AECOM Imagine it. Delivered.

Assessment of Corrective Measures at the Ash Monofill Under the Coal Combustion Residuals (CCR) Rule

Rawhide Power Plant
Larimer County, Colorado
Platte River Power Authority

August 15, 2019

Prepared for:

Platte River Power Authority
2000 East Horsetooth Road
Fort Collins, Colorado 80525

Prepared by:

AECOM
6200 South Quebec Street
Greenwood Village, CO 80111

T: +1 (303) 694 2770
F: +1 (303) 694 3946
www.aecom.com

Assessment of Corrective Measures at the Ash Monofill Under the Coal Combustion Residuals (CCR) Rule

Prepared By
Naseem Hasan P.E. (CO)
Technical Leader 1

Reviewed By
Richard Henry Ph.D.
Principal Hydrogeologist

Approved By
Vasanta Kalluri P.E (MN, WI)
Project Manager

Table of Contents

Tables

Figures

Acronyms

µg/L	micrograms per liter
AECOM	AECOM Technical Services, Inc.
ACM	Assessment of Corrective Measures
ASD	Alternate Source Demonstration
amsl	above mean sea level
bgs	below ground surface
BNSF	Burlington Northern Santa Fe Railway Company
CAO	Corrective Action Objectives
CBR	Closure by Removal
CCR	Coal Combustion Residuals
CDPHE	Colorado Department of Public Health and Environment
CFR	Code of Federal Regulations
CIP	Closure in Place
cm	centimeter
COC	constituent of concern
DO	dissolved oxygen
EPA	United States. Environmental Protection Agency
FGD	flue gas desulfurization
ft	feet
ft/d	feet/day
ft/ft	feet/foot
GWPS	Groundwater Protection Standard
HASP	Health and Safety Plan
H_2O	water
LCL	lower confidence limit
LEAF	Leaching Environmental Assessment Framework
LTM	Long-Term Monitoring
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MNA	Monitored Natural Attenuation

O&M	Operations and Maintenance
ORP	oxidation-reduction potential
PO	Purchase Order
POTW	publicly owned treatment works
PPE	personal protective equipment
ppm	parts per million
PRB	Permeable Reactive Barrier
PRPA	Platte River Power Authority
PRS	Phosphorus Recovery System
RACER	Remedial Action Cost Engineering Requirements
SPLP	Synthetic Precipitation Leaching Procedure
SSI	statistically significant increase
SSL	statistically significant level
TDS	total dissolved solids
UPL	upper prediction limit
wt %	weight percent
WOCA	World of Coal Ash
ZVI	zero valent iron

1. Introduction

AECOM Technical Services, Inc. (AECOM) was retained by Platte River Power Authority (PRPA) to complete an Assessment of Corrective Measures (ACM) for groundwater contamination at the Ash Monofill at the PRPA Rawhide Energy Station in Larimer County, Colorado. This ACM presents an evaluation of Ash Monofill closure options to achieve source control and groundwater remedial alternatives to address selenium identified as a consituent of concern (COC) to be present in groundwater.

This ACM was prepared in accordance with 40 Code of Federal Regulations (CFR) Parts 257.96 and 257.97 requirements under the Coal Combustion Residuals (CCR) Rule. In addition, the United States Environmental Protection Agency (EPA) guidance documents (EPA, 1993; EPA, 2000) were used in this ACM.

1.1 Report Organization

This report is divided into nine sections as outlined below and includes tables and figures.

- Section 1.0 includes an introduction and report organization;
- Section 2.0 provides a site description that includes the facility location, Ash Monofill operational history, monitoring well network and sampling results, and source, nature and extent of contamination;
- Section 3.0 presents a qualitative risk assessment;
- Section 4.0 presents the corrective action objectives;
- Section 5.0 presents the source control measures that would be implemented prior to groundwater remediation;
- Section 6.0 presents the detailed evaluation of source control measures;
- Section 7.0 presents the technology/process options identification and assembly of corrective measure alternatives for groundwater;
- Section 8.0 presents the detailed evaluation of corrective measure alternative for groundwaters; and
- Section 9.0 provides a list of references cited in the report.

2. Site Description and Background

2.1 Site Description

The Rawhide Energy Station (the Site) encompasses approximately 4,560 acres north of Wellington in Larimer County, Colorado. In addition to the plant buildings, the major feature of the facility is an approximately 500 acre dry-land construction reservoir of reclaimed wastewater for the City of Fort Collins, also known as Hamilton Reservoir, which contains approximately 15,000 acre-feet of water that is used for cooling processes. The power block area contains the boiler and turbine buildings, the air quality control equipment, and the administrative offices. A rail spur along the northern edge of the Site connects the Rawhide Facility with the mainline of the Burlington Northern Santa Fe Railway Company (BNSF) Railway Company and is used to deliver coal and construction materials for plant operations. Six generating units are located at the Rawhide Station. Units A, B, C, D, and F are fueled by natural gas, and Unit 1 is fueled by coal from the Powder River Basin in Wyoming.

The Ash Monofill is located northwest of the main plant and north of Hamilton Reservoir**.** CCR solid waste from Unit 1 operations is disposed in the Ash Monofill. The existing Ash Monofill includes Cell 1 (approximately 47 acres) and Cell 2A (approximately 11 acres) as shown on **Figure 1**. Cell 1 was operated from approximately 1980 to 2007 and is no longer in use. It is capped with cover soils but has not undergone final closure. Cell 2 is active, lies to the west of Cell 1, and is progressively advancing northwards as further ash material is placed within the cell.

2.2 Ash Monofill Hydrogeology

The Ash Monofill is constructed within a narrow south-sloping valley with bedrock highs along both sides. The uppermost water-bearing stratum at the Ash Monofill was identified during groundwater monitoring well installation as the weathered and fractured Pierre Shale. Groundwater at the Ash Monofill is under water table conditions and in 2018 was at depths from approximately 14 to 40 feet (ft) below ground surface (bgs). Groundwater flow is generally from northwest to south-southeast, from the Ash Monofill towards Hamilton Reservoirfollowing the topographic slope of the valley.

2.3 Monitoring Well Network and Sampling Results

A groundwater monitoring well system was installed at the Ash Monofill in 2016 to comply with 40 CFR 257.91(c). **Figure 1** shows the groundwater piezometers and monitoring wells comprising the current monitoring well network at the Ash Monofill and two borings drilled to characterize Cell 1. The monitoring well network was modified in 2018 to add three new wells, one upgradient and two downgradient. The Ash Monofill network currently includes two upgradient wells, ASH-01 and ASH-06, used to establish background groundwater constituent concentrations, and five downgradient wells, ASH-03, ASH-04, ASH-05, ASH-07 and ASH-08, along the southern edge of the Ash Monofill designated as compliance monitoring wells. Monitoring well ASH-01 was installed in 1980 as MW-01 for a site-wide monitoring well network. Monitoring wells ASH-03, ASH-04, and ASH-05 were installed in 2016 to comply with the CCR Rule. Per 40 CFR 257.95(g)(1), monitoring wells ASH-07 and ASH-08 were installed to characterize the extent of Appendix IV statistically significant increases (SSIs) downgradient of the Ash Monofill. This network satisfies the requirements of 40 CFR 257.91 because the Ash Monofill is constructed within a narrow valley that is sloped to the south that constrains groundwater flow that may have been affected by a release from the landfill. The downgradient monitoring wells extend across the width of the valley mouth and allow detection of potentially impacted groundwater from beneath the Ash Monofill.

Groundwater beneath the Ash Monofill occurs under water-table conditions in partings, joints, and fractures in the underlying variably weathered Pierre Shale. Groundwater elevations range from approximately 5,746 ft above mean sea level (amsl) at ASH-01 at the north end of the Ash Monofill to approximately 5,676 ft amsl at ASH-05 at the south end of the Ash Monofill, resulting in a horizontal hydraulic gradient of approximately 0.007 ft/ft (feet/foot). Annual groundwater elevations measured at monitoring well ASH-01 since 1984 have fluctuated about 6 feet, ranging from 5,742 to 5,748 ft amsl. **Figure 2** shows a potentiometric surface for the Ash Monofill for January 17, 2019.

Eight rounds of baseline detection monitoring data were collected at the Ash Monofill between September 2016 and July 2017 for Appendix III and IV constituents to comply with the CCR Rule. Based on statistical analysis results, SSIs over background were found for Appendix III constituents boron, calcium, chloride, sulfate, and total dissolved solids (TDS) at downgradient monitoring wells ASH-03, ASH-04, and ASH-05 (AECOM, 2018). An Alternate Source Demonstration (ASD) was performed to assess whether the observed Appendix III SSIs are from an alternative source other than the Ash Monofill. The ASD did not find any likely natural variations in groundwater quality or anthropogenic (agricultural or industrial) sources other than the Ash Monofill that caused the SSIs. The lack of a successful ASD required that assessment monitoring be initiated at the Ash Monofill.

Statistical analyses of the assessment monitoring data identified Appendix IV SSIs over background upper prediction limits (UPLs) for barium at monitoring wells ASH-03 and ASH-05, and selenium at monitoring wells ASH-03, ASH-04, ASH-05, and ASH-07. No other Appendix IV constituents exhibited SSIs. A constituent is considered present at a statistically significant level (SSL) over the groundwater protection standard (GWPS) if the 95 percent lower confidence limit (LCL) is greater than the GWPS. Selenium at monitoring wells ASH-05 and ASH-07 were found to exhibit an SSL above its GWPS because their 95% LCLs [0.067 and 0.050 milligrams per liter (mg/L), respectively] were greater than or equal to the GWPS of 0.05 mg/L. Selenium and barium were not present at a SSL above the GWPS at any of the other wells because their 95% LCLs were less than their respective GWPS.

Based on the above findings, selenium is the only Appendix IV constituent present at concentrations above the GWPS at the Site that requires an ACM per 40 CFR 257.96.

2.4 Source, Nature and Extent of Contamination

The Ash Monofill is underlain by the variably weathered and fractured Pierre Shale, an upper Cretaceous marine shale formation. The Pierre Shale is recognized by the United States Geological Survey (Schultz et al., 1980) to be composed of many of the Appendix III constituents, including calcium [2.7 ± 0.48 weight percent (wt %)], sulfur (0.37 ± 1.1 wt %), fluorine (0.71 ± 0.15 wt %), chlorine (0.16 ± 0.024 wt %), and boron [99 ± 49 parts per million (ppm)]; and, groundwater in the shale is known to have poor water quality with high TDS concentrations. These constituents are largely derived from the clays, plagioclase feldspars, calcite, dolomite, and pyrite minerals in the shale. All of these constituents are present in groundwater at upgradient (background) well ASH-01 (AECOM, 2018).

2.4.1 Ash Monofill Cell 1 Investigation

Closed Cell 1 was investigated to chemically and hydrologically characterize the ash stored within it. Two borings were drilled using a Central Mine Equipment hollow-stem auger rig by Drilling Engineers, Inc. of Fort Collins, Colorado on April 23, 2019. The borings were logged and sampled by AECOM field geologists as the borings were drilled. The locations of the borings (CELL1-1 and CELL1-2) are shown on **Figure 1**. Borings CELL1-1 and CELL 1-2 were drilled to a total depth of 79 ft bgs and terminated in the Pierre Shale.

