Pawnee Station Former Inactive CCR Impoundments

Notification of Completion of Assessment of Corrective Measures

Public Service Company of Colorado (PSCo), an Xcel Energy Company, owns and operates Pawnee Station, a coal-fired, steam turbine electric generating station. Two CCR impoundments, the Ash Water Recovery Pond (AWRP) and the Bottom Ash Storage Pond (BASP), were previously used for temporary storage of ash transport water and bottom ash prior to dewatering of the ash and disposal at the onsite CCR landfill. The AWRP and BASP ceased receiving CCR prior to October 19, 2015 and therefore met the definition of Inactive CCR Surface Impoundments that first became subject to the groundwater monitoring requirements under the Direct Final Rule effective October 4, 2016 (Extension Rule). The two impoundments were physically clean closed in 2017 by removal of all CCR.

Protecting the environment is a priority for Xcel Energy

Xcel Energy conducts all of its business in an environmentally responsible manner and that includes regularly monitoring operations and taking steps to protect air, water and other natural resources. Pursuant to 257.95(g), Xcel Energy previously made a determination that one constituent listed in Appendix IV, lithium has been detected at Statistically Significant Levels (SSLs) above the Groundwater Protection Standards (GPS) established for the site pursuant to 257.95(h). These results do not indicate there is any impact on local drinking water. The monitoring wells evaluate groundwater immediately adjacent to the CCR units, and measure groundwater conditions within the Pawnee Station property boundary. Xcel Energy will continue to monitor groundwater at the site in accordance with the assessment monitoring program as specified in 257.95.

Xcel Energy previously initiated an Assessment of Corrective Measures to identify and evaluate potential corrective measures to address this SSL over GPS. The assessment is complete, and the results are presented in the attached document, *Conceptual Site Model and Assessment of Corrective Measures*. The assessment evaluates various potential alternatives to meet the groundwater protection standard for lithium in the downgradient monitoring wells on-site. The physical closure of the two impoundments in 2017 by removal of all CCR was the most significant corrective action that could be taken to mitigate impacts to groundwater. The concentration of lithium has decreased in one downgradient monitoring well since the closure was completed, and further decreases are expected. This may indicate that source removal and monitored natural attenuation may be effective as the remedy.

Conceptual Site Model and Assessment of Corrective Measures

for Compliance with the Coal Combustion Residuals (CCR) Rule

Pawnee Station Ash Water Recovery Pond and Bottom Ash Pond

Public Service Company of Colorado

January 27, 2021

Contents

Appendices

Figures

Tables

Certification

Pawnee Station AWRP and BASP Assessment of Corrective Measures Report

I hereby certify to the best of my knowledge that this assessment of corrective measures for the Pawnee Station AWRP and BASP is an accurate demonstration of the potential corrective measures under consideration for the inactive impoundments and is in compliance with 40 CFR Part 257 of the Federal Coal Combustion Residuals (CCR) Rule.

I am duly licensed Professional Engineer under the laws of the State of Colorado.

Matthew Rohr, PE
Colorado PE License 0053467
License renewal date October 31, 2019

