CLOSURE PLAN

NUCLA STATION ASH DISPOSAL FACILITY CLOSURE PLAN

Tri-State Generation and Transmission Association, Inc.

Submitted To: Tri-State Generation and Transmission Association, Inc.
1100 West 116th Avenue
Westminster, Colorado 80234

Submitted By: Golder Associates Inc.
44 Union Boulevard, Suite 300
Lakewood, Colorado 80228

COLORADO LICENSED
JASON E. OBERMEYER
40294
PROFESSIONAL ENGINEER
Jason Obermeyer
10.13.16

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1.0 INTRODUCTION

Tri-State Generation and Transmission Association, Inc. (Tri-State) owns and operates the Nucla Generating Station, a 100-megawatt circulating fluidized bed coal-fired electric generating plant located near the town of Nucla, Colorado. Tri-State disposes of coal combustion residuals (CCRs) from the Nucla Generating Station in an existing Tri-State-owned CCR landfill, the Nucla Station Ash Disposal Facility (the Facility), which is located approximately 5.5 miles southeast of the Nucla Generating Station. Within the 81.65-acre property, the CCR disposal footprint comprises approximately 61 acres (see Figure 1).

Golder Associates Inc. (Golder) has prepared this closure plan for the Facility on behalf of Tri-State to serve as the initial written closure plan required under 40 CFR 257.102(b). The Facility will be closed with CCRs left in place in accordance with the requirements of 40 CFR 257.102(d). This closure plan includes a narrative description of the measures that will be taken for closure of the Facility, a description of the final cover system that will be constructed for closure of portions of the Facility that have not yet been closed, a description of the methods and procedures that will be used to install the final cover system, an estimate of the maximum inventory of CCRs that will be disposed in the Facility, an estimate of the largest area of the Facility that will require installation of a final cover system at any time during its active life, and a schedule for completing closure activities at the Facility.

2.0 NARRATIVE DESCRIPTION OF FACILITY CLOSURE

Within the 61-acre CCR disposal footprint, a final cover system has already been constructed over areas totaling approximately 39 acres where CCR placement has reached the final grades. Of these closed areas, approximately 22 acres are on sideslopes around the perimeter of the Facility and approximately 17 acres are on the top surface across the northern half of the Facility (see Figure 1). Soil and rock has been temporarily stored atop the final cover system across much of the closed top surface.

Approximately 22 acres of the Facility remain active CCR placement areas. These areas will be closed as they reach the final grades using two different methods. One method is applicable to the remaining sideslope areas, which total approximately 4 acres, and the other method is applicable to the remaining top surface areas, which total approximately 18 acres (see Figure 1).

The closure method that is applicable to the remaining sideslope areas involves installation of the final cover system around the perimeter of the Facility in areas where CCR placement has not yet reached the final grades. Containment berms will be placed progressively ahead of CCR placement for control of run-off from the active portion of the landfill (refer to the Facility's run-on and run-off control system plan). The containment berms will be constructed of suitable earthen materials and with a sufficient thickness perpendicular to the sideslope such that they can also serve as the final cover system for underlying CCRs. This method has been used throughout the active life of the Facility to achieve closure of sideslope areas totaling approximately 22 acres (see Figure 1).

The closure method that is applicable to the remaining top surface areas involves installation of the final cover system using conventional soil placement techniques for gently sloping areas. Prior to installation of the final cover system in these areas, excess material from the soil and rock stockpiles will be relocated from the northern half of the Facility to achieve the final grades across the southern half of the Facility. The thickness and soil composition of the existing final cover system on the top surface across the northern half of the Facility will be verified following relocation of the excess material from the soil and rock stockpiles.

3.0 FINAL COVER SYSTEM

The final cover system for closure of the remaining active areas will conform to one of the following designs, both of which comply with 40 CFR 257.102(d)(3):

- *Conventional Cover System* – This design meets the requirements for the prescription final cover system as described under 40 CFR 257.102(d)(3)(i). It will be used only for closure of top surface areas. The design of the conventional cover system is described in detail in Section 3.1.
- *Water Balance (Evapotranspiration) Cover System* – This design meets the requirements for an alternative final cover system as described under 40 CFR 257.102(d)(3)(ii). It will be used for closure of sideslope areas (for which the final cover system will be composed of containment dikes placed progressively ahead of CCR placement), for closure of top surface areas, or for both purposes. The design of the water balance cover system is described in detail in Section 3.2.

The final cover system will be installed using conventional soil placement techniques and common earthmoving equipment, such as bulldozers, haul trucks, scrapers, motor graders, and/or compactors. Soils that are suitable for use in the final cover system will be obtained from select on-site stockpiles. Disruption of the integrity of the final cover system will be inhibited by compacting the underlying CCRs to establish a firm and unyielding subgrade prior to installation of the final cover system and by establishing a slope of approximately 2 percent across the top surface to provide positive drainage, limit ponding, and mitigate the potential effects of settling and subsidence. Final cover soil placement, moisture conditioning, compaction, and testing will be in accordance with the engineering design and operations plan/report for the Facility. Monitoring and/or verification of final cover system installation will be conducted to help ensure that the constructed final cover system meets the design requirements. The final cover system will be vegetated using a seed mix and procedures that meet the requirements of the engineering design and operations plan/report.

