Valmont Station CCR Landfill and Surface Impoundments
Notification of Completion of Assessment of Corrective Measures

Public Service Company of Colorado (PSCo), an Xcel Energy Company, is the owner of Valmont Station which historically was a coal-fired, steam turbine electric generating station and is subject to requirements of the Disposal of Coal Combustion Residuals from Electrical Utilities Rule (Federal CCR Rule), finalized on April 17, 2015. The station was retired from operations on September 30, 2017. During the active coal operations, two incised CCR impoundments (3A and 3B) were used for temporary storage of bottom ash prior to disposal at the onsite CCR landfill. Both CCR impoundments ceased receiving CCR in 2017, and were closed in 2018 by removal of all CCR pursuant to 40 CFR Part 257.102(c) of the CCR Rule. The CCR landfill will continue to be used for disposal of non-CCR waste, and is scheduled to be closed in 2021. A Written Closure Plan has been prepared for the CCR landfill which includes installation of a CCR compliant final cover (HDR, 2017).

Protecting the environment is a core value for Xcel Energy

Xcel Energy conducts all of its business in an environmentally responsible manner which 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 or more constituents listed in Appendix IV have 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, and Xcel Energy will continue to monitor groundwater at the site in accordance with the assessment monitoring program as specified in 257.95.

Xcel Energy also previously initiated an Assessment of Corrective Measures to identify and evaluate potential corrective measures to address these SSLs 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 involved development of a site specific groundwater model for use in predicting the movement of these constituents in groundwater and evaluating the effectiveness of various alternatives to curtail this movement and meet groundwater protection standards. Additional site field work was conducted to obtain data necessary to develop the model, and the model was then validated by comparing model results to observed site conditions. The model has identified additional site data inputs that are necessary to refine the assessment and more accurately evaluate the effectiveness of the identified corrective measure alternatives. Field work to obtain this additional data is being implemented, after which the model and assessment will be updated and additional evaluation conducted, prior to selection of a remedy.

Conceptual Site Model and Assessment of Corrective Measures

for Compliance with the Coal Combustion
Residuals (CCR) Rule

Valmont Station

Public Service Company of Colorado

June 6, 2019

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Certification

Valmont Landfill Assessment of Corrective Measures Report

I hereby certify to the best of my knowledge that this assessment of corrective measures for the Valmont Station Landfill is an accurate demonstration of the potential corrective measures under consideration for the landfill 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 MICHAEL ROHR
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Matthew Rohr, PE
Colorado PE License 0053467
License renewal date October 31, 2019

1 Introduction

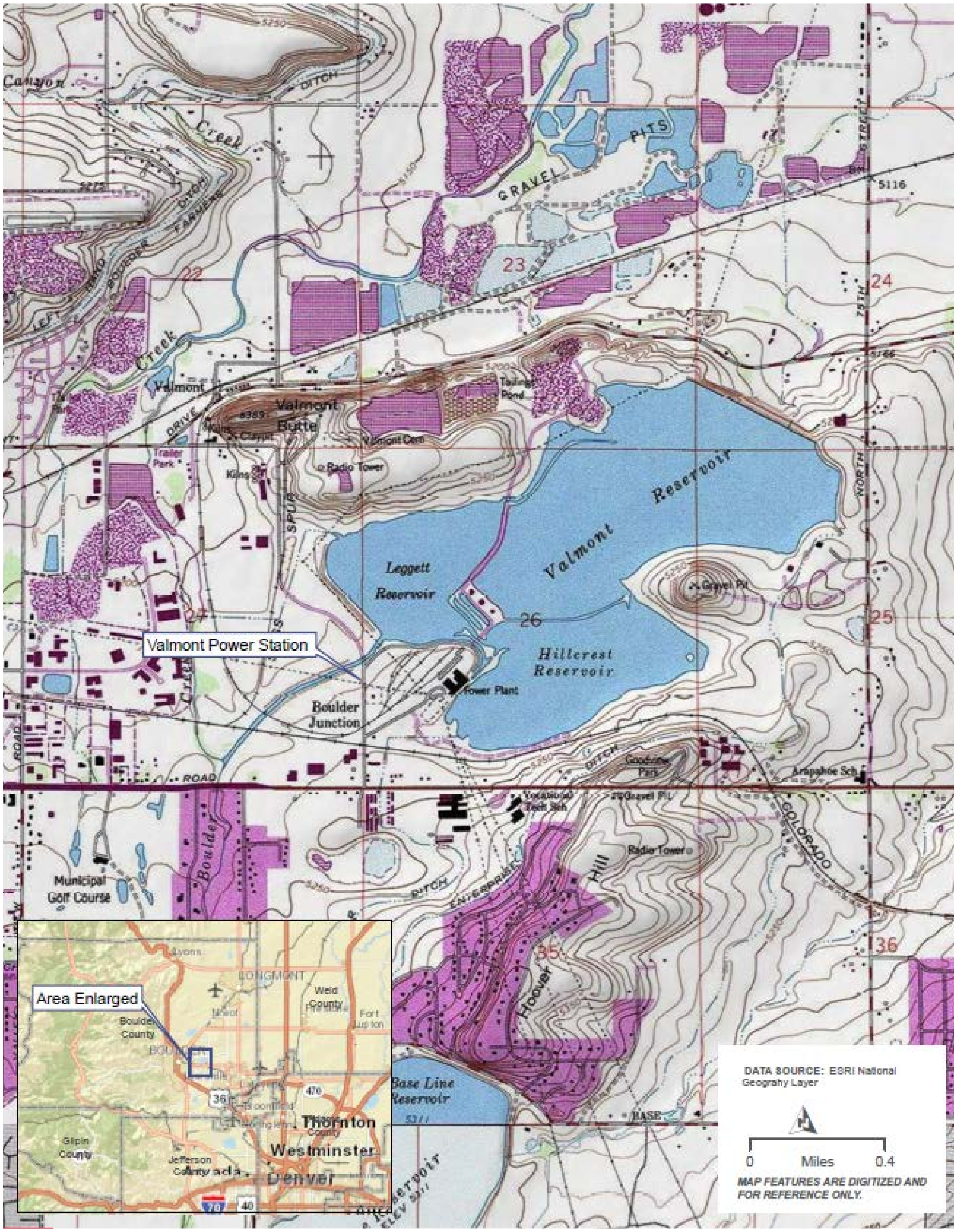
This assessment of corrective measures was performed for groundwater conditions at the Public Service Company of Colorado (PSCo) Valmont Power Plant site in Boulder, Colorado (Figure 1-1). The purpose of the assessment was to identify and evaluate potential groundwater corrective measures for the landfill and former bottom ash impoundments, showing benefits and limitations associated with each alternative. The corrective measure alternatives were evaluated with the goal of reducing groundwater concentrations to levels below the groundwater protection standards (GPS) developed for the site. The GPS values for each constituent of interest 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.

In accordance with 40 CFR §257.96(c), this assessment of corrective measures includes a preliminary analysis of the feasibility of potential corrective measures in meeting all of the requirements and objectives of the remedy as described under § 257.97. Eight potential corrective measure alternatives were evaluated for the landfill and three for the former bottom ash impoundments.

In order to assess the potential effectiveness and time to complete the remedy of each corrective measure alternative for the landfill, HDR developed a numerical groundwater flow and transport model for the landfill. The conceptual site model (CSM) is a narrative description of the hydrologic flow system that forms the basis of the numerical groundwater flow and transport model. This report describes the CSM for the Valmont Station, the model objectives, model construction, additional data collected to fill recognized data gaps, and additional data gaps identified as a result of transport model calibration and preliminary simulations.

The purpose of modeling is to predict the groundwater flow and constituent transport that will occur as a result of different corrective measure alternatives at the landfill. As discussed in Section 6.2, modeling was not necessary for the bottom ash impoundments. The study for the landfill consists of three main activities: development of a calibrated steady-state flow model of current conditions, development of a transport model for constituents identified as constituents of interest (COIs), and preliminary simulation of transport for multiple corrective measure scenarios. These steps were completed; however as described herein, transport model calibration identified data gaps that need to be satisfied before model simulations may be used to further analyze the alternatives and later select the appropriate remedies.

Figure 1-1. Valmont Station Vicinity Map



2 Background

Valmont Station has three CCR units that are the subject of this assessment: the ash landfill and two incised bottom ash impoundments (Figure 2.1-1).

2.1 Landfill

For the landfill, detection monitoring water quality data collected in 2017 were compared against the background threshold values (BTVs) as specified under CCR Rule Part 257.94, and SSIs were identified. Groundwater monitoring was subsequently conducted for assessment monitoring as specified under Part 257.95. In accordance with CCR Rule 257.95(h), GPS were established for each detected Appendix IV COI and documented in the October 10, 2018 memorandum *Groundwater Protection Standards and Determination of SSLs per 257.95(g)*.Downgradient wells were found to have concentrations of arsenic, lithium, and selenium at statistically significant levels (SSLs) above the GPS. PSCo will select, design, and implement a remedy for the landfill based upon the corrective measures assessment herein compliant with 257.96-97.

Operation of the Valmont landfill commenced in the early 1990's in the eastern portion of the landfill in the area now known as Area B-1 (Figure 2.1-2). For approximately the first 5 years of the operation, fly ash and bottom ash both were conveyed from the plant to the ash impoundments as slurry, then excavated and disposed in the landfill. This wet ash was placed in Areas B-1 and C-1, and the eastern portion of Area A-2. The ash disposal areas were prepared by first constructing starter berms by dozing soil and claystone material from the disposal area to create an earth-fill berm, and the ash was then placed behind the berm within the cell.

In 1995, equipment was installed to collect the fly ash dry at the plant, and delivery of slurried fly ash to the impoundments ceased at that time. Bottom ash continued to be conveyed as slurry to the impoundments, and was dewatered prior to excavation and transport to the landfill. The equipment installed at the plant collected fly ash in a silo and moisture conditioned the ash through a pug mill to reduce dust and improve handling and compaction of the ash. Between blading and compaction, each fly ash lift received 10 to 20 passes of the compaction equipment. After compaction, the resulting surface typically hardened due to the cementitious properties of much of the ash.

Figure 2.1-1. Valmont Station—CCR Units and Certified Monitoring Well Network For Each Facility

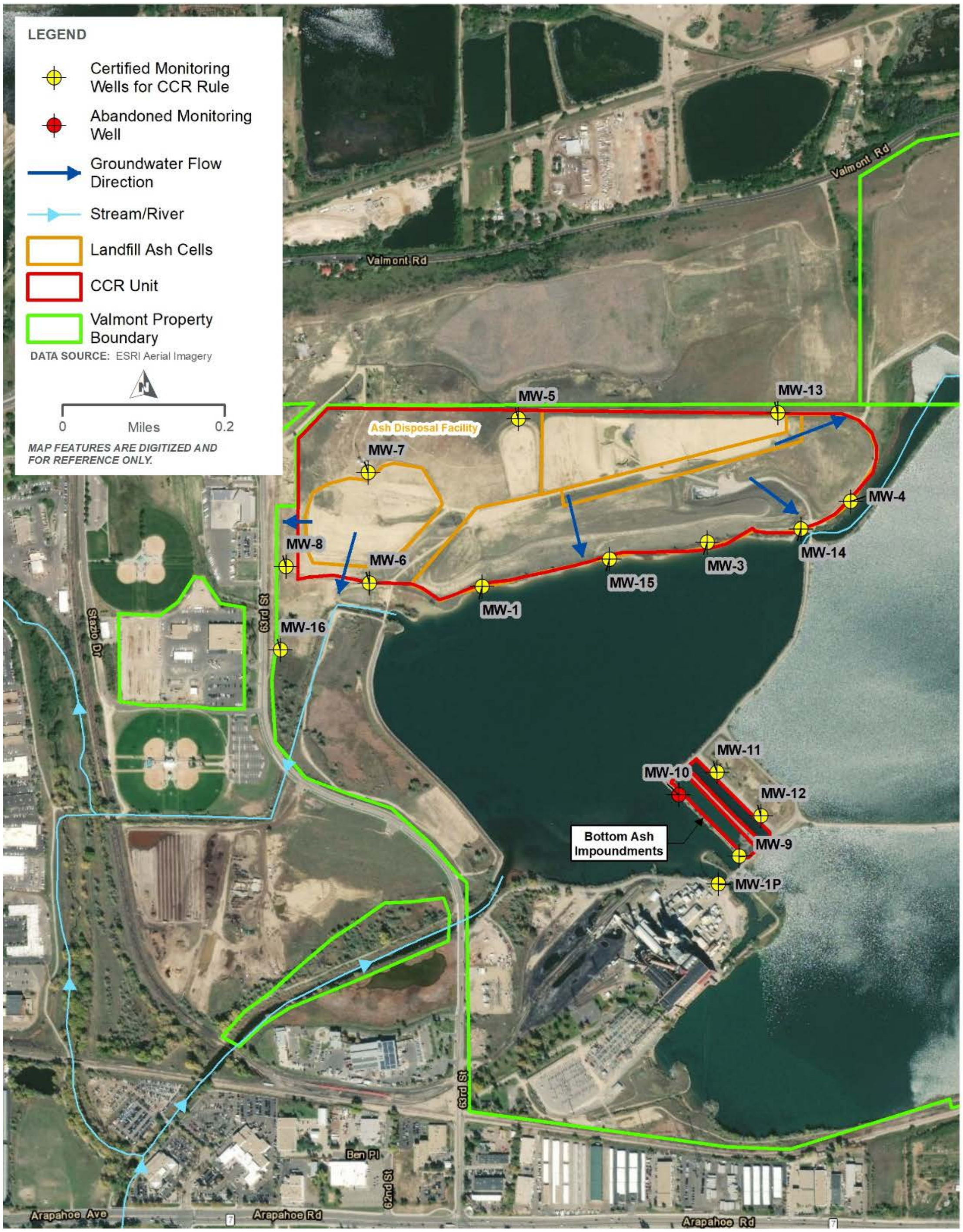
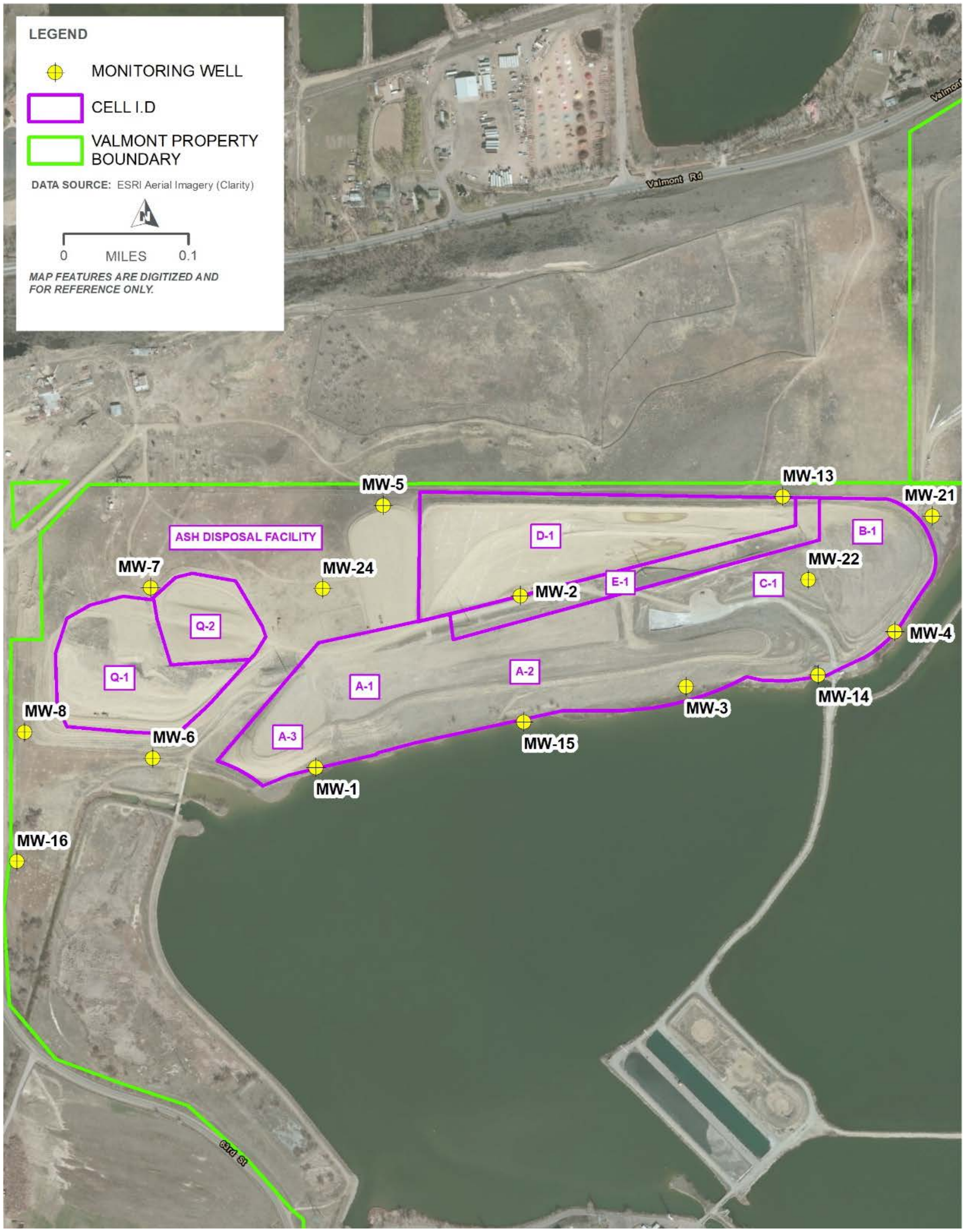


Figure 2.1-2. Valmont Ash Landfill Cell Identification and Monitoring Wells



Throughout the year, most of the material placed on a given day was fly ash. Typically one to two times per year, the bottom ash impoundments were dredged and the bottom ash transported and mixed into the fly ash at the landfill. Since the moisture content of the bottom ash was typically higher than the fly ash, it was blended with the fly ash to improve handling and compaction. Besides the ash materials, zones of compacted soil fill are present throughout the ash fill due to incorporation of daily and intermediate cover materials into the monofill as disposal activities have progressed from one cell to another. Some of the intermediate cover materials consisted of berms separating work areas or cells within the larger placement areas that were then covered by subsequent operations.

