Assessment of Corrective Measures at the Bottom Ash Transfer (BAT) Impoundments Under the Coal Combustion Residuals (CCR) Rule

Rawhide Power Plant
Larimer County, Colorado
Platte River Power Authority

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Acronyms

AECOM	AECOM Technical Services, Inc.
ACM	Assessment of Corrective Measures
amsl	above mean sea level
BAT	Bottom Ash Transfer
bgs	below ground surface
BNSF	Burlington Northern Santa Fe Railway Company
CAO	Corrective Action Objectives
CCR	Coal Combustion Residuals
CFR	Code of Federal Regulations
Co	Cobalt
DO	dissolved oxygen
ft	feet
ft/d	feet/day
ft bgs	feet below ground surface
ft/ft	feet/foot
GWPS	Groundwater Protection Standard
ISCR	In situ Chemical Reduction
LCL	lower confidence limit
LPL	lower prediction limit
LTM	Long-term Monitoring
ORP	oxidation reduction potential
Pb	Lead
PRPA	Platte River Power Authority
PVC	polyvinyl chloride
QA/QC	quality assurance and quality control
Se	selenium
SPLP	Synthetic Precipitation Leaching Procedure
SSI	statistically significant increase
SSL	statistically significant level
TDS	total dissolved solids

UPL	upper prediction limit
WOCA	World of Coal Ash

1. Introduction

AECOM Technical Services, Inc. (AECOM) was retained by the by Platte River Power Authority (PRPA) under the Master Professional Services Contract dated March 7, 2018 and novated December 10, 2018, Purchase Order (PO) 1800339-7 dated September 19, 2018 and Change Order No. 2 dated April 30, 2019 to complete an Assessment of Corrective Measures (ACM) for localized groundwater contamination at the Bottom Ash Transfer (BAT) Impoundments at the PRPA Rawhide Energy Station in Larimer County, Colorado. This ACM assumes the BAT Impoundments would be clean closed prior to the implementation of a corrective measure for localized cobalt (Co) concentrations in groundwater at monitoring well BAT-05.

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, U.S. Environmental Protection Agency (EPA) guidance documents (EPA 1993; EPA 2000) were used the assessment of corrective measures.

1.1 Report Organization

This report is divided into seven 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 and BAT Impoundments operational history, monitoring well network and sampling results, source, nature and extent of contamination; and a streamlined risk evaluation;
- Section 3.0 presents the corrective action objectives;
- Section 4.0 presents the technology/process options identification and assembly of corrective measure alternatives;
- Section 5.0 presents the detailed evaluation of corrective measure alternatives;
- Section 6.0 presents a comparative analysis of alternatives; and
- Section 7.0 provides a list of references cited in the report

2. Site Description and Background

2.1 Site Description

The Rawhide Energy Station 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 two BAT Impoundments are located northwest of the main plant, south of the coal stockpile, and north of Hamilton Reservoir (**Figure 1**). Bottom ash is produced during the coal combustion process and is hydraulically sluiced from the Unit 1 boiler to one of the BAT impoundments. These impoundments also receive resin filter backwash water from the demineralizer at the wastewater treatment plant. The impoundments were constructed in the early 1980s by excavating overburden into the underlying Pierre Shale and lining the bottom of the excavation with 18 inches of compacted clay. Each of the two impoundments measures approximately 725 feet by 225 feet at the surface (approximately 7.5 acres total) with a bottom elevation of 5,660 feet above mean sea level (amsl), and a top of berm elevation of between 5,678 and 5,679 feet amsl. The normal water elevation in the BAT Impoundments is approximately 5,674 feet amsl.

2.2 BAT Impoundments Hydrogeology

The uppermost water-bearing stratum beneath the BAT Impoundments is identified as the weathered and fractured Pierre Shale, which lies approximately 3 to 17 ft below ground surface (bgs), and appears to be largely recharged by leakage from the BAT Impoundments. Groundwater beneath the BAT Impoundments is present under water table conditions, where the depth to groundwater measured in nearby wells ranged from approximately 4.4 to 15.7 ft bgs in 2018. Groundwater flow is generally from north to south beneath the BAT Impoundments towards Hamilton Reservoir, consistent with the topographic slope. The estimated groundwater flowrate in the uppermost aquifer beneath the BAT Impoundments ranges from approximately 9.33E-6 to 1.54E-2 ft/d and a geometric mean of 1.35E-3 ft/d (AECOM 2019a). This is based on the average hydraulic gradient (0.007 ft/ft) determined between monitoring wells BAT-09 and BAT-06, and a geometric mean hydraulic conductivity (0.029 ft/d) determined from slug tests, and an assumed effective porosity of 15 percent.

The existence of a perennial water table beneath the BAT Impoundments is not known, however a water table is present within the weathered and fractured Pierre Shale at other locations at the Site. Previous reports indicate that little to no groundwater was present in geotechnical boreholes completed in the area of the BAT Impoundments at the time of their construction (Black & Veatch Consulting Engineers, 1979). The BAT Impoundments are constructed on a local topographic high, suggesting that groundwater, if present, likely flowed away from the area of the impoundments prior to construction. The currently observed water table beneath the BAT Impoundments appears to be a perched saturated zone in the underlying weathered and fractured Pierre Shale which is most likely sourced by leakage from the impoundments. The water-bearing interval identified beneath the BAT Impoundments would likely be unsaturated (dry) if the BAT impoundments and Sluice Water Pond were not present.