3.1 Conventional Cover System

The conventional cover system will consist of the following layers, from bottom to top:

- An infiltration layer consisting of a minimum of 18 inches of earthen material having a permeability (i.e., hydraulic conductivity) less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than 1×10^{-5} centimeters per second (cm/s), whichever is less.
- An erosion layer consisting of a minimum of 18 inches of earthen material that is capable of sustaining native plant growth.

Regulations pertaining to the Facility at the time of construction provided for a natural lithologic alternative to an engineered liner system in light of the favorable geologic setting, dry climate, depth to useable groundwater, and waste characteristics. The natural lithology underlying the Facility consists predominantly of sandstone. The saturated vertical hydraulic conductivity determined from falling-head permeability testing of a sandstone specimen obtained from a depth of 20 feet in close proximity to the Facility was 1.3 x 10^{-5} cm/s (GeoTrans, Inc. 2002), which exceeds 1 x 10^{-5} cm/s. Thus, the requirement for the infiltration layer to have a permeability less than or equal to 1 x 10^{-5} cm/s will apply. Unsaturated flow modeling performed using HYDRUS-1D indicated that percolation through the conventional cover system (i.e., net infiltration) is expected to be negligible. Details of the unsaturated flow modeling are provided in Appendix A[1].

3.2 Water Balance Cover System

The water balance cover system will consist of a water storage layer composed of a minimum of 30 inches of earthen material that is capable of storing moisture and sustaining native plant growth. The water balance cover system designed for the Facility was developed in accordance with the "Final Guidance Document: Water Balance Covers in Colorado" (CDPHE 2013). Unsaturated flow modeling performed using HYDRUS-1D indicated that percolation through the water balance cover system (i.e., net infiltration) is expected to be negligible. Details of the unsaturated flow modeling are provided in Appendix A.

As described in Appendix A, the water storage layer will provide a reduction in infiltration that is equivalent to that provided by the infiltration layer in the conventional cover system, in accordance with 40 CFR 257.102(d)(ii)(A). Additionally, the soils that will be used for the water storage layer in the water balance cover system will be derived from the same on-site stockpiles and placed using the same methods that will be used for the erosion layer in the conventional cover system. Thus, the water storage layer will provide protection from wind and water erosion that is equivalent to that provided by the erosion layer in the conventional cover system, in accordance with 40 CFR 257.102(d)(ii)(B).

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[1] An erosion layer thickness of 9 inches is conservatively assigned in the unsaturated flow modeling. However, an erosion layer thickness of 18 inches is provided in the conventional cover system design for protection of the underlying infiltration layer against freeze/thaw damage.

4.0 CLOSURE ESTIMATES

4.1.1 Maximum CCR Inventory Estimate

Golder used Autodesk Civil 3D to estimate the volume difference between pre-development topographic information (provided by Tri-State) and the maximum permitted grades (provided by Tri-State). Estimated soil volumes associated with the final cover system and excess stockpiled materials to be contained in the Facility were then subtracted. The resulting estimate of the maximum CCR inventory to be contained in the Facility (i.e., at closure) is 4.0 million cubic yards.

4.1.2 Largest Area Requiring Final Cover

The current active area is expected to be the largest area requiring installation of a final cover system during the remainder of the Facility's active life. As the sideslopes increase in height around the perimeter of the southern half of the Facility, the extent of the active area will decrease. The current active area comprises approximately 22 acres.

5.0 CLOSURE SCHEDULE

When placement of CCRs and excess stockpiled soil and rock has reached the final grades, closure activities will commence within 30 days of the known final receipt. Notification of intent to close the Facility will be placed in the operating record prior to the commencement of closure activities. CDPHE and Montrose County will also be notified in accordance with the engineering design and operations plan/report for the Facility. At this time, closure activities are expected to commence no later than January 30, 2023. Phased closure of areas where placement of CCRs has reached the final grades prior to the known final receipt may be performed during the active life of the Facility.

Closure activities will be completed within 180 days after commencement of closure activities, although this timeframe may be extended in accordance with 40 CFR 257.102(f)(2)(i), with approval from CDPHE and Montrose County. Closure activities to be completed during this time include preparation of bid documents and solicitation of contractors' bids (2 months estimated duration), installation of the final cover system (3 months estimated duration), and preparation and submittal of as-built documents and certifications as required under 40 CFR 257.102(f)(3) and the engineering design and operations plan/report for the Facility (1 month estimated duration). The year in which closure activities will be completed is estimated to be 2023.

Notification that closure of the Facility has been completed will be placed in the operating record within 30 days of the completion of closure activities. This notification will include certification by a qualified professional engineer that closure has been completed in accordance with the closure plan. Following closure of the Facility, Tri-State will record a notation on the deed to the property (or another instrument that is normally examined during title search) that will notify potential purchasers of the land that the land has been used as a CCR landfill and its use is restricted under post-closure care requirements described in the Facility's post-closure care plan. Within 30 days of recording the notation, notification will be placed in the operating record and CDPHE and Montrose County will be notified that the notation has been made.