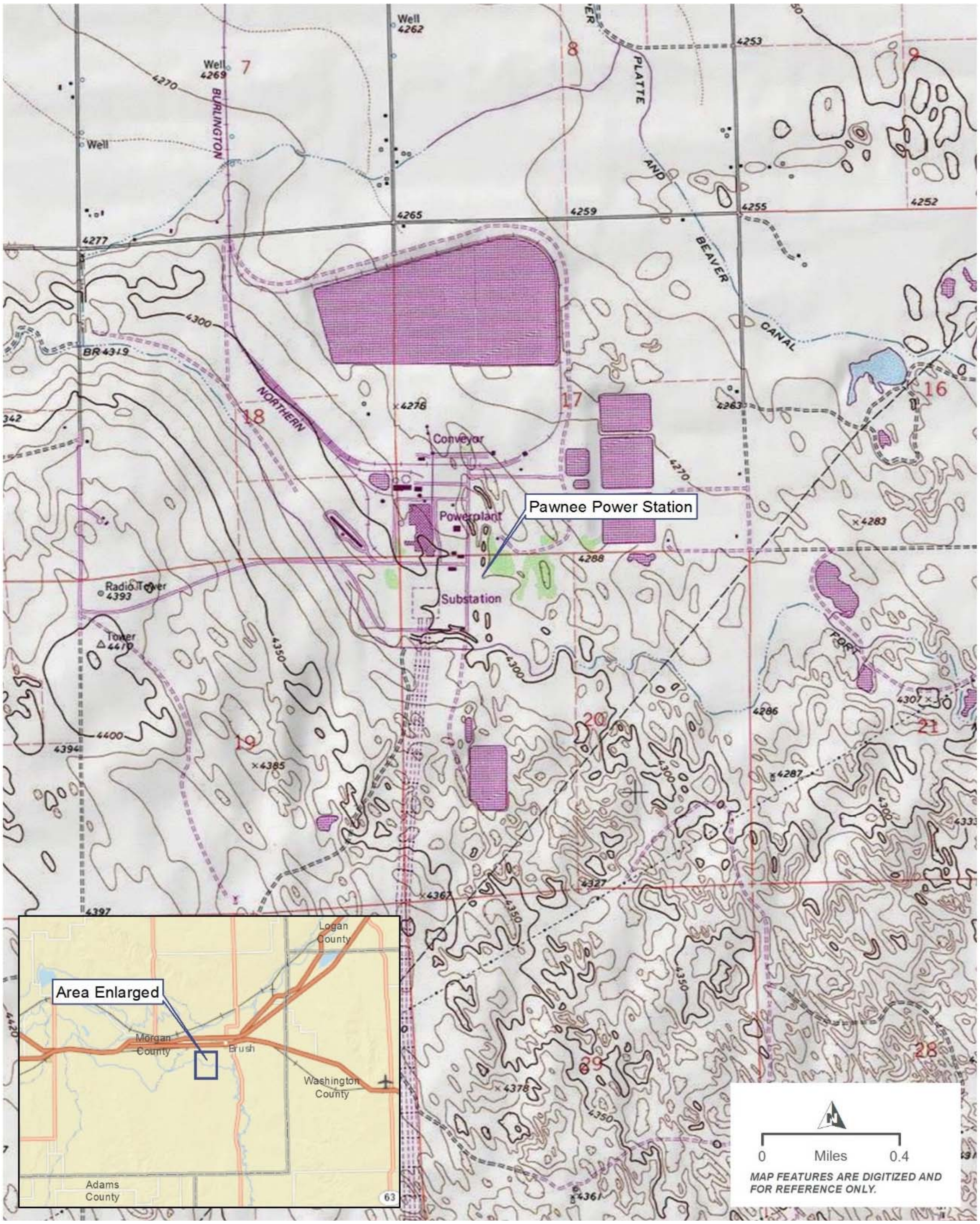
1 Introduction

This assessment of corrective measures was performed for groundwater conditions at the Public Service Company of Colorado (PSCo) Pawnee Generating Station site in Brush, Colorado (Figure 1-1). Two CCR impoundments, Ash Water Recovery Pond (AWRP) and Bottom Ash Storage Pond (BASP), were previously used for temporary storage of ash transport water and bottom ash prior to dewatering of the ash and disposal at the onsite CCR landfill. The AWRP and BASP ceased receiving CCR prior to October 19, 2015 and therefore met the definition of Inactive CCR Surface Impoundments that first became subject to the groundwater monitoring requirements under the Direct Final Rule effective October 4, 2016 (Extension Rule). The two impoundments were physically clean closed in 2017 by removal of all CCR.

The CCR Rule 40 CFR §257.96(a) requires that an owner or operator initiate an assessment of corrective measures (ACM) to prevent further release, to remediate any releases, and to restore impacted areas to original conditions if any Appendix IV constituent has been detected at a statistically significant level exceeding a Groundwater Protection Standard (GPS). This ACM was initiated based on the May 8, 2020 *Groundwater Protection Standards and Determination of SSLs per* §257.95(g), which documented that lithium was present at statistically significant levels above the federal GPS in one or more downgradient monitoring wells at the AWRP and BASP. The purpose of this assessment is to identify and evaluate potential groundwater corrective measures for the AWRP and BASP, showing benefits and limitations associated with each alternative. The corrective measure alternatives were evaluated with the goal of reducing groundwater concentrations of lithium to levels below the GPS developed for the site. The GPS values for each Appendix IV constituent are either the 1) federal Maximum Concentration Limits (MCLs), as established under 40 CFR §141.62 and 141.66; or 2) background concentrations developed in accordance with 40 CFR §257.91, whichever is greater. However, lithium is one of four Appendix IV constituents for which there are no MCL's and for which EPA adopted health-based values in place of MCLs. HDR, Inc. (HDR) has prepared this ACM for the AWRP and BASP, on behalf of PSCo, to evaluate the effectiveness of potential corrective measures in meeting the requirements and objectives of selecting a remedy that is protective of human health and the environment, achieves the GPS, and source control.

PSCo implemented source control when the AWRP and BASP were physically closed by removal of all CCR in 2017 prior to triggering the requirements for assessing corrective measures. Since source removal is complete, this ACM focuses on the evaluation of viable alternatives for meeting the GPS for lithium in the downgradient wells.

Figure 1-1. Pawnee Station Vicinity Map

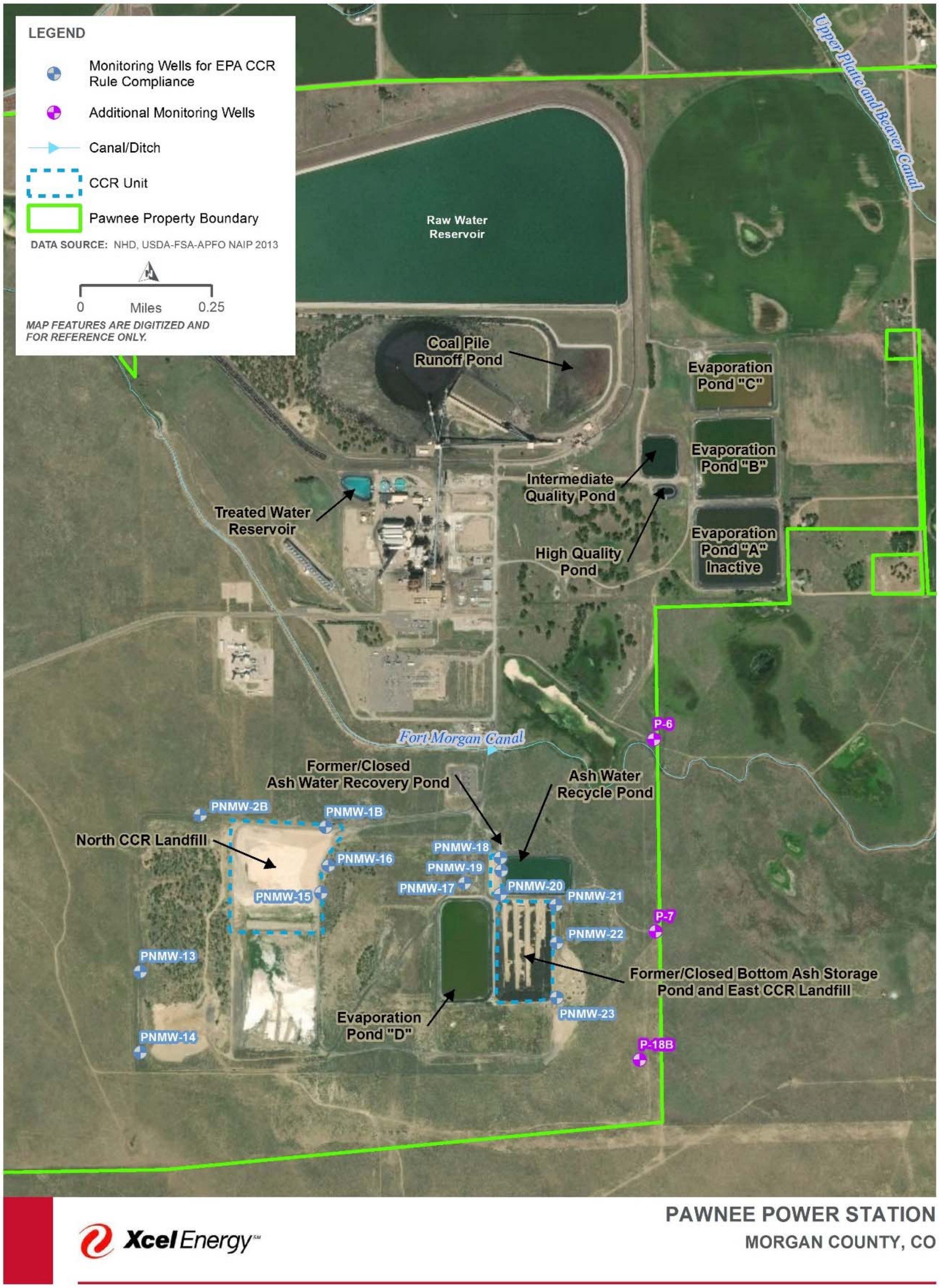


2 Background

The Station previously had two inactive CCR impoundments, the former BASP and former AWRP. Both impoundments were physically closed by removal of CCR prior to March 31, 2017, with ongoing groundwater monitoring under CCR Rule Part 257. A new lined CCR landfill, the East CCR Landfill, was constructed in 2018 in the same footprint of the former BASP, but did not take receipt of CCR until July 2019 (Figure 3.1-1).