2.2 Bottom Ash Impoundments

For the two bottom ash impoundments, detection monitoring water quality data collected in 2017 were compared against the background threshold values (BTVs) as specified under CCR Rule Part 257.94, and SSIs were identified. Groundwater monitoring was subsequently conducted for assessment monitoring as specified under Part 257.95. All Appendix IV constituents were detected in at least one well with the exception of antimony, beryllium, cadmium, chromium, mercury, selenium, and thallium. In accordance with CCR Rule 257.95(h), GPS were established for each detected Appendix IV COI and documented in the October 10, 2018 memorandum *Groundwater Protection Standards and Determination of SSLs per 257.95(g)*. Downgradient wells were found to have concentrations of cobalt and molybdenum at SSLs above the GPS. Closure of the two CCR impoundments was initiated in April 2018 prior to determining that there were any SSLs and the need for development of the Assessment of Corrective Measures. Removal of CCR, and all areas affected by releases of CCR was completed in September 2018, thus effectively implementing corrective action. The CCR material has been completely removed from the former impoundments, and concentrations of CCR constituents are expected to decrease through natural attenuation. All groundwater monitoring at the impoundments since September 2018 reflects post-corrective action conditions.

3 Conceptual Site Model

The CSM is a narrative description of the groundwater flow system that forms the basis of the numerical groundwater flow and transport model. The purpose of the CSM is to identify all relevant hydrogeologic components of the local groundwater system, including all inflows and outflows, in order to later translate this information into a numerical model that is representative of the physical processes within the groundwater system.

In addition to the narrative description and to corroborate the CSM, a three-dimensional (3D) hydrogeologic model of the subsurface underlying the Valmont landfill and the surrounding area was created using geologic interpretations of well boring lithologic logs from monitor wells and geotechnical exploratory borings. The geological model was created in Leapfrog Hydro version 2.5.2 (ARANZ Geo Limited, 2006) and can be directly translated into the numerical groundwater flow and transport model pre- and post-processing software; Groundwater Vistas Version 7, (Environmental Simulations, Inc., 2017).

3.1 Climate

The Valmont Station is situated in a semi-arid climate. Long-term climate data was reviewed in the Site EDOP, but had a period of record through 2000; therefore updated climate records were gathered from the Boulder Station (050848 Coop) from High Plains Regional Climate Center and pan evaporation data was obtained from the Fort Collins Station from the Western Regional Climate Center. 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% 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 Valmont Station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Monthly Average Temperature (Boulder 1893-2018)[1]	32.9	34.8	40.8	48.8	57.4	66.7	72.5	71.1	63.2	52.7	41.6	34.2	51.6
Monthly Average Precipitation (Boulder 1893-2018)[1]	0.61	0.84	1.71	2.65	3.07	1.85	1.79	1.56	1.67	1.49	0.99	0.79	18.99
Monthly Average Pan Evaporation (Inches) (Fort Collins 1900-2005)[2]	0	0	2.5	4.52	5.42	6.32	6.92	6.07	4.74	3.07	1.48	0	41.04

1-High Plains Regional Climate Center; 2-Western Regional Climate Center

3.2 Landfill

The landfill is located along the lower portion of the southern and eastern flanks of the Valmont Butte, a mesa-like feature bound to the north by the east-west trending Valmont Dike, to the east by the Valmont Reservoir and to the south of the Leggett Reservoir as shown on Figure 1-1. Based on a review of historical topographic maps and aerial photographs, the top of the Valmont Butte sloped gently down to the east-northeast and the southern and eastern flanks sloped moderately steeply towards the reservoirs prior to the alteration of native conditions at the landfill site.

The ash landfill was constructed by placing earthen berms at the toe of slopes and between individual units, on the south and east-facing flanks of the Valmont Butte. Areas A-1, A-2, A-3, B-1, C-1, Q-1 and Q-2, have been closed by placement of a soil cover from an on-site borrow area, and have been re-vegetated (Figure 2.1-2). Areas D-1 and E-1 have temporary soil cover in place, as these areas are scheduled to receive additional non-CCR waste. To the north, beyond the site are several vacant buildings and the former in-filled Hendricks Mill tailings pond (Saint Joe Reservoir). Also to the north is a small pioneer era cemetery. To the west are 63rd Street and several commercial buildings. To the south and east, the landfill is bound by the Leggett Reservoir and the Valmont Reservoir, respectively. A concrete spillway for the Leggett Reservoir is located near the southeast corner of Area Q-1; the outlet channel flows to the southwest towards South Boulder Creek. Vegetation at the ADF site generally consists of spares grasses, weeds, yucca and cactus. Several deciduous trees and areas of cattails are present along the northern edge of the Leggett Reservoir.

The following sub-sections detail the components of the CSM specific to the landfill.

3.2.1 Topography

The geological model created in Leapfrog Hydro, and thus the groundwater flow and transport model, requires a digital elevation model (DEM) file (or similar) to reflect the top boundary of the model. A topographic surface from late 2017 was acquired from Merrick & Company and was augmented with 2018 data from drone topographic surveys by Great Lakes Environmental & Infrastructure to create a combined topographic surface. Additionally, a portion of the groundwater modeling area, to the south and west, not included in the combined topographic surface was augmented with a 2013 publicly available DEM, as these areas are less important to the modeling effort and minor discrepancies are within tolerable limits. Once the combined topographic surface was completed, it was verified with the surveyed ground surface elevations at the onsite monitor wells. The surveyed elevations matched within tolerance to be suitable for the geological and groundwater flow and transport model surface elevation.

3.2.2 Geology

As discussed above, the Valmont ash landfill is located on the southern and eastern flanks of the Valmont Butte. The butte surface consists of a thin alluvial deposit of Slocum Alluvium and the side slopes are covered with colluvial deposits similar to the Slocum. The first bedrock encountered at the site is the Pierre Shale, a 2,000 foot thick low permeability claystone. Native colluvium is present on the undisturbed slopes adjacent to the landfill. Native pediment deposits, the Slocum Alluvium, are present on the gently-easterly sloping top of the butte, north of the landfill footprint. Approximately 2 to 10 feet of Slocum Alluvium were observed at the landfill above claystone bedrock of the Pierre Shale. Descriptions of the ash and soil fill and bedrock materials are presented below:

Ash Fill and Soil Layers: The landfill is a waste monofill. The ash has been observed to take on cementitious characteristics during compaction resulting in a very low permeability layer. The monofill contains varying mixtures of fly ash and bottom ash with intervening layers of intermediate and daily cover soil borrowed from on-site. Site borrow soil was also used for final cover in units that have been closed, and to construct the berms at the toe of slopes and between individual units. Site soil borrow areas were excavated into both colluvial and bedrock materials. Borrow material obtained from shallow excavations into colluvium and weathered claystone of the Pierre Shale formation is typically friable and readily slakes such that the process of excavation, handling, placement and compaction results in a soil-like layer. The claystone bedrock-derived material also typically had characteristics of a soil material, although some bedrock fragments up to about 1 foot in size were present.

Slocum Alluvium: The Pleistocene-age Slocum Alluvium generally consists of gravels, cobbles and occasional boulders in a silty to clayey sand matrix. According to the Geologic Map of the Niwot Quadrangle, Boulder County, Colorado (USGS, 1970), the portion of the Slocum Alluvium exposed at the top of the Valmont Butte is part of a pediment surface located approximately 110 to 130 feet above the modern stream level. Calcium carbonate is common as void fill in the matrix and as thin concretions at the bottom of cobbles and boulders.

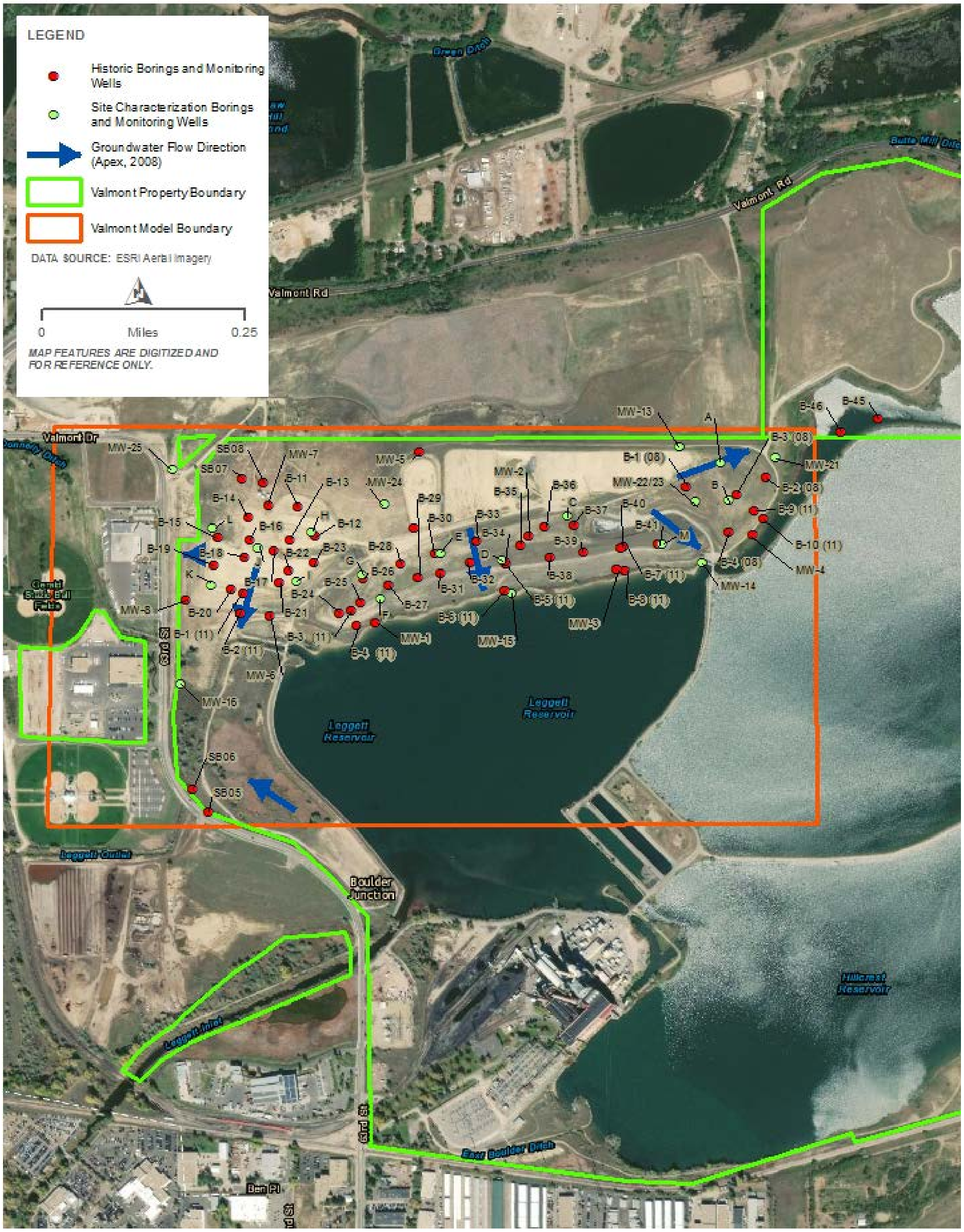
Colluvium: The colluvium generally consists of silty to clayey sand with occasional gravel and cobbles. These soils are present on the side slopes of the Valmont Butte below the elevation of the Slocum alluvial cap. The colluvial soils are a mixture of the granular alluvium and residual weathered claystone soils.

Bedrock: Bedrock of the Upper Cretaceous Pierre Shale underlays the ash monofill, colluvium and the alluvium at the site. This sedimentary bedrock unit is estimated to be on the order of 2,000 feet thick (USGS, 1975) in this area. The bedrock locally consists of claystone with occasional interbeds of siltstone and discontinuous thin cemented layers. The cemented layers exposed in cuts at Area D-1 generally appear to follow bedding within the claystone. Bedding was measured to dip approximately 6 to 8 degrees to the northeast. The claystone exposed in the excavations was very friable apparently as a result of slaking due to exposure at the ground surface. Most of the landfill ash cells are underlain one to 10 feet of weathered bedrock before borings encountered the dense consolidated bedrock where blow counts often exceed 50 counts for less than six inches of penetration.

HDR reviewed available boring logs from geotechnical studies and boring logs from well installations. HDR reviewed all available studies, gathered and interpreted the boring logs to consolidate the logged lithologies into units for use in developing the geologic model in Leapfrog that will be the framework for the groundwater model in MODFLOW. In addition to existing boring logs and wells, HDR completed an additional 17 borings and seven wells in and around the landfill to satisfy recognized data gaps and confirm lithology, collect ash and ash pore water samples, and confirm groundwater flow direction. Figure 3.2-1 provides the map of borings for building the geologic model. A table of all of the data sources is provided in Appendix B of this document.

Four geologic cross sections through the landfill that were prepared in Leapfrog are provided in Appendix A of this document. The geologic interpretations presented on the cross sections are based on the subsurface conditions encountered in exploratory borings, historical descriptions of the construction of the landfill, measurements of the cover fill berms, and review of aerial photographs.

Figure 3.2-1. Geotechnical and Monitoring Well Borings Containing Lithologic Data for Use in Developing the Geologic Framework for the Groundwater Model



3.2.3 Groundwater Flow System

Table 3.2-1. Water Elevation Data Collected in Monitoring Wells Within the Modeling Boundaries (August 2018)

Well ID	August 2018 (ft amsl)
MW-1	5207.94
MW-2	5248.69
MW-3	5220.95
MW-4	5226.07
MW-5	5259.49
MW-6	5211.71
MW-7	5265.02
MW-8	5210.93
MW-13	5219.48
MW-14	5219.51
MW-15	5217.55
MW-16	5194.36
MW-17	5214.01
MW-21*	5225.65
MW-22*	5228.60
MW-24*	5253.70

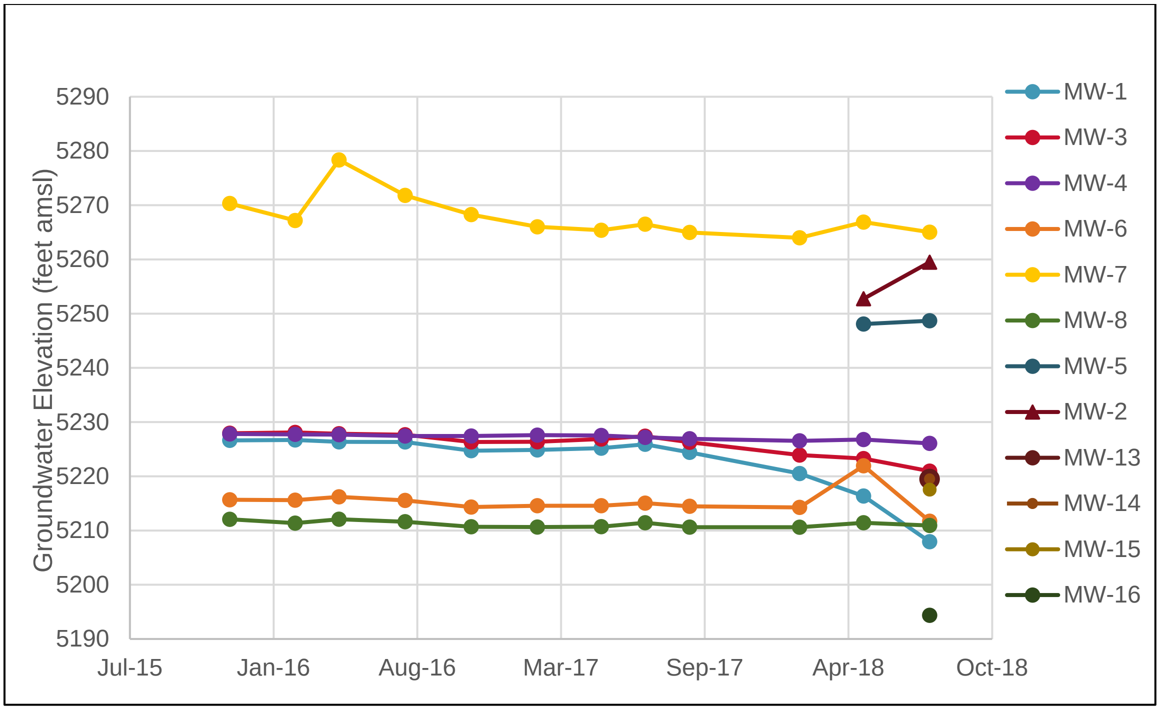
*Wells installed in late 2018 to early 2019 and static water levels gathered in late January 2019.

