers northeast of the U5 AB. Reconnaissance conducted in that area and discussions with Duke Energy personnel familiar with operations in that area suggest that the location where the pH adjustment gallery is proposed should have no major utilities and relatively few minor utilities (*e.g.,* overhead lamps) that can be rerouted.

As proposed, the southern end of the pH adjustment gallery is near the toe of the U5 AB saddle dam. Considerations for permitting, including dam safety, would be built within the design and construction schedule.

Implementation of Groundwater Remedial Alternative 2 can be achieved administratively. The surface water adjacent to Cooling Towers A and B is currently being conveyed to the Basement Basin and discharged to the Broad River via NPDES Permit NC0005088 Outfall 005. Treatment of the acidic surface water, as proposed under Alternative 2, should result in no material changes in how this waste stream is currently managed or disposed. In addition, no changes to existing WWTP infrastructure would be anticipated if Alternative 2 were implemented.

An EMP would be developed to assess the effectiveness of Alternative 2 going forward.

6.25.2.7 Time Required to Initiate and Implement Corrective Action Alternative

(CAP Content Section 6.D.a.iv.7)

The pH adjustment gallery proposed under Remedial Alternative 2 can be implemented before source control measures are initiated and as soon as authorized by NCDEQ. Prerequisites however, would include bench scale testing of reactive media having the potential to neutralize acidic surface water, designing the pH adjustment gallery.

Bench-scale testing, preparation of the final design, preparation of bid documents, and submission of bid documents to prospective bidders could

be accomplished within 26 months. No other prerequisites, such as permitting are anticipated that would delay initiation of Groundwater Remedial Alternative 2. Full-scale operation of the pH adjustment gallery could be accomplished within 8 months following the selection of a contractor.

6.25.2.8 Time Required to Achieve Remediation Goals

(CAP Content Section 6.D.a.iv.8)

Groundwater extraction under Alternative 2 can be fully implemented before source control measures are initiated. Alternative 2 can be implemented and fully functional within 3 years following selection of Alternative 2 as the groundwater remedy.

At most ash basin locations, such as the AAB, predictive modeling has been conducted at locations such as the AAB were to mitigate the concentration of a conservative non-reactive constituent, primarily boron, a conservative and non-reactive constituent, that is encroaching upon, or is beyond, the 500-foot compliance boundary. Therefore, the flow and transport modeling is calibrated to predict concentrations of a conservative constituent at locations within and beyond the 500-foot compliance boundary.

For the U5 AB, non-conservative constituents are the primary issue at and beyond the 500-foot compliance boundary. However, predictive modeling has not been conducted in the area northeast of the U5 AB because boron concentrations in this area are less than the 02L standard. Similar simulations conducted on conservative constituents other than boron predict that they would naturally attenuate to less than the 02L standard. For the U5 AB, particle tracking and hydraulic head contours were used rather than flow and transport modeling to assess the effectiveness of the alternatives (**Figures 88e** and **88f**). A flow and transport modeling report prepared for Cliffside is presented in **Appendix G**. Similarly, a geochemical modeling report specific to Cliffside is presented in **Appendix H**.

Groundwater extraction under Alternative 2 can be implemented before source control is complete.

Neutralization of acidic surface water and underlying groundwater would be implemented with the primary goal of achieving 02L standards beyond the 500-foot compliance boundary. The time to achieve 02L standards

beyond the 500-foot compliance boundary has not been estimated by predictive flow and transport modeling.

Groundwater neutralized by the pH adjustment gallery would precipitate some groundwater COIs within and beyond the 500 ft. compliance boundary. Groundwater COIs that are precipitated as a consequence of Alternative 2 would not migrate beyond the 500 ft. compliance boundary.

6.25.2.9 Cost

(CAP Content Section 6.D.a.iv.9)

Costs to implement the Cliffside U5 AB pH adjustment gallery would include capital costs for design and implementation. Implementation would include excavation of the pH adjustment gallery and components. O&M costs would include groundwater sampling, groundwater sample analysis, periodic reporting, redevelopment and replacement of some groundwater monitoring wells, and replacement of gallery components every three to five years.

Cliffside U5 AB Groundwater Remedial Alternative 2 capital costs would be significantly higher than capital costs associated with U5 AB Groundwater Remedial Alternative 1, but would be less than capital costs associated with U5 AB Groundwater Remedial Alternative 3. Long term O&M costs for Groundwater Remedial Alternative 3 would be higher than long term O&M costs associated with U5 AB Groundwater Remedial Alternatives 1 and 2.