In accordance with the CCR Rule, PSCo initiated background groundwater monitoring at the AWRP and BASP, conducted detection monitoring at the landfill in 2019, and has been performing assessment monitoring since 2019. As described in the *Groundwater Protection Standards and Determination of SSLs per 257.95(g)*, downgradient wells at the AWRP and BASP were first found to have concentrations of constituents at statistically significant levels (SSLs) above the GPS in May 2020 (HDR, 2020). Concentrations of lithium have been observed at statistically significant levels (SSLs) above the GPS in one downgradient AWRP monitoring well (PNMW-20) and two downgradient BASP wells (PNMW-21 and PNMW-22). The reduction of hydraulic loading and recharge of the aquifer are expected to have changed groundwater redox conditions (e.g., from aerobic to anaerobic) and the physical removal of CCR is expected to slowly improve groundwater quality.

Figure 3.1-1. Pawnee Station—CCR Units and Certified Monitoring Well Systems



3 Conceptual Site Model

The conceptual site model (CSM) is a description of the groundwater flow system that is representative of the physical processes within the groundwater system site. This section describes each component of the groundwater system.

3.1 Climate

The climate of the station location can be described as semi-arid continental steppe.

Annual total precipitation is 13.34 inches per year in Fort Morgan, which is approximately 7 miles west of the site, with annual mean snowfall of 21.8 inches (Western Regional Climate Center). The wettest month is May, with an average of 2.47 inches of total precipitation. The average maximum temperature is 64.3 degrees Fahrenheit (°F) and the average minimum temperature is 34.9 °F. The warmest month is July with an average high of 90.1 °F and an average low of 60 °F. The coldest month is January with an average high of 39.0 °F and an average low of 10.3 °F. Table 3.1-1 summarized key characteristics.

The groundwater model will use net recharge, which is a combination of rainfall and evaporation as one model variable. Typically, the net recharge is approximately 10% to 50% of rainfall. However, the net recharge variable may be modified to calibrate the model to actual measured monitor well water levels.

Table 3.1-1. Key Climate Characteristics at Pawnee Station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Monthly Average Temperature (Fort Morgan 1896-2018)	24.53	29.55	37.79	47.87	57.67	67.74	74.12	71.76	62.63	50.38	36.78	26.65	48.72
Monthly Average Precipitation (Fort Morgan 1896-2016)	0.25	0.25	0.73	1.49	2.36	1.94	2.07	1.55	1.17	0.83	0.40	0.30	13.34
Monthly Average Pan Evaporation (Inches) (Akron 1918-2005)	0.00	0.00	0.00	7.30	9.29	11.43	13.26	11.16	9.09	6.16	0.00	0.00	67.69

3.2 Surface Water

Two surface water drainages are located in the vicinity of Pawnee Station. The South Platte River is located about 3.5 miles north of the Station and Brush Creek about 3.5 miles to the east. The South Platte River flows east-northeast and Brush Creek flows in a northerly direction, joining the South Platte about 7 miles beyond Brush, Colorado.

One irrigation ditch, Fort Morgan Canal, managed by the Fort Morgan Irrigation Company runs west to east through the Pawnee Station north of the AWRP and south of the plant. The ditch is concrete lined through most of the property, and discharges from the concrete lined ditch to unlined irrigation ditches near the augmentation ponds on the east side of the Station (Figure 2.1-1). Small artificial wetland areas have been created on and immediately east of Pawnee Station by the augmentation ponds, which were created and are operated by the Fort Morgan Irrigation Company. The ponds are downgradient of the AWRP and BASP. The Fort Morgan Canal is used, in part, to fill these ponds, which are consequently used for groundwater recharge. The augmentation pond bottoms are above the water table.