6.0 CERTIFICATION

The undersigned attest to the completeness and accuracy of this closure plan and certify that the closure plan meets the requirements of 40 CFR 257.102(b). The undersigned further certify that the design of the final cover system (the conventional cover system and the water balance cover system) meets the requirements of 40 CFR 257.102(d)(3).

GOLDER ASSOCIATES INC.

Jason Obermeyer

Jason Obermeyer, PE
Associate and Senior Engineer

Tammy Rauen

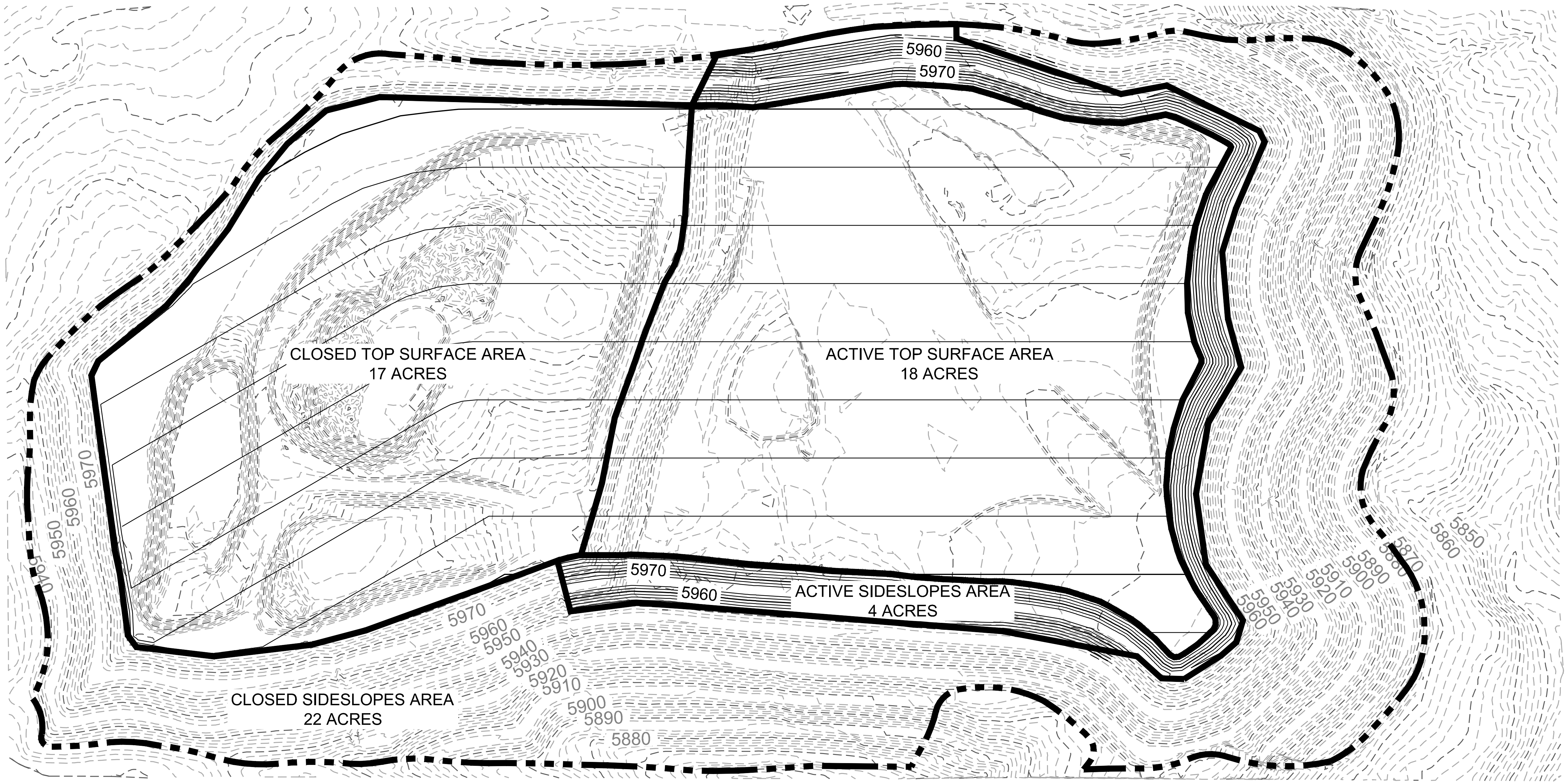
Tammy Rauen, PE
Senior Project Engineer

7.0 REFERENCES

Colorado Department of Public Health and Environment, 2013. Water Balance Covers in Colorado. Final guidance document. March 2013.

GeoTrans, Inc., 2002. Engineering Design and Operations Report, Nucla, Colorado Ash Disposal Facility. Prepared on behalf of Tri-State Generation and Transmission Association, Inc. March 2002.