6.25.2.10 Community Acceptance

(CAP Content Section 6.D.a.iv.10)

It is likely that some community stakeholders are sufficiently familiar with the concept of neutralizing acidic water such that they might not have significant concerns pertaining to operation of the pH adjustment gallery. Similarly, mitigating transport of untreated groundwater to the Broad River should be well received. Stakeholders might not be as familiar with the indirect treatment of groundwater by way of infiltration. Potential concerns of stakeholders would likely be alleviated when they know that acidic groundwater would be neutralized, there would be an overall improvement in groundwater quality, and that the pH adjustment process would not pose unacceptable risks to human health or the environment.

It is possible that some community stakeholders would have concerns with potential exposure to surface water treated by the pH adjustment gallery

via NPDES permit. Assurances that any means of wastewater disposal would be permitted and monitored by NCDEQ should alleviate the concerns of many stakeholders. Stakeholder concerns should be further alleviated when they know that pH adjustment gallery effluent would undergo pretreatment and that constituent concentrations in the discharged groundwater would be well below permitted limits.

6.25.2.11 Adaptive Site Management and Remediation Considerations

Following full-scale implementation, it would be important to evaluate Groundwater Remedial Alternative 2 performance. The following are potential metrics and associated questions regarding the critical evaluation of Alternative 2 performance:

- Non-conservative constituent trends – Are the concentrations of reactive constituents trending downward?
- Predictive modeling – How have modeling results changed since model refinement using post-implementation data?
- Groundwater neutralization – is acidic groundwater northeast of the U5 AB being neutralized as a consequence of Alternative 2?
- Constituent mass removal – Is the concentrations of soluble constituents in treated groundwater decreasing?
- Performance - How is Alternative 2 performance change before, during, and after implementation of source control measures?
- Remediation timeframe - Has the predicted time frame to achieve groundwater remediation goals changed?

Groundwater Remedial Alternative 2 is readily amenable to modifications if it is later determined that operational changes could result is greater efficiencies or shorter remediation timeframes. For example, if a more effective reactive media is identified, it could replace a less effective reactive neutralization media.

Groundwater Remedial Alternative 2 is readily amenable to contingencies. For example, the pH adjustment gallery could be removed and Alternative 3 implemented in short order if Alternative 2 is determined to be ineffective.

6.25.2.12 Sustainability

Sustainability analysis was completed as described in **Section 6.6**. The environmental footprint was quantified based on energy use and associated emissions, during the construction phase (e.g., material quantities and transportation), active remediation activities (e.g., groundwater pumping and treatment) and groundwater monitoring activities (e.g., transportation). The results of the environmental footprint calculations for Alternative 2 are summarized in **Table 6-38**. A summary of sustainability calculations for Alternative 2 can be found in **Appendix L**.

The environmental footprint of Alternative 2 is the most energy-intensive of the remedial alternatives being considered. Alternative 1 (MNA) requires significantly less materials and energy than Alternative 2 and is therefore characterized by a dramatically smaller environmental footprint. Alternative 2 presents higher, but generally comparable, environmental footprint metrics when measured against Alternative 3. Alternative 2 utilizes reactive media in a pH adjustment gallery compared to Alternative 3, which utilizes source control trench, this generates a higher material-related environmental footprint. The analysis indicates operating the pH adjustment gallery in Alternative 2 to be slightly more energy intensive, but generally similar, to Alternative 3.

6.25.3 Groundwater Remedial Alternative 3: Groundwater Extraction

A detailed description of Alternative 3 is presented in **Section 6.23.3**. Detailed analysis of groundwater remedial Alternative 3 is presented in the following subsections.

6.25.3.1 Protection of Human Health and the Environment

(CAP Content Section 6.D.a.iv.1)

Groundwater Remedial Alternative 3 is protective of human health and the environment. Groundwater COIs do not pose an unacceptable risk to potential receptors under conservative risk assessment exposure scenarios (**Appendix E**). Alternative exposure scenarios are not anticipated as long as Duke Energy owns and controls the property where groundwater COIs exist and institutional controls (*e.g.*, 15A NCAC 02L) remain in place. Furthermore, the Broad River surface water immediately downgradient of the U5 AB has been sampled and analyzed and complies with applicable

15A NCAC 02B standards (**Appendix J**). If implemented, Alternative 3 would be protective of human health and the environment.