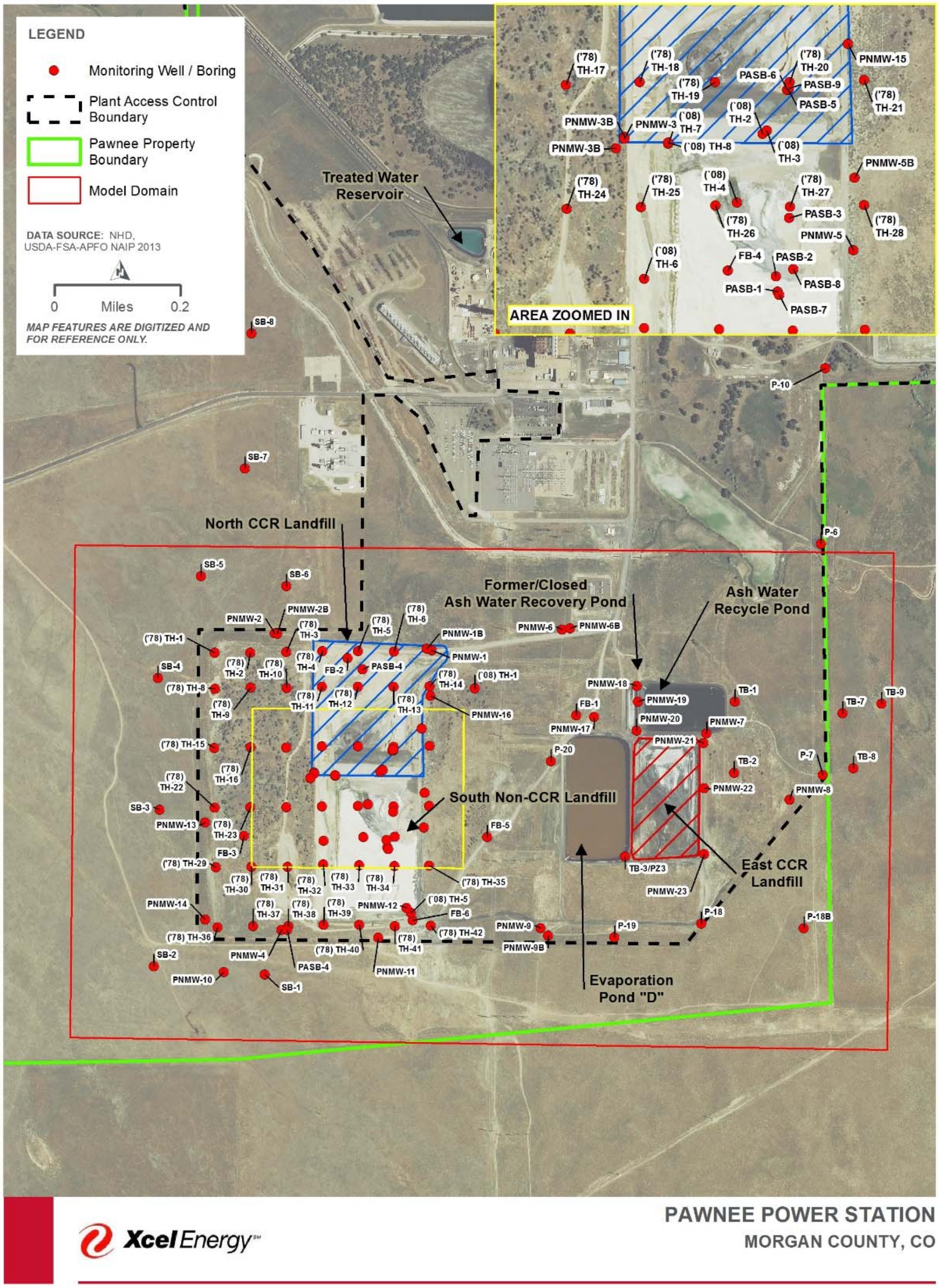
3.3 Geology

Dune sand deposits are present under the entire Pawnee Station, which overlie a fine-grained residual soil and shale bedrock (the Pierre Shale Formation).

- The dune sand deposit is a well-sorted fine sand and ranges from approximately 8 to 70 feet thick from the land surface (Xcel Energy, 2018).
- The fine-grained deposit underlying the dune sand is unconsolidated very fine sand, silt, and clay derived from in-situ weathering of the Pierre Shale and is approximately 8 to 125 feet thick (Xcel Energy, 2018). The thickness of the residual soil is greatest in the northeast portion of the power station. The base of the residual soil is characterized by a transition zone from partially weathered bedrock to the underlying competent bedrock.
- The Pierre Shale bedrock underlies the units described above and consists of shale to sandy shale (claystones and siltstones) and is approximately 4,500 to 5,000 feet thick in this region of Colorado. The depth to the Pierre Shale at the site ranges from approximately 40 to 80 feet in the southern portion of the site to approximately 110 to 140 feet in the northeastern portion of the property (Xcel Energy, 2018).

HDR reviewed available boring logs from geotechnical studies and boring logs from well installations. Figure 3.3-1 provides the map of borings for building the site geologic model. A table of all of the data sources is provided in Appendix A of this document.

Figure 3.3-1. Geotechnical and Monitoring Well Borings Containing Lithologic Data



3.4 Groundwater Flow System

Groundwater flows primarily within the transition zone bedrock located at the base of the residual soil and above the consolidated shale bedrock. Groundwater is recharged from infiltration from above and is confined below by the competent, low conductivity, Pierre Shale bedrock. Dune sands in the area overlay the residual soil and generally do not contain water.

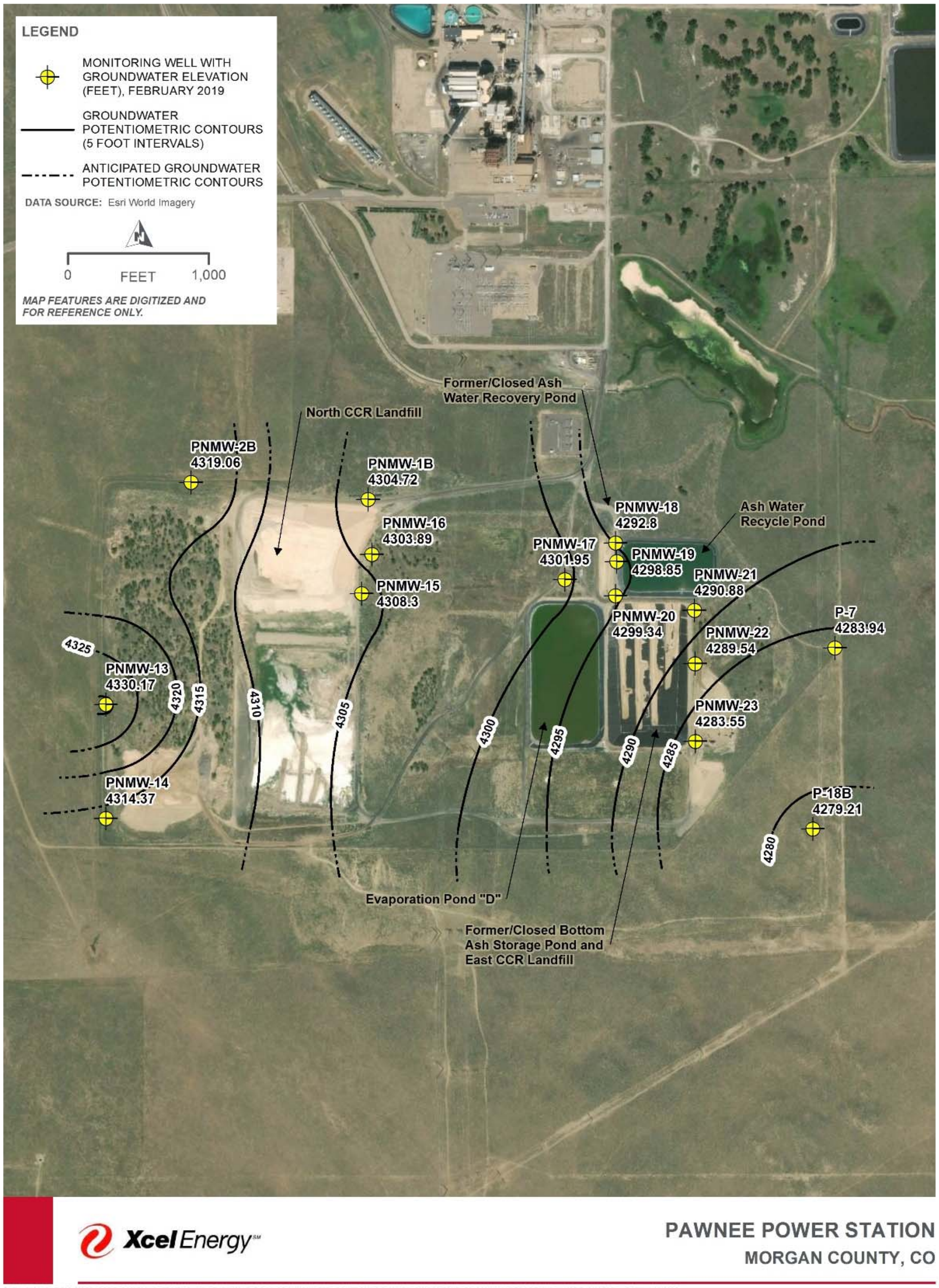
Regional groundwater flow is generally to the east under the AWRP and BASP towards the South Platte River.