2.3 Monitoring Well Network and Sampling Results

A groundwater monitoring well system was installed at the BAT Impoundments in 2016 to comply with 40 CFR 257.91(c). The BAT Impoundments network includes one upgradient well, BAT-09, that is used to establish background groundwater constituent concentrations, and seven downgradient wells, BAT-01 through BAT-06, and BAT-08, along the perimeter of the BAT Impoundments. Historical monitoring well BAT-04 was destroyed and was replaced by monitoring well BAT-04R. These monitoring wells were installed in 2016 to comply with the CCR Rule. Monitoring well BAT-09 was selected as an upgradient well based on the regional north to south groundwater flow towards Hamilton Reservoir. The remaining wells were installed because there is a localized radial groundwater flow pattern around the BAT Impoundments. The monitoring well network was subsequently modified in 2018 by the abandonment of monitoring well BAT-07 because of the construction of a new concrete settling tank and the installation of new monitoring wells BAT-10, BAT-11, and BAT-12. BAT-12 was installed to replace monitoring well BAT-07. The groundwater monitoring well network for the BAT Impoundments is shown on **Figure 1**.

Assessment monitoring was initiated at the BAT Impoundments in March 2018. Three rounds of Appendix IV assessment monitoring data were collected in the uppermost aquifer beneath the BAT Impoundments in March, June, and October 2018. Appendix IV constituents include antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, fluoride, lead, lithium, mercury, molybdenum, radium 226/228 combined, selenium, and thallium.

Statistical analyses of the assessment monitoring data identified Appendix IV statistically significant increases (SSIs) over background upper prediction limits (UPLs) for barium (Ba) at monitoring well BAT-08, cobalt (Co) at monitoring wells BAT-03 and BAT-05, lead (Pb) at monitoring well BAT-05, and selenium (Se) at monitoring well BAT-04R. No other Appendix IV constituents exhibited SSIs.

Groundwater protection standards (GWPS) were selected for the BAT Impoundments using the criteria specified in 40 CFR 257.95(h). The GWPS were selected from the U.S. Environmental Protection Agency drinking water Maximum Contaminant Levels (MCLs), groundwater standards provided in 40 CFR 257.95(3)(h)(2), or the background UPLs where they exceed either of the previous standards.

Appendix IV constituents, Ba, Co, Pb, and Se, that exhibited SSIs over background were further evaluated to determine whether they are present at statistically significant levels (SSLs) relative to GWPS. Co at monitoring well BAT-05 was found to exhibit an SSL above its GWPS because its 95 percent lower confidence limit [LCL; 0.067 milligrams per liter (mg/L)] was greater than the GWPS of 0.05 mg/L. Ba, Co, Pb, and Se were not present at an SSL above the GWPS at any of the other wells. The Appendix IV statistical analysis results are summarized in the 2018 Annual Report (AECOM 2019a).

Based on the above findings, Co is the only Appendix IV constituent present at concentrations above the GWPS at the site that requires an assessment of corrective measures per 40 CFR 257.96.

2.4 Source, Nature and Extent of Contamination

The BAT Impoundments are underlain by the weathered and fractured Pierre Shale, an upper Cretaceous marine shale formation. All of the BAT Impoundments monitoring wells are screened in the Pierre Shale. Co concentrations consistently above the GWPS are only found at monitoring well BAT-05. The Pierre Shale appears to be a potential Co source based on the soil and synthetic precipitation leaching procedure (SPLP) sampling results. Marine shales like the Pierre Shale are known to have elevated Ba, Co, Pb, and Se and may be the source of the SSIs. The Pierre Shale, and similar Cretaceous marine shales, are recognized by the U.S. Geological Survey (Schultz et al. 1980) and others (U.S. DOE 2011; Bern and Stogner 2017; Coleman et al. 1993; Gates et al. 2009; and Skinner-Martin and Vance 2002) to have elevated Co concentrations compared to other rocks. Coal is also known to contain elevated Co concentrations compared to its average crustal abundance. Co in both the shales and coal is largely found as trace concentrations in sulfide minerals (e.g., pyrite), and varies in amount spatially and vertically within the shale or coal formations.

An alternate source demonstration (ASD) was performed to assess whether the observed Appendix IV Co SSL above the GWPS at BAT Impoundments monitoring well BAT-05 is from an alternate source. The Co in the Pierre Shale is released to the environment during weathering, resulting from the oxidation of the sulfide minerals and the formation of soluble Co (AECOM 2019b). However, the Pierre Shale was not conclusively identified as the source for the Co at monitoring well BAT-05 because of the limited occurrence of elevated Co concentrations at other wells (also completed in Pierre Shale) around the BAT Impoundments.

Co contamination found at the BAT Impoundments at a SSL above the GWPS is localized and limited to monitoring well BAT-05 which is screened from 23 to 38 feet below ground surface (ft bgs). The Co concentration at the nearest downgradient well, BAT-12, screened from 25 to 40 ft bgs, is less than 0.001 mg/L. BAT-12 is located approximately 250 ft downgradient of BAT-05 confirms that the Co concentration at BAT-05 is localized and of limited extent.