The risk assessment (**Appendix E**) has determined that there are no imminent hazards to public health and safety or the environment associated with coal ash or coal ash constituents in Site soil and groundwater. Potential risks to human health and the environment are within acceptable levels prescribed by the USEPA. The effect of Groundwater Remedial Alternative 3 would be to achieve regulatory compliance in a shorter timeframe than MNA by:

- Implementing active groundwater remedial measures before source control measures are complete.
- Reducing the mass and concentrations of coal ash constituents in Site groundwater in a shorter timeframe.

6.25.3.2 Compliance with Applicable Regulations

(CAP Content Section 6.D.a.iv.2)

Alternative 3 can be implemented in compliance with applicable laws and regulations. Those regulations would include: CAMA, groundwater standards, and extraction well installation and permitting**.**

As stated in the previous subsection, Alternative 3 would be protective of human health and the environment. Alternative 3 would eventually satisfy GWPS. Waste generated by Alternative 3 would include IDW (*e.g.*, soil cuttings, purge water) and extracted groundwater. IDW can be managed in compliance with applicable management standards.

Regulations pertaining to the management and disposal of extracted groundwater would have the greatest influence on the implementability of Alternative 3. No outfall listed in NPDES permit NC0005088 is currently authorized to receive extracted groundwater. Consequently, NPDES permit NC0005088 must be modified before extracted groundwater can be discharged to the Broad River. If extracted groundwater is ever discharged via an existing NPDES permitted outfall, Outfall 005 is the most likely outfall that might be used. WWTP operator certification requirements are being met for ongoing WWTP operations. Duke Energy would continue to satisfy WWTP operator certification requirements going forward.

Groundwater extracted under Alternative 3 would likely be discharged to the Basement Basin. Basement Basin effluent is treated and discharged to the Broad River through Outfall 005. Treatment prior to discharge through Outfall 005 is a physical/chemical treatment system consisting of pH adjustment, coagulation and flocculation. Solids are removed from the wastewater using high-rate clarifiers and polishing filters, if necessary. The concentrations of COIs contained in extracted groundwater are expected to be less than permitted limits (**Table 6-35**). There is no mandated limit on the volume of water discharged via Outfall 005.

WWTP operator certification requirements are being met for ongoing WWTP operations. Duke Energy would continue to satisfy WWTP operator certification requirements going forward.

Alternative 3 would be conducted with the goal of achieving 02L groundwater standards (15A NCAC 02L) beyond the compliance boundary. A contingency groundwater remedy would be implemented if Alternative 3 is later determined to be ineffective.

Samples of the Broad River surface water immediately downgradient of the U5 AB has been sampled and analyzed and comply with applicable 15A NCAC 02B standards (**Appendix J**). Given the amount of dilution provided by surface water in the Broad River, there is no reason to expect that 15A NCAC 02B standards would not be satisfied in the future if Alternative 3 were implemented.

Monitoring well and groundwater extraction well installations must satisfy applicable requirements of NCAC Title 15A Subchapter 2C, Well Construction Standards, including 15A NCAC 02C .0108 (*Standards of Construction*) and 15A NCAC 02C .0112 (*Well Maintenance*).

6.25.3.3 Long-Term Effectiveness and Permanence

(CAP Content Section 6.D.a.iv.3)

Alternative 3 would permanently reduce the mass and concentrations COIs in local groundwater. Groundwater and COIs captured by the extraction system would be treated to meet applicable standards of NPDES Permit NC0005088 before being discharged to the Broad River. NPDES discharge requirements are protective of human health and the environment. Extracted groundwater discharged through NPDES Outfall 005 would be

treated as necessary to comply with applicable discharge requirements and would not pose an unacceptable risk to human health and the environment.

Coal ash constituents within the compliance boundary do not pose an unacceptable risk to human health since there are no complete routes for potential exposure. Construction of water supply wells is prohibited within the compliance boundary of an individually permitted disposal system (15A NCAC 02L .0107 (d)). Groundwater monitoring would continue at the compliance boundary in accordance with 02L requirements.

The risk to human health and the environment is within acceptable levels prescribed by the USEPA. The risk to human health and the environment is also expected to decrease over time following implementation of Alternative 3. Performance monitoring would be conducted in accordance with 02L requirements. Institutional controls, including 15A NCAC 02L .0107(d), restrict activities that could result in exposure to groundwater COIs. Natural attenuation mechanisms would further reduce COI concentrations when groundwater beyond the 500-foot compliance boundary satisfies 02L standards.