Water level data has been collected in monitoring wells across the site over many years. Water level data was collected by HDR in all monitoring wells in February 2019 (Table 3.4-1). Figure 3.5-1 is a potentiometric map of the groundwater surface using wells monitored by HDR in February 2019. This illustrates the flow direction under the AWRP is east and under the BASP is east to southeast.

Table 3.4-1. Water Elevation Data Collected in Monitoring Wells (February 2019)

Well ID	May 2018 (ft amsl)
PNMW-1B	4304.72
PNMW-2B	4319.06
PNMW-13	4330.17
PNMW-14	4314.37
PNMW-15	4308.30
PNMW-16	4303.89
PNMW-17	4301.95
PNMW-18	4292.80
PNMW-19	4298.85
PNMW-20	4299.34
PNMW-21	4290.88
PNMW-22	4289.54
PNMW-23	4283.55
P7	4283.94
P18B	4279.21

Figure 3.4-1. Groundwater potentiometric surface from February 2019



Data from the monitoring wells place the uppermost groundwater in the silty sand (also described as the residual soil) or the weathered bedrock, above the 5,000 foot thick Pierre Shale bedrock. Table 3.4-2 displays all available data for the hydraulic conductivity for geologic units on site.

Table 3.4-2. Hydraulic Conductivity Values for Subsurface Materials

Well I.D.	Depth of Screened Interval (feet below surface)	Screened Interval Lithology	Hydraulic conductivity (ft/day)	Method	Data Source
Two samples from TH-2(08), TH-3(08), and TH-4(08)	Top of Pierre Shale	Pierre Shale Bedrock	$1.5x10^{-4}$-$2.4x10^{-4}$	Lab permeability	URS (2009)
3 test borings in landfill	unk	Weathered Bedrock	$8.5x10^{-4}$ - $1.7x10^{-4}$	Permeability values on six remolded clayey samples	Dames and Moore (1976)
PNMW-1	34-39	Sand	0.132	Single Well Pump Test	EPRI, 2006. Field Evaluation of the Co-management of Utility Low-Volume Wastes With High-Volume Coal Combustion By-Products: PA Site.
PNMW-5	44-49	Weathered Bedrock	0.128		
PNMW-6	51-56	Weathered Bedrock	0.447		
PNMW-7	59-64	Weathered Bedrock	0.341		
PNMW-10	50-60	Sand	0.056		
PNMW-12	20-50	Sand/Silty Sand/Weathered Bedrock	6.78	Slug Test	HDR, 2018. Monitoring Well Installation Report for Compliance with the Coal Combustion Residuals (CCR) Rule – Pawnee Station.
PNMW-13	20−50	Sand	16.72		
PNMW-14	40−70	Sand/Silty Sand	58.39		
PNMW-15	25−55	Weathered Bedrock	2.49		
PNMW-17	5−35	Silt/Weathered Bedrock	1.05		
PNMW-18	20-55	Silty Sand	2.27		
PNMW-19	23-53	Silty Sand/Clay	0.88		
PNMW-20	20-50	Silty Sand/Weathered Bedrock	16.16		
PNMW-21	30−60	Sand/Silt	1.30		
PNMW-22	30−60	Sand/Weathered Bedrock	0.82		
PNMW-23	30−60	Silt/Silty Sand/Weathered Bedrock	0.91		
P-19	39-69	Silty Sand	1.28	Slug Test	HDR, 2017 Analysis
PZ-3	45.6-55.6	Sand/Weathered Bedrock	0.57	Slug Test	HDR, 2017 Analysis

Using the hydraulic conductivity values between 0.056 and 0.447 feet per day (ft/day) and a representative effective porosity of 30%, the groundwater velocities were calculated to range between 1.8 and 6.0 feet per year (ft/yr) to the east.

According to the Colorado Geological Survey, the Pierre Shale formation is not a viable aquifer due to its low yield and poor water quality and is considered a regional semi-confining unit.

3.5 Groundwater Withdrawal

No groundwater withdrawal wells were located within or near the southern portion of the PSCo property.

3.6 Water Quality

Three downgradient monitoring wells were sited at the waste boundary of the AWRP (PNMW-18, PNMW-19, and PNMW-20) and three at the waste boundary of the BASP (PNMW-21, PNMW-22, and PNMW-23) for CCR compliance. One upgradient monitoring well (PNMW-17) is located upgradient of the ponds, and downgradient of the North CCR Landfill, another CCR unit (Figure 3.1-1). The network is described in detail in the Groundwater Monitoring System Certification report (HDR, 2018). As stipulated in the CCR Rule, eight rounds of background groundwater sampling occurred between June 14, 2017 and January 2018 and the initial round of detection monitoring was completed in February 2019. Background values were calculated and described in detail in the *Background Water Quality Statistical Certification* (HDR, 2020). In the June 27, 2019 PSCo memorandum, *Determination of Statistically Significant Increases over Background per 257.93(h)(2)*, concentrations of COIs at downgradient monitoring wells at the AWRP and BASP were compared against background values and COIs were shown to have SSIs over background concentrations. These SSIs triggered the assessment monitoring program for the inactive surface impoundments. As stipulated in CCR Rule 257.95 assessment monitoring was completed in 2019 and GPS were established and documented in *Groundwater Protection Standards and Determination of SSLs per 257.95(g)* (HDR, 2020).

Due to the active status of the North Landfill, the monitoring program for that CCR unit is operated under a separate schedule than the AWRP and BASP, though it is also in Assessment of Corrective Measures status.