FIGURE

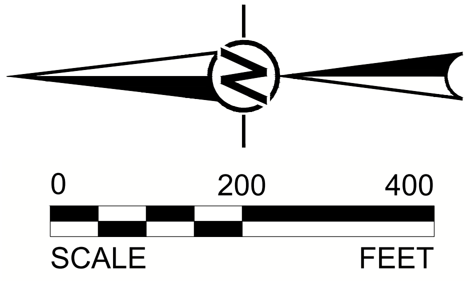


LEGEND

5950	EXISTING GROUND TOPOGRAPHY (SEE REFERENCE 1)
5960	MAXIMUM CLOSURE GRADES
▬	CLOSURE AREA DELINEATIONS
▬ ▪ ▪ ▪ ▬	APPROXIMATE ASH DISPOSAL FOOTPRINT LIMIT (SEE REFERENCE 2)

REFERENCES

1. EXISTING GROUND TOPOGRAPHY WAS PROVIDED BY TRI-STATE GENERATION AND TRANSMISSION ASSOCIATION, INC. TOPOGRAPHY IS A COMPOSITE BASED ON SURVEYS PERFORMED BY DEL-MONT CONSULTANTS BETWEEN 2008 AND 2015.
2. APPROXIMATE ASH DISPOSAL FOOTPRINT LIMIT PROVIDED BY TRI-STATE GENERATION AND TRANSMISSION ASSOCIATION, INC.



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Golder Associates

TRI-STATE GENERATION AND TRANSMISSION ASSOCIATION, INC.
NUCLA STATION ASH DISPOSAL FACILITY
CLOSURE AREAS

FIGURE 1

APPENDIX A
ASSESSMENT OF FINAL COVER HYDRAULIC PERFORMANCE

REPORT

ASSESSMENT OF FINAL COVER HYDRAULIC PERFORMANCE

Tri-State Generation and Transmission Association, Inc.
Nucla Station Ash Disposal Facility

Submitted to: Tri-State Generation and Transmission Association, Inc.
1100 W. 116th Avenue
Westminster, Colorado 80234

Submitted by: Golder Associates Inc.
44 Union Boulevard, Suite 300
Lakewood, Colorado 80228

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1.0 INTRODUCTION

Tri-State Generation and Transmission Association, Inc. (Tri-State) is planning for the eventual closure of the Nucla Station Ash Disposal Facility (Site), located near Nucla in Montrose County, Colorado. The Nucla Station Ash Disposal Facility accepts fly ash, bottom ash, slag, pond sediments, and other non-hazardous wastes from Tri-State-owned Nucla Generating Station, a coal-fired generation station located approximately 5.5 miles northwest of the Site. As part of the closure plan for the Site, approximately 4 acres of final cover remains to be placed on the ash landfill sideslopes and 18 acres of final cover remains to be placed on the top plateau area. Two final cover design options have been proposed for the Site: 1) a prescriptive cover system, and 2) an evapotranspiration cover. This report presents the analysis and evaluation of predicted unsaturated flow and net infiltration through each cover, performed as a comparative assessment of hydraulic performance. Net infiltration is defined as the water that infiltrates deep into the soil cover and ash waste material and is not returned to the atmosphere through evaporation or transpiration.

2.0 INFILTRATION MODEL CODE AND SETUP

Unsaturated flow modeling was performed using the one-dimensional soil-atmosphere modeling software HYDRUS-1D (Simunek et al. 2013). The HYDRUS-1D program is a finite element model which numerically solves Richards' equation for variably-saturated water flow. The HYDRUS-1D model code is widely accepted by the professional community for evaluating variably saturated flow and solute transport processes.

Cover model simulations were set up to be consistent with the final cover requirements of Colorado's Subtitle D Solid Waste Regulations – 6 CCR 1007-2, Part 1, "Regulations Pertaining to Solid Waste Sites and Facilities." The model profile for the prescriptive cover system and ash landfill consists of a 9-inch erosion layer capable of sustaining native plant growth, 18-inch infiltration (barrier) layer with saturated vertical hydraulic conductivity no greater than 1 x 10^{-5} cm/s[1], and 24-inch ash waste layer. This profile also meets the prescriptive final cover requirements of the Environmental Protection Agency's 40 CFR Part 257, Subpart D, "Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments." The model profile for the evapotranspiration cover, also known as a "water balance" or "monolithic" cover, and ash landfill consists of a 30-inch water storage layer[2] and a 24-inch ash waste layer. The 30-inch water storage layer thickness was selected for consistency with the Final Guidance Document: Water Balance Covers in Colorado (Colorado Department of Public Health and Environment 2013)[3].

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[1] The CDPHE-approved engineering design and operations plan/report provides for a natural lithologic alternative to an engineered liner system in light of the favorable geologic setting, dry climate, depth to useable groundwater, and waste characteristics. Historical permeability testing of the predominant lithologic material underlying the Site indicates a saturated vertical hydraulic conductivity in excess of 1 x 10^{-5} cm/s.

[2] The same on-Site materials and placement methods that would be used for the erosion layer in the prescriptive cover will be used for the water storage layer in the evapotranspiration cover, since 40 CFR Part 257, Subpart D requires the alternative cover system to provide equivalent protection from wind or water erosion to the prescriptive cover system.