6.25.3.4 Reduction of Toxicity, Mobility and Volume

(CAP Content Section 6.D.a.iv.4)

The greatest reductions in groundwater COI toxicity, mobility, and volume achieved under Alternative 3 would occur as a consequence of groundwater extraction. Consequently, constituents most amenable to groundwater extraction are those that are conservative/non-reactive (*e.g.,* sulfate and TDS) followed by variably reactive constituents (*e.g.,* cobalt, iron and manganese). Groundwater extraction would have the least effect on non-conservative/reactive constituents (*e.g.,* strontium).

Dissolved constituents within the capture zone of groundwater extraction well would be drawn toward the extraction well and could be extracted. Consequently, the mass of constituents in groundwater would be reduced as a consequence of groundwater extraction.

Groundwater constituents beyond the capture zone of the groundwater extraction well would be subject to the influences of natural attenuation. The mechanisms that naturally attenuate the concentrations of COIs are dilution, dispersion, advection, sorption (including ion exchange and precipitation) and phyto-attenuation, the uptake of COIs by plants.

However, natural attenuation mechanisms would be least effective where constituent concentrations are highest. For example, sites for adsorption of non-conservative/reactive and variably reactive constituents might be saturated. This would result in elevated concentrations of these constituents in groundwater until adsorption sites become available.

The volume of groundwater containing COIs at concentrations greater than applicable standards would be reduced over time.

Groundwater extracted under Alternative 3 would be disposed of via NPDES discharge. COIs captured by groundwater extraction would be routed to the Basement Basin. Effluent from the Basement Basin is treated before being discharged to the Broad River via Outfall 005. The concentration of constituents remaining in the NPDES discharge would be maintained at levels that do not pose an unacceptable risk to human health or the environment.

6.25.3.5 Short-Term Effectiveness

(CAP Content Section 6.D.a.iv.5)

Implementation of Groundwater Remedial Alternative 3 would be protective of private residences and communities near CSS. The installation of groundwater extraction well and associated infrastructure would not create dust or air emissions during implementation or system operation. Duke Energy has ample means of dust suppression in the unlikely event of dust generation.

Installation of groundwater the source control trench, manhole and wells, the discharge line, and related infrastructure are straight forward and routine tasks that can be conducted safely. Groundwater COIs do not pose an unacceptable risk to potential receptors under conservative risk assessment exposure scenarios (**Appendix E**). Regardless, remediation worker exposure to COIs in groundwater should be minimal since they would be wearing PPE if there is the potential for exposure to COIs in ash, soil, or groundwater.

Other potential environmental impacts that could occur during implementation of Alternative 3 are accidental releases of vehicle fluids (*e.g.,* gasoline, oil, hydraulic fluid) or unearthed soils into the Broad River. Duke Energy diligently requires contractors to prepare and adhere to erosion and sediment control plans when conducting intrusive work

activities. Likewise, Duke Energy strictly enforces secondary containment be placed under stationary heavy equipment (*e.g.,* drill rig) to capture and manage an accidental release of fluids.

Extracted groundwater would be disposed via NPDES discharge. Compliance with NPDES Permit NC0005088 should make discharges of extracted groundwater protective of potential onsite and offsite receptors.

Hydraulic capture of groundwater near the groundwater extraction wells would occur soon after the groundwater extraction system is placed into service. The advancement of COIs beyond the 500-foot compliance boundary would be mitigated as long as hydraulic capture is sustained.

6.25.3.6 Technical and Logistical Feasibility

(CAP Content Section 6.D.a.iv.6)

Groundwater Remediation Alternative 3 is technically feasible and readily implementable. Alternative 3 can be implemented before U5 AB source control measures are complete.

- Construction of Alternative 3 would include:
- Installation of an source control trench and collection sump
- Installation of vertical groundwater extraction wells
- Installation of extraction pumps within the source control trench collection sump and in 6-inch vertical groundwater extraction wells
- Installation of a manhole and discharge piping to convey extracted groundwater to a sump where the extracted groundwater would be conveyed to the Basement Basin (Holding Cell) and WWTP
- Installation of wellhead valves and instrumentation
- Distribution of electrical service to pump
- Modify NPDES Permit NC0005088 to include discharge of extracted groundwater at Outfall 005

All of these tasks are routine with respect to the maturity of technologies used, material requirements, material availability, and the availability of specialized services (*e.g.,* licensed drillers, electricians) and labor. Similarly, Alternative 3 is technically implementable with respect to the suitability of

extraction well installation locations and associated infrastructure. There is ample room west and south of the cooling towers northeast of the U5 AB.