3. Risk Assessment

This section discusses potential risk posed by the constituent of concern, cobalt, considering the human and environmental receptor groundwater exposure pathways present at the BAT Impoundments.

3.1 Constituent of Concern

Co is the only Appendix IV constituent under the CCR Rule that has been detected at a SSL exceeding the GWPS of 0.006 mg/L as defined under 40 CFR 257.95(h) (Federal Register 2018). Therefore, Co has been identified as a constituent of concern (COC) in groundwater. However, it should be noted that the Co detection of 0.0101 mg/L in March 2018 is a localized occurrence limited to one monitoring well (BAT-05) that marginally exceeds the GWPS of 0.006 mg/L. Co was not detected (< 0.001 mg/L) at monitoring well BAT-12, which is hydraulically connected and located approximately 250 ft downgradient from monitoring well BAT-05.

Co at monitoring well BAT-05 is the only Appendix IV SSI found to exhibit an SSL above its GWPS at the BAT Impoundments because its 95 LCL [0.0083 milligrams per liter (mg/L)] was greater than the GWPS of 0.006 mg/L. **Figure 2** shows the Co distribution in groundwater during 2018-2019. A summary of the Co groundwater monitoring data are presented in Table 1 below.

Table 1. Summary of Groundwater Cobalt Concentrations

Monitoring Well (sampled on March, June and October 2018)	Cobalt Concentration Range (mg/L)	Background Concentration (mg/L)	Groundwater Protection Standard (mg/L)	Cleanup Level (mg/L)
BAT-01	0.0015-0.0035	0.003	0.006	0.006
BAT-02	<0.001-0.0021			
BAT-03	0.0031-0.0069			
BAT-04	<0.001			
BAT-05	0.0069-0.0101			
BAT-06	<0.003			
BAT-07	<0.001-0.0018			
BAT-08	<0.001-0.0013			
BAT-09	<0.001			

3.2 Exposure Pathways

Co contamination at monitoring well BAT-05 is present downgradient of the BAT Impoundments in the uppermost Pierre Shale formation at well screen depths of 20 to 40 ft bgs. Depths to groundwater at this well vary from 7.40 to 9.41 feet bgs. The Co contamination marginally exceeds the GWPS at a SSL and appears to be of limited areal occurrence as Co at the nearest downgradient well, BAT-12, is not detected (< 0.001 mg/L). This Co occurrence is likely associated with seepage from the BAT Impoundments or leaching of naturally-occurring Co in the weathered and fractured Pierre Shale.

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 a depth of 20 to 40 ft bgs, therefore incidental construction or excavation activities are not likely to occur at such a depth that would expose groundwater to human or environmental receptors. There are also no known groundwater seepages or discharge to surface water. Therefore, the groundwater exposure pathway is considered incomplete which eliminates any potential exposure risk. Furthermore, the inherent non-volatile nature of metals such as Co eliminates also eliminates the vapor intrusion pathway.

There are also no known contaminated groundwater discharge or seepage to surface water; therefore potential surface water exposure pathway is also eliminated.

4. Corrective Action Objectives

This section presents the corrective action objectives (CAOs) that were developed to address groundwater contamination locally present at monitoring well BAT-05, downgradient of the BAT impoundments. CAOs are the 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 CAOs included constituents and 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 (40 CFR 257.96(b) in accordance with the assessment monitoring program as specified in 40 CFR 257.95. Corrective action objectives 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 groundwater protection standard 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. 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 a the localized occurrence of Co in groundwater at monitoring well BAT-05. 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 3.0** considering screening criteria of effectiveness, implementability, and cost.

5.1 Technology Screening and Identification

Potentially applicable groundwater remediation technologies for this ACM were identified based on site-specific conditions including Co contamination determined to be present locally at monitoring well BAT-05. The ACM 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 Co remediation in groundwater were identified from a multitude of sources based on literature research (Goldermund and Ahrens 2017; and 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);

- In-Situ Chemical Reduction (ISCR);
- 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 5 and 6. Those technologies that were not effective, had implementation concerns, and/or were excessively expensive in comparison to other technologies were rejected from further consideration.

5.2 Description of Applicable Technologies

Groundwater technologies identified in Section 4.1 are described in the following subsection.

5.2.1 Monitored Natural Attenuation

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 Co include a variety of physical and chemical processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in groundwater. Physical attenuation includes dispersion and dilution. Chemical attenuation includes adsorption of contaminants, ion exchange, and precipitation of contaminant-containing 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 long-term monitoring to track contaminant concentrations over time and to determine whether site-specific CAOs identified in remedy decision documents 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 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 collection to characterize site chemistry and hydrology (EPA 2008).

The geochemical behavior of Co generally follows that of the iron-manganese system, and its concentration in sediment is mainly controlled by adsorption and coprecipitation reactions with manganese and iron oxide minerals. Co is typically regarded as being moderately to highly adsorbed by minerals in most terrestrial systems in the absence of organic ligands (CH2M Hill 2002).

MNA is a viable option for this site considering that Co contamination is a localized occurrence limited to the BAT-05 monitoring well area and marginally exceeds the GWPS at a SSL. Natural processes such as adsorption or precipitation are expected to decrease Co concentrations at BAT-05 over time once the BAT Impoundments are closed.