[3] Soil samples collected at the Site consistently fall within the acceptable zone for a 30-inch water storage layer, as prescribed in the Final Guidance Document: Water Balance Covers in Colorado (Colorado Department of Public Health and Environment 2013).

3.0 INFILTRATION MODEL INPUTS

This section summarizes soil cover and ash waste material properties, vegetation properties, the climate record, initial conditions, and boundary conditions used for the unsaturated flow modeling and net infiltration analysis.

3.1 Material Properties

Material properties were developed for the modeling using geotechnical laboratory test results from previous studies conducted at the Nucla Station Ash Disposal Facility. Based on index test results, two soil samples collected from on-site stockpiles in 2012 were considered representative of overburden soils at the Site and appropriate for use in the final cover. Overburden soils will be used either as an erosion layer and/or infiltration layer in the prescriptive cover system or as a water storage layer in the evapotranspiration cover. Two representative soil samples (TP-1 and TP-3B) were used in the infiltration modeling to help bracket the range of hydraulic performance for different on-site soils. Other soil samples from the on-site stockpiles generally fall between the two representative soil samples, in terms of particle-size distribution.

Additional testing was conducted on the two samples, including flexible-wall permeability testing, to estimate the saturated vertical hydraulic conductivity of the soils, and soil water characteristic curve (SWCC) testing, to estimate the unsaturated hydraulic properties of the soils. The soil water characteristic curve provides the lab-measured relationship between soil suction and volumetric water content, which is then used to estimate the relationship between volumetric water content and unsaturated hydraulic conductivity.

The SWCC laboratory data and model fit for the cover material (TP-1 at 85% and 92% compaction relative to the standard Proctor maximum dry density and TP-3B at 85% compaction relative to the standard Proctor maximum dry density) are provided in Figure A-1. As shown in Figure A-1, the three tests of the cover material display a bimodal shape with two curved sections between the residual water content and saturated water content, which are separated by an inflection point approximately between a volumetric water content of 0.22 and 0.28. Given the bimodal shape of the Site SWCC lab data, the Durner model (Durner 1994), a multimodal, van Genuchten-Mualem-type function (van Genuchten 1980), was used to fit the SWCC data and estimate the unsaturated hydraulic characteristics of each soil cover sample.

The hydraulic properties of the ash waste sample (LF Ash) were estimated based on the particle-size distribution of a sample collected in 2015 (USCS classification of silty sand, USDA soil texture of loamy sand) and the default properties for loamy sand from the Rosetta database (Schapp et al. 2001). In contrast to the cover material, the ash waste material displays a unimodal shape in Figure A-1, since the default Rosetta properties for loamy sand were used for this sample. The Durner model fit to the loamy sand data was constrained to a unimodal, van Genuchten fit (van Genuchten 1980) by setting the Durner weighting factor, w_2, to zero. Table A-1 summarizes the hydraulic properties of the soil cover samples and ash waste sample used for modeling infiltration.

3.2 Vegetation Data

The surrounding plant communities to the Nucla Station Ash Disposal Facility include Colorado-Plateau Piñon-Juniper Shrubland, Inter-Mountain Basin Big Sagebrush Shrubland and Inter-Mountain Basin Mixed Salt Desert Scrub. The reclamation goals are to establish vegetation; however, the resulting species composition and community structure will likely be different than pre-disturbance conditions. The Natural Resource Conservation Service (NRCS) U.S. Department of Agriculture (USDA), Norwood, Colorado, recommended a reclamation seed mix consisting of 40% thickspike wheatgrass (Elymus lanceolatus), 40% crested wheatgrass (Agropyron cristatum), and 20% pubescent wheatgrass (Thinopyrum intermedium spp barbulatum). The Site will be revegetated with this or another CDPHE-approved seed mix at each phase of cover placement; however, over the long-term, native shrub and forb species are expected to be volunteered onto the cover from the surrounding undisturbed landscape by the wind or local wildlife. Thus, a deep-rooted perennial shrubland community was also evaluated as part of the modeling.

For the soil-atmosphere model, four inputs are required to simulate transpiration by local vegetation including leaf area index (LAI), root distribution with depth, total root depth, and water uptake parameters (critical suction limits), which define the relationship of transpiration with soil suction. Vegetation inputs were developed for the reclamation seed mix and a shrubland plant community. The grass vegetation inputs were used for simulations of the prescriptive cover system and the shrubland vegetation inputs were used for simulations of the evapotranspiration cover. This assumes the shrubs would be discouraged through maintenance in order to reduce root intrusion to the infiltration layer for the prescriptive cover.