Implementation of Alternative 3 can be achieved administratively. However, NPDES Permit NC0005088 must first be modified because no outfall listed in the permit is currently authorized to receive extracted groundwater. If extracted groundwater from U5 AB is ever discharged via an existing NPDES permitted outfall, Outfall 005 is the most likely outfalls that might be used. Outfall 005 is located near the Holding Basins, which are in the footprint of the U1-4 AB.

An EMP would be developed to assess the effectiveness of Alternative 3 going forward.

6.25.3.7 Time Required to Initiate and Implement Corrective Action Alternative

(CAP Content Section 6.D.a.iv.7)

Groundwater extraction proposed under Remedial Alternative 3 can be implemented before source control measures are complete. Modifying NPDES Permit NC0005088 to include the discharge of extracted groundwater must be conducted prior to full-scale implementation of Alternative 3. Preparation of the final design, preparation of bid documents, and submission of bid documents to prospective bidders could be accomplished within 26 months following NCDEQ approval of the CAP. Full-scale operation of the groundwater extraction system could be accomplished within 8 months following the selection of a contractor.

6.25.3.8 Time Required To Achieve Remediation Goals

(CAP Content Section 6.D.a.iv.8)

Groundwater extraction under Alternative 3 can be implemented before source control is complete.

Groundwater extraction would be implemented with the primary goal of achieving 02L standards beyond the 500-foot compliance boundary. The time to achieve 02L standards beyond the 500-foot compliance boundary has not been estimated by predictive flow and transport modeling because boron, the CCR constituent most often used to calibrate predictive flow and transport models is below the 02L standard. However, groundwater captured by the groundwater extraction system will be removed from beyond the 500 ft. compliance boundary or prevented from migrating

beyond the 500 ft. compliance boundary as soon as the groundwater extraction system is made operational.

6.25.3.9 Cost

(CAP Content Section 6.D.a.iv.9)

Costs to implement the Cliffside U5 AB groundwater extraction system would include capital costs for design and implementation. Implementation would include installation of groundwater monitoring wells, groundwater extraction wells, groundwater discharge piping, telemetry system, and other system components. O&M costs would include groundwater sampling, groundwater sample analysis, periodic reporting, redevelopment and replacement of some wells, submersible pumps and other components on an annual basis.

Cliffside U5 AB Groundwater Remedial Alternative 3 capital costs would be significantly higher than capital costs associated with Remedial Alternative 1 and higher than estimated capital costs associated with U5 AB Groundwater Remedial Alternative 2. Long term O&M costs for Groundwater Remedial Alternative 3 would be higher than long term O&M costs associated with U5 AB Groundwater Remedial Alternative 1, but lower than the estimated long term O&M costs associated with U5 AB Groundwater Remedial Alternative 2.

6.25.3.10 Community Acceptance

(CAP Content Section 6.D.a.iv.10)

It is likely that community stakeholders are sufficiently familiar with the concept of groundwater extraction that they would not have significant concerns pertaining to the installation or operation of the groundwater extraction system. Similarly, mitigating transport of untreated groundwater to the Broad River should be well received by some community stakeholders.

It is possible that some community stakeholders would have concerns with potential exposure to discharged groundwater via NPDES permit. Assurances that any means of groundwater disposal would be permitted and monitored by NCDEQ should alleviate stakeholder concerns. Stakeholder concerns should be further alleviated when they know that extracted groundwater might undergo treatment and that constituent concentrations in the discharged groundwater would be within permitted limits.

6.25.3.11 Adaptive Site Management and Remediation Considerations

Following full-scale implementation, it would be important to evaluate Groundwater Remedial Alternative 3 performance. The following are potential metrics and related questions regarding the critical evaluation of Alternative 3 performance:

- Groundwater extraction rates – How do actual groundwater extraction rates compare to predicted extraction rates?
- Groundwater extraction well capture zones - How do actual capture zones compare to predicted capture zones?
- Conservative constituent trends – Are the concentrations of conservative constituents trending downward?
- Predictive modeling – How have modeling results changed since model refinement using post-implementation data?
- Constituent mass removal – Are constituent concentrations in extracted groundwater sufficient to achieve predicted mass removal?
- Performance - How does Alternative 3 performance change before, during, and after initiation of U5 AB source control measures?
- Remediation timeframe - Has the predicted time frame for achieving groundwater remediation goals changed?