Water level data has been collected in monitoring wells across the site over many years. A full suite of water level data was collected by HDR in all monitoring wells within the project area and modeling boundary in August 2018 (Table 3.2-1). Data is provided below for those wells for August 2018 only; and historical water level data for wells is available for interpretation and impact from the reservoir (Figure 3.2-2). The water elevations from the newer wells at the landfill, MW-21, MW-22, and MW-24, were included in the dataset even though water levels from those wells were collected five months later because the water levels appeared consistent with the surface mapped without their inclusion. Figure 3.2-3 provides the potentiometric surface of first water under the landfill.

The reservoir level throughout the period of landfill operations has been typically maintained at an elevation of approximately 5,222 to 5,225 feet with some fluctuation. The reservoir level was lowered in 2018 to assist in the clean out of the bottom ash impoundments. The reservoir elevation at the time of the August 2018 water level suite was approximately 5,205 feet.

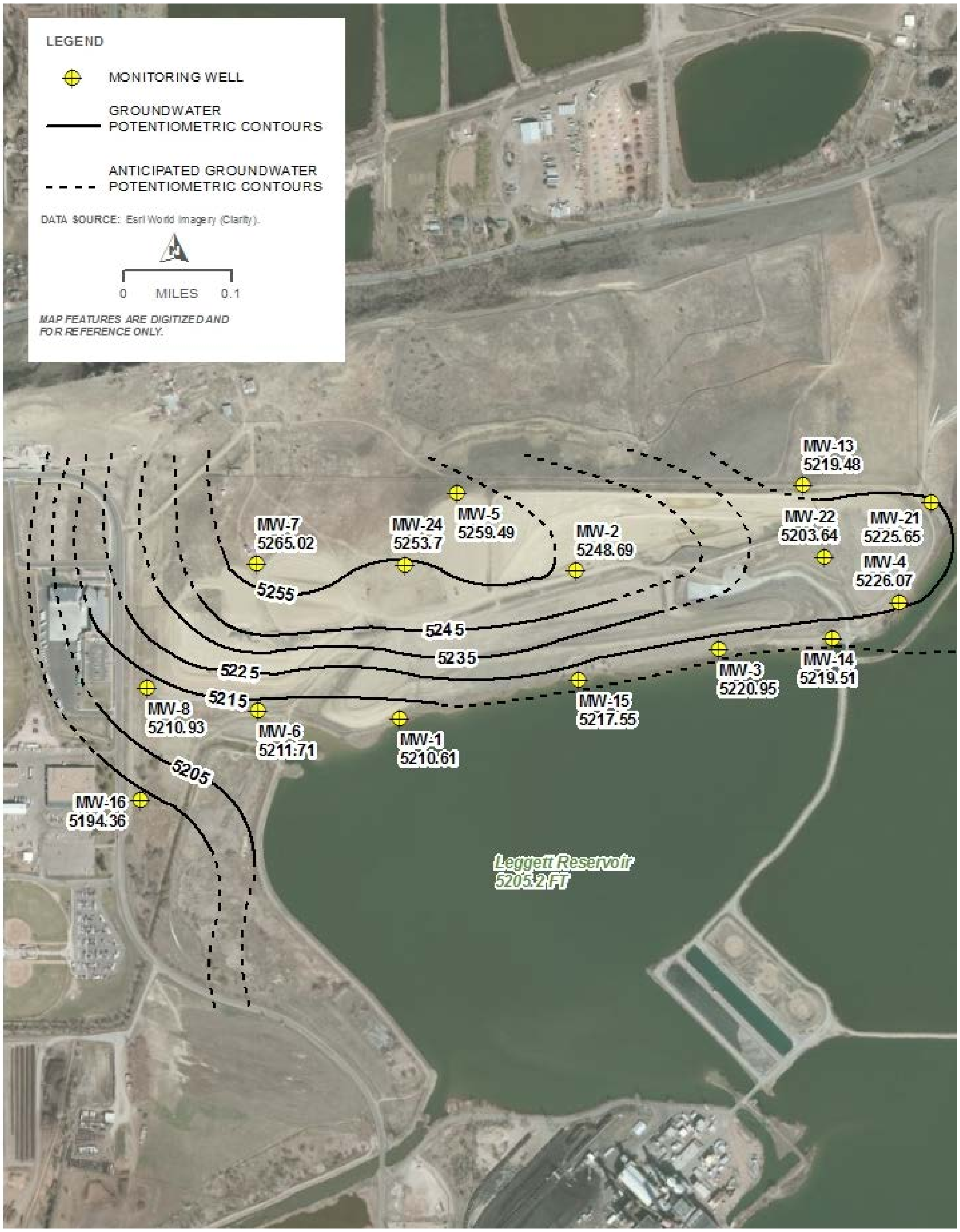
According to the Colorado Geologic Service the first regional groundwater exists at an elevation of 5,200 feet and flows north, discharging to South Boulder Creek. The USGS identified the landfill as being in an area where localized water tables may occur within fractures of consolidated materials of the Valmont Butte. The wells at the landfill depict local groundwater at higher elevations (5,210 to 5,265 feet) than the first regional groundwater and water level data from landfill wells show groundwater flowing radially from the topographic high of the Butte and landfill to the southwest, south, southeast and northeast compared to the regional water table that flows to the northwest.

Figure 3.2-2. Water Level Graph of Landfill Wells



MW-16 has the lowest water elevation and is furthest downgradient at the site and in alignment with a surface channel that flows to South Boulder Creek

Figure 3.2-3. Valmont Station Potentiometric Surface



Data from the landfill wells place the first localized water table in the Pierre Shale, either in the weathered bedrock or consolidated bedrock, and above the first regional aquifer which is at a much deeper elevation. The EDOP states that an average shale permeability of 7.9x10^{-7} feet per minute was determined by slug tests and a porosity of 30%. Table 3.2-2 displays all available data for the hydraulic conductivity for geologic units on site and Table 3.2-3 provides permeability data for the ash material and cover materials. Literature values for the overburden materials were used to a limited extent.

Table 3.2-2. Hydraulic Conductivity Values for Subsurface Materials at the Landfill

Well I.D.	Depth of Screened Interval (feet below surface)	Screened Interval Lithology	Hydraulic conductivity (ft/min)	Method	Data Source
MW-1	29-39	Silt	5.6 x 10-8	Slug	Xcel Energy, 2002. Valmont Station Ash Disposal Facility Monitoring Well Installation Report. December 23, 2002.
MW-2	90-105	Bedrock	NA	Insufficient water	
MW-3	40-50	Weathered bedrock	1.5 x 10-5	Slug	
MW-4	12-22	Silty clay Weathered bedrock	1.1 x 10-6	Slug	APEX Consulting Services, Inc., 2008. Valmont Station Ash Disposal Facility Additional Monitoring Well Installation Report. February 11, 2008.
MW-5	50-65	Bedrock	NA	Insufficient water	
MW-6	15-30	Weathered bedrock Bedrock	1.0 x 10-6	Slug	
MW-7	50-65	Bedrock	6.8 x 10- 7	Slug	
MW-8	15-30	Weathered bedrock Bedrock	5.9 x 10-6	Slug	
MW-13	59-69	Weathered Bedrock	NA	Insufficient water	HDR, 2018
MW-14	33-43	Weathered Bedrock	9.8 x 10-6	Slug	
MW-15	29-39	Silt with fine sand Weathered Bedrock	8.0 x 10-6	Slug	
MW-16	19-29	Weathered Bedrock	NA	Insufficient water	
Overburden—silts, sands, gravel, and cobbles			2.0 x 10-2 to 2.0 x 10-3	NA	Dames & Moore, 1985

Table 3.2-3. Landfill Material Description by Area, Cover Permeabilities, and Ash Infiltration Rates

Landfill Area	Landfill Cover Material Description	Cover Material Average Permeability (cm/s) (Flex Wall Permeability Test)	Ash Material Description	Ash Infiltration Rate Falling Head (in/hr)
A1	Lean Clay (CL) to Sandy Lean Clay (CL) to Clayey Sand (SC) with variable gravel and cobble content (SC), fine to coarse, slightly moist to moist, light brown to brown	6.3 x 10-5	Fine to coarse sand fraction, slightly moist to very moist, white to dark gray	0.20
A2	Silty Sand (SM) to Clayey Sand (SC) to Lean Clay (CL) with variable sand, gravel and cobble content, fine to coarse, slightly moist to moist, light brown to brown	5.6 x 10-5	Fine to medium sand fraction, slightly moist to very moist, dark gray to dark brown	0.003
A3	Silty Sand (SM) with gravel to Clayey Sand (SC) to Lean Clay with sand (CL), variable sand, gravel, and cobble content, slightly moist to moist, light brown	1.73 x 10-5	Fine to coarse sand fraction, slightly moist, dark gray	0.01
B1	Silty Sand (SM) with gavel and cobbles to Lean Clay (CL) with sand and gravel, fine to coarse, slightly moist to moist, light brown to brown	1.76 x 10-6	Fine to medium sand fraction, slightly moist to moist, dark gray	2.84
Q1	Lean Clay (CL) with variable fine to coarse sand fraction and occasional to frequent claystone fragments, moist, brown. Upper 8 inches disturbed and hydro-seeded.	7.95 x 10-6	Fine to medium sand fraction, slightly moist to moist, dark gray.	0.38
Q2	Lean clay (CL) to Lean Clay (CL) with sand, fine to coarse sand fraction, variable claystone fragments, slightly moist to moist, light brown to brown to gray. Upper 8 inches disturbed and hydro-seeded.	8.85 x 10-6	Fine to coarse sand fraction, slightly moist to moist, dark gray to black.	0.51
D-1	No description	No data	No description	0.46

Source: Kumar & Associates Geotechnical Engineering Services, Ash Disposal Project, Xcel Energy Valmont Power Station, February 8, 2018.

Groundwater elevation data collected from monitor wells indicates that groundwater is present within the upper Pierre Shale (siltstone and shale) and flow is to the northeast in the northeastern portion of the landfill, flow is to the south-southeast within the southeastern portion of the facility and to the south-southwest at the western portion of the facility. Generally, groundwater flow is radial from the topographic high area at the northeastern portion of the facility towards Leggett Reservoir, which is at the topographic low for the site.

Groundwater flow is calculated to travel at a rate of 0.05 to 0.09 feet per year (ft/yr) to the south-southeast and 0.07 ft/yr to the south-southwest, except within the eastern area of the facility. A hydraulic conductivity value of 7.9 x 10^{-7} feet per minute (ft/min) (Apex Consulting Services, 2008), 2018 water levels, and a representative porosity for silty sediments of 35% (Freeze and Cherry, 1979), were used to calculate the groundwater travel times. Apex Consulting Services, 2008 calculated a groundwater flow velocity of 0.03 ft/yr, which is slightly lower than current estimates, but within the same order of magnitude.

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. There are 16 off-site wells located downgradient in the local water table and no off-site wells are located within the same weathered bedrock system as that which exists beneath the landfill, which is at a higher elevation. While the groundwater at the landfill may be perched and may not meet the definition of an aquifer, PSCo is conservatively treating the groundwater under the landfill as if potentially connected to the local water table.

3.2.4 Groundwater Recharge

Annual average precipitation from 1893 through 2018, as provided by the Boulder Station (050848 Coop) from High Plains Regional Climate Center, is 18.99 inches per year (in/yr). Annual average pan evaporation, as provided by the Fort Collins Station from the Western Regional Climate Center, is 41.04 in/yr. Evaporation is more than double the precipitation. However, it is unlikely that all precipitation that falls onto the ground evaporates before entering the groundwater system.

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

3.2.5 Groundwater Withdrawal

No groundwater withdrawal wells were located within or near the model domain.

3.2.6 Water Quality

A total of six monitoring wells were originally sited at the landfill for CCR compliance: one upgradient monitoring well (MW-7) and five downgradient monitoring wells (MW-1, MW-3, MW-

4, MW-6, and MW-8) (Figure 2.1-1). The network is described in detail in the Groundwater Monitoring System Certification report (HDR, 2019). As stipulated in the CCR Rule, eight rounds of background groundwater sampling and the initial round of detection monitoring were completed before October 17, 2017 for the landfill. Background values were calculated and described in detail in the *Background Water Quality Statistical Certification* (HDR 2018). The initial round of detection monitoring was conducted in September 2017. In the January 15, 2018 PSCo memorandum, *Determination of Statistically Significant Increases over Background per 257.93(h)(2)*, concentrations of COIs at downgradient monitoring wells at the landfill were compared against background values and COIs were shown to have SSIs over background concentrations. These SSIs triggered the assessment monitoring program for the landfill. As stipulated in CCR Rule 257.95 assessment monitoring was completed in 2018 and GPS were established and documented in *Groundwater Protection Standards and Determination of SSIs per 257.95(g)*. In 2018 and early 2019, seven new wells were installed at the landfill (MW-13, MW-14, MW-15, MW-16, MW-21, MW-22, and MW-24) to more thoroughly characterize the groundwater gradient under the landfill and delineate water quality conditions (Figure 2.1-1). The water quality of groundwater at the landfill has been well established and a database is available for use in calibrating the transport model and identifying specific areas of concern within the landfill.

3.3 Bottom Ash Impoundments

The two CCR impoundments (3a and 3b) at Valmont Station are located on a small penninsula surrounded by reservoirs (Figure 2.1-1). The groundwater gradient in the immediate vicinity of the impoundments is very flat and coincident with the reservoir water level. There was inadequate access for drilling between the two impoundments; therefore, a multi-unit monitoring network was installed, consisting of four wells (MW-9, MW-10, MW-11, MW-12), along the perimeter of the impoundments to serve as downgradient wells (Figure 2.1-1). Borings from well installation revealed the lithology from surface to approximately 20 to 25 feet below surface is clayey silt above weathered Pierre Shale. The water table is approximately 5 to 7 feet below the surface between 5,226.5 to 5,226.8 feet AMSL, and coincides with the Leggett Reservoir water surface. Because the gradient is so flat under the impoundments and the hydraulic conductivity measured by slug tests in the wells around the impoundments was so low, the groundwater velocity under the impoundments is very low, calculated as approximately 0.007 ft/d or 141 days to move one foot.

4 Constituents of Concern in Groundwater

4.1 Constituents Exceeding the Groundwater Protection Standard

4.1.1 Landfill

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 landfill for each of the detected Appendix IV COIs. Downgradient well MW-4 was found to have concentrations of arsenic, lithium and selenium at statistically significant levels (SSLs) above the GPS; and downgradient well MW-8 had concentrations of lithium at SSLs above the GPS. Since that time, additional downgradient landfill wells have been installed and sampled that also have one-time concentration exceedances of the GPS, including MW-13 and MW-14 for lithium and selenium and MW-15 for selenium. Additional samples are necessary from these wells to calculate the LCLs and determine if the concentration exceedences are statistically significant; however, the existing data points are useful in characterizing nature and extent of constituents of concern. All other detected Appendix IV COIs are below the GPS. Therefore the contaminants that will be modeled and evaluated moving forward are arsenic, lithium and selenium (these constituents are referred to herein as constituents of concern (COCs)).

The groundwater transport model will utilize the total arsenic, selenium, and lithium concentrations for wells at the landfill collected in November 2018 as a starting point for transport model calibration. The historic water quality data is helpful to review for seasonal effects and reasonableness of the model during calibration.

For each COC at the landfill, Table 4.1-1 lists the EPA established MCL from 40 CFR 141.62 and 141.66, the BTV for the Valmont landfill, and the site specific GPS.

Table 4.1-1. Groundwater Protection Standards for Appendix IV COIs with SSLs above the GPS at the Landfill 257.95(d)(3)

Constituent	Unit	Maximum Contaminant Level	Background Concentrations (MW-7 UTL)	Groundwater Protection Standards
Arsenic	mg/l	0.0100	0.00700	0.0100
Lithium	mg/l	0.0400*	0.0830	0.0830
Selenium	mg/l	0.0500	0.0203	0.0500

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

4.1.2 Bottom Ash Impoundments

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. Downgradient wells MW-9, MW-11, and MW-12 have SSLs above the GPS for cobalt; and downgradient well MW-9 has an SSL of molybdenum above the GPS. However, since the impoundments were closed by removal of all CCR in 2018, additional corrective measures may not be necessary. Therefore, while assessment monitoring will continue in compliance with the Rule, monitoring will be focusing on reviewing the concentrations of cobalt and molybdenum decrease in wells around the former impoundments.

For each COI with an SSL at the impoundments, Table 4.1-2 lists the EPA established MCL from 40 CFR 141.62 and 141.66, the BTV for the Valmont bottom ash impoundments, and the site specific GPS.

Table 4.1-2. Groundwater Protection Standards for Appendix IV COIs with SSLs above the GPS at the Impoundments 257.95(d)(3)

Constituent	Unit	Maximum Contaminant Level	Background Concentrations (MW-1P UTL)	Groundwater Protection Standards
Cobalt	mg/l	0.00600*	0.00530	0.00600
Molybdenum	mg/l	0.100*	0.0267	0.100

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

4.2 Constituents of Concern Source Areas

4.2.1 Landfill

Operation of the landfill began in 1990 in the eastern portion of the landfill in the area known as B-1. For the first 5 years, commingled fly ash and bottom ash were saturated when placed in the landfill at lower elevations in Areas B-1 and C-1, and the eastern part of Area A-2. These zones exhibit high moisture contents and are very loose. Placement of commingled ash ceased in 1995. Since that time most of the material placed at the landfill has been fly ash, and once or twice a year the bottom ash impoundments were dewatered, the bottom ash was dredged and transported to the landfill where it was placed with the fly ash.

The landfill is an unsaturated waste monofill. The ash has been observed to take on cementitious characteristics during compaction resulting in a very low permeability layer. Table 4.2-1 provides the potential pathways for groundwater impacts and likelihood for each pathway at the Valmont Landfill given operating conditions.