5.2.2 In-Situ Chemical Reduction (ISCR)

The use of ISCR has been successful at many metals-impacted sites, and significant research and testing is ongoing related to the use of ISCR amendments to treat CCR-related metals. ISCR amendments can be utilized to manipulate the valence state of metals or to modify the subsurface geochemical conditions such that the dissolved metals bind and precipitate from groundwater. Typical ISCR amendments include zero-valent iron (ZVI), ferrous sulfide (FeS), calcium polysulfide, and others. ISCR amendments are added to the aquifer by direct-push points or injection wells depending on subsurface conditions. The groundwater geochemistry must be well understood and bench-scale and pilot tests need to be conducted to determine site-specific effectiveness and define operating parameters for dissolved metal precipitation.

5.2.3 Extraction Wells

Groundwater collection using extraction wells are suitable for removing contaminated 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 in a downgradient direction, and/or to provide hydraulic containment. The extraction well flowrates and spacing are based on aquifer hydraulic characteristics. Groundwater is then be pumped through subsurface piping to an aboveground storage tank for disposal or to a centralized treatment system, which would be housed in a building in the vicinity of a CCR unit.

5.2.4 Ex-Situ Groundwater Treatment Technologies

Ex-situ groundwater treatment technologies would be selected to remove the 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 BAT Impoundments because of the low concentration of Co contamination present at monitoring well BAT-05 could not be treated ex-situ cost effectively.

5.2.5 On-site/Off-site Discharge of Groundwater

Discharge technologies involve the disposal of untreated groundwater to an off-site waste facility or treated groundwater into on-site or off-site POTW, discharge into surface water, or re-injection into the aquifer. The discharge of treated groundwater must satisfy effluent limitations.

5.2.6 Long-Term Monitoring

Long-term monitoring 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 determine contaminant migration and track the progress of contaminant reduction, as well as provide an early indication of unforeseen environmental or human health exposure. LTM allows assessment of the remedy protectiveness over time, including an early indication of any changed site conditions if they occur.

5.3 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: Monitored Natural Attenuation and LTM
- Alternative G-2: In-Situ Chemical Reduction and LTM
- Alternative G-3: Hydraulic Containment

6. Detailed Evaluation of Corrective Measure Alternatives

A detailed evaluation of the three alternatives developed in Section 4.0 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, and actual costs of implementation may vary (typically around -30 to +50 percent). The alternative evaluation criteria are broadly categorized under effectiveness, implementability and cost and listed in Table 2 below.

Table 2. 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
O&M Cost
Total Cost

6.1 Alternative G-1 MNA and LTM

This alternative consists of MNA and LTM. Once the BAT Impoundments are closed, Co at monitoring well BAT-05 is expected to decrease in concentration by naturally occurring processes such as adsorption and advection and dispersion. As part of MNA, a LTM network would be established in the vicinity of BAT-05 to document that MNA is reducing Co concentrations over time. LTM would be performed using existing wells which may be supplemented by newly installed wells, as necessary. Groundwater would be monitored for the 20 to 40 ft bgs depth interval because Co is found at this depth. At a minimum, the LTM network would include an upgradient well (BAT-10), the affected well (BAT-05) and a hydraulically downgradient well (BAT-12). Groundwater samples will be collected annually and analyzed for Appendix IV constituents in accordance with the BAT Impoundments Sampling and Analysis Plan (AECOM 2014). The LTM network would be finalized in the design phase and optimized periodically based on LTM data review. The remediation timeframe for MNA to attain GWPS for Co would be determined by statistically-based trend analyses or modeling during design.

If during LTM, the data review indicates Co concentrations in groundwater at BAT-05 are not declining over time or that Co is migrating further downgradient towards BAT-12 at concentrations exceeding the GWPS, a contingency remedy such as ISCR would be triggered. Appropriate corrective action would be implemented until the GWPS for Co is met.

An evaluation of Alternative G-1 is presented in **Table 3**.

Table 3. Evaluation of Alternative G-1 (Monitored Natural Attenuation)

Effectiveness	
Protective of Human Health and the Environment	Following closure of the BAT Impoundments, the low Co concentration at monitoring well BAT-05 is expected to attenuate over time through naturally occurring processes such as adsorption and/or precipitation combined with dilution and/or dispersion. Considering the low Co concentration present at monitoring well BAT-05, natural attenuation is expected to be adequate to achieve the Co GWPS of 0.006 mg/L in a reasonable timeframe. Source control would be achieved by the clean closure of the BAT Impoundments which is addressed separately from this ACM. The closure would consist of removing all liquid and solid waste and waste residual contamination to meet acceptable levels in soil and groundwater. As a result, there would be no potential continuing source of Co leaching into the groundwater that could impede the progress of MNA. Source control resulting from the closure of the impoundments would prevent further releases of Co to groundwater upgradient of monitoring well BAT-05. Groundwater in the Pierre Shale is of limited quality and quantity. Therefore, there are no current or planned future domestic or agricultural uses of the groundwater at the facility. Therefore, exposure of Co-contaminated 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 the Co-contaminated groundwater at monitoring well BAT-05. Alternative G-1 is protective of human health and the environment.
Attain GWPS	Once the BAT Impoundments are closed, MNA is expected to meet the GWPS of 0.006 mg/L (40 CFR Part 257(h) for Co within a reasonable timeframe. As part of MNA, LTM would be conducted to periodically assess Co trends. This would ensure that the remedy in place 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 BAT Impoundments (addressed separately from this ACM).
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 BAT Impoundment closure, dissolved Co in groundwater is expected to be attenuated by natural effects such as adsorption and precipitation into the matrix of soil minerals of the aquifer. LTM data would be used to demonstrate that natural attenuation is in occurrence and that Co 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 Co would occur through treatment.
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

Table 3. Evaluation of Alternative G-1 (Monitored Natural Attenuation)

	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 and could be 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	$30,249
O&M Cost	$182,601
Total Cost	**$212,850**

For cost estimating purposes, the following assumptions were made:

LTM network consists of 3 existing wells (BAT-10, BAT-05 and BAT-12) and 1 newly installed well between BAT-05 and BAT-12.