4 Constituents of Concern in Groundwater

4.1 Constituents Exceeding the Groundwater Protection Standard

In accordance with CCR Rule 257.95(f), downgradient well concentrations from the assessment monitoring events were compared against GPS and found to exceed GPS. Therefore, following CCR Rule 257.95(g), downgradient well concentrations were compared against GPS to determine "if one or more constituents in Appendix IV to this part are detected at statistically significant levels above the groundwater protection standard." To determine if an exceedance of a GPS was statistically significant, the lower confidence limit (LCL) was calculated for each of the downgradient wells at the SWRP and BASP for each of the detected Appendix IV COIs. Downgradient wells PNMW-20 and PNMW-21 and -22 were found to have concentrations of lithium at statistically significant levels (SSLs) above the GPS. All other detected Appendix IV COIs are below the GPS. Therefore, the constituent that will be evaluated moving forward is lithium (this constituent is referred to herein as the constituent of concern (COC)).

Table 4.1-1 lists the MCL, the BTV, and the GPS for lithium for the SWRP and BASP. Since there is no EPA established MCL for lithium from 40 CFR 141.62, the MCL value is the EPA adopted health-based value for lithium, per the amended rule.

Table 4.1-1. Groundwater Protection Standard for Appendix IV COIs with SSLs above the GPS at the AWRP and BASP 257.95(d)(3)

Constituent	Unit	Maximum Contaminant Level	Background Concentration (UTL)	Groundwater Protection Standard
Lithium	mg/l	0.0400*	0.0451	0.0451

*EPA adopted health-based value in place of MCL.

4.2 Constituents of Concern Source Areas

The former ponds were built in 1980, as part of the original site construction. During active operation, the AWRP was used to recycle ash transport water from the BASP back to the plant. They were constructed with a composite liner system and were inactive since 2005.

As documented in *Groundwater Protection Standards and Determination of SSLs per 257.95(g)*, the wells at the downgradient waste boundary of the North CCR Landfill have exceedances of lithium above the GPS. However the concentration of lithium in PNMW-17, the upgradient well for the AWRP and BASP units does not have exceedances of lithium; the plume of lithium from the North CCR Landfill is estimated to end approximately 1,150 feet downgradient of the North CCR Landfill and 500 feet upgradient of the AWRP and BASP. Therefore, the North CCR Landfill does not appear to be a source of the lithium at the monitoring wells for the AWRP and BASP.

PSCo conducted pond sampling at the AWRP in 2006 and annually between 2009 and 2013. The concentration of total lithium in pond water was 1.42 mg/L in 2006 and from 0.40 to 0.74 mg/L between 2009 and 2013. PSCo conducted pond sampling at the BASP annually between 2000 and 2006 (with the exception of 2005). The concentration of lithium in BASP pond water was 0.40 to 0.70 mg/L between 2000 and 2004 and was 1.42 mg/L in 2006. These concentrations of lithium in pond water relative to background groundwater suggests that the AWRP and BASP were potential sources of groundwater impact.

4.3 Potential Receptors and Exposure Pathways

There is no primary or secondary drinking water standard for lithium. The agricultural water quality standard for lithium in Colorado is 2.5 mg/L. Therefore, the locations where groundwater concentrations of lithium exceed the CCR Rule GPS, all of which are on Pawnee Station property meet agricultural standards for lithium.

The City of Brush obtains its municipal water supply from six wells drilled into the Beaver Creek Alluvium about 3 miles east of the south boundary of the plant site. The Brush Wellfield area is classified for Domestic Use and Agricultural use.

The Fort Morgan Canal is used for delivery of irrigation water to farmers in the region and water is supplied to augmentation ponds operated by the Fort Morgan Canal. The Fort Morgan Canal traverses the plant site from west to east, bisecting the plant property. The Fort Morgan Canal is contained within a concrete culvert across the plant property, except for a short section at each end. There are two augmentation ponds on the Pawnee Station property, one on the northwest side of the property, near where the canal enters the plant site, and one on the east side where the Fort Morgan Canal exits the property. These ponds are used to provide wildlife habitat, and to recharge the groundwater. In addition, more augmentation ponds are located east of the power plant, in close proximity to the plant property and along the canal, out to a distance of approximately two miles. The canal water is obtained from the South Platte River, about 20 miles northwest of the plant (13 miles northwest of Fort Morgan), and shows seasonal water quality variations typical of the South Platte River. The augmentation pond on the east side of the property is downgradient of the AWRP and BASP but recharges groundwater. Therefore, this pond is not a potential receptor for potentially contaminated groundwater from the AWRP or BASP.

4.3.1 Domestic Wells and Springs Distances

There are 98 well permits within 1 mile of the eastern property boundary, 18 of which are domestic well permits (Xcel Energy, 2018). The closest downgradient domestic well (permit number 64719) is located 316 feet east of the eastern property boundary. No wells are located south of the Station within one mile.

5 Corrective Measures Alternatives

Consideration of corrective measure alternatives to address CCR related impacts to groundwater at the impoundments is discussed in this section. The alternatives include the CCR removal that has already been completed, as well as MNA options.

5.1.1 Alternative 1—CCR Source Removal

Description. Closure of the two CCR ponds was complete by March 31, 2017 by removal of CCR. CCR removal was overseen by a Professional Engineer (PE) and confirmation soil samples were collected from the impoundments after CCR removal and analyzed for CCR Rule COIs and statistically evaluated to demonstrate that "…all areas affected by releases of CCR…" were removed. A preliminary report documenting the closure by removal was prepared and certified by the oversight PE. The closure report will be finalized once COC concentrations in groundwater are confirmed to meet the GPS according to the requirements of the CCR Rule. The CCR material has been removed from the former impoundments, and concentrations of CCR constituents are expected to decrease through natural attenuation. All groundwater monitoring at the impoundments since April 2017 reflects post-corrective action.

Considerations. Closure by CCR removal was the most significant corrective action that could be taken to mitigate impacts to groundwater. CCR removal was timely, being completed within six months, and effective, as demonstrated through confirmation sampling.

Additional Data Needs. None.

5.1.2 Alternative 2—Monitored Natural Attenuation

Description. Since the most conservative corrective action remedy, CCR removal has already been implemented and completed, and given the impoundment site characteristics and constraints (limited open ground downgradient of the AWRP and the active East Landfill at the former BASP location), MNA may be the most appropriate additional alternative to address lithium in groundwater. MNA is well accepted as an appropriate mitigation factor that should be considered when evaluating passive and active remedial options (USEPA, 1999, 2007a, b). The USEPA has established a tiered series of steps to determine whether MNA would sufficiently lower concentrations of COIs on an appropriate timescale, and whether there is sufficient system capacity and stability for MNA mechanisms (USEPA, 1999, 2007a, b). Natural attenuation mechanisms include adsorption of COIs, ion exchange, precipitation of COI-containing minerals, and dispersion. Additional details of the MNA alternative are described in Table 5-1.