Table 4.2-1. Potential Pathways for Impacts to Groundwater at Valmont Landfill

Potential Pathways for Impacts to Groundwater/ Recharge Sources	Potential for each Pathway at Valmont Landfill
Precipitation infiltration through the dry ash leaching metals and discharging to groundwater	Occurs on site, though precipitation would not be expected to build-up saturated conditions to drive enough transport through the compacted ash. In addition, soil covers have been in place for unused sections of the landfill. This impact would be expected to be minor. This is a potential pathway for the site.
Stormwater ponding on the surface of the ash landfill infiltrating the ash, leaching metals, and discharging to groundwater	Review of site records indicates that stormwater ponding periodically occurred in Cell D1 and Q1 on the ash. Ponding would provide sufficient head and saturated conditions to drive pore water through the ash, leaching metals along the path and potentially impacting groundwater. This is a potential pathway for the site.
Ash in direct contact with groundwater	Cross-sections from the site geologic model were completed that illustrate ash in contact with groundwater. Drilling completed at MW-22 in cell B confirmed this, as depicted in cross sections. This is a potential pathway for the site.

Besides the ash materials, zones of compacted soil are present throughout the ash landfill due to incorporation of daily and intermediate cover materials into the monofill as disposal activities progressed from one cell to another. Some of the intermediate cover materials consisted of berms separating work areas or cells within the larger placement areas that were then covered by subsequent operations. The relatively thick soil fill layer encountered in boring B-5 is believed to consist of such a berm between operational cells within Area A-2. Older areas of fill have been covered with locally derived earthen fill and revegetated.

To the north is the Hendricks Mill site that was remediated and is owned by City of Boulder. To the west is 63rd Street and commercial buildings and recreation facilities. To the south and east the site is bound by Leggett Reservoir and Valmont Reservoir. A concrete spillway for the Leggett Reservoir is located near the southeast corner of Area Q-1, the outlets channel flows to the southwest towards South Boulder Creek. High water reservoir levels are normally maintained at elevations of 5,222 to 5225 feet.

In 2017 PSCo conducted a comprehensive geotechnical study of the ash landfill, with over 40 borings covering all landfill cells. These borings were entered as inputs into the geologic database and model to ensure that the existing soil covers and ash depths accurately reflect the waste deposit in the groundwater model. The planned closure scenarios will be considered in evaluating corrective action alternatives. The planned closure scenario for the landfill, as described in the EDOP, and as implemented on Cell B-1, A-1, A-2, A-3, Q-1, and Q-2, is for the ash to be covered with a 24 inch soil cover that will consist of a 6 inch plant rooting layer and an 18-inch infiltration layer. Cells D-1 and E-1 were not closed as of October 2015 and are planned to be closed with an alternative cover system consisting of a geosynthetic cover with engineered turf and a geomembrane.

4.2.2 Bottom Ash Impoundments

While the impoundments were still in operation, the surface water in the impoundments was very similar in elevation to the elevation of the reservoirs surrounding the island on which the impoundments are located. The contractor that conducted the periodic excavation of the impoundments during operations reported that the impoundments required dewatering when they were excavated for maintenance, and after excavation, the impoundments filled back in with water up to approximately the same elevation as the reservoir. This indicates there was some hydraulic connectivity between the impoundments and the reservoir. However, measured transmissivity was low in the bedrock monitoring wells and hydraulic connectivity between the groundwater and the reservoir has not been observed based on measured monitoring well groundwater level data as compared to reservoir levels. However, the monitoring wells are small diameter and may not have encountered preferential pathways that may allow hydraulic connection between the impoundments and the reservoir. It is this hydraulic connection between the groundwater under and surrounding the impoundments and the impoundments that provided the pathway for groundwater to be impacted by the impoundments. The pathway for impact to groundwater no longer exists because there was complete source removal (certified by professional engineer) by September 2018.

4.3 Source Characterization

For the groundwater modeling of the landfill, the source characterization is an input for the model. Pore water was collected from the landfill where sufficient moisture was available for sampling and analysis. This was primarily in areas where the ash was saturated.

Borings were drilled in four locations distributed across the landfill, and a temporary well was installed for pore water collection. This approach yielded no pore water. A second drilling effort completed 15 borings throughout the landfill cells. Dry ash samples were collected and submitted to the lab for Synthetic Precipitation Leaching Procedure (SPLP) at discrete depths and analysis for COC concentrations; and where saturated ash was observed, samples were collected and submitted to the lab for pore water extraction followed by analysis. The saturated ash samples resulted in pore water analysis that was ultimately used in the groundwater transport model to establish COC source concentrations. Results of SPLP testing of the ash resulted in highly variable concentrations around the landfill and lower concentrations of leachate COCs than the pore water results and therefore were not used for source terms in the model.

5 Groundwater Flow and Transport Model

The groundwater flow and transport model is the numerical representation of the CSM. The 3D geological model created in Leapfrog Works (ARANZ Geo Limited t/a Seequent, 2017) was used as input for the elevations and thicknesses of aquifer units in the numerical groundwater flow and transport model. The numerical groundwater flow and transport model uses the graphical user interface (GUI) Groundwater Vistas Version 7 (Environmental Simulations, Inc., 2017) as the pre- and post- processor for the groundwater flow code MODFLOW-NWT and the transport code MT3DMS.

The specific MODFLOW code chosen for the study is MODFLOW-NWT, a Newton formulation of MODFLOW-2005 that is specifically designed to improve the stability of solutions involving drying and re-wetting under conditions present at the water table (Niswonger et al. 2011). The numerical code selected for the transport model is MT3DMS (Zheng and Wang 1999). MT3DMS is a multi-species three-dimensional (3D) mass transport model that can evaluate advection, dispersion/diffusion, and chemical reaction of COIs in groundwater flow systems, and has a package that provides a link to the MODFLOW codes. The MODFLOW-NWT and MT3DMS input packages used to create the groundwater flow and transport models, as well as a brief description of their use, are provided in Table 4.3-1.

Table 4.3-1. MODFLOW and MT3DMS Input Packages Utilized

MODFLOW Input Package	Description
Name (NAM)	Contains the names of the input and output files used in the model simulation and controls the active model program
Basic (BAS)	Specifies input packages used, model discretization, number of model stress periods, initial heads and active cells
Discretization (DIS)	Contains finite-difference grid information, including the number and spacing of rows and columns, number of layers in the grid, top and bottom model layer elevations and number of stress periods
Specified Head and Concentration (CHD)	Specifies a head and/or a concentration that remains constant throughout the simulation
Recharge (RCH)	Simulates areal distribution of recharge to the groundwater system
Newton Solver (NWT)	Contains input values and the Newton and matrix solver options
Upstream Weighting (UPW)	Replaces the LPF and/or BCF packages and contains the input required for internal flow calculations
Flow Transfer Link File (LMT)	Used by MTDMS to obtain the location, type, and flow rates of all sources and sinks simulated in the flow model

Table 4.3-1. MODFLOW and MT3DMS Input Packages Utilized

MT3DMS Input Package	Description
Flow Transfer Link File (FTL)	Reads the LMT file produced by MODFLOW
Basic Transport Package (BTN)	Reads the MODFLOW data used for transport simulations and contains transport options and parameters
Advection (ADV)	Reads and solves the selected advection term
Dispersion (DSP)	Reads and solves the dispersion using the explicit finite- difference formulation
Source and Sink Mixing (SSM)	Reads and solves the concentration change due to sink/source mixing using the explicit finite-difference formulation
Chemical Reaction (RCT)	Reads and solves the concentration change due to chemical reactions using the explicit finite-difference formulation
Generalized Conjugate Gradient (GCG) Solver	Solves the matrix equations resulting from the implicit solution of the transport equation

5.1 Modeling Objectives

The primary modeling objectives are to simulate the rate of movement, potential pathway(s) and the potential offsite migration of arsenic, lithium and selenium within the local groundwater system. Predictive simulations will simulate the movement of COCs over a pre-determined time period and determine if offsite migration is likely or unlikely. If likely, simulation of source control alternatives (such as, pumping, injection, barriers) will be performed for alternatives that are not removed from consideration for reasons other than performance or timing.

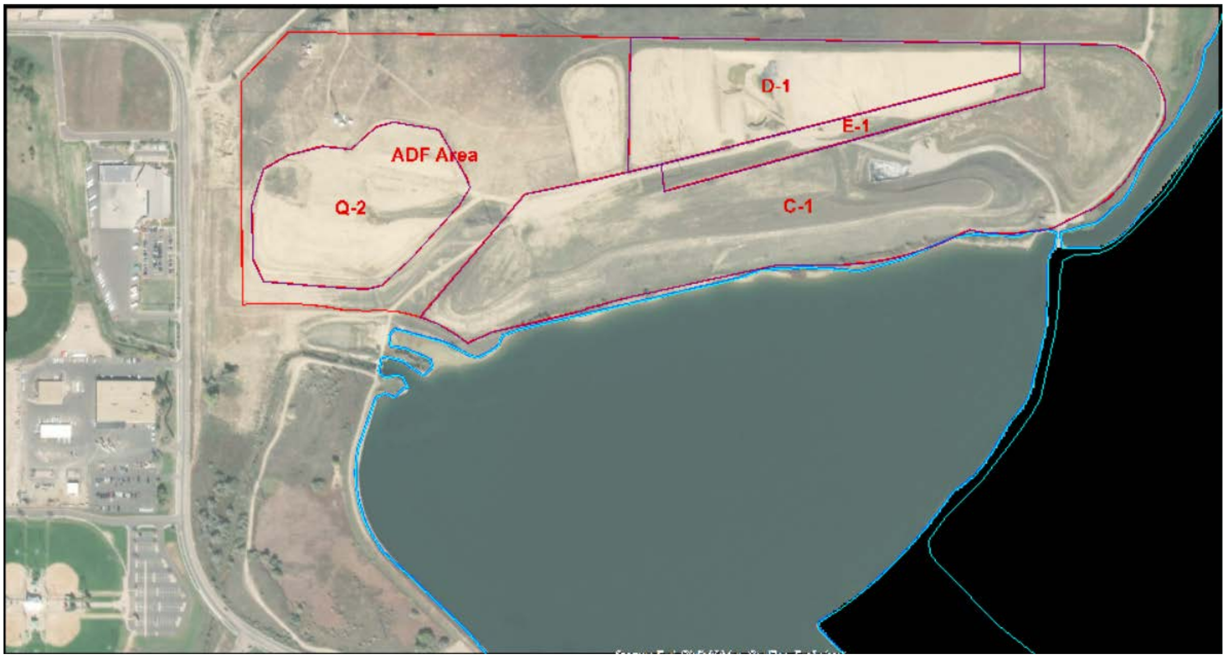
5.2 Model Domain and Grid

The 3D geological model was used as input for the elevations and thicknesses of aquifer/lithology units in the groundwater flow and transport model. The geological model constructed in Leapfrog Hydro was imported into Groundwater Vistas, Version 7, which is the pre and post-processor for the groundwater modeling software used to simulate groundwater flow (MODFLOW) and contaminant transport (MT3DMS). The imported geologic units include top and bottom elevations of each layer beginning at ground surface to a pre-determined bottom elevation of bedrock. The following geologic units were used in the Leapfrog geological model and the groundwater flow and transport model:

- Ash
- Silt
- Sand
- Sandy silt
- Clayey sand
- Gravelly sand
- Clay
- Clayey sand
- Silty gravel
- Weathered bedrock
- Bedrock

The model domain encompasses ash landfill areas and surrounding property and extends to Xcel property boundaries to the north and east and offsite to the west approximately 800 feet. The model extends to the water's edge of the Leggett Reservoir to the south and east and the Valmont reservoir to the east (Figure 5.2-1). The model domain extends 2,640 feet north to south and 4,960 feet east to west and has a grid consisting of uniform 10 foot grid cells in 14 layers. The bottom of the bedrock unit in the model is assigned a uniform elevation of 5,100 feet, which equates to an average thickness of 100 feet.

Figure 5.2-1. Model Domain



The geologic units identified in the boring logs are not always continuous across the site and may be modeled as one or more layers with different hydraulic conductivity values to designate discontinuities and spatial changes of geologic units.

5.3 Hydraulic Parameters

Horizontal hydraulic conductivity and the ratio of horizontal to vertical hydraulic conductivity, which are specific for each hydrostratigraphic unit, are the primary determinants of groundwater flow for a given configuration of boundary conditions and sources and sinks, including recharge. Field measurement of these parameters have been performed through slug testing of onsite monitor wells and are included in consultant reports completed shortly after drilling (reference). Since monitor wells are completed in the saturated zone, measured values are only available for silt, weathered bedrock, and bedrock. The majority of units above the weathered bedrock, except where ash has been deposited directly on weathered bedrock or bedrock, are unsaturated. MODFLOW does not simulate flow in unsaturated sediments, so does not use the hydraulic conductivity of unsaturated units in the flow and transport computation. However, values were assigned to the unsaturated units for completeness.

Values assigned to the model, with a comparison of literature and measured values are provided in Table 5.3-1.

Table 5.3-1. Summary of Hydraulic Conductivity Values Used in the Calibrated Model

Geologic Unit	Model Values			Measured Values
	Horizontal Hydraulic Conductivity (ft/d)	Vertical Hydraulic Conductivity (ft/d)	Model Zone	Horizontal Hydraulic Conductivity (ft/d)
Ash	0.35	0.35	2	0.35
Bedrock	0.001	0.001	3	0.001 or less
	0.0001	0.0001	19	
Clay	0.002	0.002	4	Literature Value
Clayey Sand (Int)	0.01	0.01	5	Literature Value
Fill	0.05	0.05	6	Literature Value
Gravelly Sand	10	10	7	Literature Value
Sand	10	10	8	Literature Values
	1	0.1	18	
Sand (Lower)	10	10	9	Literature Value
Sandy Silt	0.01	0.01	10	Literature Values
	0.1	0.1	16	
Silt	0.001	0.001	11	Literature Value
Silt (Lower)	0.001	0.001	12	Literature Value
Silty Gravel	0.001	0.001	13	Literature Value
Weathered Bedrock	0.02	0.02	14	0.5–0.001
	0.001	0.001	15	
	0.05	0.05	17	
	0.5	0.5	20	

5.4 Boundary Conditions

The outer model boundary is simulated with Constant Head boundary conditions set to elevations that approximately represent late 2018 water level elevations that align with the water level contours developed for the site (Figure 5.4-1). Constant Head boundaries were used to represent the stage of Leggett Reservoir, which was approximately 5,205.2 feet around late 2018, and also for the area of Valmont Reservoir that is present at the eastern area of the site at 5,216.9 feet.

Figure 5.4-1. Valmont Site Water Level Contours

A constant recharge rate of 0.00001 feet/day was assigned to non-ash landfill areas, which is slightly less than 1% of average annual rainfill. The ash landfill cell areas were assigned variable recharge based on the variable ash infiltration rates measured by Kumar and Associates, 2018. Table 5.4-1 provides the recharge rates applied to individual ash landfill areas, which are based on the variability of infiltration rates measured by Kumar and associates through the cover material. Calibrated recharge rates assigned to the ash landfill areas did not exceed 25% of average annual rainfall and most were less than 5% of annual average rainfall. The infiltration rates measured by Kumar and Associates was the maximum and above the average annual rainfall amounts, so lesser values were used that provided the best calibration to water levels.

Table 5.4-1. Summary of Aquifer Recharge values used in the Calibrated Model.

Ash Landfill Cell	Modeled Recharge Values (feet/day)		Measured Infiltration Rates (feet/day)
		Model Zone	
B1	0.00001	6	0.005
A2	0.001	2	0.159
C1	0.001	2	Not measured
A1	0.00005	3	0.179
A3	0.00005	3	0.049
D1	0.00002	4	0.025
Q1	0.000035	5	0.023
Q2	0.000035	5	0.025

5.5 Contaminant Transport Properties

The calibrated, steady-state flow model was used to apply flow conditions for the transport model at the ash landfill areas using groundwater quality data obtained from monitor wells during the November 2018 sampling event. The relevant transport input parameters were constant concentrations at the source zone, effective porosity, advection and dispersion, and linear sorption coefficient (K_d) for Se and As,

5.5.1 Constant Concentration Source Zone

The flow model hydrogeologic properties (hydraulic conductivity) were slightly modified during transport calibration to better match COC concentrations. To calibrate the transport model to existing conditions, constant concentration source zones were applied for ash in the ash landfill areas. Concentrations were based on measured pore water samples, adjusted as needed, as some ash cells required slightly higher assumed source concentrations to achieve transport calibration.

The background concentrations for Li, Se, and As are the calculated UTL values provided in Table 5.5-1. These values were applied to the saturated weathered bedrock and bedrock layers.

Constant concentration source zones in the ash landfill areas are activated in the model at the date each area was placed in service, as shown in Table 5.5-1. The model terminated in November 2018 to match the water quality calibration sample date, which resulted in a transport model total time length of 25.9 years (1993 to November 2018)

Table 5.5-1. Constant Concentration Source Zone Model Start Times

Ash Landfill Cell	Constant Concentration Model Start Times
B1	1993
A1–A3	1996
C1	1996
D1	2014
Q1	2011
Q2	2009

5.5.2 Effective Porosity

No effective porosity measurements of the saturated sediments have been collected at the Valmont Site, so the following literature values provided in Table 5.5-2 (Freeze and Cherry, 1979, Domenico and Schwartz, 1990) were used. Effective porosity is a fraction of the total porosity.