Collection of four groundwater samples per year for analyses of Appendix IV constituents and specified MNA parameters (pH, oxidation-reduction potential (ORP), dissolved oxygen (DO), sulfate, and boron) for an anticipated MNA period of 2 years. This would be followed by post-remedy, semiannual monitoring period of 3 years for Appendix IV constituents.

6.2 Alternative G-2 In-Situ Chemical Reduction and LTM

Alternative G-2 involves the application of ISCR for the remediation of the localized Co contamination at BAT-05 and LTM. ISCR is an active remedy involving injection of a strong reductant such as zero-valent iron (ZVI) combined with carbon substrate, into the subsurface to generate sulfate-reducing conditions to facilitate precipitation of Co as Co sulfide or Fe-Co sulfide minerals in or adsorption of Co on iron hydroxides formed during the oxidation of ZVI. Field scale ISCR application to treat Co for a site in Ontario, Canada showed a removal efficiency of 85 percent (Chemco 2014). The Co concentration at this field scale application was reduced from an initial value of 260 ppb to 40 ppb within 150 days. A treatability study (bench or field scale) would be required to assess site-specific effectiveness of ISCR for Co at BAT-05. Treatability study data would also define the operating parameters reductant dosage, radius of injection, for full-scale ISCR application at this site if needed. ISCR would be performed by delivery of ISCR amendments at one or more locations using hydraulic fracturing. Injection borings would be installed to the target depths using conventional hollow-stem auger drilling technology. At each injection point, fracturing and injection would be accomplished in the open boring using injection tooling consisting of a nozzle and straddle packer assembly. Three injection points in close proximity to BAT-05 are assumed for this alternative. Performance monitoring would be conducted on a bi-monthly basis for Appendix IV constituents and geochemical parameters (pH, ORP, DO, sulfate, sulfide, total and ferrous iron, total and dissolved organic carbon, and alkalinity) for a period on one year.

LTM would be performed by sampling groundwater at three existing wells (BAT-05, BAT-10 and BAT-12) semiannually and analyzing the samples for Appendix IV constituents to determine when Co meets the GWPS.

An evaluation of Alternative G-2 is presented in **Table 4**.

Table 4. Evaluation of Alternative G-2: In-Situ Chemical Reduction and LTM

Effectiveness	
Protective of Human Health and the Environment	Following closure of the BAT Impoundments, this alternative involves injection of ZVI and carbon substrate to facilitate reductive precipitation and adsorprtion to reduce dissolved Co concentrations in groundwater. Source control would be achieved by closure of the BAT Impoundments which is addressed separately from this ACM. Source control would prevent further releases of Co, if any from this CCR unit to downgradient groundwater including the BAT-05 area. Active remediation such as ISCR combined with source control is expected to achieve the GWPS for Co in groundwater within 6 months. Performance monitoring would be implemented to determine whether the Co concentration in groundwater is being reduced at a reasonable rate to meet the GWPS within a specified remediation timeframe. There are no short-term human health or environmental concerns during the remedy implementation period since groundwater is not currently used at the site. Exposure of Co-contaminated 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 be adversely impacted by the Co-contaminated groundwater at monitoring well BAT-05. Alternative G-2 is protective of human health and the environment.
Attain GWPS	This alternative is expected to meet the GWPS of 0.006 mg/L (40 CFR Part 257(h) for Co within a timeframe of 6 months. LTM would be implemented to evaluate whether ISCR, supported by the induced geochemical conditions is reducing Co concentrations at an expected 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 closure BAT Impoundments (addressed separately from this ACM).
Comply with Standards for Management of Wastes	This alternative would include installation of direct push points or injection wells that would generate minimal investigation-derived wastes.
Long-Term Effectiveness and Permanence	ISCR is expected to result in significant reduction of Co concentrations in groundwater. Under favorable reducing conditions, Co would precipitate out of groundwater as Co or Fe-Co sulfides or sorb to iron hydroxides developed on the ZVI or in the aquifer soil matrix. Once precipitated or sorbed, these compounds are stable even if conditions revert back to a more oxygenated environment (Golemund and Ahrens 2017). LTM data would be used to demonstrate the effectiveness of the ISCR process over time. Alternative G-2 would provide long-term effectiveness and permanence.
Reduction of Toxicity, Mobility or Volume through Treatment	ISCR is expected to reduce the toxicity, mobility, and volume of Co in the groundwater at monitoring well BAT-05.