Soil and ash materials encountered in boring CELL1-1 included an approximately 4-ft thick vegetated soil cover, 0.5-ft thick layer of lithified coal ash, 32 ft of unconsolidated to lithified coal ash, 18 ft of interbedded sand and clay alluvium, and 29 ft of variably weathered Pierre Shale. Groundwater was not found in boring CELL1-1 after it stood open overnight. The base of the coal ash at boring CELL1-1 lies about 44 ft above the potentiometric surface shown in **Figure 2**.

Soil and ash materials encountered in boring CELL1-2 included an approximate 2-ft thick vegetated soil cover, 0.5-ft thick layer of lithified coal ash, 50 ft of unconsolidated to lithified coal ash, and 27 ft of variably weathered Pierre Shale. Visual observation of the unlithified coal ash encountered during drilling suggested that it was typically dry. A grab sample of groundwater was collected in boring CELL1-2 after it stood open overnight. Selenium was not detected (< 5 micrograms per liter [µg/L]) in the sample. The base of the coal ash at boring CELL1-2 lies about 5 ft above the potentiometric surface depicted in **Figure 2**. However, it is possible that the capillary fringe along the water table in the southern portion of the Ash Monofill may periodically extend into the lower portion of the coal ash in this area. It is also possible that waters discharged to the unlined Phosphorus Recovery System (PRS) Impoundments may influence groundwater elevations beneath the southern portion of the Ash Monofill.

2.4.2 Coal Ash Moisture Content

Coal ash samples collected during drilling were submitted to D. B. Stephens & Associates in Albuquerque, New Mexico for gravimetric moisture analysis to confirm visual moisture observations. The moisture content analysis results are listed on **Table 1**. Two coal ash samples [CELL1-1 (10 to 20 ft bgs) and CELL1-2 (30 to 40 ft bgs)] were also selected to determine moisture characteristic curves (**Figure 1**). The highest moisture contents were noted in coal ash from boring CELL1-2 at a depth of 5 to 10 ft bgs (35%) and near the base of the ash at a depth of 45 to 50 ft bgs (38%). The moisture characteristic curves shown in **Figure 3** show the coal ash moisture contents range from saturated at atmospheric pressure (0 centimeter [cm] water [H_2O]) and steadily decreases below saturation at successively lower negative pressure heads (- cm H_2O).

Figure 3 shows that all of the coal ash samples had moisture contents less than field capacity (approximately -300 cm H_2O). Field capacity is the amount of water remaining in the ash a few days after having been wetted and after free drainage has ceased. Four of the coal ash samples had moisture contents less than the permanent wilting point (approximately -15,000 cm H_2O). The permanent wilting point is the water content of a soil when most plants (corn, wheat, sunflowers) growing in that soil wilt and fail to recover their turgor upon rewetting. The coal ash moisture contents measured during this investigation indicate that the ash is dry to extremely dry and that little moisture movement, i.e. percolation, occurs at these moisture contents. This also suggests that the existing vegetative soil cover, as well as the lithified coal ash layer immediately below the cover soils, appears effective at limiting moisture influx. The potential for leaching of coal ash constituents at these moisture contents is likely minimal.

Table 1. Gravimetric Moisture Content of Coal Ash

Boring Number	Sample Depth (ft bgs)	Gravimetric Moisture Content (%)
CELL 1-1	5-10	29.3
CELL 1-1	10-20	18.2
CELL 1-1	20-25	18.8
CELL 1-1	30-35	28.4
CELL 1-2	5-10	35.0
CELL 1-2	20-25	17.1
CELL 1-2	30-40	25.0
CELL 1-2	45-50	38.2

Notes:
% = percent
ft bgs = feet below ground surface

2.4.3 Coal Ash and Pierre Shale Leaching Characteristics

Ten samples of coal ash from borings CELL1-1 and CELL1-2 in Cell 1 of the Ash Monofill were collected during drilling and submitted for total and synthetic precipitation leaching procedure (SPLP) EPA Method 1312 analysis for selenium. Two coal ash samples were submitted for Leaching Environmental Assessment Framework (LEAF – EPA Methods 1313 and 1316) analysis for selenium. Pierre Shale samples were also collected during drilling from the borings in Cell 1, and monitoring well ASH-08, and submitted for total and SPLP (7 samples) and LEAF (1 sample) analyses. The analyses were performed by Eurofins TestAmerica in Pittsburg, Pennsylvania.

Total analyses indicate that selenium concentrations ranged from 3.6 to 15 milligrams per kilogram (mg/kg) and averaged 8.6 mg/kg. Total concentration of selenium in the Pierre Shale was lower than those in the coal ash and ranged from 2.6 to 4.4 mg/kg, respectively, averaging 3.1 mg/kg.

SPLP analyses indicate that selenium concentrations in coal ash leachate ranged from < 2.6 to 13 µg/L and averaged 7.7 µg/L. SPLP concentrations of selenium in the Pierre Shale were similar to those in the coal ash and ranged from <2.6 to 5.3 µg/L, averaging 3.5 µg/L, respectively. **Figure 4** shows boxplot of selenium concentrations in SPLP leachates for the coal ash and Pierre Shale compared to groundwater concentrations. This figure shows that selenium SPLP leachate concentrations in coal ash and Pierre Shale are similar, but are less than the observed groundwater concentrations. SPLP analyses are extracted at a 20:1 liquid to solid ratio which likely reduces constituent concentrations in leachates from what would be expected under actual field leaching conditions.

The results of the LEAF tests for coal ash are summarized in **Figures 5** (LEAF Method 1313) and **Figure 6** (LEAF Method 1316). LEAF Method 1313 leaches solids at various pH values and a fixed liquid to solid ratio of 10:1. LEAF Method 1316 leaches solids at varying liquid to solid ratios and the natural pH of the liquid-solid mixture (approximately 10 for the coal ash and 8 for the Pierre Shale). **Figure 5** shows that selenium concentrations in the LEAF leachates (200 to 16 µg/L) decrease with increasing pH but increase above pH 10. For the typical pH (approximately 8) in groundwater beneath the Ash Monofill, **Figure 5** suggests that selenium could be leached from the coal ash at constituent concentrations consistent with those found in groundwater. **Figure 6** shows that the concentrations of selenium decrease with increasing liquid to solid leaching ratios. Liquid to solid leaching ratios less than 2 would likely be needed to achieve the observed groundwater concentrations, while accounting for dilution as the leachate is released to groundwater.

2.4.4 Source of Contamination

An ASD was performed to assess whether a natural or other anthropogenic source, other than the Ash Monofill, is responsible for the SSIs over background for Appendix III constituents boron, calcium, chloride, sulfate, and TDS at downgradient monitoring wells ASH-03, ASH-04, and ASH-05. The Appendix III constituents are also present in the coal ash. To distinguish constituent sources derived from the Pierre Shale or coal ash, molar concentration ratios of some of the Appendix III constituents were calculated for average constituent concentrations in upgradient and downgradient groundwater and are presented in the ASD. The average molar ratios varied considerably between the upgradient and downgradient groundwaters, suggesting that a source other than the Pierre Shale is likely causing the Appendix III SSIs. Some of the molar ratios (boron/chloride, fluoride/chloride, calcium/chloride, sulfate/chloride) decreased in response to increased chloride and sulfate concentrations, whereas other molar ratios (boron/fluoride and calcium/sulfate) increased in response to increased boron and calcium concentrations. The most likely source for the increased boron, calcium, chloride, and sulfate concentrations is the coal ash disposed in the Ash Monofill. Coal ash, particularly fly ash, and comingled flue gas desulfurization (FGD) wastes are known to contain elevated concentrations of boron, calcium, chloride, and sulfate (AECOM, 2018).

3. Risk Assessment

This qualitative risk assessment discusses potential risks posed by selenium, the only COC, considering the human and environmental receptor groundwater exposure pathways present at the Ash Monofill site.

3.1 Constituents of Concern

Selenium is the only Appendix IV constituent under the CCR Rule that has been detected at a SSL exceeding the GWPS of 0.05 mg/L as defined under 40 CFR 257.95(h) (Federal Register, 2018). Therefore, selenium has been identified as a COC in groundwater. Based on assessment monitoring results, selenium was detected at an SSL above or equal to its GWPS at monitoring wells ASH-05 and ASH-07.

Recent groundwater monitoring data for selenium in groundwater is tabulated below.

Table 2. Summary of Groundwater Selenium Concentrations

<table>
<tr><th>Monitoring Well (sampled on June and October 2018)</th><th>Selenium Concentration Range (mg/L)</th><th>Maximum Background Concentration (mg/L)</th><th>GWPS (mg/L)</th><th>Cleanup Level (mg/L)</th></tr>
<tr><td colspan="2">Upgradient Wells</td><td rowspan="11">0.0228</td><td rowspan="11">0.05</td><td rowspan="11">0.05</td></tr>
<tr><td>ASH-01</td><td><0.001-<0.003</td></tr>
<tr><td>ASH-06</td><td>0.0206-0.0228</td></tr>
<tr><td colspan="2">Downgradient Wells</td></tr>
<tr><td>ASH-02</td><td>< 0.0005-<0.003</td></tr>
<tr><td>ASH-03</td><td>0.0406-0.0747</td></tr>
<tr><td>ASH-04</td><td>0.0426-0.0554</td></tr>
<tr><td>ASH-05</td><td>0.0924-0.105</td></tr>
<tr><td>ASH-07</td><td>0.0688-0.0919[1]</td></tr>
<tr><td>ASH-08</td><td>0.0073[1]</td></tr>
</table>

Notes:
[1]denotes 2019 data
Green highlight denotes SSL exceedance of GWPS
mg/L = milligrams per liter

3.2 Exposure Pathways

Selenium is detected in groundwater at the Ash Monofill at downgradient monitoring wells ASH-03, ASH-04, ASH-05, ASH-07 and ASH-08 and upgradient monitoring well ASH-06. Selenium was not detected in upgradient well ASH-01 or downgradient well ASH-02 (which is MW-2 under sitewide monitoring program). All of these wells are completed in the Pierre Shale. Selenium exceeds the GWPS at a SSL at monitoring wells ASH-05 and ASH-07. Groundwater in this area occurs at an approximate potentiometric elevation of 5676 ft amsl (**Figure 2**). Depths to groundwater in this area range from approximately 3 to 40 ft bgs, averaging approximately 18 ft bgs.

Groundwater in the Pierre Shale is naturally of poor quality, thus it has no current or planned future use as a source of domestic or agricultural water supply. The affected groundwater is primarily confined to an approximate depth of 20 to 40 ft bgs. Incidental construction or excavation activities are not likely to occur at such a depth that would expose human or environmental receptors to groundwater. Accordingly, the groundwater exposure pathway is considered incomplete which eliminates any potential exposure risk. Furthermore, the inherent non-volatile nature of metals such as selenium eliminates also eliminates the vapor intrusion pathway. There is no known contaminated groundwater discharge or seepage to surface water; therefore, potential surface water exposure pathwaysare also eliminated.