Table 5.5-2. Effective Porosity Values used in the Transport Model

Geologic Unit	Model Values	
	Effective Porosity (%)	Model Zone
Ash	30	2
Bedrock	8	3
Clay	40	4
Clayey Sand (Int)	25	5
Fill	25	6
Gravelly Sand	25	7
Sand	25	8
Sand (Lower)	25	9
Sandy Silt	35	10
Silt	35	11
Silt (Lower)	35	12
Silty Gravel	35	13
Weathered Bedrock	5	14
	1.2*	15

*Porosity may vary over the site and the lower value was used in some areas with tighter weathered bedrock as observed in boreholes to aid in a better calibration.

5.5.3 Advection and Dispersion

Contaminants move through the groundwater system via advection and dispersion. Advection is the movement of contaminant mass due to the flow of water in which the mass is dissolved. Dispersion is the process of mixing that occurs with the native groundwater, in which the mass is spread. Advection does not have specific parameters outside of the hydraulic gradient, hydraulic conductivity and porosity.

Dispersion is a physical property of the aquifer medium and is normally a fraction of the field scale condition (i.e., plume length), commonly considered to be approximately 10 percent (Zheng and Bennett 2002). The dispersivity quantifies the degree to which mechanical dispersion of COIs occurs. Dispersion is site dependent and since plume length is usually unknown, this parameter is usually determined through the transport model calibration process. Dispersion is measured in the longitudinal, horizontal transverse, and vertical transverse tensors. These values usually have a ratio of 100/10/1 and are measured in feet. Consistent with this ratio, values of 30/3/0.3 were used in the transport model.

5.5.4 Linear Sorption Coefficients (K_d)

Sorption is the process in which certain dissolved chemical constituents bind to surrounding sediments. This process slows the rate of travel and dispersion. The nomenclature for sorption is K_d and has units of mL/g. Since these values are usually site specific and require determination through lab analysis, values were acquired from other sites (confidential) with similar sediment properties. Lithium was not assigned a K_d value as this constituent does not bind to surrounding sediments and is considered conservative (more mobile). The following K_d values were assigned to Arsenic and Selenium:

- Arsenic = 20 mL/g
- Selenium = 0.2 mL/g

The bulk density of the weathered bedrock and bedrock is also required when specifying linear sorption. The bulk density used in the model for the saturated shale derived sediments is 2 g/cm^3, which is a common value for shale sediments (Manger, 1963).

5.6 Calibration to Current Conditions

Model calibration is the process of adjusting hydraulic parameters, transport parameters, and boundary conditions within reasonable ranges to achieve an acceptable match between modeled and measured calibration targets. The flow model was calibrated to monitoring well water levels from August 2018 (Table 3.2-1). The transport model was calibrated to porewater and monitor well concentrations from late November 2018.

5.6.1 Flow Model Calibration

The flow model was calibrated to groundwater elevations calculated from depth to water measurements in all wells obtained during the August 2018 sampling event. The observation data from this single point in time were used as a steady-state flow model calibration data set.

The initial iterative calibration assumed homogeneous conditions in each hydrostratigraphic layer (model layers received varying hydrogeologic parameters from the 3D geologic model). Recharge was also fixed at reasonable values early in the calibration process, and then refinements were made by adjusting hydraulic conductivity and recharge rates.

Modeled and observed water levels (post-calibration) are compared in Table 5.6-1 and on Figure 5.6-1. The calibrated flow model is assumed to represent long-term, steady-state flow conditions for the site and the ash basin system under long-term, average conditions. Iso-contours for each calibrated constituent concentration are also provided in Figure 5.6-2, Figure 5.6-3, and Figure 5.6-4.

The square root of the average square error (also referred to as the root mean squared error, or RMS error) of the modeled versus measured water is an industry standard means to validate model calibration to water levels. The model calibration goal is an RMS error less than 10 percent of the change in head across the model domain. The ratio of the average RMS error to total measured head change is the normalized root mean square error (NRMSE). The NRMSE of the calibrated model is 5.5 percent. MW-16 has a relatively high water level residual of -9.32, which indicates that the model is simulating 9.32 feet higher than measured values at this target. However, MW-16 is not close to the ash landfill and is not anticipated to impact results associated with contaminant transport.

Table 5.6-1. Measured vs. Model Calibrated Water Levels

Monitor Well ID	Measured Water Level (Feet)	Model Calibrated Water Level (Feet)	Residual (Feet)
MW-1	5210.61	5208.62	1.99
MW-2	5248.69	5253.49	-4.80
MW-3	5220.95	5217.84	3.11
MW-4	5226.07	5220.74	5.33
MW-5	5259.49	5257.39	2.10
MW-6	5211.71	5215.37	-3.66
MW-7	5265.02	5266.94	-1.92
MW-8	5210.93	5212.50	-1.57
MW-13	5219.48	5222.83	-3.35
MW-14	5219.51	5216.49	3.02
MW-15	5217.55	5213.12	4.43
MW-16	5194.36	5203.68	-9.32
MW-17	5214.01	5213.31	0.70
MW-21	5225.65	5224.44	1.21
MW-22	5228.60	5228.69	-0.09
MW-24	5253.70	5258.83	-5.13

Figure 5.6-1. Water Level Calibration Residuals (Feet Difference between Measured and Modeled Water Levels)

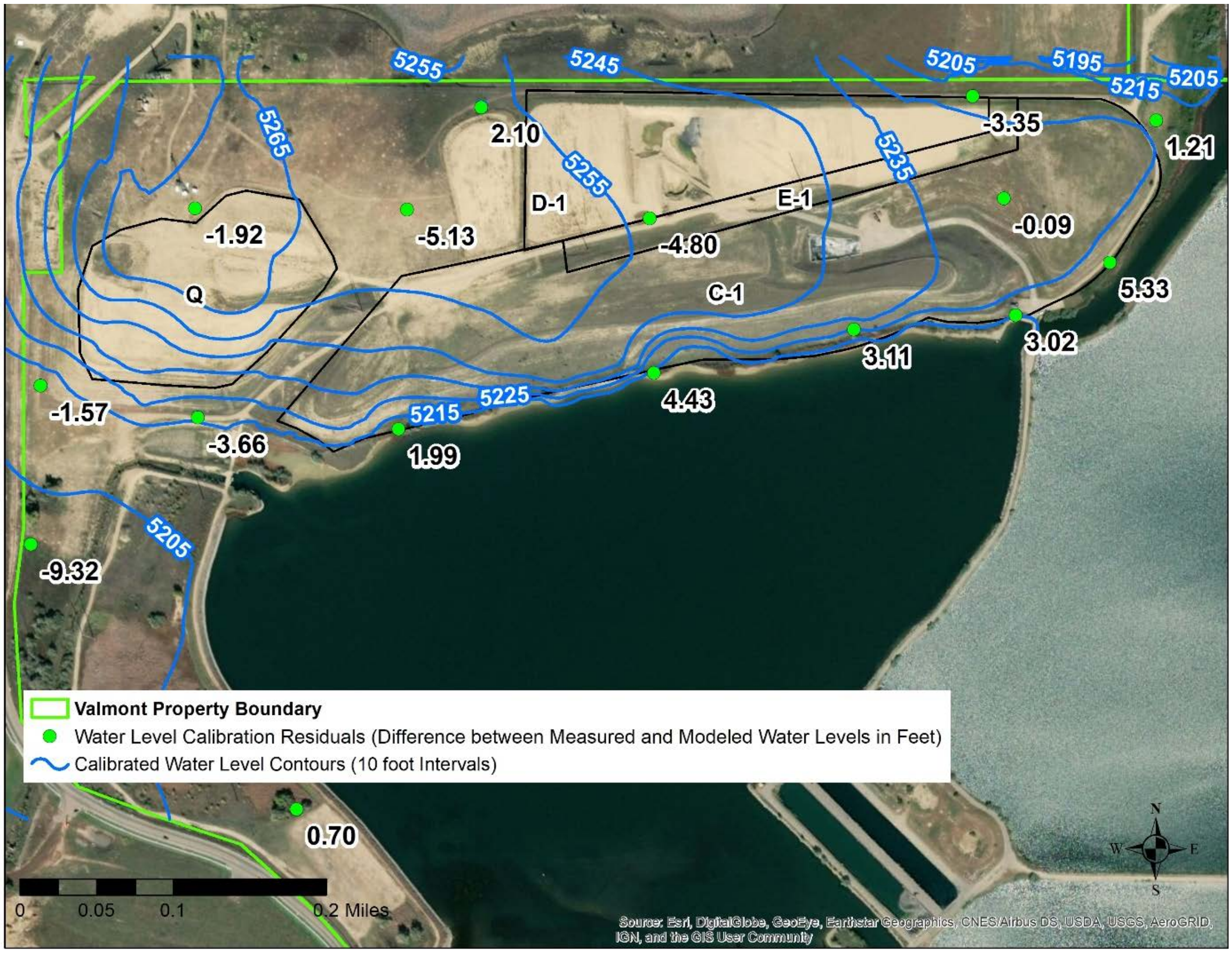
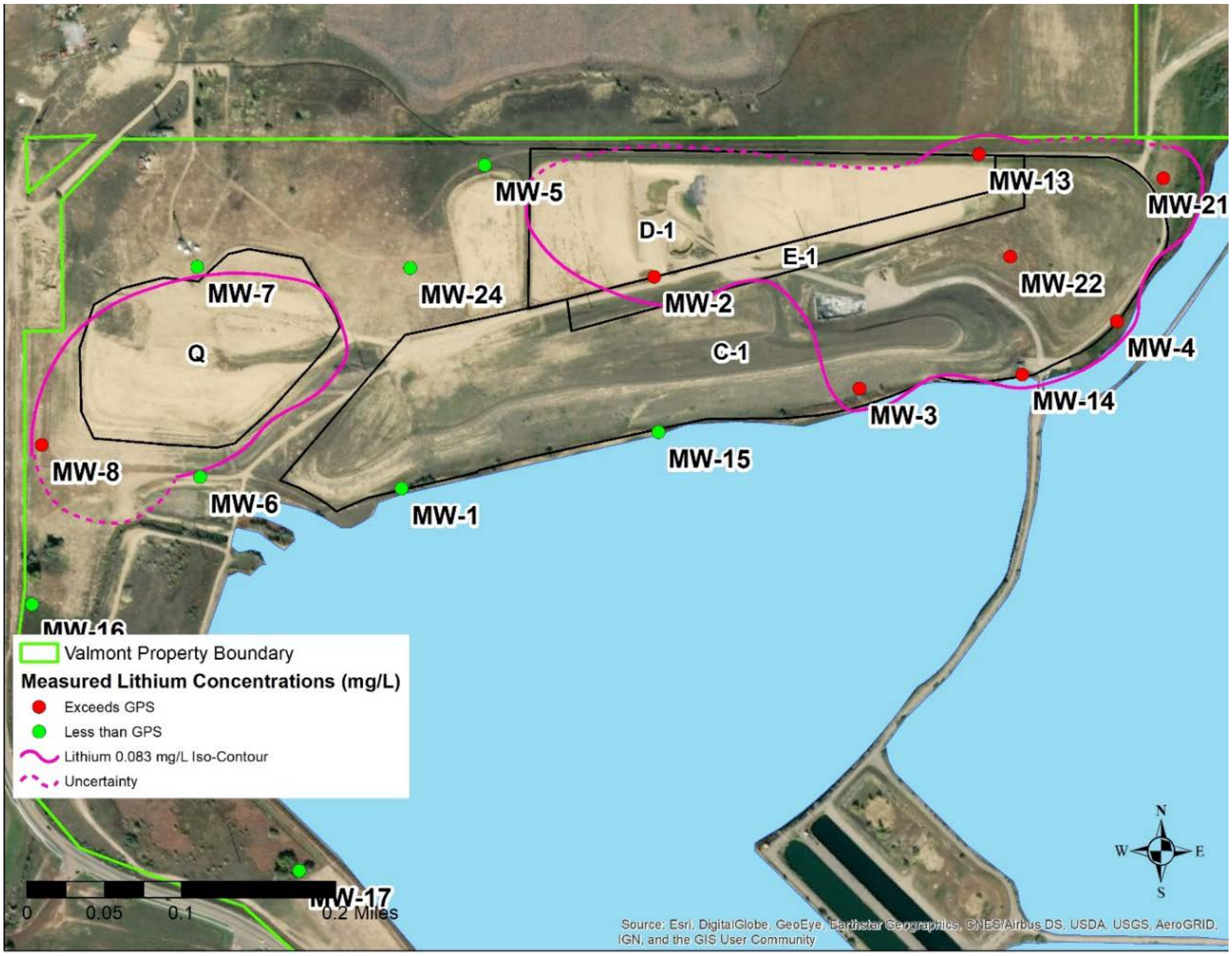
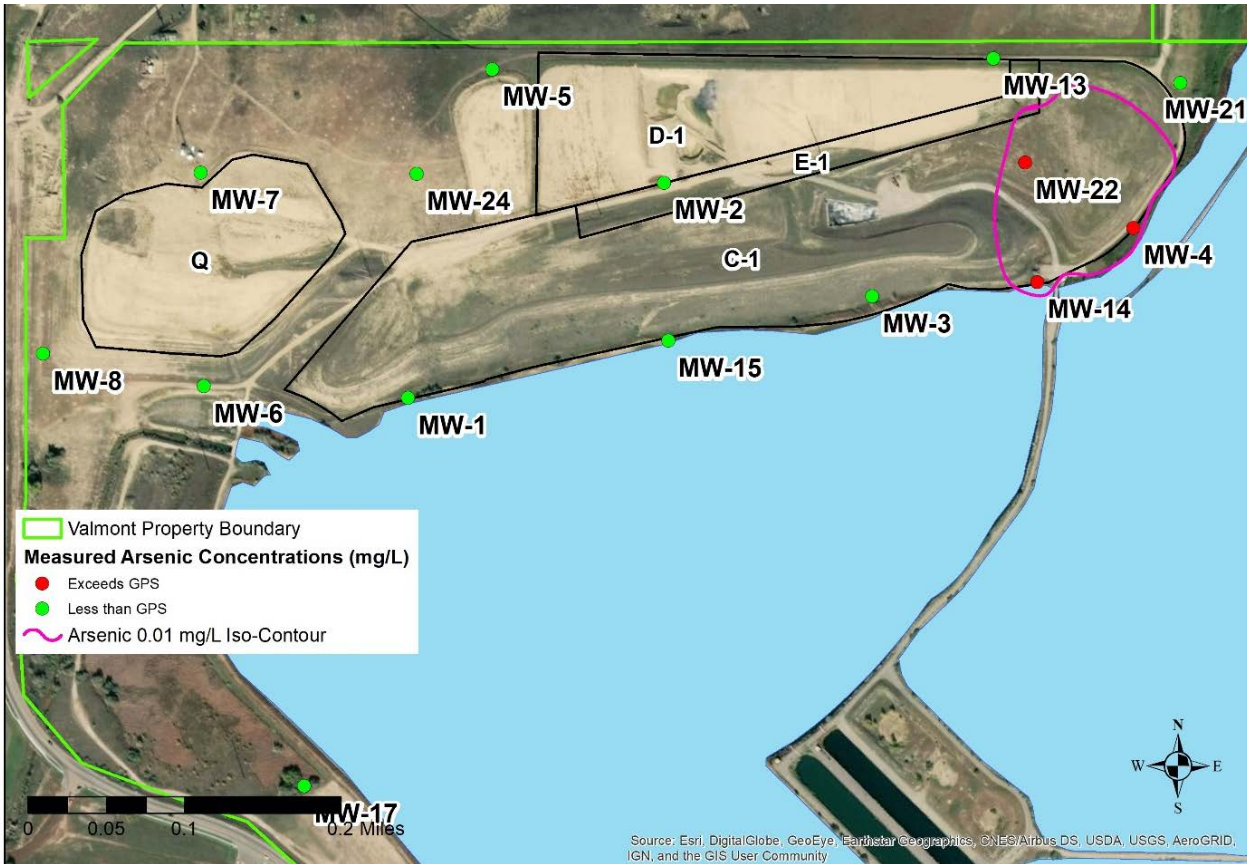