Table 4. Evaluation of Alternative G-2: In-Situ Chemical Reduction and LTM

Effectiveness	
Short-Term Effectiveness	Implementation of this alternative would include installation of injection wells, injection of ZVI and carbon substrate, and routine groundwater sampling. Both ZVI and carbon substrate 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 ISCR treatment and LTM. This alternative would not have an adverse air quality impact or fugitive dust emissions, or generation of hazardous wastes that would adversely affect human health or the environment.
Implementability	
Technical Feasibility	This alternative is easily implemented. ISCR treatment has been used to successfully remediate metals-impacted sites and significant research and testing is ongoing related to the use of ISCR amendments to treat CCR-related metals. The construction activities required to install injection wells and inject ZVI are routine remediation activities and would be implemented easily.
Administrative Feasibility	Implementation of this alternative would require coordination with state and local agencies to comply with underground injection control (UIC) regulations. Coordination with well drillers who specialize in pressure injection/environmental fracturing would also be required. Coordination would be important for proper storage and handling of chemicals.
Availability of Services and Materials	Vendors and contractors are readily available to supply treatment chemicals and implement the ISCR injection program. Availability and scheduling of equipment and supplies is not expected to be an issue.
Cost	
Capital Cost	$369,915
O&M Cost	$189,897
Total Cost	**$559,812**

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

- ZVI and carbon susbtrate are used as ISCR amendments
- Three injection wells would need to be installed. Approximately 500 lbs of ZVI and carbon substrate would be injected using hydraulic fracturing at each injection well location
- Remediation timeframe of 6 months
- Bi-monthly groundwater samples would be collected during the first month for analysis of Appendix IV constituents and geochemical parameters; thereafter LTM would be performed semiannually for Appendix IV constituents for 4 years.

6.3 Alternative G-3 Hydraulic Containment and LTM

This alternative would consist of groundwater extraction wells for hydraulic containment, above ground storage tank and associated piping in combination with LTM. Treatment is not required because of the low Co concentration in the 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 well BAT-05. The extraction network would be designed to provide hydraulic containment of the impacted groundwater, preventing it from flowing downgradient towards BAT-12. 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 Co-contaminated groundwater from the interval between 20 feet 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 Phosphorus Recovery System (PRS) Ponds for evaporation. The number of extraction wells and spacing, storage tank capacity would be determined during the design phase.

Performance monitoring would be required to demonstrate hydraulic containment and contaminant reduction. Performance monitoring would include quarterly 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 Co concentrations are at or below the Co GWPS, the extraction system would be shut-off. Subsequently, post-remediation monitoring would be performed for a period of 2 years to confirm that Co concentrations do not rebound over time. LTM would be conducted as performance and post-remediation monitoring. The LTM network would include 3 existing wells (BAT-5, BAT-10, and BAT-12).

An evaluation of Alternative G-3 is presented in **Table 5**.

Table 5. Evaluation of Alternative G-3 : Hydraulic Containment and LTM

Effectiveness	
Protective of Human Health and the Environment	Following closure of the BAT Impoundments, this alternative would consist of groundwater extraction in a limited area to remediate the localized Co contamination at BAT-05. With removal of groundwater from the aquifer, Co concentrations in the affected area would be expected to decrease over time. A field pilot test may be performed to predict number of wells, well spacing and pumping rate. Considering the low level of Co contamination present at the site, the GWPS is expected to be achieved in one year. 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. 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 Co-contaminated 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 Co-contaminated groundwater at BAT-05 area. Alternative G-2 is protective of human health and the environment.
Attain GWPS	This alternative is expected to meet the GWPS of 0.006 mg/L (40 CFR Part 257(h) for Co within a timeframe of 1 year. LTM would be implemented to evaluate whether groundwater extraction from the contaminated aquifer is reducing Co 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 implementation of the BAT Impoundments closure (addressed separately from this ACM).

Table 5. Evaluation of Alternative G-3 : Hydraulic Containment and LTM

Effectiveness	
Comply with Standards for Management of Wastes	This alternative would generate Co-contaminated groundwater that would be disposed at an 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 monitoring well BAT-05. Groundwater extraction is an irreversible process that would reduce the mass and concentrations of Co. 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 Co in the groundwater at monitoring well BAT-05.
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 an 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 related to transportation of contaminated 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.

Table 5. Evaluation of Alternative G-3 : Hydraulic Containment and LTM

Cost	
Capital Cost	$524,613
O&M Cost	$190,570
Total Cost	**$715,183**

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

- 3 extraction wells in the BAT-05 area
- Flowrate of 1 gpm per extraction well
- No groundwater treatment is required
- Remediation timeframe of 1 year, followed by semiannual LTM for 2 years
- Quarterly sampling during the remediation period.

7. Comparative Analysis of Alternatives

The three alternatives were compared relative to criteria used in the individual analysis of the alternatives, focusing on the relative advantages and disadvantages of the alternatives. The comparative analysis of alternatives is presented in **Table 6**.