Groundwater Remedial Alternative 3 is readily amenable to modifications if it is later determined that operational changes could result in greater efficiencies or shorter remediation timeframes.

6.25.3.12 Sustainability

Sustainability analysis was completed as described in **Section 6.6**. The environmental footprint was quantified based on energy use and associated emissions, during the construction phase (e.g., material quantities and transportation), active remediation activities (e.g., groundwater pumping and treatment) and groundwater monitoring activities (e.g., transportation). The results of the environmental footprint calculations for Alternative 3 are summarized in **Table 6-38**. A summary of sustainability calculations for Alternative 3 can be found in **Appendix L**.

The environmental footprint of Alternative 3 is the second-most, energy-intensive remedial alternative being considered. Alternative 1 (MNA)

requires significantly less materials and energy than Alternative 3 and is therefore characterized by a dramatically smaller environmental footprint. Alternative 3 presents lower, but generally comparable, environmental footprint metrics when measured against Alternative 2. Alternative 3 utilizes a source control trench compared to a pH adjustment gallery as used in Alternative 3. This generates a lower material-related environmental footprint for the due to the lack of reactive media required for pH adjustment. Instead, the water is collected and conveyed for treatment. The quantitative analysis of the environmental footprints of the remedial alternatives under consideration for this CAP indicates Alternative 3 to be the second-most sustainable option, although not significantly less impactful than Alternative 2. Opportunities for system optimization and energy savings could be pursued throughout the remediation timeframe, as conditions change and component technologies possibly evolve.

6.26 SA3 Proposed Remedial Alternative Selected for Source Area

(CAP Content Section 6.E)

Groundwater Remediation Alternative 3, Groundwater Extraction, is the proposed groundwater remedial alternative. Alternative 3 is detailed in **Sections 6.23.3** and 6.25**.3**. Rationale and details pertaining to selection of the proposed groundwater remediation alternative are presented in the following subsections.

6.26.1 Rationale for Selection

(CAP Content Section 6.E.a)

Groundwater Remedial Alternatives 1, 2, and 3 are all protective of human health and the environment, would comply with applicable regulations, and are readily implementable. Groundwater Remediation Alternatives 1 and 2 were not selected because they do not directly treat groundwater COIs within and beyond the compliance boundary northeast of the U5 AB.

The low pH originates near the saddle dam for the U5 AB at the south end of Cooling Tower B (**Figure 6-73**). A historical aerial photograph of the site (**Figure 1-3**) indicates that the sluice line for the U5 AB entered the basin in that approximate location. It is suspected, but not confirmed, that pyritic material such as unused coal, also referred to as “mill rejects” or “clinkers” might have been deposited near the sluice outfall with the ash. Because the unused coal is more dense than ash, it is likely that it would have deposited near the end of the sluice line.

Alternative 3 is the recommended groundwater remedy because the trench would intercept the groundwater and would significantly reduce the acidic water currently flowing adjacent to Cooling Tower B. This acidic water is responsible for elevated COI concentrations beyond the 500 ft. compliance boundary. Eliminating the source responsible for elevated COI concentrations in groundwater will benefit downgradient groundwater quality.

In addition, Groundwater Remedial Alternative 3 also proposes the construction of vertical groundwater extraction wells south and north of Cooling Tower A. Evacuating groundwater from these areas would induce the migration of groundwater having lower COI concentrations into these areas. The introduction of groundwater having lower COI concentrations into these areas would advance groundwater remedial efforts in these areas and should satisfy NCAC 02L standards over time.

Groundwater Remedial Alternative 3, coupled with closure of the U5 AB, is evaluated to be the most effective and cost efficient means to restore groundwater quality in compliance of applicable groundwater standards under Site conditions (02L .0106 (j); *6.E.a.i; 6.E.a.ii, 6.E.a.iii).*

Seep Corrective Action

Non-dispositioned seeps, where monitoring conducted has indicated the presence of CCR affects (S-2), are evaluated for whether corrective action would be anticipated for the seep location, and if so, potential corrective action technologies that would be feasible for the location. The evaluation considers seep location, effects of decanting on seep thus far, approximate average flow rate, and predicted change in water elevations after decanting is complete from flow and transport model simulations. Potential correction action strategies for seep locations are included in **Table 6-34** and discussed herein.

As of November 2019, seep S-2 has not shown any visual reduction in flow and is not anticipated to, based on its location relative to AAB where decanting is occurring (**Figure 1-2**). This seep location is located north of the toe of the U5 AB main dam. Corrective action at this location may consist of capturing and treating the seep or other remedial actions. Final corrective action plans for seeps that are not dispositioned after completion of decanting will be proposed in an amendment to this CAP Update and submitted based on the schedule outlined in the SOC.