Figure 5.6-2. Calibrated Lithium Concentrations



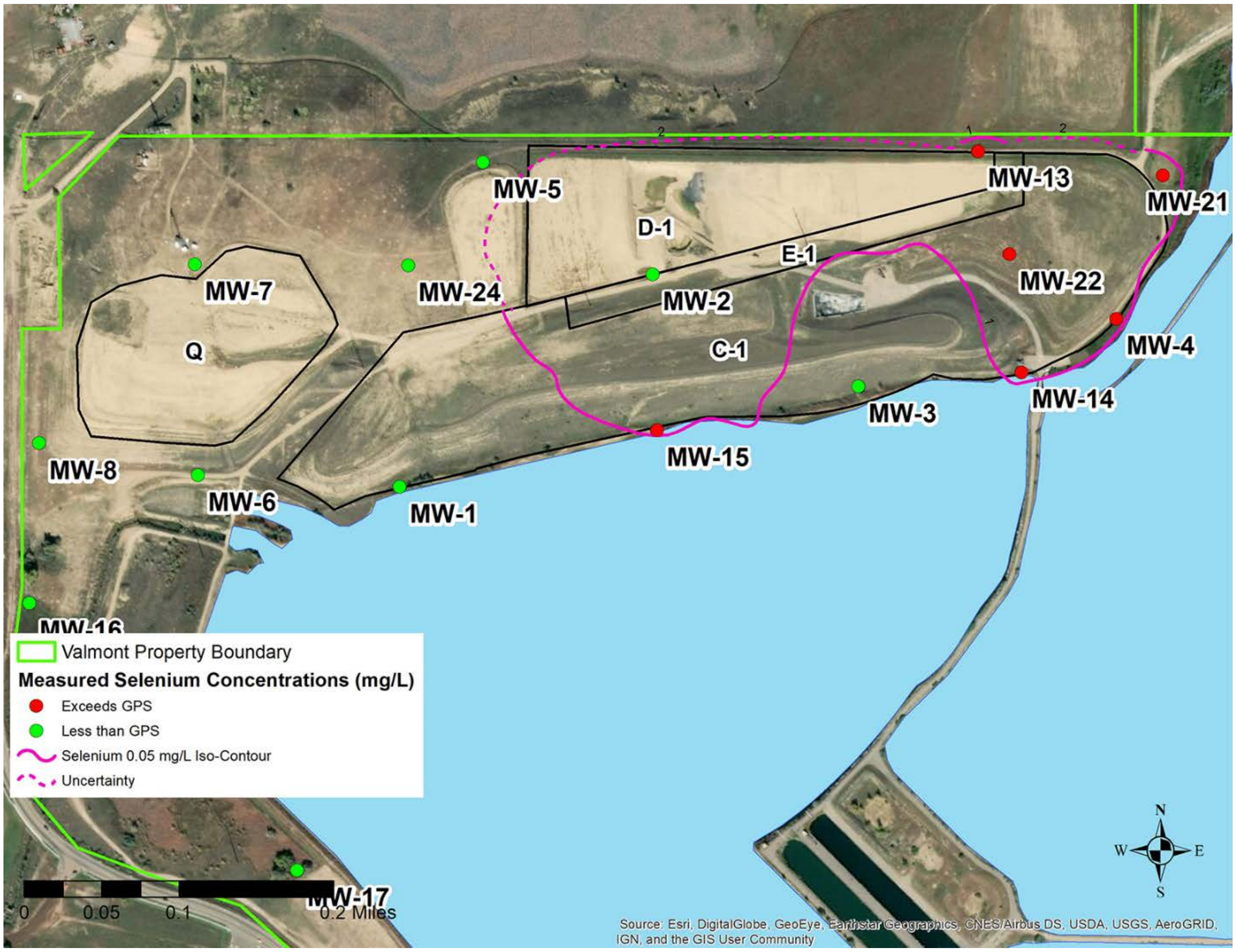
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 5.6-3. Calibrated Arsenic Concentrations



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 5.6-4. Calibrated Selenium Concentrations



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

5.6.2 Transport Model Calibration

For the transport model calibration, the calibration parameters consisted of constant source concentrations in the ash landfill areas, porosity and the linear sorption coefficient (K_d) for each COI, and slight modifications to the flow model parameters that improved both flow and transport calibrations. These parameters were adjusted to minimize residual concentrations (difference between modeled and measured) in monitor wells. The model assumed an initial concentration matching the UTLs within the groundwater system for all constituents at the beginning of the model simulation. A constant concentration source zone (concentration area) matching the porewater concentrations for each constituent, was applied within the ash landfill areas at the start of the calibration periods. For some constituents, the source term concentrations were higher than measured pore water concentrations when down gradient wells had concentrations greater than porewater measurements. The source concentrations were adjusted in order to match measured porewater concentrations with the concentrations in downgradient monitoring wells.

Modeled and observed groundwater concentrations for each constituent (post-calibration) are compared in Table 5.6-2, Table 5.6-3 and Table 5.6-4 for arsenic, selenium, and lithium, respectively. Overall, the calibration to measured concentrations shows a good match and is acceptable as a starting point for predictive simulations.

Table 5.6-2. Measured vs. Model Calibrated Arsenic Concentrations

Monitor Well ID	Measured Concentration (mg/L)	Model Calibrated Concentration (mg/L)	Residual (mg/L)
MW-1	0.001	0.007	-0.006
MW-3	0.002	0.007	-0.005
MW-4	0.011	0.011	0.000
MW-5	0.000	0.007	-0.007
MW-6	0.002	0.007	-0.005
MW-7	0.001	0.007	-0.006
MW-8	0.001	0.007	-0.006
MW-13	0.003	0.007	-0.004
MW-14	0.011	0.009	0.002
MW-15	0.003	0.007	-0.005
MW-16	0.013	0.007	0.006
MW-21	0.007	0.007	0.000
MW-22	0.015	0.014	0.001

Table 5.6-3. Measured vs. Model Calibrated Selenium Concentrations

Monitor Well ID	Measured Concentration (mg/L)	Model Calibrated Concentration (mg/L)	Residual (mg/L)
MW-1	0.001	0.008	-0.007
MW-3	0.002	0.022	-0.020
MW-4	0.210	0.209	0.001
MW-5	0.004	0.020	-0.017
MW-6	0.010	0.019	-0.009
MW-7	0.003	0.020	-0.017
MW-8	0.009	0.020	-0.011
MW-13	0.330	0.332	-0.002
MW-14	1.500	1.505	-0.005
MW-15	0.130	0.126	0.004
MW-16	0.001	0.019	-0.018
MW-21	1.300	0.285	1.015
MW-22	0.790	0.718	0.072

Table 5.6-4. Measured vs. Model Calibrated Lithium Concentrations

Monitor Well ID	Measured Concentration (mg/L)	Model Calibrated Concentration (mg/L)	Residual (mg/L)
MW-1	0.033	0.083	-0.050
MW-2	0.150	0.083	0.067
MW-3	0.095	0.098	-0.003
MW-4	0.230	0.230	0.000
MW-5	0.060	0.082	-0.022
MW-6	0.081	0.080	0.001
MW-7	0.038	0.082	-0.044
MW-8	0.130	0.128	0.002
MW-13	0.110	0.114	-0.004
MW-14	0.160	0.162	-0.002
MW-15	0.051	0.112	-0.061
MW-16	0.064	0.071	-0.007
MW-17	0.009	0.083	-0.074
MW-21	0.220	0.219	0.001
MW-22	0.390	0.323	0.067
MW-24	0.038	0.083	-0.045

5.7 Data Limitations

The following limitations, based on necessary assumptions, will be inherent within the completed groundwater flow and transport model. Where data was unavailable, use of published literature values, appropriate assumptions and professional judgment are routinely employed in modeling and are sufficient to complete the model.

- The geological interpretation of boring logs has been completed by multiple people from different engineering companies over a 16-year period. It's possible that geological interpretations are not uniform.
- The development of the geological model requires interpolation of geologic units between boreholes that may be inaccurate despite professional judgment and reasonable interpretations.
- Hydraulic conductivity values are sparse and are likely not representative of each entire geological unit underlying the site, as most geological units are heterogeneous.
- Site-specific aquifer recharge is not known and testing has not been conducted. However, data from infiltration testing within the landfill areas provides insight into recharge rates.
- Dispersion or dispersivity of a contaminant within the subsurface is difficult to quantify.

- Site-specific effective porosity values are not known. However, literature values are extensive and can be correlated to known site specific soil characteristics.
- The water level stage of the Leggett and Valmont Reservoir has not been constant over time, which may have impacted the velocity and spreading of lithium and selenium over time.
- Groundwater levels at the model boundaries are inferred from interpreted groundwater level contour maps, but actual groundwater levels at the model boundaries are non-existent.
- Pore water measurements may not represent the concentrations of arsenic, lithium and selenium over the entire ADF, as these concentrations may vary spatially.
- The model will represent stead-state conditions and does not account for transient impacts, such as aquifer storage or fluctuations of water level gradients over time.
- The model predicts groundwater flow and transport onsite, and predicts the direction and velocity of flow, but does not evaluate the extent or velocity of offsite movement beyond the model boundaries.

5.8 Data Gaps

Development of the model illustrated two areas of uncertainty:

1. As illustrated in Figure 5.6-2, the calibrated transport model maintains concentrations of lithium greater than GPS at the northern boundary east of MW-13. These model results may erroneously over predict concentrations of lithium and selenium moving offsite than have been observed. Therefore, the model has pointed out a data gap that installation of a new monitoring well east and west of MW-13 directly south of the property boundary would confirm actual COC concentrations.
2. Similarly, as illustrated in Figure 5.6-2, the calibrated transport model maintains concentrations of lithium greater than GPS at the western boundary south of MW-8 and north of MW-16. These model results may erroneously over predict higher concentrations of lithium moving offsite than have been observed. Therefore, the model has pointed out a data gap that installation of a new monitoring well south of MW-8 and north of MW-16 would confirm actual COC concentrations.

These areas of uncertainty have the effect of the model predicting concentrations of COCs being transported offsite and therefore have a significant effect on the use of the model simulations to assess corrective measures. If the areas of uncertainty are determined to not have concentrations greater than GPS, the approach to and areas impacted by corrective measures may change.

After additional well installations, sampling and analysis, the transport model will be re-calibrated and predictive simulations can then be run and reviewed. For each alternative simulated, once completed and re-calibrated, the model will:

- Evaluate concentrations of COCs over time, transport directions, potential for movement offsite and quantify mass flux moving offsite or into reservoirs; and
- Evaluate the time required for each alternative to “complete the remedy” (per 257.96(c)(2)).

5.9 Plume Evaluation

Based on the current understanding of the site hydrogeology, water quality sampling and preliminary model simulations, groundwater is impacted by arsenic, selenium, and lithium in the southern portion of the Cell B1/C1 (MW-4 and MW-14); by lithium and selenium in the Cell D1 (MW-2) and northern portion of Cell B1 at MW-13 and MW-21. Therefore it appears that groundwater is impacted under the Cell B1 and C1, where ash appears to be below the water table, and also in the northeastern portion of Cell D1. Groundwater is also impacted at MW-8 by lithium, indicating that the groundwater under the western half of the Cell Q is impacted in the southwestern portion of the landfill. In addition, groundwater in the southern portion of Cell A2 (MW-15) is impacted by selenium.

The vertical extent of impacted groundwater is limited to the saturated portion of the weathered bedrock and the upper 10 feet of the bedrock (as measured by MW-2) as the bedrock becomes less permeable with depth. This appears to be limited to the localized groundwater beneath the landfill, and is not connected to the deeper regional aquifer.

5.10 Potential for Offsite Transport

Water quality sampling and preliminary model simulations demonstrate that there is potential for concentrations of lithium and selenium to move offsite at the northeastern and southwestern property boundaries; however in very small mass fluxes. This potential for offsite transport will be confirmed through well installations to fill recently demonstrated data gaps, and these mass fluxes, if present, will be quantified after the model is updated.

Groundwater at the southern and eastern boundaries of the landfill discharge to Leggett and Valmont reservoirs; however mass fluxes of COCs into the reservoirs are very low. Given the relatively minor mass fluxes, COC concentrations are expected to be rapidly diluted by the large volumes of the reservoir. However, these fluxes will be quantified after the data gaps are filled and the groundwater model is updated.

6 Corrective Measures Alternatives

Corrective measure alternatives are described for consideration at the Valmont CCR units to address CCR-related impacts to groundwater. The alternatives are listed and compared with respect to their anticipated effectiveness, ease of implementation, institutional requirements, and time table for implementation per 257.96(c). Additional data inputs are also identified. The time required to complete the remedy (257.96(c)(2)) will be better estimated after the model updates have been made, as described in Section 5.8. Results of additional modeling and final alternative selection will be compiled in a Remedy Selection Report.

6.1 Landfill Corrective Measure Alternatives

Table 6.1-1 provides brief descriptions of eight potential corrective measure alternatives for consideration at the Valmont landfill to address CCR-related impacts to groundwater. The selection of the remedy will take into consideration each of the COCs identified at the landfill and the transport pathways identified in the model. The COCs for the landfill include arsenic, selenium and lithium in one location of the landfill (MW-4 and MW-14); and lithium and selenium at MW-13; lithium only at MW-8; and selenium only at MW-15. Of the alternatives reviewed, most appear to be feasible and will be carried forward for further consideration after the data gaps identified during initial calibration have been addressed. Certain natural site-specific characteristics, such as low groundwater velocities and depth to bedrock are common to multiple alternatives and will factor in the effectiveness, feasibility, and timeliness of each, and therefore warrant additional evaluation, but do not eliminate the alternatives from further considerations. The alternatives are briefly discussed in the sections below.

6.1.1 Alternative 1—Monitored Natural Attenuation

Description. Monitored natural attenuation (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. In addition to adsorption to soil, clay particles, and organic matter, iron and manganese oxides that commonly precipitate down-gradient of CCR disposal sites will, in turn, remove other COIs by adsorption. While model predictions can simulate long-term attenuation using a soil-water partitioning coefficient to estimate adsorption, natural conditions will dictate how COIs migrate through the strata and how much is removed en route. Empirical data are the best indicator of natural attenuation mechanisms, but long-term groundwater monitoring is required. (EPRI, 2015; USEPA, 1999, 2007a, b). Dispersion of COIs should also be fully considered, modeled, and if possible, validated using naturally present ions like chloride and sulfate that are generally not affected by interactions with soil, clay particles, and mineral precipitates.

Considerations. MNA as an alternative is primarily carried forward as a comparative tool to evaluate concentrations of COC without any source control or groundwater treatment.

Additional Data Needs. This alternative will require additional modeling simulations to be run after the data gaps have been resolved.

6.1.2 Alternative 2—Landfill Cover

Description. The existing final cover for all closed cells is a two foot native soil layer that is revegetated with native grasses. Model simulations will be run for multiple final cover systems for the landfill including a geosynthetic cover and an evapotranspirative/water balance cover. These cover systems could be installed to prohibit vertical migration of precipitation into ash to cut off the continued source of COCs to groundwater. After the cover is installed, MNA will occur and groundwater monitoring will continue to evaluate the predicted decrease in COCs leaching to groundwater.

Considerations. Covering the landfill will substantially decrease or eliminate infiltration of surface water through the ash thereby significantly decreasing leaching of COCs into groundwater. This alternative would not address the minimal areas of ash that may remain below the water table. It also may take a long time to meet GPS because the groundwater transmissivity is so low; however this alternative significantly decreases the source of COCs to groundwater.

Additional Data Needs. Different scenarios of the landfill cover will be modeled, including targeting cover in certain portions of the landfill, and varying the recharge rates (including zero recharge) based on cover type and thickness. The model results will determine the most effective cover approach to achieve the decrease in COCs required to meet the relevant criteria in a reasonable timeframe followed by MNA.

6.1.3 Alternative 3—Ash Removal

Description. The ash removal alternative assumes that all or a large portion of ash from the landfill will be excavated and moved offsite for disposal or beneficial use.

Considerations. This alternative would provide source removal, and MNA. MNA will continue after the ash is removed and groundwater monitoring will continue to evaluate the predicted decrease in COCs in groundwater over time. Removal of the ash will take time, and MNA may prove slow to meet GPS because the groundwater transmissivity is so low. However this alternative drastically decreases or removes the source of COCs to groundwater.

Additional Data Needs. Different scenarios of ash removal will be modeled, including ash removal to various depths and from different landfill units.

6.1.4 Alternative 4—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. Reactive material may be media that adsorbs COCs or forms precipitates with COCs to reduce concentrations. The design of a PRB can involve the use of multiple types of reactive material depending on the specific COCs to treat. Depending on the COCs, 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 Valmont include zero valent iron (ZVI) and ZVI-carbon to sorb selenium and arsenic, 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 into a fracture that is created at the desired depth(s) using a series of wells.

Considerations. Space is very limited for construction between the downgradient edge of the ash and the downgradient wells, ranging from 50-70 feet, and the depth to consolidated bedrock ranges from approximately 40-70 feetbelow ground surface. The combination of limited surface area and required depth of trench within that area, may limit feasibility. The trenchless PRB would have fewer space constraints, and has several other potential advantages for this site. 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.

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 contaminate mobilization.

6.1.5 Alternative 5—In-Situ Solidification

Description. Injection of Portland cement or other binding agent to physically bind ash below the localized water table via creation of a monolith. The mixture is intended to encapsulate the source material resulting in the COCs becoming inert. This is accomplished through bench testing of the ash and surrounding soils with potential binding agents to determine the effectiveness of the mixture in immobilizing the COCs. Multiple injection techniques are available depending on the binding agent used.

Considerations. In-situ solidification is a potential option to immobilize COCs in the source below the water table rendering it inert. It may not be sufficient as a sole remedy and may need to be paired with source control or other alternatives.

Additional Data Needs. Additional groundwater flow modeling would be needed to evaluate potential changes to the physical setting. Geochemical, bench-scale, and possible pilot-scale testing will be required to evaluate the optimal binding agent.

6.1.6 Alternative 6—Slurry Wall

Description. Excavation of a trench system coupled with injection of a high slump slurry that when solidified forms an impermeable cutoff wall to prevent groundwater flow from off-site to beneath the landfill and become in contact with ash. The slurry is typically a combination of the excavated trench soils, bentonite, and other potential additives. The slurry mixture forms into a material similar to a soft, clayey soil. This method typically results in a cutoff wall with a permeability ranging from 1x10-6 to 1x10-8 cm/sec.

Considerations. Could have some benefit along the north perimeter of the landfill; however space is limited. The wall may result in groundwater mounding as the gradient changes to flow around the wall. Potential impacts of mounding on the adjacent property to the north of the landfill would need to be evaluated as well as potential mounding impacts to adjacent landfill units to ensure that the change in groundwater flow does not result in additional impacts to groundwater. Also, depth to bedrock is greatest in this area, and slurry wall would need to be keyed into bedrock.

Additional Data Needs. This alternative will require modeling scenarios to be run and would need to be paired with other alternative(s).