Table 6. Comparative Analysis of Alternatives

Evaluation Criteria	Alternative G-1 MNA and LTM	Alternative G-2 ISCR and LTM	Alternative G-3 Hydraulic Containment and LTM
Effectiveness	**Qualitative Ranking**		
Protective of Human Health and the Environment	Moderate (3)[1]	Moderate (3)	Moderate (3)
Attain GWPS	Moderate (2)	Moderate (2)	Moderate (2)
Control the Source of Release	Not Applicable	Not Applicable	Not Applicable
Comply with Standards for Management of Wastes	High (3)	Moderate (2)	Low (1)
Long-Term Effectiveness and Permanence	Moderate (2)	Moderate (2)	High (3)
Reduction of Toxicity, Mobility or Volume through Treatment	Low (1)	Moderate (2)	Moderate (2)
Short-Term Effectiveness	High (3)	Moderate (2)	Low (1)
Implementability	**Qualitative Ranking**		
Technical Feasibility	High (3)	Moderate (2)	High (3)
Administrative Feasibility	High (3)	High (3)	High (3)

Table 6. Comparative Analysis of Alternatives

Evaluation Criteria	Alternative G-1 MNA and LTM	Alternative G-2 ISCR and LTM	Alternative G-3 Hydraulic Containment and LTM
Availability of Services and Materials	High (3)	High (3)	High (3)
Cost	**Qualitative Ranking**		
Total Cost	High (3)	Moderate (2)	Low (1)
Total Scoring	26	23	22

[1]Number within parenthesis denotes scoring; (1) = least favorable, (2) = moderately favorable and (3) = most favorable.

7.1 Recommended Corrective Action Alternative

All three alternatives would provide adequate protection of human health and the environment. Considering the low concentration of localized Co contamination present at monitoring well BAT-05 with no current of potential future receptors, the effectiveness offered by all three alternatives are comparable. Similarly, all three alternatives would be technically and administratively feasible, and the services and materials necessary to implement these alternatives would be readily available. A pilot scale study would be required to assess site-specific applicability to confirm technical feasibility of ISCR under Alternative G-2.

Based on **Table 6**, Alternative G-1 is the highest scoring alternative for the site. This alternative is particularly suitable to address Co contamination present at relatively low concentrations that marginally exceed the GWPS. Alternative G-1 is the most cost effective of the alternatives because it affords overall effectiveness proportional to its costs. Alternative G-1 has been identified as the recommended alternative.

The success of Alternative G-1 would be iteratively evaluated based on LTM data. If Co concentrations continue to decline and are sufficient to achieve remedy completion in a reasonable timeframe as anticipated, then the remedy would be continued until CAOs are met. Otherwise, the remedial strategy would be re-evaluated and alternative corrective action would be taken, as appropriate.

8. References

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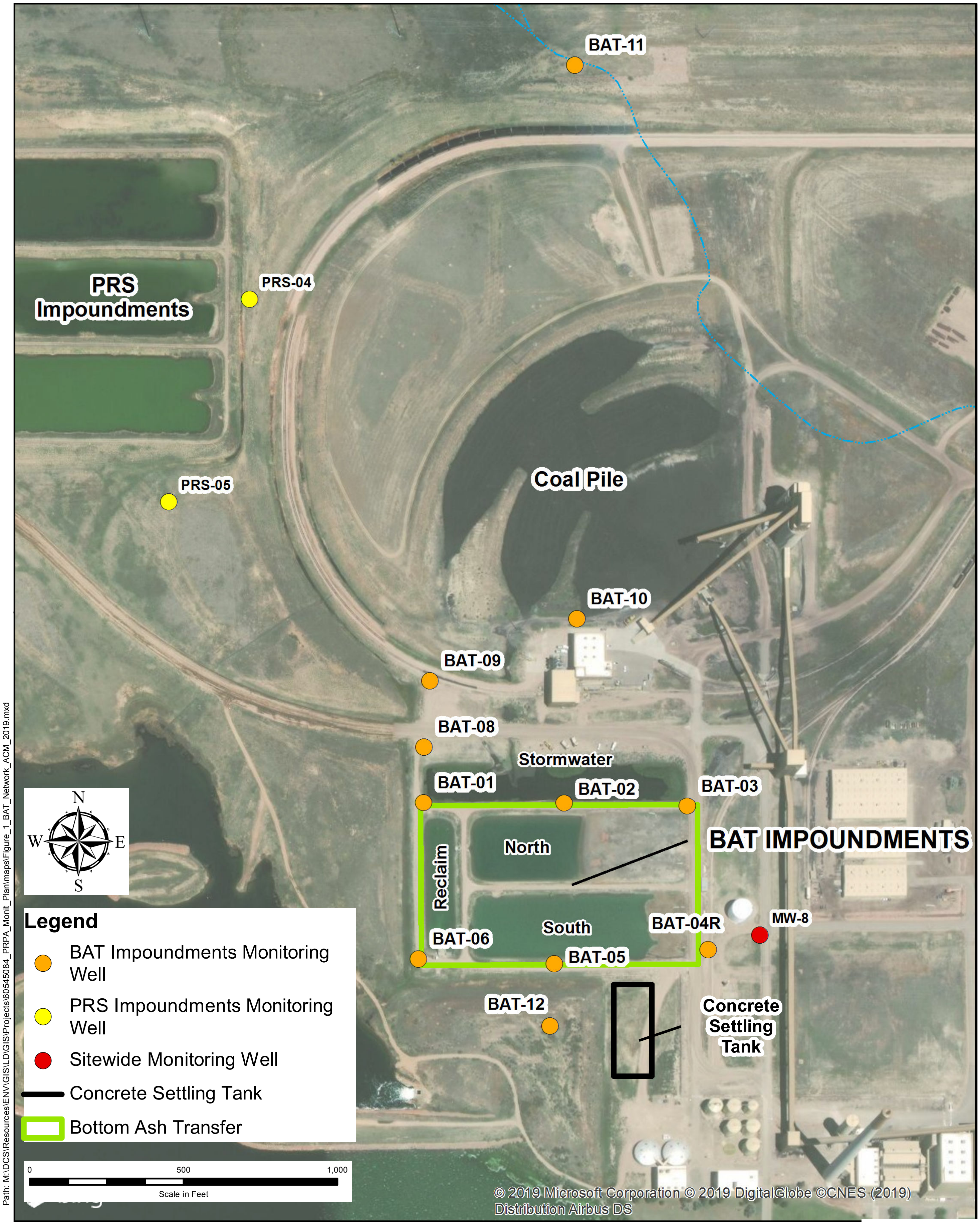
Figures