6.26.2 Design Details

(CAP Content Section 6.E.b)

Design of Groundwater Remedial Alternative 3 would require predesign pumping tests and aquifer evaluation to determine the final number and locations of groundwater extraction wells. The design process would culminate in the preparation of a design package suitable for bidding and construction.

Basic aspects of the recommended alternative call for installation of:

- 12 vertical groundwater extraction wells and appurtenances
- 1 horizontal source control trench and appurtenances with a collection sump and sump pump
- Well vault and wellhead piping, fittings, and instrumentation
- A system to control water level within the source control trench and each groundwater extraction well
- Groundwater extraction system discharge piping

A conceptual process flow diagram for the groundwater extraction system is provided on **Figure 6-89.** The detailed design elements may be adjusted based on a final technical review. A summary of select well construction details is provided in **Table 6-37**.

6.26.2.1 Process Flow Diagram

(CAP Content Section 6.E.b.i)

A process flow diagram of Groundwater Remedial Alternative 3, Groundwater Extraction, is presented in **Figure 6-89**. This process flow diagram depicts the groundwater extraction system including vertical groundwater extraction wells and the source control trench, discharge lines to the storm water discharge. The storm water discharge conveys the extracted groundwater and storm water to the Basement Basin. The detailed design elements may be adjusted based on a final technical review.

Site Preparation (STEP 1 – CREATE ACCESS)

(CAP Content Section 6.E.b.i)

Installation of the proposed groundwater extraction system would require significant efforts in planning, designing, and execution of site preparation. Well installation and trenching will be a challenge north of Cooling Tower A due to the possibility of buried utilities and because this area can be relatively busy with site activities. However, with early awareness of the

aforementioned complexities and effective communications between the design, implementation and project management teams, successful construction of the system would be anticipated.

A certain level of flexibility regarding well placement is expected to be required due to site conditions encountered during construction. To prevent possible delays due to vetting field changes, predetermined well-location parameters (e.g., 50-foot placement radius) that ensure remediation system effectiveness should be established and included as part of the construction drawings.

Land disturbance associated with construction of Alternative 3 includes:

- Significant trenching with an excavator to install the source control trench
- Shallow digging associated with the installation of extraction well vaults
- Trenching for the installation of buried groundwater discharge piping, infiltration water supply piping, and electrical conduit

A soil erosion and sedimentation control plan would be prepared for the purpose of getting a soil erosion and sedimentation control permit.

Pumping Test (STEP 2 – TO FINALIZE DESIGN)

(CAP Content Section 6.E.b.i)

Pumping tests would be conducted to determine the pumping rates of groundwater extraction wells. It is anticipated that two groundwater extraction wells would be installed for the purpose of pumping tests. Pumping tests would include an 8-hour step test and 24-hour continuous pumping test conducted at both groundwater extraction wells.

Pumping test results would be used to:

- Determine site-specific well yields for screened flow zones
- Measure groundwater extraction well capture zones in the saprolite and transition zone flow zones
- If warranted, make adjustments to the groundwater extraction system design

- If warranted, make design adjustments to conveyances for extracted groundwater

The extraction wells used for testing would be included in the final groundwater remediation system design.

Vertical Groundwater Extraction Well Design (STEP 3 – INSTALL WELLS)

(CAP Content Section 6.E.b.i)

The preliminary groundwater remediation system design includes installation of 12 vertical groundwater extraction wells (Figure6-88a). The proposed extraction wells would be installed north and south of Cooling Tower A. These groundwater extraction wells would be completed in the saprolite and transition zones with total well depths ranging from approximately 50 feet bgs to 120 feet bgs. No groundwater extraction wells would be installed within the bedrock. All groundwater extraction wells would be installed by a North Carolina licensed well driller in accordance with North Carolina Administrative Code Title 15A, Subchapter 2C – Well Construction Standards, Rule 108 Standards of Construction: Wells Other Than Water Supply (15A NCAC 02C .0108).