4. Corrective Action Objectives

This section presents the corrective action objectives (CAOs) that were developed to address selenium in groundwater above the GWPS downgradient of the Ash Monofill. The CAOs are response action completion criteria that can be practicably achieved to ensure reliable protection of human health and the environment within a reasonable time. Factors considered during the selection of the CAOs included constituents characteristics, the medium of concern, current and future exposure pathways, and regulatory requirements under the CCR Rule (40 CFR Part 257).

40 CFR 257.96(a) in the CCR Rule specifies that an owner or operator must initiate an ACM to prevent further releases, to remediate any releases and to restore the affected area to original conditions. While conducting the ACM, the owner or operator of the CCR unit must continue to monitor groundwater in accordance with the assessment monitoring program as specified in 40 CFR 257.95. CAOs for the ACM are specified in 40 CFR 257.97(b) which states that the selected corrective measures remedy must:

- Be protective of human health and the environment;
- Attain the GWPS as specified pursuant to 40 CFR 257.95(h);
- Control the source(s) of releases so as to reduce or eliminate, to the maximum extent feasible, further releases of constituents in Appendix IV to this part into the environment;
- Remove from the environment as much of the contaminated material that was released from the CCR unit as is feasible, taking into account factors such as avoiding inappropriate disturbance of sensitive ecosystems; and
- Comply with standards for management of wastes as specified in 40 CFR 257.98(d).

5. Source Control Measures

CCR solid waste from Unit 1 operations is disposed in the existing Ash Monofill which is comprised of two cells, Cell 1 and Cell 2A . Cell 1 is capped with a vegetated soil cover while Cell 2A is currently active. Ash Monofill appears to be the source of selenium identified as a COC in groundwater.

Future development of Cell 2B at the Ash Monofill will be lined to protect groundwater. The design of Cell 2B will comply with applicable requirements under the CCR Rule as well as the Colorado Department of Public Health and Environment (CDPHE) “Regulations Pertaining to Solid Waste Sites and Facilities”, 6 Code of Colorado Regulations 1007-2, Part 1.

Source control would be achieved by closure of Ash Monofill Cells 1 and 2A prior to groundwater remediation. Closure would be performed in compliance with the requirements specified under 40 CFR 257 Part 102. This CCR Rule provides two basic closure options: closure in place (CIP) and closure by removal (CBR) as summarized below.

Closure in Place (CIP): CIP is accomplished by covering the CCR in place with a final cover designed to control, minimize or eliminate, to the maximum extent feasible, post-closure infiltration of liquids into the waste and releases of CCR, leachate, or contaminated run-off to the ground to meet the closure performance requirements specified under 40 CFR 257 Part102(d)(3)(i).

Closure by Removal (CBR): CBR is accomplished by excavating and removing the disposed CCR, and decontaminating all areas affected by releases from the CCR unit. CCR removal and decontamination are considered complete when COC concentrations throughout the CCR unit and any areas affected by releases from the CCR unit have been removed and groundwater concentrations do not exceed GWPS established pursuant to 40 CFR part 257.95(h). The excavated CCR would be disposed of in an appropriately designed on-site or off-site landfill, or recycled or reused for beneficial use in lieu of disposal. The excavated CCR would be transported to a Subtitle D landfill for disposal or to a beneficial use location. CBR is not subject to post-closure care requirements per 40 CFR Part 257 paragraph 104 (a)(2).

The alternatives for source closure of the Ash Monofill are:

- Alternative S-1: Ash Monofill Closure in Place
- Alternative S-2: Ash Monofill Closure by Removal

6. Detailed Evaluation of Ash Monofill Closure Alternatives

A detailed evaluation of the closure options in Section 5.0 is presented in the following subsections. Each alternative is evaluated against the requirements specified in 40 CFR 257.96 and 257.97. The cost for each alternative is estimated using the Remedial Action Engineering and Requirements (RACER) version 11.4, AECOM's in-house cost-estimating software. These costs are for the evaluation of the alternatives. Actual costs of implementation may vary from -30 to +50 percent. The alternative evaluation criteria are broadly categorized under effectiveness, implementability and cost as listed in **Table 3** below.

Table 3. Criteria for Evaluation of Alternatives

Effectiveness
Protective of Human Health and the Environment
Attain GWPS
Control the Source of Release
Comply with Standards for Management of Wastes
Long-Term Effectiveness and Permanence
Reduction of Toxicity, Mobility or Volume through Treatment
Short-Term Effectiveness
Implementability
Technical Feasibility
Administrative Feasibility
Availability of Services and Materials
Cost
Capital Cost
Operations and Maintenance (O&M) Cost
Total Cost

Notes:
GWPS = Groundwater Protection Standard
O&M = Operations and Maintenance

6.1 Alternative S-1 Ash Monofill Closure in Place

Cell 1 is currently overlain by a 2-ft thick earthen cover with a vegetated soil cover (AECOM, 2019a) and ceased operation in 2007. Final closure is currently being reviewed by the CDPHE. Cell 1 was not designed with a composite liner since disposal operation began in 1980. At that time, landfill design practices did not call for composite liner systems. Visual observations during recent drilling in Cell 1 indicate that the coal ash below the soil cover has hydrated and formed an approximately 6-inch thick concrete-like layer that likely limits precipitation infiltration into the underlying unconsolidated coal ash as discussed in Section 2.4.2. This is supported by moisture characteristics determination discussed in Section 2.4.3. The coal ash moisture contents measured during this investigation indicate that the ash is dry to extremely dry and that little moisture movement, i.e., percolation, occurs at these moisture contents. This also suggests that the existing vegetated soil cover appears effective at limiting moisture influx and that the potential for leaching of CCR constituents at these moisture contents is likely minimal. Based on the above discussion and considering that selenium only exceeds the GWPS at SSL at monitoring wells ASH-05 and ASH-07, which may not be sourced from the Ash Monofill (based on the low selenium concentrations in ASH-03), the existing cover at Cell 1 is considered adequate to limit infiltration and leaching of CCR constituents.

Cap designs for closure of Cell 2A can range from a prescriptive cover (utilizing a geomembrane liner, geocomposite drainage layer, infiltration layer and a vegetated soil cover to minimize erosion) to an alternative cap meeting the performance standard as specified under 40 CFR 257.102 (d). Alternative caps such as as evapotranspiration cover, exposed geomembrane liners or synthetic turf have recently emerged in the CCR industry and may provide cost-effective options that meet the performance standards. The cap type for Cell 2A closure would be finalized during closure phase.

The evaluation of Alternative S-1 is presented in **Table 4**.

Table 4. Evaluation of Alternative S-1 (Ash Monofill CIP)

Effectiveness	
Protective of Human Health and the Environment	Existing soil cover at Cell 1 appears to be effectively controlling infiltration of liquids into the ash material and releases of CCR to groundwater or to the atmosphere. This is supported by SPLP data for selenium in the coal ash leachate with an average concentration of 0.0035 mg/L which is an order of magnitude lower than the GWPS of 0.05 mg/L. The Cell 2A cap would be designed to meet the performance standards specified in 40 CFR 257.102(d) and CAOs . Potential risks associated with Ash Monofill wastes would be reduced by eliminating exposure pathways such as dermal contact, ingestion and inhalation of contaminated soil. Capping would also prevent infiltration of precipitation and surface water run-off into the wastes and therefore, limit downward migration of constituents into the aquifer. Capping would prevent ecological receptors such as birds and mammals from penetrating the contaminated soil/debris. The Ash Monofill is located within an industrial facility and not accessible to public. No digging or constrution activities would occur at this site. Standard health and safety procedures would protect workers during Cell 2A cap installation. Risks to community are minimal. Alternative S-1 would provide adequate protection of human health and the environment.
Attain GWPS	Capping limits precipitation infiltration and leaching of coal ash and protects underlying groundwater from future constituent releases, thereby minimizing the time to achieve GWPS.
Control the Source of Release	Capping is a well-developed technology and is typically implemented for landfill closure to meet regulatory requirements. Capping would minimize infiltration of precipitation and surface run-off and achieve adequate source control, since coal ash has not been placed below or into the groundwater at Cells 1 and 2A.
Comply with Standards for Management of Wastes	No wastes would be generated under this alternative.
Long-Term Effectiveness and Permanence	The integrity of the cap would be preserved by long-term maintenance and repairs, as necessary. Long-Term Monitoring (LTM) data would be used to review and confirm remedy effectiveness over time, otherwise appropriate corrective action would be triggered.
Reduction of Toxicity, Mobility or Volume through Treatment	Capping utilizes “containment” and not “treatment” to reduce the risks associated with the CCR constituents. Capping would reduce the mobility but not the toxicity or volume of the constituents.

Table 4. Evaluation of Alternative S-1 (Ash Monofill CIP)

Effectiveness	
Short-Term Effectiveness	Construction of a cap would be completed with standard equipment and would entail no additional risks to workers beyond those inherent in construction projects. Short-term risks to the public, workers, or the environment during cap installation are expected to be minimal. Engineering controls and personal protective equipment (PPE) would be used to ensure workers' health and safety. Dust suppressants would be used to minimize the possibility of windblown emissions of contaminated dust. All construction activities would be performed in accordance with the Site-Specific Health and Safety Plan (HASP).
Implementability	
Technical Feasibility	The Ash Monofill is generally accessible to equipment such as grader, roller and vibrating compactors that would be used for construction of the cap. Materials such as soil, asphalt, gravel or crushed stones are readily locally available.
Administrative Feasibility	The closure of Ash Monofill Cells 1and 2A would require CDPHE approval.
Availability of Services and Materials	The construction of a cap is a well-established technology and materials are offered by several vendors.
Cost	
Capital Cost	$ 3,424,000
O&M Cost	$ 1,279,000
Total Cost	**$ 4,703,000**

Notes:
CAOs = Corrective Action Objectives
CCR = Coal Combustion Residuals
CDPHE = Colorado Department of Public Health and Environment
CFR = Code of Federal Regulations
GWPS = Groundwater Protection Standard
LTM = Long-term Monitoring
mg/L = milligram per liter
O&M = Operation and Maintenance
SPLP = Synthetic Precipitation Leaching Procedure

For the purposes of cost-estimating, the following assumptions were made:

- Cell 2A would consist of a 6-inch vegetative cover underlain by a 24-inch compacted soil layer.
- Groundwater monitoring of six existing wells for Appendix IV constituents for a 30-year period;
- Post-closure care maintenance of Cells 1 and 2A for a 30-year period.

6.2 Alternative S-2 Ash Monofill Closure by Removal

This alternative consists of excavating all of the coal ash in Ash Monofill Cell 1 (approximately 47 acres) and Cell 2A (approximately 11 acres), and contaminated native soils, to achieve clean closure.

Excavation would be performed using equipment such as a hydraulic excavator, scrapers or backhoes, as applicable. Following coal ash and contaminated soil removal, confirmation samples would be collected from the soils in the sidewalls and bottom of the excavated area of each cell to verify that the coal ash was successfully removed. Depending on the depths of the required excavation, benching and/or sloping would likely be required. If the need arises, shoring and bracing will be installed or suitable sides will be constructed to prevent cave-ins or slope failure. Dewatering would not be necessary as excavation does not extend below the water table.