Leaf area index and canopy cover were estimated based on professional judgment and literature values. The LAI distribution describes the ratio of leaf surface area to the soil surface area. HYDRUS requires an annual LAI distribution. The growing season for the site was estimated to last about 139 days between mid-May to late-September. LAI was modified for a grass-dominated reclamation plant community. The range in total LAI for sagebrush communities according to Clark and Seyfried (2002) is 0.03 to 1.10. These ranges are for established native sagebrush communities. Thus, conservative values near 0.50 were chosen as the peak LAI since the reclamation community establishment will likely lag behind the native vegetation communities. The annual LAI distribution selected for the Site assumes a range from about 0.02 in the winter to 0.50 during the peak growing season. The LAI increases rapidly in May when the average prevailing air temperatures climb over 40°F (biological zero) and decreases abruptly in late September when the average daily air temperatures fall below 40°F. Cool season grasses are effective in the spring and fall, whereas evergreen shrubs are effective in the winter. Maximum LAI for the grass-dominated community was increased to 0.52 and winter values were reduced to near zero. The annual LAI distributions for grass and shrubland used in the simulations are provided in Figure A-2.

The root density function allocates water removal from the model domain. The rooting depth for the grass simulations were set at 200 cm (6.6 feet), with a cumulative distribution having 50% of the roots above 15 cm (0.5 feet) (Jackson et al. 1996). Inputs for the shrubland community were modeled after big sagebrush (Artemisia tridentata) as described in Ryel et al. (2002). The root density function and the maximum rooting depth for the shrubland simulations were truncated at the base of the cover at 76 cm (2.5 feet), with a cumulative distribution having 50% of the roots above 21 cm (0.7 feet). The grass and shrubland cumulative root distributions used in the simulations are provided in Figure A-3.

The water uptake parameters (critical suction head limits) include wilting point, initial transpiration, decreased transpiration, and transpiration rate. Wilting point is typically about 15 bars for crop plants and 25 to 30 bars for prairie grasses, and may exceed 60 bars for some desert shrubs. The default critical suction values for pasture in HYDRUS (Wesseling 1991) were used for the grass simulations. The critical suction head limits selected for the shrubland simulations included 30,000 cm (30 bars) for wilting point and 10 cm (0.01 bars) as the point where transpiration starts. The decreased transpiration for shrubland was set at 500 cm (0.5 bars) and 1,000 cm (1 bar) for the upper and lower transpiration rates of 0.10 and 0.96 cm/day (Ryel et al. 2002).

3.3 Climate Data

A long-term climate record was developed for the Nucla Station Ash Disposal Facility to provide inputs of precipitation, potential evaporation, and potential transpiration for the soil-atmosphere model. A long-term climate record in close proximity and elevation to the Site provides the most appropriate model inputs. If an on-site long-term climate record is unavailable, then a co-located precipitation and potential evapotranspiration (PET) record close to the site can be adjusted to simulate site conditions and provide a synthetic climate record. Co-location of precipitation and PET data is required since these two parameters are highly correlated and using data that are not co-located would introduce error into the model.

For the Nucla Station Ash Disposal Facility, the closest co-located precipitation and potential evapotranspiration data record is located at the Nucla Remote Automated Weather Station (RAWS), approximately four miles northwest of the Site. However, only a limited climate dataset, i.e., less than 18 years of data, exists at this station. As a result, data from the nearby Montrose 2 meteorological station (NOAA 2016a) was adjusted to extend the Nucla RAWS dataset based on a linear regression analysis of the overlapping records of these two stations.

Potential evapotranspiration was calculated daily by the Western Regional Climate Center of the Desert Research Institute, using the Kimberly-Penman reference PET method, and provided in the Nucla RAWS climate dataset (WRCC 2016). Since the Montrose 2 station dataset did not include daily PET data, the adjusted precipitation at the Montrose 2 station was used as a guide to choose similar days at the Nucla RAWS station. The method was developed based on the month of the year, whether or not precipitation occurred on a given day, the magnitude of the precipitation, and whether or not precipitation occurred the previous day. Using this method, PET data were added to the longer period of record available at the Montrose 2 station. Climate records were compiled from the adjusted Montrose 2 dataset and the original Nucla RAWS dataset and then reduced to exclude missing and incorrect data. Following the data reduction, a 112-year period of climate record was compiled for the Nucla Station Ash Disposal Facility. Information about the meteorological stations is summarized in Table A-2.

The annual range of precipitation over the 112-year climate record is as follows:

- Driest year in 2001 with annual precipitation = 3.7 inches
- Average year in 1952 with annual precipitation = 9.8 inches, nearest to annual average precipitation of 9.7 inches/year
- Wettest year in 1941 with annual precipitation = 17.2 inches
- Wettest 5-year period from 1983 to 1987 with average annual precipitation = 12.8 inches

Potential plant transpiration was estimated using the Ritchie and Burnett (1971) equation, which is based on potential evapotranspiration and leaf area index estimates for the Site, as described in Section 3.2. Potential evaporation was then calculated as the difference between potential evapotranspiration and potential transpiration. Annual precipitation, potential evaporation, and potential transpiration for the 112-year period of climate record are presented in Figure A-4.

3.4 Initial Conditions and Boundary Conditions

The top boundary condition of the model was defined by atmospheric input of daily precipitation, potential evaporation, and potential transpiration, while also allowing for surface runoff. The bottom boundary condition was defined as free drainage, which is equivalent to a unit vertical hydraulic gradient. To condition the soil moisture profile to average climate conditions, soil moisture was equilibrated to typical precipitation, potential evaporation, and potential transpiration by applying ten cycles of the average year, i.e., 1952, prior to the start of the 112-year long-term climate record.