6.1.7 Alternative 7—Enhanced Natural Attenuation

Description. The intent of this method is to increase the adsorptive capacity of the CCR within the landfill and, thereby, reduce COC mobility. Iron hydroxide waste materials that contain ferrihydrite, such as the treated coal mine drainage by-product that is readily available, can be used to adsorb many of the contaminants that commonly leach from the CCR and is especially effective in binding arsenic (Ko et al., 2013; Nicomel et al., 2016; Pawlak et al., 2002; Rait et al., 2010). Other metals are also removed by ferrihydrite (Sajih et al., 2014). Although this approach has not yet been used at CCR sites, it has been successfully implemented elsewhere. An advantage to this approach is that the treated mine drainage by-product, which is mostly water, can be easily injected into already deposited CCR materials. Other materials, such as lime and paper mill sludge have also been found to effectively reduce COC levels like arsenic (Amin et al., 2006; Hartuti et al., 2017; Hegazi, 2013; Mathew et al., 2016; Ozturk and Kavak, 2004)..

Considerations. Use of sorbents for in-situ chemical fixation of COCs is a well-established method to reduce COC concentrations in groundwater. However, space downgradient of the landfill and therefore residence/contact time of sorbent in groundwater is limited. Injection of sorbents and changes to redox conditions in groundwater could result in mobilization of additional COCs downgradient of the source.

Additional Data Needs. Geochemical modeling to evaluate reduction in COC concentrations and potential for enhanced mobility of COCs. Bench-scale screening and treatability testing followed by pilot-scale field tests of the most viable material(s)

Table 6.1-1. Summary of the Corrective Measure Alternatives at the Landfill

Alternative	Description	Performance and 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/ Completion of 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
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.	• Accepted as a valid remedial approach. COC concentrations in groundwater should decrease over time if leaching of COCs are reduced or eliminated by source control. • O&M is limited to performance monitoring and would not be reliant on operation or periodic maintenance of engineered systems. • Requires a determination of the existence of sufficient aquifer materials down-gradient of the landfill to attenuate COCs in groundwater within the property boundary. • Transport modeling with slow groundwater flow velocities on site may predict long term presence of elevated COCs in groundwater.	This alternative will require modeling scenarios to be run after it is paired with various other alternatives.	1	No additional impacts	1/5 with source control	Notification to adjacent property owners of COCs in groundwater being transported onto their properties. Landfill will continue to be monitored per state regulations. Selected alternative will require approval from the State.	Yes
Landfill Cover (partial or complete)	Impermeable cap(s) are placed over existing ash landfill cells. Currently D and E cells have a geosynthetic cover detailed in the closure plan; however remaining cells with existing cover could be reinforced to limit recharge to groundwater, thus limiting the ash leachate to groundwater from the unsaturated ash above the water table.	• Complete or partial source control. • Recharge to groundwater and leaching of COCs is reduced or eliminated from the ash above the water table. • COC concentrations in groundwater will decrease over time • Transport modeling with slow groundwater flow velocities on site may predict long term presence of elevated COCs in groundwater.Model simulations may show ash below the water table continuing to be a source of COCs to groundwater.	Additional groundwater modeling scenarios will allow for determination of most effective: • Locations for capping • Cover materials • Cover thickness	2	No additional impacts	1/5	Landfill will continue to be monitored per state regulations. Selected alternative will require approval from the State.	Yes
Ash Source Removal (partial or complete)	Removal of landfill ash.	• Ash removal will result in a reduction or elimination of COCs from the ash leaching to groundwater. • COC concentrations in groundwater should decrease over time after removal of the source. • Complete or partial source control, including ash below the water table. • Transport modeling with slow groundwater flow velocities on site may predict long term presence of elevated COCs in groundwater.	Additional groundwater modeling scenarios will allow for determination of effectiveness of varying the volume and locations of ash removed.	2	No additional impacts	1/4-5	Landfill will continue to be monitored per state regulations. Selected alternative will require approval from the State.	Yes
Pump and Treat	Extraction of groundwater from areas with COC discharging offsite, or newly installed extraction wells targeting the weathered bedrock beneath the ash, and above-ground treatment of COCs.	• Hydraulic capture and treatment for arsenic has been successfully implemented at many sites. • Does not remove the source therefore required into perpetuity, or until the COCs were completely leached out of the ash.	None. Alternative eliminated from further consideration due to low transmissivity of the perched	5	No additional impacts	1/3 with source control	Landfill will continue to be monitored per state regulations. Selected alternative will require approval from the State.	No, transmissivity at the site too low

Table 6.1-1. Summary of the Corrective Measure Alternatives at the Landfill

Alternative	Description	Performance and 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/ Completion of 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
		• Very low transmissive unit, pumping would be very low and purge dry awaiting recharge to pump further.	groundwater unit.					
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 COCs beyond the landfill. • Has been successfully implemented at other sites nationwide. • An evaluation is required to determine if sufficient space is available for construction between the downgradient edge of the ash and the downgradient wells. • Depth to consolidated bedrock (approximately 40-70 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 COCs will be present long term in groundwater.	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 contaminate mobilization. Availability and quantity of material required for the respective application locations will drive feasibility.	3-4	Addition of reagents or adjustment of pH/redox conditions may mobilize other contaminants in groundwater.	1-2/3	EPA application may be required. Landfill will continue to be monitored per state regulations. Selected alternative will require approval from the State.	Yes
In-situ solidification	Injection of Portland cement or other mixture to physically bind ash below the water table via creation of a monolith. Encapsulates source material and immobilizes COCs	• Encapsulates the source of COCs below the water table, and limits further migration • One time implementation with no ongoing O&M • Ease of implementation when compared to some other remedial alternatives, e.g., ash removal. • Contaminants are not destroyed or removed • Modeling simulations may show groundwater mounding potential • Transport modeling with slow groundwater flow velocities on site may predict long term presence of elevated COCs in groundwater. • Modeling may show leaching of COCs still occurring from the ash above the groundwater table which is not bound in cement.	Groundwater flow modeling to evaluate potential changes in physical setting.	3	Groundwater mounding potential	1/2-3	Landfill will continue to be monitored per state regulations. Selected alternative will require approval from the State.	Yes
Slurry Wall	Cutoff wall to prevent perched groundwater flow from off-site to beneath the landfill in contact with ash.	• Reduces recharge of groundwater, contact with CCR and leaching of COCs. • Low maintenance once installed. • Modeling simulations may show groundwater mounding potential	This alternative will require modeling scenarios to be run to evaluate degree of effectiveness and.	3	Groundwater mounding potential	1/additional remedy dependent	Landfill will continue to be monitored per state regulations. Selected alternative will require approval from the State.	Yes

Table 6.1-1. Summary of the Corrective Measure Alternatives at the Landfill

Alternative	Description	Performance and 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/ Completion of 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
		• Feasibility of installation should be evaluated due to depth of bedrock may be too deep as wall must be keyed into bedrock • Modeling simulations may show incomplete diversion of groundwater flow from off-site.	assist in assessing potential for groundwater mounding.					
Enhanced Natural Attenuation	Increase the adsorptive capacity of the CCR within the landfill and, thereby, reduce COC mobility.	• In-situ chemical fixation and air sparging are well established procedures. • Given the ratios of dissolved iron to arsenic in the groundwater, should significantly reduce COC concentrations. • Ease of implementation and O&M (performance monitoring). • Media could be replenished trough additional injection periodically if effectiveness plateaus. • Attains established cleanup goals faster than MNA. • An evaluation is required to determine if sufficient space is available down-gradient to blend adsorptive material into aquifer material to achieve required adsorption efficiencies. • Pilot tests are required to determine if addition of material or adjustment of pH/redox conditions may mobilize COC and/or other contaminants in groundwater downgradient of the source. • Transport modeling with slow groundwater flow velocities on site may predict long term presence of elevated COCs in groundwater.	Geochemical modeling to evaluate reduction in COC concentrations and potential for enhanced mobility of COCs. Bench-scale screening and treatability testing followed by pilot-scale field tests of the most viable material(s). Availability and quantity of material required for the respective application locations will drive feasibility.	4	Addition of reagents or adjustment of pH/redox conditions may mobilize other contaminants in groundwater.	2/2-3	An underground injection permit may be required. Air permits may be required for air exhaust.	Yes

6.2 Corrective Measures Alternatives for the Bottom Ash Impoundments

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.

6.2.1 Alternative 1—CCR Source Removal

Description. Closure of the two CCR impoundments was initiated in April 2018. Removal of CCR, and all areas affected by releases of CCR was complete in September 2018. CCR removal was overseen by a Professional Engineer and confirmation samples were collected from the impoundments after CCR removal 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 completely removed from the former impoundments, and concentrations of CCR constituents are expected to decrease through natural attenuation. All groundwater monitoring at the impoundments since September 2018 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.

6.2.2 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, MNA may be the most appropriate additional alternative to address COCs 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 Section 6.1.1.

Considerations Concentrations of CCR constituents that exceeded GPS (cobalt and molybdenum) are still fairly low at the monitoring wells, and the extent of impacts to groundwater is relatively confined to the area of the peninsula. Additionally, groundwater velocity is very slow in the bedrock beneath and surrounding the impoundments due to the very flat gradient that is consistent with the reservoir level and the low conductivity clays in the subsurface materials (based on slug testing results). Therefore, it may take considerable time for the COCs 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, groundwater flows radially from the impoundments towards the reservoir, and if COCs in groundwater entered the reservoir, concentrations are expected to disperse relatively near the shoreline, based on the low rate of groundwater transport, relatively low COC concentrations and the significant volume of reservoir water.

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 COC 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.

6.2.3 Alternative 3—Enhanced MNA

Description. The CCR Rule recognizes that, "…Typically, any metals in these "subsoils" in excess of background levels are allowed to either naturally attenuate, or are removed by flushing." During closure of the two impoundments, the outlet structures were removed, thereby physically connecting the area of the former impoundments with Leggett reservoir, and depending on the reservoir operating level, providing a conduit for flow from the reservoir into the former impoundment area. During the operating life of the Valmont Generating Station, the level of Leggett reservoir was typically maintained between about 5,222 to 5225 feet, based on the level of the boiler water supply intake. After retirement of coal fired operations, the reservoir level was lowered to approximately 5,210' elevation to facilitate closure of the impoundments. In the future, PSCo expects that the reservoirs will be operated to meet water rights/calls, and that the reservoir level will fluctuate accordingly. As the reservoir levels rise and fall, there will be inflow and outflow from the reservoir to the former impoundment area. During periods when the reservoir level is high enough to inundate the former impoundment area, the ponded water may provide a driving hydraulic head that may increase the rate of groundwater movement away from the impoundment area, effectively flushing the groundwater.

Considerations. As discussed above in 6.2.2, concentrations of CCR constituents that exceeded GPS (cobalt and molybdenum) are fairly low at the monitoring wells, and the extent of impacts to groundwater is relatively confined to the area of the peninsula. Future operation of the reservoirs to meet water rights/calls and associated reservoir level fluctuations are expected to result in inflow and outflow from the reservoir to the former impoundment area. This intermittent inundation of the area and subsequent outflow is expected to increase the rate of groundwater movement away from the impoundment area, effectively flushing the groundwater from the sediments and bedrock and accelerating attainment of the GPS.

Additional Data Needs. None. Reservoirs will be operated as needed to exercise water rights, which will result in flushing of groundwater around the impoundments. 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.

A summary of the corrective measure alternatives for the ash impoundments is presented in Table 6.2-1.

Table 6.2-1. Summary of the corrective measure alternatives for the ash impoundments.

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 2018
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 and are bounded by the adjacent reservoir. • Very slow groundwater flow velocities on site and lack of horizontal or vertical hydraulic head may result in COCs remaining in 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
Enhanced MNA/Flushing	A driving head of clean water source (e.g. stormwater or reservoir water) within the area of the former impoundments would allow infiltration to groundwater, flushing the groundwater and accelerating movement of contaminated groundwater through sediments and bedrock	• Flushing of groundwater is recognized by EPA in the CCR Rule as a valid method remediating residual COCs • Infiltration should force groundwater under the impoundments to move outward and allow the infiltrated water to flush the sediments and bedrock. • Should accelerate reduction of COC concentrations in groundwater since the CCR source has been removed. • Ease of implementation by ongoing operation of reservoirs as needed to exercise water rights. • 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 and are bounded by the adjacent reservoir. • Very slow groundwater flow velocities on site may limit effectiveness of flushing and result in COCs remaining in groundwater indefinitely.	None	1	Potential for residual contamination	1 for implementation/ 2 or 3 for completion	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

7 References

Apex Consulting Services, 2008. Valmont Station, Ash Disposal Facility, Additional Monitoring Well Installation, APEX Job No.: 1-0013.004.01.

Aranz Geo Limited t/a Seequent, 2017. Leapfrog Works Software.

Domenico, P.A. and Schwartz, F.W., 1990. Physical and Chemical Hydrogeology. John Wiley and Sons, New York, 824 p.

Environmental Simulations Inc., 2017. Groundwater Vistas Version 7 Software.

Freeze, R.A., and Cherry, J.A., 1979. Groundwater. Englewood Cliffs, NJ, Prentice-Hall, 604 p.

Kumar and Associates, 2018. Ash Disposal Project, Xcel Energy Valmont Power Station, February 8, 2018.

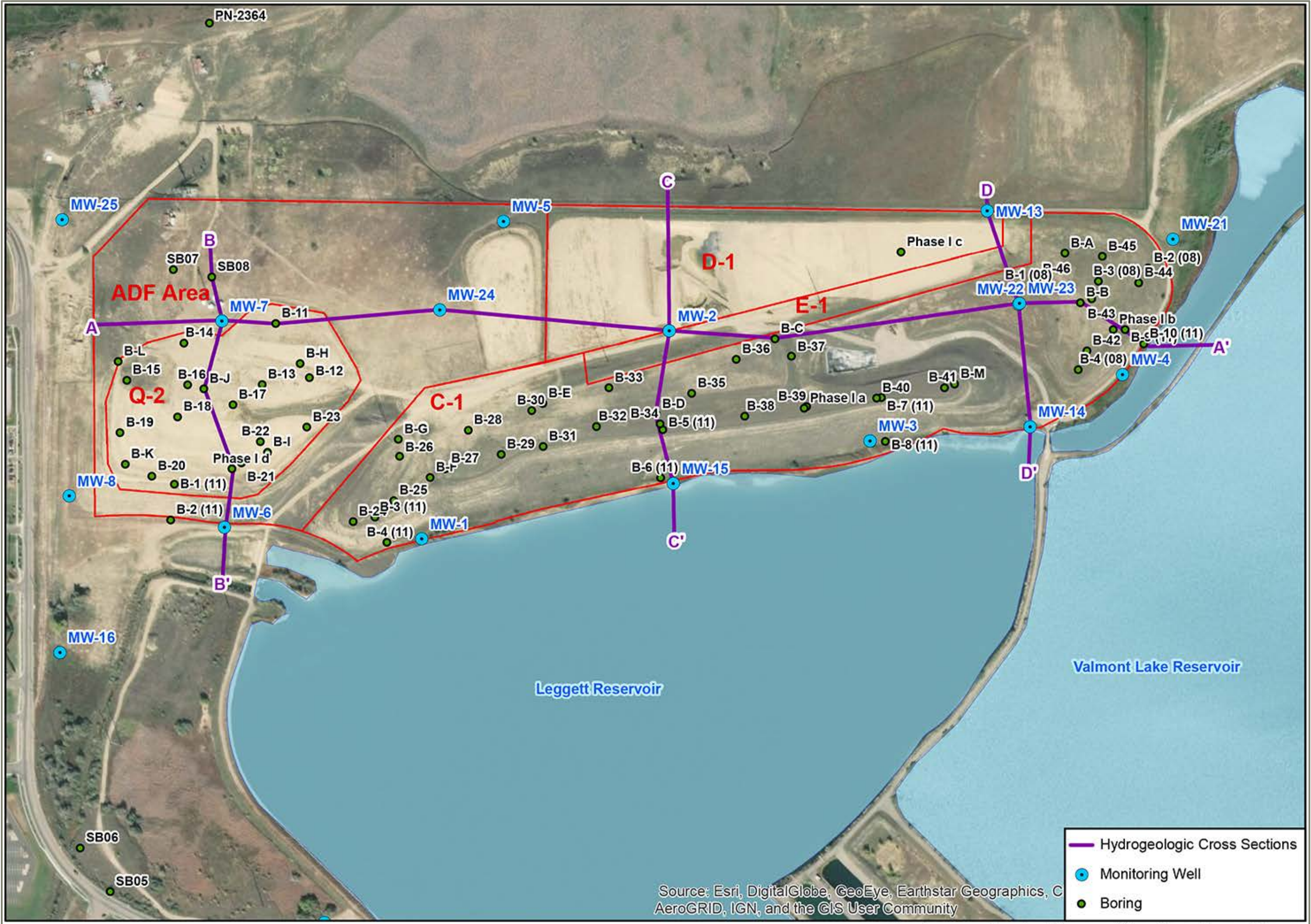
Manger, G.E., 1963. Porosity and Bulk Density of Sedimentary Rocks. Geological Survey Bulletin 1144-E.

Niswonger, R.G., Panday, S., and Motomu, I., 2011. MODFLOW-NWT, A Newton Formulation for MODFLOW-2005. U.S. Geological Survey Techniques and Methods, 6-A37, 44p.

Zheng, C., and Wang, P.P., 1999. MT3DMS: A Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion and Chemical Reactions of Contaminants in Groundwater Systems. Prepared for the U.S. Army Corps of Engineers.