The extraction wells might be drilled using hollow stem auger, air percussion/hammer, rotosonic methods, or a combination thereof. The drilling method would depend on Site conditions and drill rig availability. It is anticipated that the 12 groundwater extraction wells would be completed as 6-inch diameter wells to facilitate the installation of pumps and instrumentation (e.g., level control) in groundwater extraction wells. The top of the sand pack would extend a minimum of 2 feet above the top of well screens. A bentonite well seal at least 2 feet thick would be installed on top of the sand pack. Neat cement grout with 5 percent bentonite would be placed on top of the bentonite well seal and would fill the remaining well annulus to within 3 feet of the ground surface. All materials and installations would be in accordance with 15A NCAC 02C. Typical well construction schematics for groundwater extraction wells are presented in **Figure 6-88b**.

Source Control Trench Design (STEP 4)

(CAP Content Section 6.E.b.i)

The preliminary groundwater remediation system design includes installation of a source control trench in the storm water conveyance west of

Cooling Tower B (**Figure 6-88a**). The source control trench would be approximately 380 feet long, 20 feet deep, and 2 to 4 feet wide. The bottom and sides of the trench would be lined with a geotextile that would inhibit fines from entering the trench. The trench would be filled with gravel or small stone (Figure 6-86c). At the northern-most end of the trench will an offset collection sump will be installed with a submersible pump. The bottom of the collection sump will be approximately 25 feet bgs. The sump is offset from the trench to allow storm water to continue to be collected. The top of the trench is lined with concrete or some other impervious material to reduce storm water infiltration and intrusion into the trench (**Figure 6-88c**).

The submersible pump would be controlled by a level controller that would energize the pump when the water level in the manhole was within 8 feet bgs and would de-energize the pump when the water level in the manhole dropped to 15 feet bgs. The pump would be sized and the discharge would be controlled to minimize cycling of the manhole pump.

The sump pump would discharge extracted water into a new manhole between Cooling Towers A and B. The new manhole would be connected to existing storm water piping to the Basement Basin (Holding Cell) where it would be comingled with process water (**Figure 6-88a**). The extracted groundwater would be treated and discharged through Outfall 005.

Well Head Configuration (STEP 5a – CONSTRUCT WELL HEADS)

(CAP Content Section 6.E.b.i)

The proposed extraction well vaults would be precast concrete with aluminum access doors that include a drainage channel (**Figure 6-88b**). The concrete enclosures would be finished below grade and the piping and fittings in the enclosures would be Type 304 stainless steel to reduce risk of damage during O&M. Any above ground piping would be insulated and heat traced. The piping would transition from the Type 304 stainless steel to HDPE at a flange near the opening where the HDPE pipe leaves the enclosure. The buried sections of pipe would be fusion-welded HDPE.

The enclosures would have a 2-inch drain with a compression cap for controlled release of rainwater or condensate. A water level sensor would be mounted on the wall of the enclosure approximately 6-inches above the floor. Should water accumulate to that level, the extraction pump would be

stopped and an alarm sent to the operator, who can ascertain the cause of the high water level.

Groundwater Extraction Wells (STEP 5b)

(CAP Content Section 6.E.b.i)

A pump would be installed in each groundwater extraction well (**Figure 88b**). Similarly, a pump would be installed in the trench collection sump (**Figure 6-88c**) which would receive ground water from the source control trench. If the water level in a well, or the manhole, is above the top water level switch, the pump would run to pump the water to lower water level switch, which would cause the pump shut off. Groundwater extraction well water level controls would de-energize the submersible pump when the water level is within 3 feet to 5 feet above the well screen. Similarly, the water level controls in the source control trench manhole would de-energize the submersible pump when the water level is within 3 feet to 5 feet above the horizontal well screen that discharges to the manhole. In both cases, water level controls would prevent groundwater levels to drop below the well screen and expose the well screen to oxygen. Oxygenation of groundwater containing soluble ferric iron (Fe^{+3}) would generate iron hydroxide precipitates $Fe(OH)_3$ that could build up over time and clog well screens.

The flow of extracted groundwater from the submersible pump would be measured using a flow rate and flow totalizer meter before being conveyed to groundwater discharge piping for treatment and disposal. Other appurtenances in the piping system would include a check valve to prevent back flow into the well, sampling port, pressure gauge to indicate the pressure generated by the pump, ball valves to isolate piping for maintenance, and a flow control valve such as a stainless steel globe or gate valve.

Operational parameters, such as flow and water level, and critical malfunctions, such as accumulation of water in the well vault, would be transmitted via telemetry system to inform the system operator of the status in the well and enclosure.

Pipelines (STEP 6a – PIPELINE SPECIFICS)

(CAP Content Section 6.E.b.i)

The piping systems would be constructed in accordance with Duke Energy and Station-specific guidance. Final sizing would be based on load and