Considerations Concentrations of lithium are still fairly low at the monitoring wells, and the extent of impacts to groundwater is relatively confined to the area well inside of the project boundary. Additionally, groundwater velocity is relatively slow beneath and surrounding the impoundments due to the very flat gradient and the relatively low conductivity in the subsurface materials. Therefore, it may take considerable time for the lithium to decrease below GPS concentrations, or may even have the potential to remain indefinitely without the presence of a driving hydraulic head to accelerate groundwater movement. However, these same factors may also limit the lateral extent of the exceedances, and concentrations are expected to disperse near the ponds.

The CCR Rule recognizes that "…as part of attaining this (*statistically meet background level or MCL, sic)* standard…contaminants left in the subsoils (i.e., contaminated groundwater left in subsoils below the former landfill or impoundment)…(*that, sic*) will not impact any environmental media…" may remain in place. Given that the bottom of the impoundments were sampled and confirmed to meet soil background levels, the relatively low mobility of the adjacent groundwater, and relatively low lithium concentrations, this may be an acceptable outcome.

Additional Data Needs. None. Assessment monitoring will continue until constituent concentrations are reduced to levels which allow transition back to detection monitoring, and ultimately attainment of GPS for three consecutive years.

5.1.3 Alternative 3—Permeable Reactive Barrier

Description. Form of in-situ groundwater treatment that can be constructed to remove contaminants. Constructed by excavating a trench that penetrates the saturated zone perpendicular to the direction of groundwater flow, which is keyed into an underlying barrier to groundwater movement such as bedrock. The trench is then backfilled with reactive material while maintaining a transmissivity greater than the surrounding subsurface so that groundwater continues to flow through, rather than around the PRB. The reactive material would likely be media that adsorbs or precipitates the lithium to reduce downgradient concentrations. The design of a PRB can involve the use of multiple types of reactive material depending on the target COC. Depending on the COC, multiple types of reactive material may be mixed together to create a single reactive zone or sequentially so that the groundwater passes through several different reactive zones. Example reagents for Pawnee include manganese-oxide, zero valent iron (ZVI), and apatite (phosphate) to precipitate lithium.

A variation of the conventional PRB is a trenchless PRB, which involves the injection of reactive components, in a starch medium that subsequently breaks down, leaving the reactive components behind. The reactive components are injected at the desired depth(s) using a series of wells.

Considerations. The depth to consolidated bedrock is approximately 50 to 60 feet below ground surface, this required depth of trench may limit the feasibility. A trenchless PRB would not have this difficulty. First, a trenchless PRB can be installed to depths greater than that achievable using traditional trenching technologies. A funnel-and-gate system can be used to channel the contaminant plume into a gate that contains the reactive material (Obiri-Nyarko et al., 2014). The funnels are non-permeable (e.g., slurry wall), and the simplest design consists of a single gate with walls extending from both sides. The main advantage of the funnel-and-gate system is that a smaller reactive zone can be used to treat the plume, thereby, potentially reducing costs. This alternative would treat groundwater downgradient of the AWRP and BASP.

Additional Data Needs. Geochemical, bench-scale, and possible pilot-scale testing will be required to evaluate the optimal reactive media composition, PRB lifespan, selection of the most appropriate reagent(s), and to evaluate potential additional contaminant mobilization.

A summary of the corrective measure alternatives for the ash impoundments is presented in Table 5-1.

5.2 Next Steps

PSCo will continue assessment monitoring at the former impoundments to evaluate concentration trends of lithium and to assess if the implemented corrective measures (source removal, combined with MNA) appears to be an effective remedy. It is anticipated that the remedy selection process for addressing affected groundwater will proceed following several semi-annual sampling events that are evaluating if there is a trend in water quality as a result of CCR source removal. The groundwater chemistry from 2020 appears to have decreased concentrations of lithium in PNMW-21 downgradient well; therefore, groundwater chemistry is expected to further improve as a result of the source removal.

The following activities are proposed to be completed in the next 6-month period:

- Continued semiannual groundwater assessment monitoring.
- Continued evaluation of lithium concentration trends.

Table 5-1. Summary of the corrective measure alternatives for the AWRP and BAP.

Alternative	Description	Performance/ Reliability	Additional Data Needs	Relative Ease of Implementation 1 = easy 2 = moderately easy 3 = moderate 4 = moderately difficult 5 = difficult)	Potential Impacts of the Remedy (Safety, cross-media impacts, exposure to residual contamination)	Relative Time Required for Implementation/Remedy 1 = 1-5 yrs 2 = 5-10 yrs 3 = 10-50 yrs 4 = 50-100 yrs 5 = 100+ yrs	Institutional Requirements (Permits or other environmental or public health requirements	Recommended for Further Evaluation
CCR Source Removal	Removal of all CCR and all areas affected by releases of CCR.	• Complete source removal. • Ease of implementation. • Does not address existing COCs in groundwater.	None	2	No additional impacts	1	Approval by State.	Implementation was completed in 2017
Monitored Natural Attenuation (MNA)	Well accepted by state and federal regulators as an appropriate mitigation factor that should be considered when evaluating passive and active remedial options (USEPA, 1999, 2007a, b). Natural attenuation mechanisms include adsorption of COIs, ion exchange, precipitation of COI-containing minerals, and dilution/dispersion. In addition to adsorption to soil, clay particles, and organic matter, iron and manganese oxides that commonly precipitate downgradient of CCR disposal sites will, in turn, remove other COIs by adsorption	**Advantages** • Accepted as a valid remedial approach. COC concentrations in groundwater should decrease over time since the CCR source has been removed. • O&M is limited to performance monitoring and would not require operation or periodic maintenance of engineered systems. • COC concentrations in groundwater are relatively low. • Very slow groundwater flow velocities on site and lack of horizontal or vertical hydraulic head may result in COCs remaining in adjacent groundwater indefinitely.	None	1	Potential for residual contamination	Already occurring/4	Impoundments will continue to be monitored per state regulations. Selected alternative will require approval from the State. May require environmental covenant if residual contamination exists	Yes
Permeable Reactive Barrier (PRB)	A form of in-situ groundwater treatment that can be constructed to remove contaminants. Constructed by excavating a trench that penetrates the saturated zone perpendicular to the direction of groundwater flow, which is keyed into an underlying barrier to groundwater movement such as bedrock. The trench is then backfilled with reactive material while maintaining a transmissivity greater than the surrounding subsurface so that groundwater continues to flow through, rather than around the PRB.	• Remedial alternative that, once installed, will prevent discharge of the COC beyond the barrier. • Has been successfully implemented at other sites nationwide, has not been implemented for lithium. • Depth to consolidated bedrock (approximately 60 feet below ground surface). • Effectiveness and frequency of reactive material recharge unknown without laboratory bench-scale testing. • Conventional PRB design life is commonly based on decades; therefore, ~~if~~ it is anticipated that the COC will be present long term in groundwater upgradient of the PRB.	Geochemical, bench-scale and possible pilot-scale testing to evaluate the optimal reactive media composition, PRB lifespan, select the most appropriate reagent(s), and evaluate potential additional contaminant mobilization. Availability and quantity of material required for the respective application locations will	3-4	Addition of reagents or adjustment of pH/redox conditions may mobilize other contaminants in groundwater.	1-2/3	Selected alternative will require approval from the State.	Yes