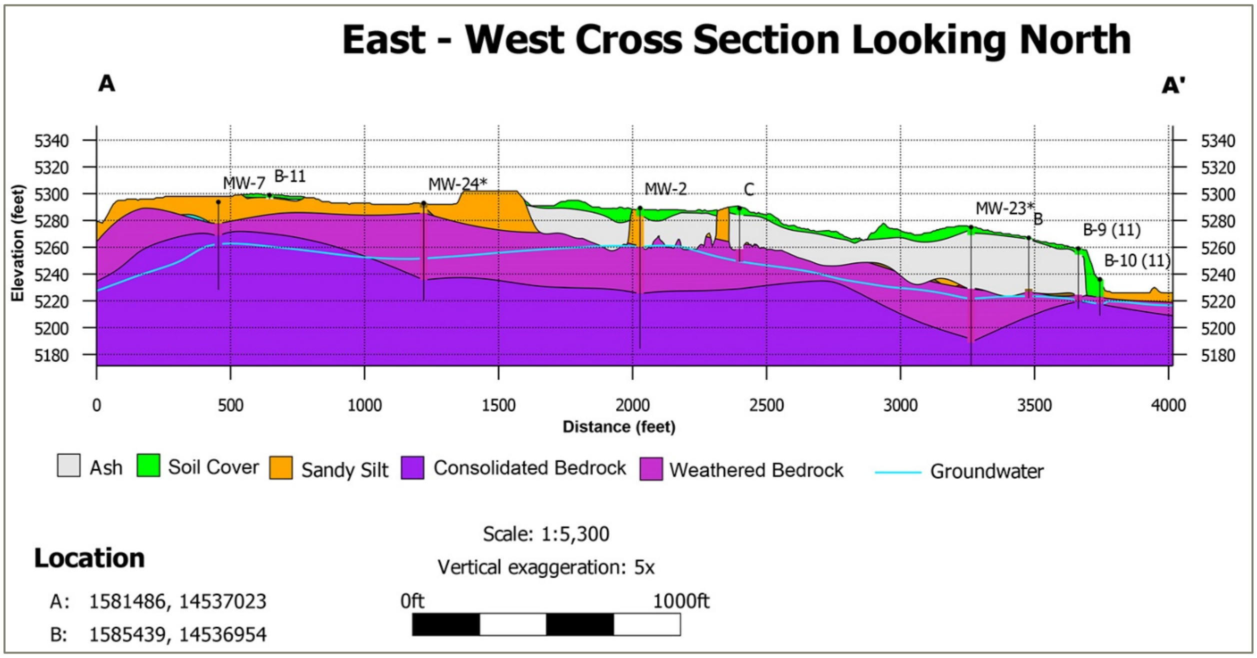
Appendix A.

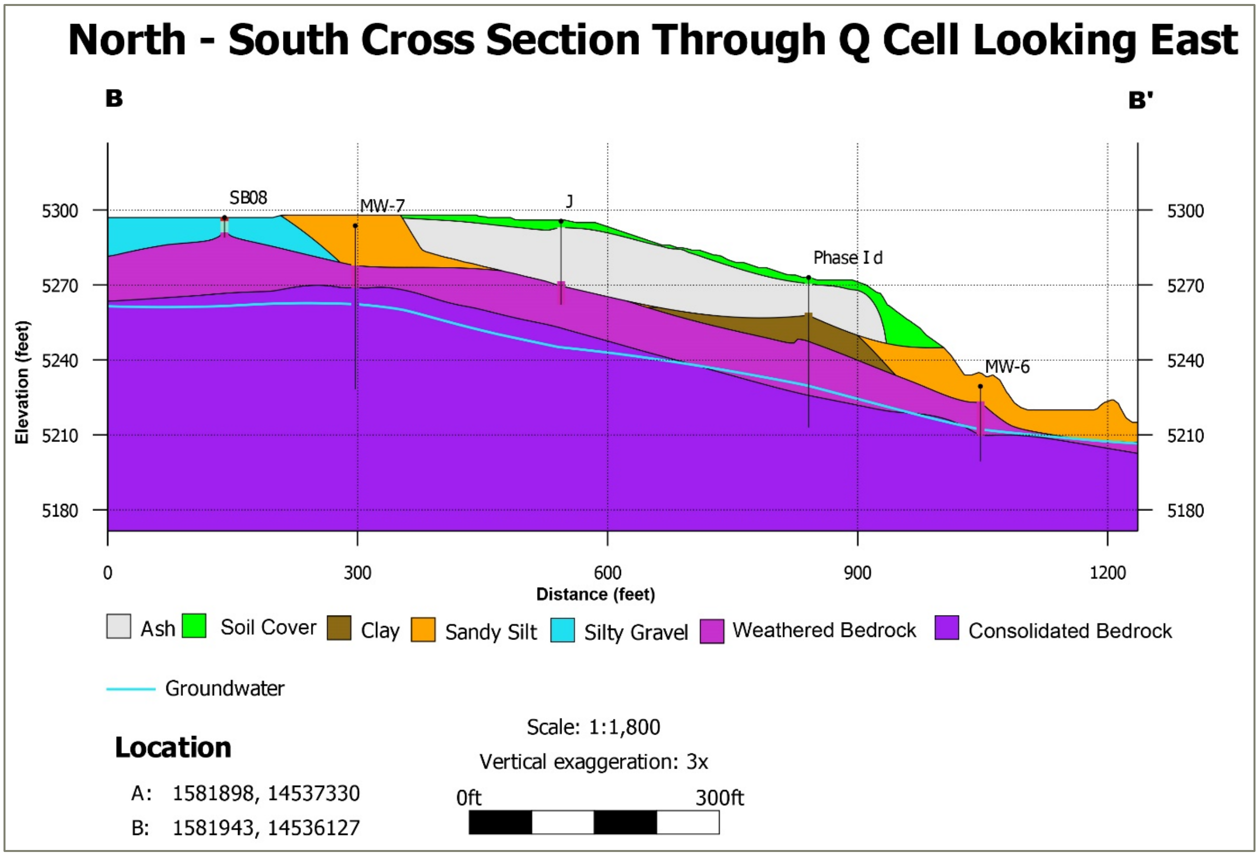
Landfill Geologic Cross-Sections

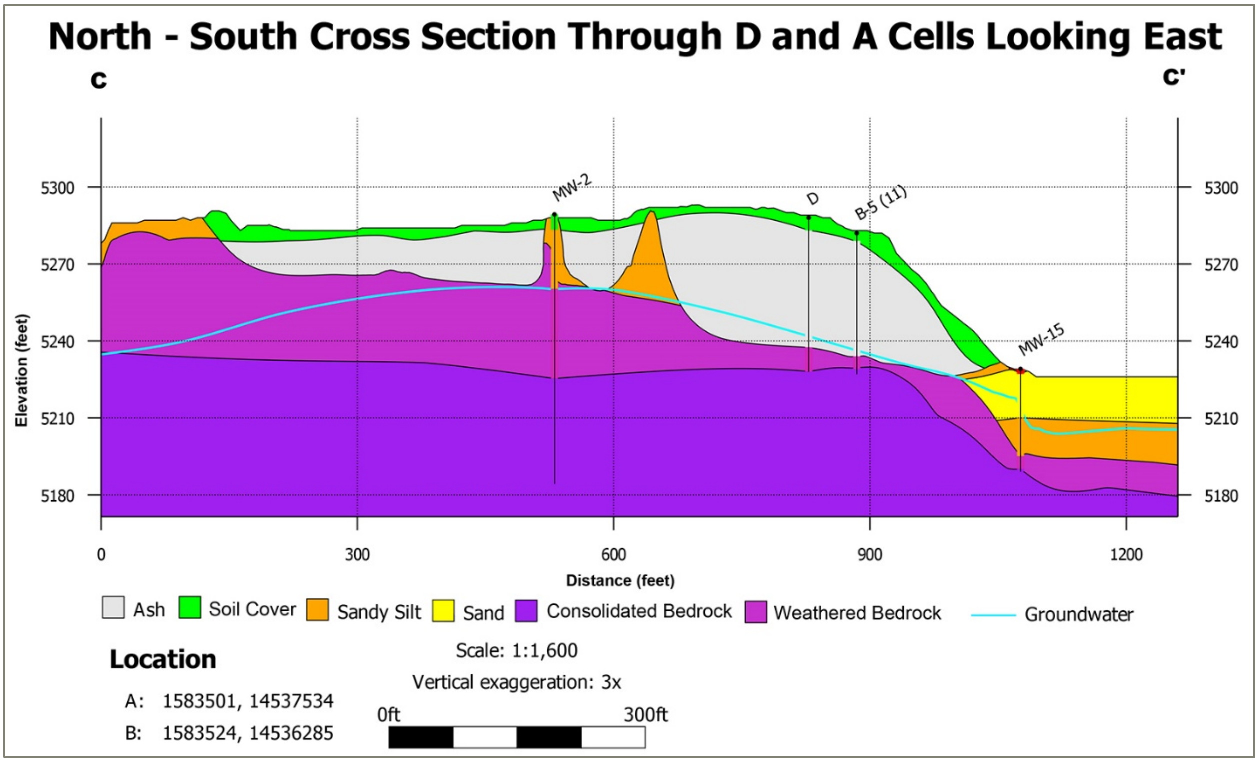


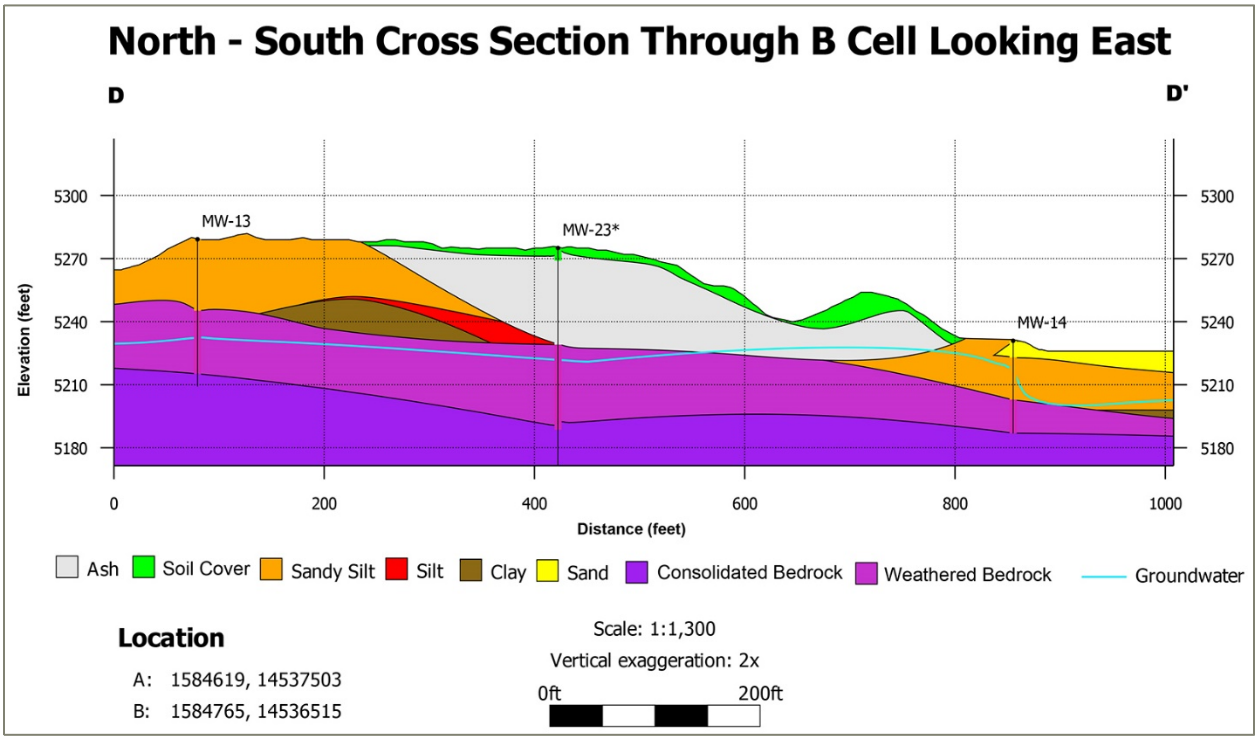
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, C
AeroGRID, IGN, and the GIS User Community

Hydrogeologic Cross Section Locations


East - West Cross Section Looking North
A
A'
MW-7
B-11
MW-24*
MW-2
C
MW-23*
B
B-9 (11)
B-10 (11)
5340
5320
5300
5280
5260
5240
5220
5200
5180
Elevation (feet)
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (feet)
Ash
Soil Cover
Sandy Silt
Consolidated Bedrock
Weathered Bedrock
Groundwater
Location
A: 1581486, 14537023
B: 1585439, 14536954
Scale: 1:5,300
Vertical exaggeration: 5x
0ft
1000ft


North - South Cross Section Through Q Cell Looking East
B
B'
SB08
MW-7
J
Phase I d
MW-6
5300
5270
5240
5210
5180
Elevation (feet)
0
300
600
900
1200
Distance (feet)
Ash
Soil Cover
Clay
Sandy Silt
Silty Gravel
Weathered Bedrock
Consolidated Bedrock
Groundwater
Location
A: 1581898, 14537330
B: 1581943, 14536127
Scale: 1:1,800
Vertical exaggeration: 3x
0ft
300ft


North - South Cross Section Through D and A Cells Looking East
C
C'
MW-2
D
B-5 (11)
MW-15
Elevation (feet)
5300
5270
5240
5210
5180
0
300
600
900
1200
Distance (feet)
Ash
Soil Cover
Sandy Silt
Sand
Consolidated Bedrock
Weathered Bedrock
Groundwater
Location
A: 1583501, 14537534
B: 1583524, 14536285
Scale: 1:1,600
Vertical exaggeration: 3x
0ft
300ft


North - South Cross Section Through B Cell Looking East
D
D'
MW-13
MW-23*
MW-14
Elevation (feet)
5300
5270
5240
5210
5180
0
200
400
600
800
1000
Distance (feet)
Ash
Soil Cover
Sandy Silt
Silt
Clay
Sand
Consolidated Bedrock
Weathered Bedrock
Groundwater
Location
A: 1584619, 14537503
B: 1584765, 14536515
Scale: 1:1,300
Vertical exaggeration: 2x
0ft
200ft

Appendix B.

Boring Data

Geotechnical boring and monitoring well boring lithology data that was used to develop the geologic model

Boring ID	Source File Name	Citation
SB05	HDR_2017_SB_Boring_Logs_Map.pdf	HDR, 2016. Valmont Station Background Soil Study. Prepared for Xcel.
SB06		
SB07		
SB08		
B-11	Kumar_borings_Map-logs_2018.pdf	Kumar and Associates, 2018. Valmont Ash Disposal Project, Boulder, Colorado—Exploratory Boreholes. Prepared for Xcel.
B-12		
B-13		
B-14		
B-15		
B-16		
B-17		
B-18		
B-19		
B-20		
B-21		
B-22		
B-23		
B-24		
B-25		
B-26		
B-27		
B-28		
B-29		
B-30		
B-31		
B-32		
B-33		
B-34		
B-35		
B-36		
B-37		
B-38		
B-39		
B-40		
B-41		
B-42		
B-43		

Boring ID	Source File Name	Citation
B-44		
B-45		
B-46		
MW-4	Valmont_Boring_and_MW_Install_logs	Apex Consulting Services, Inc., 2008. Valmont Station, Ash Disposal Facility, Additional Monitoring Well Installation, APEX Job No.: 1-0013.004.01. Prepared for Xcel.
MW-5		
MW-6		
MW-7		
MW-8		
MW-1	Valmont Ash Disposal Survey—5-24-2016[MOD]	Xcel Energy, 2002. Valmont Station Ash Disposal Facility Monitoring Well Installation report. Prepared by Xcel Energy.
MW-2		
MW-3		
MW-13	Valmont Boring Logs.pdf	HDR, 2019. Valmont CCR Well Installation Report.
MW-14		
MW-15		
MW-16		
MW-17		
MW-18		
MW-19		
MW-20		
MW-21		
MW-22		
MW-24		
MW-25		
B-1 (11)	Kumar_borings_B1_B10_2011.pdf	Kumar and Associates, 2011. Ash Disposal Facility, Valmont Station Logs of Exploratory Borings. Prepared for Xcel.
B-2 (11)		
B-3 (11)		
B-4 (11)		
B-5		
B-6		
B-7		
B-8		
B-9		
B-10		
B-1 (08)	Kumar August 2008 Letter report.pdf	Kumar and Associates, 2008. Geotechnical Engineerint Study, Valmont Ash Disposal Facility, 63rd Street and Arapahoe Road, Boulder, Colorado. Prepared for Xcel. August 15, 2008.
B-2 (08)		
B-3 (08)		
B-4 (08)		
MW-1*	Voluntary-cleanup-plan-application-1-201303291210.pdf	Casey Resources, 2010 “Voluntary Cleanup Plan Application for the Valmont Butte Property, 3000 North 63rd Street, Boulder, Colorado” dated June 2010.
MW-2*		
MW-3*		
MW-4*		
B-A	Valmont Boring Logs.pdf	HDR, 2019. Valmont Draft Boring Logs.
B-B		

Boring ID	Source File Name	Citation
B-C		
B-D		
B-E		
B-F		
B-G		
B-H		
B-I		
B-J		
B-K		
B-L		
B-M		

*This study provides some lithology data and the screened interval; however full boring logs are not provided nor survey data. Elevations are unknown and water level data is limited to data collected years ago.