A berm would be constructed around the excavation to prevent surfacewater runon from entering the excavation prior to backfilling. The excavated areas would be backfilled with soil that may be obtained from on-site or off-site. All activities would be performed in accordance with the Site-Specific HASP.

The excavated coal ash could be transported to appropriate vendors (cement industry, structural fill) for the beneficial use, or placed in an approved on- or off-site landfill. Haul routes and temporary staging areas, including dust control measures, would be planned to ensure transportation of coal ash in a safe manner without adverse impacts to the community.

The evaluation of Alternative S-2 is presented in **Table 5**.

Table 5. Evaluation of Alternative S-2 (Ash Monofill Cells CBR)

Effectiveness	
Protective of Human Health and the Environment	With removal of coal ash from Cells 1and 2A, any Appendix IV constituents that could pose risks or the environment to human health upon exposure or become a source of groundwater contamination would be removed. Therefore, this alternative would provide maximum protection for human health and the environment. Any short-term risks such as fugitive dust emissions during excavation and transportation would be addressed through the use of engineering controls and PPE. Standard health and safety procedures would protect workers during excavation. Off-site traffic planning and dust control measures would be incorporated during transportation to minimize risks to community. Alternative S-2 would provide adequate protection of human health and the environment.
Attain GWPS	Removal of the coal ash eliminates future leaching of coal ash and constituent releases to underlying groundwater, thereby minimizing the time to achieve GWPS.
Control the Source of Release	With removal of coal ash and associated contaminated soil, if any, this alternative would provide maximum source control.
Comply with Standards for Management of Wastes	Excavation of the 58-acre Ash Monofill would generate more than 2,000,000 cubic yards of coal ash. Waste would be managed to comply with applicable standards, although there would be logistical challenges in managing such high volume of waste.
Long-Term Effectiveness and Permanence	This alternative would provide maximum long-term effectiveness and permanence because the coal ash would be completely and permanently removed from Cells 1and 2A. Upon completion of this alternative, no LTM or maintenance of the specified cells would be required.
Reduction of Toxicity, Mobility or Volume through Treatment	The toxicity, mobility and volume of coal ash would be completely eliminated from Cells 1 and 2A. However, the toxicity, mobility and volume

Table 5. Evaluation of Alternative S-2 (Ash Monofill Cells CBR)

Effectiveness	
	of CCR constituents in the excavated material itself would remain unchanged unless it is subsequently treated through beneficial use or at an approved waste disposal facility.
Short-Term Effectiveness	The excavation and transportation activities associated with this alternative could generate fugitive dust. This alternative involves the greatest potential impact to the community during transportation since all coal ash would be removed from Cells 1 and 2A. The potential worker and community exposures would be minimized through the use of PPE and dust control measures.
Implementability	
Technical Feasibility	Excavation can be accomplished using standard construction equipment. There are no buildings or other infrastructure that could pose accessibility concerns at the Ash Monofill. There are no wetlands, historic areas or wildlife refuge that could preclude implementation of this alternative. However, the terrain and significantly high volume of excavated coal ash and soil may pose technical constraints.
Administrative Feasibility	The engineering design and operations plans for this alternative would require CDPHE approval.
Availability of Services and Materials	Excavation is a well-established technology and offered by several vendors.
Cost	
Capital Cost	$283,816,000
O&M Cost	$0
Total Cost	**$ 283,816,000**

Notes:
CBR = Closure by Removal
CCR = Coal Combustion Residuals
GWPS = Groundwater Protection Standard
O&M = Operation and Maintenance
PPE = personal protective equipment

For the purpose of cost-estimating, the following assumptions were made:

- Approximately 2,600,000 cubic yards of coal ash and underlying contaminated soil from Cells 1 and 2A based on a disposal rate of 71,600 cubic yard per year.

Alternative S-2 is cost-prohibitive and not an economically viable option. In addition, implementation of this alternative poses safety concerns, and logistical constraints in transportation and disposal of such large volumes of ash wastes.

7. Groundwater Technology Identification and Corrective Action Alternatives

The purpose of this section is to identify potentially applicable groundwater treatment technologies that can be used to remediate selenium-contaminated groundwater downgradient of the Ash Monofill. The selected treatment technologies were assembled into corrective action alternatives and evaluated to determine whether they are capable of achieving the CAOs presented in **Section 4.0** considering screening criteria of effectiveness, implementability, and cost.

7.1 Technology Screening and Identification

Potentially applicable groundwater remediation technologies were identified based on selenium characteristics and site-specific hydrogeologic and geochemical conditions determined to be present downgradient of Ash Monofill. The technology identification process focused only on those technologies that have proven to be effective at other CCR or metal-impacted sites. Potentially applicable groundwater technologies for selenium remediation in groundwater were identified from a multitude of sources based on literature research (Goldermund and Ahrens, 2017; Kleinmann, 2017; Geosyntec, 2018).

The following remedial technologies, as standalone or in combination, were identified for consideration to achieve the groundwater CAOs:

- Monitored Natural Attenuation (MNA);
- Permeable Reactive Barrier (PRB);
- Groundwater Collection (via Extraction Wells);
- Off-Site Groundwater Discharge;
- On-Site Groundwater Discharge; and
- Long-Term Monitoring (LTM)

The above selected groundwater remediation technologies were screened based on effectiveness, technical implementability, and relative life-cycle cost. Those technologies that passed screening were used to develop corrective action alternatives, and these alternatives are subjected to detailed analysis and comparison in Sections 8 and 9. Those technologies that were not effective, had implementation concerns, and/or were excessively expensive in comparison to other technologies were rejected from further consideration.

7.2 Description of Applicable Technologies

Groundwater technologies identified in Section 7.1 are described in the following subsection.

7.2.1 Monitored Natural Attenuation (MNA)

MNA relies on a combination of physical, chemical and biological processes including dilution, dispersion, adsorption, intrinsic biodegradation, volatilization, and stabilization to reduce toxicity, mobility, or volume of contaminants. At CCR sites, the natural attenuation processes for inorganic contaminants such as selenium include a variety of physical and chemical processes that, under favorable conditions, act without human intervention to reduce a constituents' mass, toxicity, mobility, volume, or concentration in groundwater. Physical attenuation includes dispersion and dilution. Chemical attenuation includes constituent adsorption, ion exchange, and precipitation of minerals. Adsorption of metals to iron and manganese oxides, clay particles, or organic matter in soils is typically the most common sequestration mechanism naturally active at CCR disposal sites (Kleinmann, 2017).

MNA requires LTM to track constituent concentrations over time and to determine whether site-specific CAOs are achieved. Monitoring trends in a carefully designed monitoring network typically is a key part of informed decision making for both (1) selecting MNA as an appropriate response action for a site, and (2) assessing the effectiveness of MNA over time. Initial assessments of constituent extent, aquifer pH, whether the aquifer is generally oxidizing or reducing, and whether it is influenced by external hydrologic forces (for example, interactions between groundwater and surface water, recharge from precipitation or episodic regional withdrawals from an aquifer) should be considered in designing the dimensions of the monitoring network and the frequency of data collected to characterize site geochemistry and hydrology (EPA, 2008).

MNA is a viable option for this site considering that selenium, the sole COC that exceeds the GWPS at a SSLs only at monitoring wells ASH-05 and ASH-07. Natural processes such as sorption, biogeochemical reactions, and dilution/dispersion are expected to decrease selenium concentrations in the downgradient groundwater once Ash Monofill Cells 1 and 2A achieve final closure and construction of lined Cell 2B is completed.

7.2.2 Permeable Reactive Barrier (PRB)

PRBs are a feasible alternative for in-situ treatment of various inorganic constituents that may be present in groundwater at CCR sites. PBRs must be engineered with appropriate reactive media, effective residence time of impacted groundwater in the reactive media, and strategic location to passively capture the entire extent of the plume. Various design configurations have been constructed, including continuous barriers, funnel-and-gate systems, in situ deep slurry injections, and in situ reactive vessels (ITRC, 2005). Remediation is achieved as contaminated groundwater passes through a reactive subsurface zone that either removes the COC from groundwater or facilitates its transformation into a less toxic form. Some potential reactive media, such as zero valent iron (ZVI), promote both adsorption and precipitation of a broad range of constituents, while others, such as hybrid ion exchange resins, specifically promote one reaction to target a single or narrow range of constituents. Media such as ZVI, organic matter, ion-exchange resins, surfactant-modified zeolites, ferrous sulfate, red muds, and Granular Ferric Hydroxide™ show promise for remediation of CCR leachate. Overall, performance and cost data are needed for a wide range of constituents, and for varying mixtures of these constituents (EPRI, 2006). A wide range of PRB reactive media including ZVI, organic matter and limestone is available for selenium remediation.

7.2.3 Hydraulic Containment Using Extraction Wells

Groundwater collection using extraction wells is suitable for removing impacted groundwater from an aquifer for subsequent treatment and/or discharge. An extraction well is a component of a groundwater pump and treatment system. An extraction network is designed to capture impacted groundwater, preventing it from migrating further downgradient, and/or to provide hydraulic containment. The extraction well flowrates and spacing are based on aquifer hydraulic characteristics. Groundwater is then pumped through subsurface piping to an aboveground storage tank for disposal or to a centralized treatment system.

7.2.4 Ex-Situ Groundwater Treatment Technologies

Ex-situ groundwater treatment technologies are used to remove metal constituents from groundwater to meet regulatory discharge requirements. Treatment options for metal constituents may include pH adjustment, coagulation/chemical precipitation, or constructed treatment wetlands. Groundwater treatment technologies have not been considered for the impacted groundwater downgradient of the Ash Monofill because the low selenium concentrations cannot be treated ex-situ cost effectively.

7.2.5 On-Site/Off-Site Discharge of Groundwater

Groundwater discharge technologies involve the disposal of untreated groundwater at an approved on-site or off-site treatment facility, a publicly owned treatment works (POTW), discharge to surface water, or re-injection into an aquifer. The discharge of treated groundwater must satisfy effluent limitations and typically requires regulatory approval.

7.2.6 Long-Term Monitoring (LTM)

LTM of groundwater is an effective tool in evaluating remedial progress and attainment of CAOs. During remedy implementation, groundwater is typically monitored and evaluated periodically to assess constituent migration and track the progress of constituent concentration reduction, as well as provide an early indication of unforeseen environmental or human health exposures. LTM allows assessment of the remedy protectiveness over time, including an early indication of any changed site conditions if they occur.

7.3 Assembly of Corrective Measure Alternatives

Based on the results of the identification and screening of remedial technologies/process options, the following corrective measure alternatives were developed and retained for detailed evaluation:

- Alternative G-1: MNA and LTM
- Alternative G-2: PRB and LTM
- Alternative G-3: Hydraulic Containment (via Extraction Wells) and LTM

8. Detailed Evaluation of Corrective Measure Alternatives

A detailed evaluation of the three alternatives developed in Section 7.0 is presented in the following subsections. Each alternative is evaluated against the requirements specified in 40 CFR 257.96 and 257.97. The cost for each alternative is estimated using RACER Version 11.4.