Table 5-1. Summary of the corrective measure alternatives for the AWRP and BAP.

Alternative	Description	Performance/ Reliability	Additional Data Needs	Relative Ease of Implementation 1 = easy 2 = moderately easy 3 = moderate 4 = moderately difficult 5 = difficult)	Potential Impacts of the Remedy (Safety, cross-media impacts, exposure to residual contamination)	Relative Time Required for Implementation/Remedy 1 = 1-5 yrs 2 = 5-10 yrs 3 = 10-50 yrs 4 = 50-100 yrs 5 = 100+ yrs	Institutional Requirements (Permits or other environmental or public health requirements	Recommended for Further Evaluation
			drive feasibility.					

6 References

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HDR, 2018b. Groundwater Monitoring System Certification report. December 18, 2018.

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Manger, G.E., 1963. Porosity and Bulk Density of Sedimentary Rocks. Geological Survey Bulletin 1144-E.

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Appendix A.

Boring Data

Geotechnical boring and monitoring well boring lithology data that was used to develop a geologic model for the southern half of the PSCo property boundary.

Boring ID	Source File Name	Citation
PNMW-1 (PAMW-1)	URS Final North Landfill Eval rpt Xcel_Complete.pdf	URS, 2009. Pawnee North Landfill Evaluation, Pawnee Station Brush, Colorado. Prepared for Public Service Company of Colorado (PsCo).
PNMW-2 (PAMW-2)		
PNMW-3 (PAMW-3)		
PNMW-4 (PAMW-4)		
PNMW-5 (PAMW-5)		
PNMW-6 (PAMW-6)		
PNMW-7 (PAMW-7)		
PNMW-8 (PAMW-8)		
PNMW-9 (PAMW-9)		
PNMW-1B	Pawnee North Landfill EDO Plan February 2011 Rev. 2.0 Final.pdf	Xcel Energy, 2010. Pawnee Station North Landfill Engineering Design and Operations Plan. Revised 2011.
PNMW-2B		
PNMW-3B		
PNMW-5B		
PNMW-6B		
PNMW-9B		
PNMW-11		
PNMW-10	Pawnee North Landfill EDO Plan_Revised Feb 2017.pdf	Xcel Energy, 2010. Pawnee Station North Landfill Engineering Design and Operations Plan. Revised 2017.
PNMW-12	Pawnee_DRAFT_CCR Amended Well_Install_Report.pdf	HDR, 2017. Monitoring Well Installation Report: for Compliance with the Coal Combustion Residuals (CCR) Rule. Prepared for Xcel.
PNMW-13		
PNMW-14		
PNMW-15		
PNMW-16		
TB-4/PNMW-21		
TB-5/PNMW-22		
TB-6/PNMW-23		
PNMW-17	Eastern_CCR_LF_Geotechnical_Report_Final.pdf	HDR, 2017. Consolidation, Slope Stability and Liquefaction Analysis, Pawnee Station – East CCR North Landfill. Prepared for Xcel.
TB-3/PZ-3		
PNMW-20	Pawnee_CCR Well_Install_Report_12262018.pdf	HDR, 2016. Monitoring Well Installation Report: For Compliance with the Coal Combustion Residuals (CCR) Rule: Pawnee Station. Revised 2018. Prepared for Xcel.
P-19		
PNMW-18		
PNMW-19		
SB-1	Background Study Field Summary_Pawnee_050217.pdf	HDR, 2017. Pawnee Background Soil Study Results Memo. Prepared for Xcel.
SB-2		
SB-3		
SB-4		

SB-5		
SB-6		
PASB-1	EPRI 1996 Boring Logs.pdf	URS, 2009. Pawnee North Landfill Evaluation, Pawnee Station Brush, Colorado. Prepared for Public Service Company of Colorado (PsCo). (in Appendix 3.4)
PASB-2		
PASB-3		
PASB-4		
PASB-5		
PASB-6		
TH-4	1978 Lincoln Devore Boring Logs.pdf	URS, 2009. Pawnee North Landfill Evaluation, Pawnee Station Brush, Colorado. Prepared for Public Service Company of Colorado (PsCo). (in Appendix 3.4)
TH-5		
TH-6		
TH-11		
TH-12		
TH-13		
TH-15		
TH-16		
TH-18		
TH-25		
TH-26		
TH-27		
TH-28		
TH-32		
TH-33		
TH-34		
TH-41		
FB-1	Dames & Moore Test Boring Logs.pdf	URS, 2009. Pawnee North Landfill Evaluation, Pawnee Station Brush, Colorado. Prepared for Public Service Company of Colorado (PsCo). (in Appendix 3.4)
FB-2		
FB-3		
FB-4		
FB-6		
('08) TH-1	URS Test Hole Logs.pdf	URS, 2009. Pawnee North Landfill Evaluation, Pawnee Station Brush, Colorado. Prepared for Public Service Company of Colorado (PsCo). (in Appendix 3.2)
('08) TH-2		
('08) TH-3		
('08) TH-4		
('08) TH-5		
('08) TH-6		
('08) TH-7		
('08) TH-8		
PAW-N1	Pawnee Boring Logs.pdf	HDR, 2019. Pawnee Landfill Draft Boring Logs.
PAW-N2		
PAW-N3		
PAW-N4		

PAW-S1		
PAW-S2		
PAW-S3		
PAW-S4		