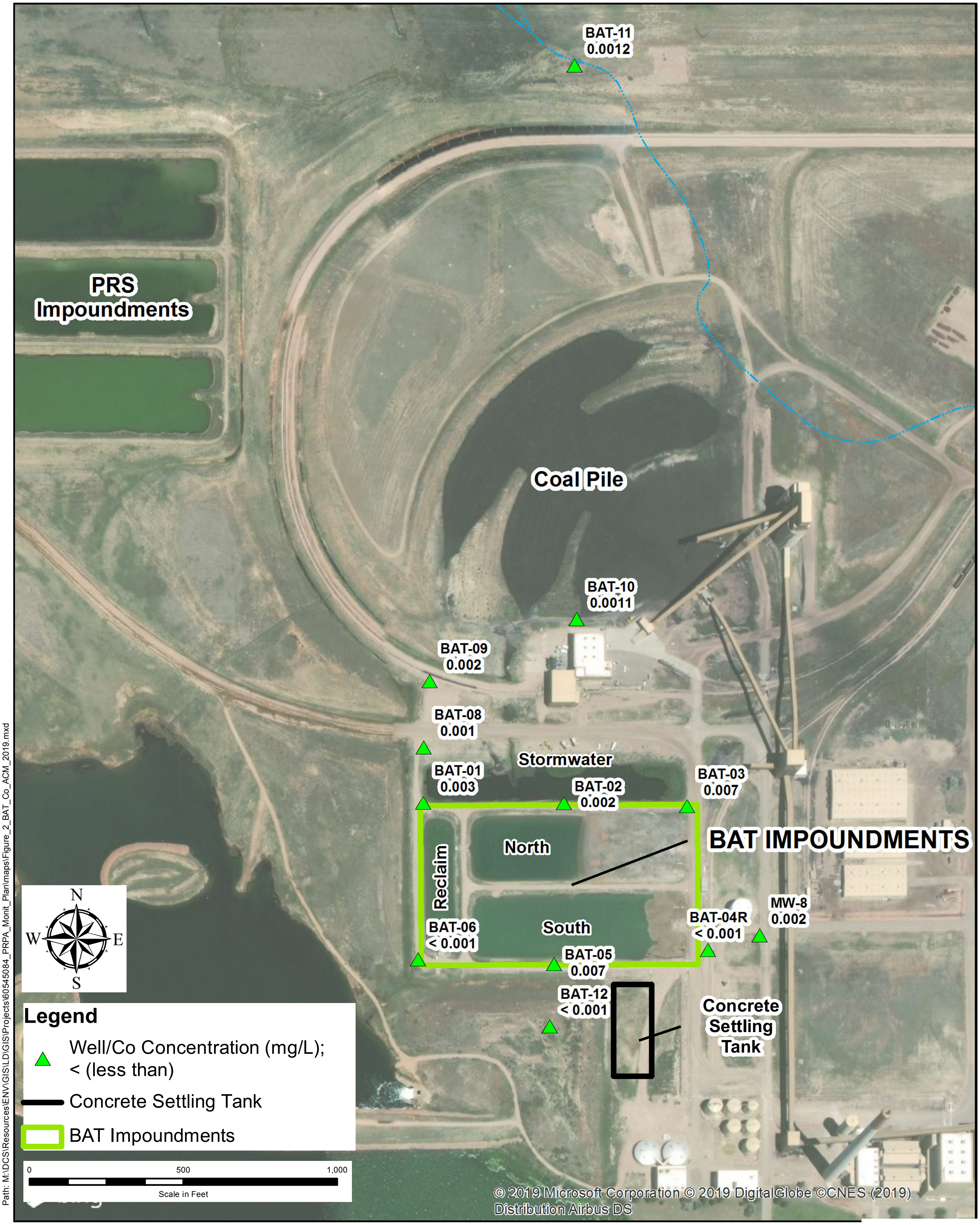


BAT Impoundments Cobalt ACM
Platte River Power Authority Larimer County, CO
Project No.: 60588513 Date: 06-10-2019

Rawhide Energy Station
BAT Impoundments
Monitoring Well Network

AECOM

Figure 1



BAT Impoundments Cobalt ACM
Platte River Power Authority Larimer County, CO
Project No.: 60588513 Date: 06-10-2019

Rawhide Energy Station
BAT Impoundments
Cobalt in Groundwater
2018-2019

AECOM

Figure 2