8.1 Alternative G-1 MNA and LTM

This alternative consists of MNA and LTM. Once the Ash Monofills Cells 1 and 2A are closed, selenium concentrations in groundwater downgradient of the Ash Monofill is expected to decrease by naturally occurring processes such as sorption, biogeochemical reactions, and advection/ dispersion. As part of MNA, LTM would be conducted downgradient of Ash Monofill to document that MNA is reducing selenium concentrations over time. LTM would be performed using existing wells which may be supplemented by newly installed wells, as necessary. Groundwater would be monitored over the 20 to 40 ft bgs depth interval because selenium are currently found at this depth. At a minimum, the LTM network would include an upgradient well (ASH-01) and a hydraulically connected existing downgradient well(s), such as ASH-03, ASH-04, ASH-05, ASH-07, ASH-02 and/or ASH-08). Groundwater samples will be collected semi-annually and analyzed for Appendix IV constituents consistent with the assessment monitoring program. The LTM network would be finalized during design and optimized periodically based on LTM data review. The remediation timeframe for MNA to attain the GWPS and background concetration for selenium would be determined by statistically-based trend analyses or modeling during design.

If during LTM, data review indicates selenium concentrations in groundwater at downgraadient wells are not declining over time or that selenium is migrating further downgradient towards Hamilton Reservoir at concentrations exceeding the GWPS, a contingency remedy such as hydrualic containment would be considered. Appropriate corrective action would be implemented until the selenium GWPS is met.

An evaluation of Alternative G-1 is presented in **Table 6**.

Table 6. Evaluation of Alternative G-1: MNA and LTM

Effectiveness	
Protective of Human Health and the Environment	Following closure of the Ash Monofill Cells 1 and 2A, the relatively low selenium concentrations in the downgradient groundwater are expected to attenuate over time through naturally occurring processes such as sorption and/or precipitation combined with dilution/dispersion. Source control would prevent precipitation infiltration and mitigate further releases of selenium from the coal ash to the underlying groundwater. Although Cell 2B is expected to remain active until 2046, the disposal area would be constructed with a composite liner and a leachate collection system that would prevent release of CCR constituents from the active portion of the Ash Monofill. However, the low selenium concentrations that had been historically released to the underlying groundwater from the Ash Monofill, would continue to migrate further downgradient. It would likely take MNA less than 10 years to achieve the selenium GWPS. Furthermore, groundwater in the Pierre Shale is of limited quality and quantity and there are no current or planned future domestic or agricultural uses of the groundwater at the facility. Therefore, exposure of selenium in groundwater through ingestion, inhalation, dermal contact or agricultural use is unlikely to occur at the site. There are no potential off-site groundwater pathways, human receptors, or known sensitive environmental habitat or species that would be adversely impacted by selenium in groundwater at the site. Alternative G-1 is protective of human health and the environment.
Attain GWPS	Once the Ash Monofill Cells 1 and 2A achieve final closure, MNA is expected to meet the GWPS of 0.05 mg/L (40 CFR Part 257(h) for selenium within a reasonable timeframe. As part of MNA, LTM would be conducted to periodically assess selenium trends. This would ensure that the remedy continues to be protective of human health and the environment or determine if additional review/corrective action is warranted.
Control the Source of Release	Source control would be achieved with the closure of Ash Monofill Cells 1 and 2A.
Comply with Standards for Management of Wastes	No wastes would be generated under this alternative.
Long-Term Effectiveness and Permanence	Given that source control would be achieved through the closure of Ash Monofill Cells 1 and 2A, dissolved selenium in groundwater is expected to be attenuated by natural effects such as sorption, precipitation onto the soil minerals of the aquifer matrix combined with dilution/dispersion. LTM data would be used to demonstrate that natural attenuation is occurring, and that selenium is being attenuated over time.
Reduction of Toxicity, Mobility or Volume through Treatment	This alternative would not employ any active treatment technologies; therefore, no reduction in the toxicity, mobility, or volume of selenium would occur through treatment.

Table 6. Evaluation of Alternative G-1: MNA and LTM

Effectiveness	
Short-Term Effectiveness	Implementation of Alternative G-1 would not include on-site activities other than periodic groundwater sampling to monitor MNA progress. Proper use of PPE and following a Site-Specific HASP would minimize or eliminate impacts to workers during groundwater sampling. No construction activities would be involved that could adversely impact the ambient water or air quality at the site.
Implementability	
Technical Feasibility	This alternative includes no active remediation components. Periodic groundwater sampling and reporting are easily implemented.
Administrative Feasibility	No additional approvals and permits would be required to implement this alternative.
Availability of Services and Materials	This alternative would include standard sampling methods and equipment. No special equipment or technical specialists would be required during implementation.
Cost	
Capital Cost	$0
O&M Cost	$464,500
Total Cost	**$464,500**

Notes:
CCR = Coal Combustion Residuals
GWPS = Groundwater Protection Standard
LTM = Long-term Monitoring
MNA = Monitored Natural Attenuation
PPE = personal protective equipment

For cost estimating purposes, the following assumptions were made:

- LTM network consists of 6 existing wells (ASH-01, ASH-03, ASH-04, ASH-05, ASH-07, and ASH-08).
- Collection of twelve groundwater samples per year for analyses of Appendix IV constituents and specified MNA parameters (pH, oxidation-reduction potential (ORP), dissolved oxygen (DO), sulfate), for an anticipated MNA period of 10 years. This would be followed by post-remedy, semiannual monitoring period of 3 years for Appendix IV constituents.

8.2 Alternative G-2 PRB and LTM

Alternative G-2 involves the application of a PRB for the remediation of selenium in groundwater downgradient of the Ash Monofill. As groundwater passes through the PRB under natural gradients, dissolved constituents such as selenium would be immobilized through precipitation and/or adsorption to remove them from groundwater. Since selenium is an inorganic constituent and is not subject to degradation, the remediation strategy is to remove it from solution or cause it to become immobile in the subsurface. Once groundwater passes through the PRB, the concentrations of selenium would be attenuated to meet the GWPS. The PRB would be installed downgradient of monitoring wells ASH-03, ASH-04, ASH-05, and ASH-07 to intercept and treat selenium in groundwater. There are no site constraints in this area such as buildings and major overhead and underground utilities that would affect PRB positioning and construction methods.

The PRB would be installed either using continuous trenching equipment or through the use of a series of injection points. The PRB would be designed with appropriate reactive media and an effective residence time in the reactive media to meet CAOs for groundwater remediation. Some potential reactive media, such as ZVI, promote both adsorption and pecipitation of a broad range of constituents, while others, such as hybrid ion exchange resins,can specifically promote one reaction to target a single or narrow range of constituents. A variety of PRB media such as ZVI, limestone and organic carbon is available to remediate selenium contamination in groundwater. A treatability study would be required to determine site-specific effectiveness, appropriate reactive media for the PRB, and operational parameters such as the projected longevity of the PRB. Treatability study is an important consideration in the design process because environmental factors such as pH, ORP and competing ions in the groundwater would affect the ability of various media which may degrade due to clogging and due to reactions with constituents that are not identified as COCs.

Performance monitoring would be conducted using wells located immediately upgradient, cross-gradient and downgradient of the PRB. This monitoring would be used to assess remediation effectiveness, short-circuiting, if any of impacted groundwater flowed around the PRB, changes in media reactivity, and decreases in PRB permeability, etc.

Performance monitoring would be conducted on semi-annual basis for Appendix IV constituents and geochemical parameters (pH, ORP, DO, sulfate, sulfide, total and ferrous iron, total and dissolved organic carbon, and alkalinity) followed by LTM. Monitoring would be performed by sampling groundwater at six existing wells (ASH-01, ASH-03, ASH-04, ASH-05, ASH-07 and ASH-08) and newly installed monitoring wells as required.

An evaluation of Alternative G-2 is presented in **Table 7**.

Table 7. Evaluation of Alternative G-2: PRB and LTM

Effectiveness	
Protective of Human Health and the Environment	Following final closure of Cells 1 and 2A, this alternative involves the installation of a PRB to facilitate precipitation/adsorption to reduce dissolved selenium concentrations in groundwater. Source control would be achieved by closure of Cells 1 and 2A. Source control would prevent further releases of selenium, if any from Cells 1 and 2A to downgradient groundwater. Although Cell 2B is expected to remain active until 2046, the disposal area would be constructed with a composite liner and a leachate collection system that would prevent leaching of CCR constituents from the active portion of the Ash Monofill. Source control combined with a PRB would likely achieve the GWPS for selenium in groundwater within 5 to 10 years. Performance monitoring would be implemented to determine whether the selenium concentrations in groundwater are being reduced at a reasonable rate to meet their respective GWPS within a specified remediation timeframe. There are no short-term human health or environmental concerns during remedy implementation since groundwater is not currently used at the site. Exposure to selenium-impacted in groundwater through ingestion, inhalation, dermal contact or agricultural use is unlikely to occur at the site There are no potential off-site groundwater exposure pathways, human receptors, or known sensitive environmental habitat or species that would

Table 7. Evaluation of Alternative G-2: PRB and LTM

	be adversely impacted by the selenium-impacted groundwater downgradient of the Ash Monofill. Alternative G-2 is protective of human health and the environment.
Effectiveness	
Attain GWPS	This alternative is likely to meet the selenium GWPS of 0.05 mg/L (40 CFR Part 257(h) within a timeframe of 7 years. LTM would be implemented to evaluate whether the PRB is reducing concentrations at a rate to meet the GWPS within a reasonable timeframe, or if remedy optimization or an alternative remedy is warranted.
Control the Source of Release	Source control would be achieved with the final closure of Cells 1 and 2A. In addition, the operation of Cell 2B would include safe disposal practice by employing a composite liner and a leachate collection system to control release of CCR constituents to the underlying groundwater.
Comply with Standards for Management of Wastes	This alternative would include trenching for the PRB installation. This would generate excavated material that would be disposed of at an approved on-site location or off-site facility. Management including disposal of the excavated material would comply with standards specified under 40 CFR 257.98(d).
Long-Term Effectiveness and Permanence	PRB is expected to result in significant reduction of selenium concentrations in groundwater. The PRB would be designed to intercept the entire width of the contaminated groundwater zone. Upon contact with the PRB, selenium in the groundwater would precipitate and/or sorb onto the reactive media of the PRB. The thickness of the PRB would be designed to provide sufficient residence time for precipitation/adsorption processes to occur. The longevity of a typical PRB with ZVI is estimated to be 10 to 20 years. Less information is available for the longevity of other media, which may still be from 5 to 10 years (EPRI 2006). Performance monitoring would be performed to demonstrate the effectiveness of the PRB process over time. Alternative G-2 would provide long-term effectiveness and permanence.
Reduction of Toxicity, Mobility or Volume through Treatment	PRB is expected to reduce the toxicity, mobility, and volume of selenium in the groundwater downgradient of the Ash Monofill.
Short-Term Effectiveness	Implementation of this alternative would include trenching and backfilling with reactive media and routine groundwater sampling. Reactive media such as ZVI, organic matter or other media are relatively safe products to handle in the field. The use of proper PPE and following the Site-Specific HASP is expected to provide adequate protection of workers during implementation of the PRB treatment and long-term groundwater monitoring. Any potential adverse air quality impacts as a result of fugitive dust emissions during PRB installation and transportation of excavated materials that could adversely impact air quality would be addressed by engineering controls, PPE, and following the Site-Specific HASP.