4.0 PREDICTIVE SIMULATIONS

4.1 Base Case

Base case predictive simulations were performed for the prescriptive cover system and the evapotranspiration cover using material properties from both soil cover samples (TP-1 and TP-3B), vegetation properties, climate inputs, and other model parameters described in the previous sections. The model profiles for the four base case simulations are summarized in Table A-3.

4.2 Sensitivity Analyses

To assess the sensitivity of the base case models to heterogeneity in material properties and variability in climate and vegetation, additional simulations were analyzed which incorporate the following changes (one at a time):

- Increase the saturated vertical hydraulic conductivity (K_{sat}) of the erosion layer (prescriptive cover system) and water storage layer (evapotranspiration cover) by half an order of magnitude. K_{sat} for TP-1 at 85% compaction relative to the standard Proctor maximum dry density was increased from 4.3×10^{-4} cm/s (base case) to 2.2×10^{-3} cm/s.
- Decrease the average annual potential evapotranspiration to equal 70% of average pan evaporation from the Montrose 1 meteorological station [(NOAA 2016b), see summary in Table A-2]. Average annual PET was decreased from 47.3 inches/year (base case) to 41.0 inches/year.
- Decrease leaf area index of the grass and shrubland by 20%. The annual LAI distribution for grass and shrubland presented in Figure A-2 was decreased by 20%, e.g., the maximum grass LAI was 0.42 and the maximum shrubland LAI was 0.40.
- Truncate grass and shrubland roots 0.5 feet from the maximum rooting depth.

To maintain conservatism, these sensitivity analyses were conducted on the prescriptive cover model and the evapotranspiration cover model with the highest K_{sat} erosion layer and water storage layer, i.e., the two models with TP-1 at 85% compaction relative to the standard Proctor maximum dry density.

5.0 INFILTRATION MODEL RESULTS

5.1 Predicted Net Infiltration and Predicted Water Balance

Based on results from the base case simulations and the sensitivity analyses of the prescriptive cover system and the evapotranspiration cover, net infiltration through each cover is predicted to be negligibly small, i.e., < 0.01 inches per year on average, in all model simulations. This is a consequence of potential evapotranspiration far exceeding precipitation as shown in Figure A-4.

Table A-4 provides a summary of the predicted long-term water balance for each cover simulation, with rates averaged over the 112-year climate record. Since the combined effect of evaporation from the soil cover and transpiration by grass or shrubland is significant and does not vary appreciably between the base case simulations and the sensitivity simulations, the results provided below include the range in predicted water balance fluxes for all simulations.

Based on annual averaging of simulation results over the 112-year period of climate record, the predicted water balance fluxes for the prescriptive cover system and comparisons of these fluxes to annual average precipitation at the Site are as follows:

- Net Infiltration = < 0.01 inches/year = negligible
- Evaporation = 6.9 to 7.9 inches/year = 71 to 81% of annual average precipitation
- Transpiration = 1.8 to 2.7 inches/year = 19 to 28% of annual average precipitation
- Runoff = ≤ 0.12 inches/year = < 2% of annual average precipitation
- Change in Storage = minimal = < 1% of annual average precipitation

Similarly, the predicted water balance fluxes for the evapotranspiration cover (annually averaged over the 112-year period of climate record) and comparisons of these fluxes to annual average precipitation at the Site are as follows:

- Net Infiltration = < 0.01 inches/year = negligible
- Evaporation = 6.5 to 7.1 inches/year = 67 to 73% of annual average precipitation
- Transpiration = 2.5 to 3.2 inches/year = 26 to 33% of annual average precipitation
- Runoff = ≤ 0.10 inches/year = ≤ 1% of annual average precipitation
- Change in Storage = minimal = < 1% of annual average precipitation

6.0 CONCLUSIONS

Results from the soil-atmosphere modeling indicate that evaporation from the soil cover is the dominant water balance flux. In combination with transpiration by grass or shrubland for each cover, these two fluxes account for the removal of more than 98 percent of precipitation, on average. In comparison to the prescriptive cover system, the evapotranspiration cover is predicted to be more efficient at transpiring water using shrubs and, consequently, less evaporation is possible based on available water. Considering long-term variations in climate, these results indicate that an evapotranspiration cover will perform as well as the prescriptive cover system since both cover systems are highly effective at storing and releasing water back to the atmosphere. In accordance with 40 CFR Part 257, Subpart D, the water storage layer in the evapotranspiration cover is expected to achieve an equivalent reduction in infiltration relative to the infiltration layer in the prescriptive cover system.

Likewise, considering short-term flux variations due to greater intensity climate cycles, both covers are still expected to perform well. Results from short-term response in the each cover to the wettest single year and wettest 5-year period indicate that the evaporation rate and transpiration rate are predicted to increase and the predicted net infiltration is expected to remain negligibly small.