Table 7. Evaluation of Alternative G-2: PRB and LTM

Implementability	
Technical Feasibility	This alternative is implementable. Site conditions and hydrogeology are amenable to PRB construction. PRB technology has been used to successfully remediate metals-impacted sites and significant research and research is ongoing related to the use of reactive media to treat CCR constituents in groundwater. A treatability study would be required to determine site-specific effectiveness and appropriate PRB media for the Ash Monofill. The construction activities required to install a PRB are routine remediation activities and would be implemented easily.
Administrative Feasibility	Implementation of this alternative would require coordination with construction contractors.
Availability of Services and Materials	Vendors and contractors are available to provide reactive media and install a PRB. Availability and scheduling of equipment and supplies is not expected to be an issue.
Cost	
Capital Cost	$2,372,000
O&M Cost	$393,300
Total Cost	**$2,765,300**

Notes:
CCR = Coal Combustion Residuals
CFR = Code of Federal Regulations
GWPS = Groundwater Protection Standard
HASP = Health and Safety Plan
LTM = Long-term Monitoring
PPE = personal protective equipment
PRB = permeable reactive barrier
ZVI = zero valent iron

For the purpose of cost-estimating, the following assumptions were made:

- ZVI and crushed limestone are used as reactive media
- Remediation timeframe of 7 years followed by 3 years of LTM. Semi-annual groundwater analysis would be performed during this 9-year period.
- Monitoring network would consist of 6 existing and 2 newly installed wells.

8.3 Alternative G-3 Hydraulic Containment (via Extraction Wells) and LTM

This alternative would consist of groundwater extraction wells for hydraulic containment, an above ground storage tank and associated piping in combination with LTM. Treatment is not required because of the relatively low selenium concentrations in groundwater. Groundwater extraction would be performed using multiple vertical extraction wells. These wells would be placed along a line perpendicular to the groundwater flow direction at monitoring wells ASH-03, ASH-04 and ASH-05. The extraction network would be designed to provide hydraulic containment of the impacted groundwater, preventing it from migrating further downgradient. Groundwater would be extracted using a submersible pump in each well to form a cone of depression that contains the contaminated groundwater. The wells would be installed to collect selenium impacted groundwater from a depth interval between 20 and 40 ft within the Pierre

Shale. Depending on the aquifer yield, pumping may be performed in a continuous or pulsed manner. The extraction wells would be monitored to determine the extent of mineral precipitation in the extraction system and take corrective action, as necessary. Following extraction, groundwater would be conveyed to an aboveground storage tank prior to disposal at an approved off-site non-hazardous facility or disposed in an on-site retention pond, such as the PRS Ponds for evaporation. The number of extraction wells, spacing,and storage tank capacity would be determined during the design phase.

Performance monitoring would be required to demonstrate hydraulic containment and constituent concentration reduction. Performance monitoring would include semi-annual groundwater elevation measurements and groundwater sampling and analysis for Appendix IV constituents throughout the hydraulic containment period. When two consecutive groundwater monitoring events indicate that groundwater selenium concentrations are at or below its GWPS, the extraction system would be shut-off. Subsequently, post-remediation monitoring would be performed for a period of 3 years to confirm that selenium concentrations do not rebound over time. Upon completion of groundwater remediation, LTM would be performed to meet the post-closure care requirements per 40 CFR 257.104, assuming Ash Monofill Cells 1 and 2A would be CIP. The LTM network would include six existing wells (ASH-01, ASH-03, ASH-04, ASH-05, ASH-07 and ASH-08).

An evaluation of Alternative G-3 is presented in **Table 8**.

Table 8. Evaluation of Alternative G-3: Hydraulic Containment (via Extraction Wells) and LTM

Effectiveness	
Protective of Human Health and the Environment	Following final closure of the Ash Monofill Cells 1 and 2A, this alternative would consist extraction of selenium-impacted groundwater above the GWPS. With removal of groundwater from the aquifer, selenium concentrations in the affected area would be expected to decrease over time. A field pilot test may be performed to predict the number of wells, well spacing and pumping rate. The extracted groundwater would be stored onsite in an aboveground storage tank and disposed at an approved off-site facility or within the PRS Ponds. Source control combined with hydraulic containment is expected to achieve the GWPS for selenium in groundwater in 5 years. This is based on the assumptions that historically released selenium in the underlying groundwater would continue to migrate downgradient. There are no short-term human health or environmental concerns during the remedy implementation period since Pierre Shale groundwater is naturally of poor quality and quantity and is not currently used for domestic or agricultural purposes at the site. Exposure of selenium-impacted groundwater through ingestion, inhalation, dermal contact or agricultural use is unlikely to occur. There are no potential off-site groundwater pathways, human receptors, or no known sensitive environmental habitat or species that would be adversely impacted by the selenium in groundwater at the site. Alternative G-3 is protective of human health and the environment.
Attain GWPS	This alternative is expected to meet the GWPS of 0.05 mg/L (40 CFR Part 257(h) for selenium within a timeframe of 5 years. LTM would be implemented to evaluate whether groundwater extraction reduces selenium concentrations at a reasonable rate to meet the GWPS, or if extraction well network optimization is warranted.
Control the Source of Release	Source control would be achieved with the final closure of Ash Monofill Cells 1 and 2A.

Table 8. Evaluation of Alternative G-3: Hydraulic Containment (via Extraction Wells) and LTM

Effectiveness	
Comply with Standards for Management of Wastes	This alternative would generate selenium-impacted groundwater that would be disposed at an approved off-site facility or within the PRS Ponds for treatment. A chemical precipitation unit could be employed if the final effluent concentration in the above storage tank equals or exceed the GWPS; however, this would require disposal of the chemical precipitate on-site or off-site.
Long-term Effectiveness and Permanence	Hydraulic containment would provide an effective long-term solution to groundwater contamination at the Ash Monofill. Groundwater extraction would reduce the mass and concentrations of selenium. The timeframe for this alternative is expected to be shorter than Alternative G-1. LTM data would be used to demonstrate the remedy effectiveness over time. Alternative G-3 would provide long-term effectiveness and permanence.
Reduction of Toxicity, Mobility or Volume through Treatment	This alternative is expected to reduce the toxicity, mobility, and volume of selenium in the groundwater at the Ash Monofill.
Short-term Effectiveness	Construction of a hydraulic containment system consisting of extraction wells and aboveground storage unit would be completed with standard construction equipment and would entail no additional risks to workers beyond those risks inherent in construction projects. The operation of the groundwater pumping system is not expected to increase the risk to human health or the environment. The extracted groundwater would be disposed of as non-hazardous waste at an approved on-site or off-site facility. The use of proper PPE and following the Site-Specific HASP is expected to provide adequate protection of workers during construction and implementation of this alternative. This alternative would not have adverse air quality impacts or fugitive dust emissions, or generation of hazardous wastes that would adversely affect human health or the environment.
Implementability	
Technical Feasibility	Hydraulic containment is a proven technology for containing and removing metals from groundwater. System operation is generally reliable without major disruptions. The system would have to be designed based on site-specific conditions including stratigraphy, hydraulic conductivity, porosity, aquifer thickness, seasonal water-level variations, groundwater recharge/discharge etc. Hydraulic containment has been used effectively at numerous remediation sites. The construction activities required to install extraction wells, piping and aboveground storage tank are routine remediation activities and would be implemented easily.
Administrative Feasibility	Implementation of this alternative would require coordination with construction contractors. Additional coordination and permits would be required for transportation of impacted groundwater to an off-site non-hazardous waste disposal facility.
Availability of Services and Materials	Construction contractors are readily available to install a hydraulic containment system.
Cost	

Table 8. Evaluation of Alternative G-3: Hydraulic Containment (via Extraction Wells) and LTM

Capital Cost	$ 605,700
O&M Cost	$ 752,000
Total Cost	**$ 1,357,700**

Notes:
CFR = Code of Federal Regulations
GWPS = Groundwater Protection Standard
HASP = Health and Safety Plan
LTM = Long-Term Monitoring
mg/L = milligrams per liter
PPE = personal protective equipment
PRS = phosphorus recovery system
ZVI = zero valent iron

For the purpose of cost-estimating, the following assumptions were made:

- 5 extraction wells downgradient of the Ash Monofill
- Flowrate of 1 gpm per extraction well
- No groundwater treatment is required
- Remediation timeframe of 5 year, followed by semiannual LTM for 3 years
- Semi-annual sampling during the remediation period.

9. References

AECOM, 2019a. Solid Waste Disposal Facility Closure Plan. Platte River Power Authority. Fort Collins, Colorado. August.

AECOM, 2019b. Ash Monofill Annual Groundwater Monitoring and Corrective Action Report for 2018. January 2019.

AECOM, 2018. Ash Monofill Appendix III Alternate Source Demonstration Technical Memorandum. April.

CHEMCO Inc., 2014. Chemical Reduction Processes for In situ Soluble Metals Remediation and Immobilization in Groundwater. 2014 RPIC Federal Contaminated Sites National Workshop. Ottawa.

40 Code of Federal Regulations (CFR) Part 257. 2015. Disposal of Coal Combustion Residuals from Electric Utilities. Federal Register Vol. 80, No. 74. April 17.

Electric Power Research Institute (EPRI), 2006. Groundwater Remediation of Inorganic constituents at Coal Combustion Product Management Sites. October.

EPA, 2007. Monitored Natural Attenuation of Inorganic Contaminants in Groundwater. Technical Basis for Assessment. October.

EPA, 2008. Ground Water Issue. Ford et al. Site Characterization to Support Use of Monitored Natural Attenuation for Remediation of Inorganic Contaminants in Groundwater. November.

Geosyntec Consultants, 2018. Current Overview of Groundwater Remediation Options for CCR Units. March.

Goldermund, H. and J. Ahrens, 2017. Conceptual Groundwater Remedial Alternatives at Coal Combustion Residuals Sites. May.

ITRC. Technical and Regulatory Guidance for In Situ Chemical Oxidation of Contaminated Soil and Groundwater. Second Edition. January 2005

Kleinmann, 2017. Coal Combustion Residuals and Groundwater: It's Complicated. 2017 World of Coal Ash (WOCA) Conference in Lexington, Kentucky. May.

Miller, G.P., 2011. Monitored Natural Attenuation: A Remediation Strategy for Groundwater Impacted by Coal Combustion Product Leachate. May.

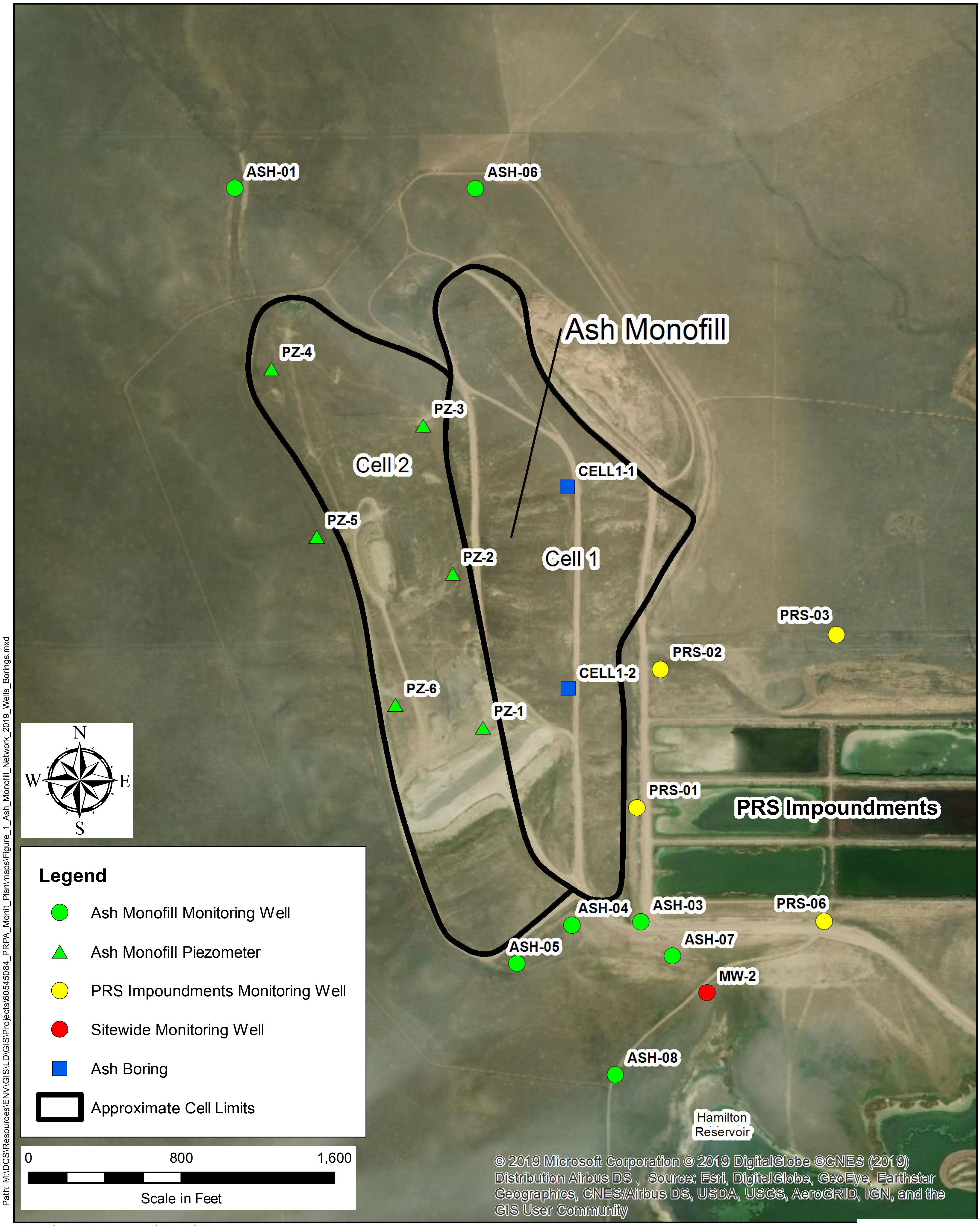
NAVFAC, 2008. Cost and Performance Report for a Zero Valent Iron (ZVI) Treatability Study at Naval Air Station North Island. July.

Schultz, L.G., H. A. Tourtelot, J.R. Gill, and J.G. Boerngen. 1980. Composition and Properties of the Pierre Shale and Equivalent Rocks, Northern Great Plains Region. U.S. Geological Survey Professional Paper 1064-B. 114 pp.

Steven et al., 2017. Selecting the Right Closure Option for your Surface Impoundment or CCR Landfill. 2017 World Coal Ash Conference.

Figures

Figures

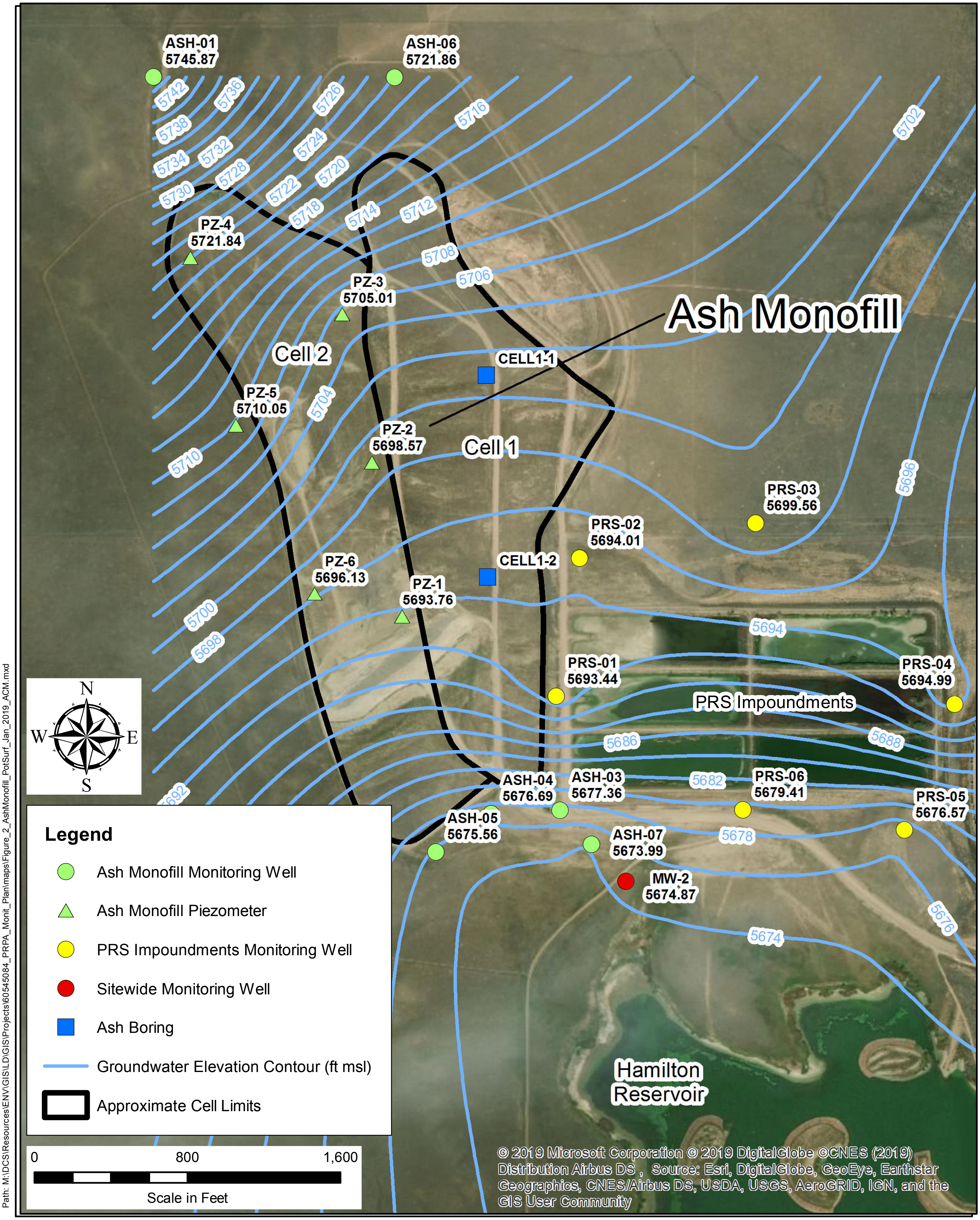


Draft Ash Monofill ACM
Platte River Power Authority Larimer County, CO
Project No.: 60514657 Date: 07-31-2019

Rawhide Energy Station
Ash Monofill
Wells, Piezometers, and Borings

AECOM

Figure 1



Ash Monofill ACM
Platte River Power Authority Larimer County, CO
Project No.: 60514657 Date: 08-07-2019

RAWHIDE ENERGY STATION
ASH MONOFILL
POTENTIOMETRIC SURFACE MAP
JANUARY 17, 2019

AECOM

Figure 2

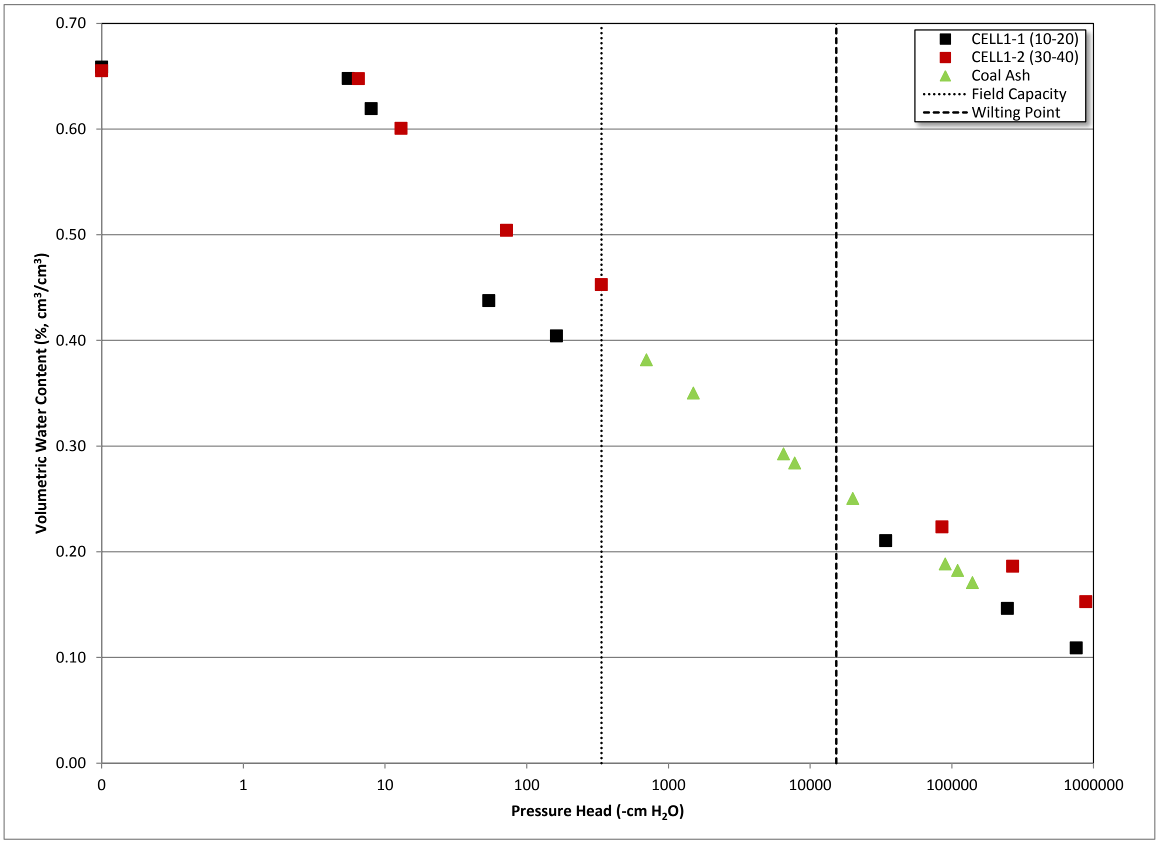


Figure 3. Coal Ash Moisture Characteristic Curves

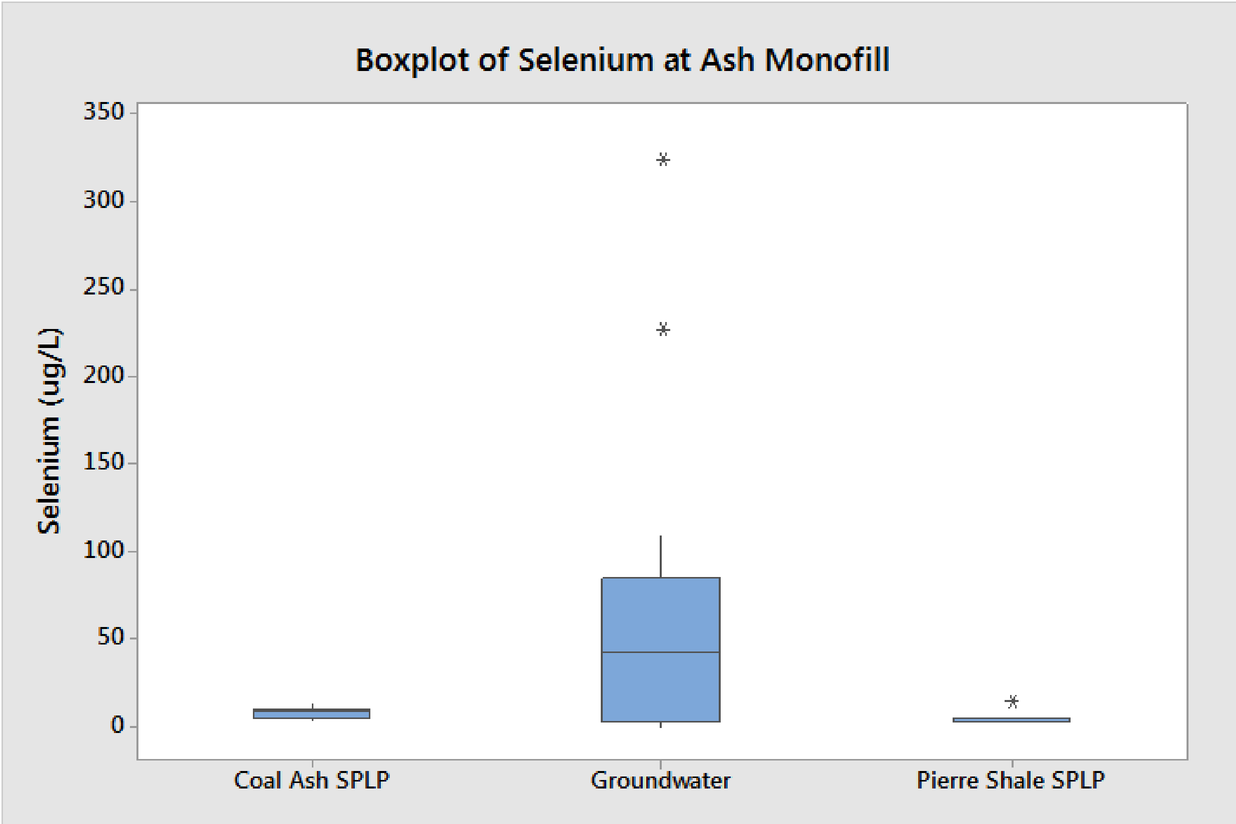


Figure 4. Boxplots of Selenium Concentrations in SPLP Leachates and Groundwater

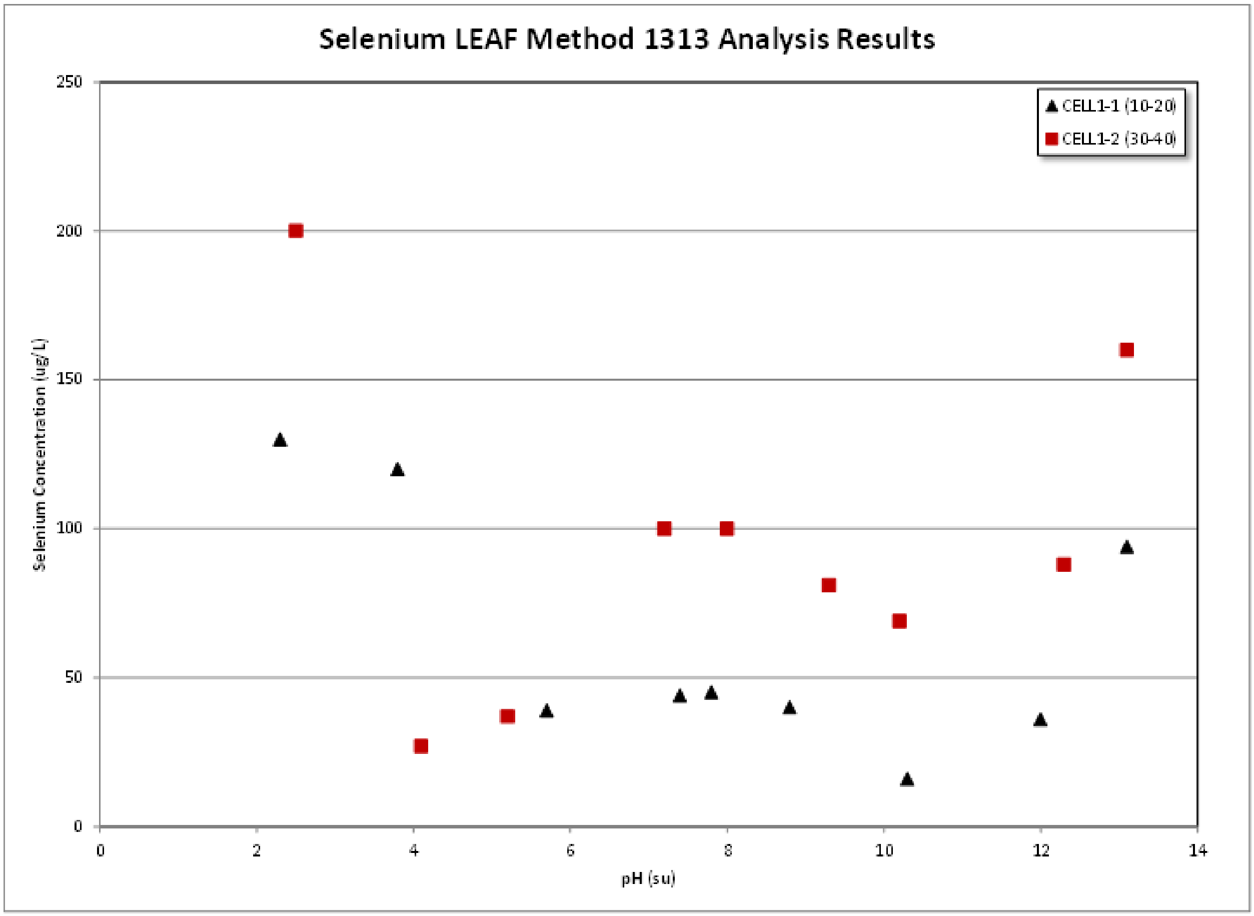


Figure 5. LEAF Method 1313 Results for Selenium in Coal Ash

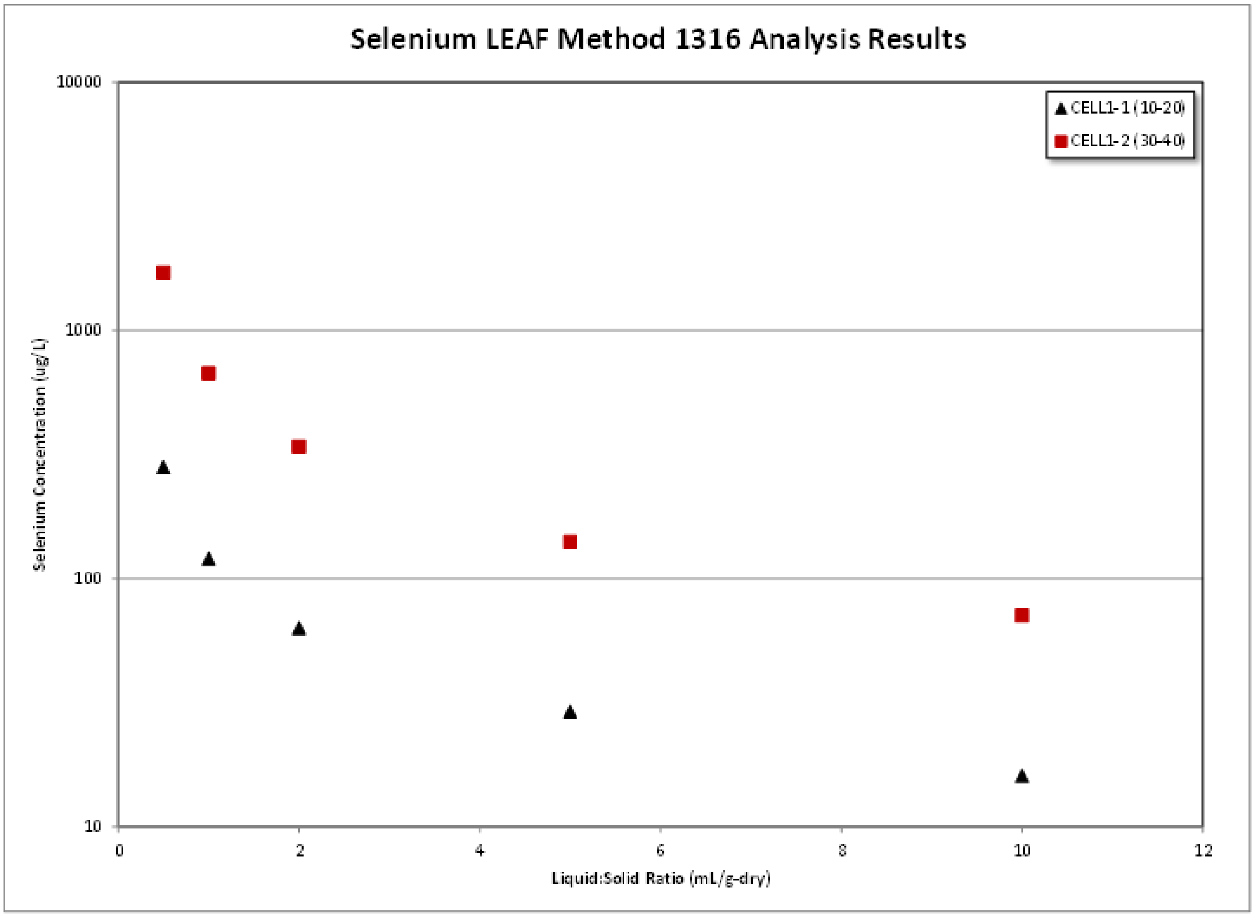


Figure 6. LEAF Method 1316 Results for Selenium in Coal Ash