7.0 REFERENCES

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TABLES

Table A-1: Summary of Hydraulic Properties for Infiltration Model

		Geotechnical Test Data(1)				Unsaturated Hydraulic Characteristics(2)							
Sample ID	**Soil Layer**	**USCS Classification**	**Compaction (%)**	**MDD (pcf)**	**K_{sat} (cm/s)**	**θ_R**	**θ_S**	**$alpha_1$ (1/cm)**	**n_1**	**l**	**w_2**	**$alpha_2$ (1/cm)**	**n_2**
TP-1 @ 85% MDD	Erosion Layer, Water Storage Layer	Sandy lean clay (CL)	85	101.3	4.3E-04	0	0.464	0.1246	1.4004	0.5	0.54	6.26E-05	1.3722
TP-1 @ 92% MDD	Infiltration Layer		92		1.1E-05	0	0.425	0.0771	1.3739	0.5	0.63	6.29E-05	1.3639
TP-3B @ 85% MDD	Erosion Layer, Water Storage Layer	Sandy lean clay (CL)	85	108.8	6.8E-06	0	0.457	0.0096	1.5011	0.5	0.47	5.71E-05	1.4129
LF Ash	Ash Waste	Silty sand (SM)	--	--	1.2E-03	0.049	0.390	0.0347	1.7466	0.5	0.00	0.0347	1.7466

Notes:

(1) Geotechnical laboratory test data are for samples collected at the Site, with the exception of the LF Ash K_{sat}. K_{sat} for LF Ash is derived from default properties for loamy sand (USDA soil texture equivalent to silty sand), provided in the Rosetta database (Schaap et al. 2001).

(2) Unsaturated hydraulic characteristics for TP-1 (85% and 92% MDD) and TP-3B (85% MDD) samples are estimated from Durner (1994) bimodal model fit to Golder laboratory data. Unsaturated hydraulic characteristics for LF Ash sample are derived from default properties for loamy sand (USDA soil texture equivalent to silty sand), provided in the Rosetta database (Schaap et al. 2001).

USCS = Unified Soil Classification System
MDD = standard Proctor maximum dry density
pcf = pounds per cubic foot
K_{sat} = saturated vertical hydraulic conductivity
θ_R = residual water content
θ_S = saturated water content

Table A-2: Meteorological Stations used for Nucla Ash Disposal Facility (Site) Long-Term Climate Record

Station	Location	Elevation (feet above mean sea level)	Period of Record	Climate Data	Data Source
Nucla RAWS	4 miles northwest of Site	5,860	1998 to Present	Precipitation and Potential Evapotranspiration	(WRCC 2016)
Montrose 2	38 miles northeast of Site	5,789	1895 to Present	Precipitation	(NOAA 2016a)
Montrose 1	38 miles northeast of Site	5,786	1905 to 1982	Pan Evaporation	(NOAA 2016b)

Notes:
RAWS = Remote Automated Weather Station
Nucla Ash Disposal Facility is located at an elevation of approximately 5,940 feet above mean sea leve
Montrose 1 Station pan evaporation data was used only for sensitivity analysis

Table A-3: Summary of Base Case Predictive Simulations

	Thickness of Soil Layer (feet)	Prescriptive Cover Grass Vegetation Sample ID	
Erosion Layer	0.75	TP-1 @ 85% MDD	TP-3B @ 85% MDD
Infiltration Layer	1.5	TP-1 @ 92% MDD	
Ash Waste	2	LF Ash	

	Thickness of Soil Layer (feet)	Evapotranspiration Cover Shrubland Vegetation Sample ID	
Water Storage Layer	2.5	TP-1 @ 85% MDD	TP-3B @ 85% MDD
Ash Waste	2	LF Ash	

Notes:
MDD = standard Proctor maximum dry density

Table A-4: Summary of Predicted Long-Term Water Balance for Final Cover

Cover Type	Sample Used for Erosion Layer or Water Storage Layer	Sensitivity Type	Evaporation	Transpiration	Runoff	Net Infiltration
			112-year Average (inches/year)			
Base Case Models						
Prescriptive	TP-1 85% MDD		6.99	2.66	<0.01	<0.01
Evapotranspiration			6.58	3.10	<0.01	<0.01
Prescriptive	TP-3B 85% MDD		7.58	1.97	0.12	<0.01
Evapotranspiration			7.08	2.50	0.10	<0.01
Sensitivity Simulations						
Prescriptive	TP-1 85% MDD	TP-1 @ 85% MDD, K_{sat} increased to 2.2E-03 cm/s	7.86	1.81	<0.01	<0.01
Evapotranspiration			7.04	2.64	<0.01	<0.01
Prescriptive		Decrease average annual PET to 41.0 inches/year	6.90	2.74	<0.01	<0.01
Evapotranspiration			6.47	3.21	<0.01	<0.01
Prescriptive		Decrease grass and shrubland LAI by 20%	7.11	2.53	<0.01	<0.01
Evapotranspiration			6.70	2.98	<0.01	<0.01
Prescriptive		Truncate grass and shrubland roots 0.5 feet from the maximum rooting depth	6.98	2.66	<0.01	<0.01
Evapotranspiration			6.55	3.13	<0.01	<0.01

Notes:

Average annual precipitation for the Site climate record is 9.7 inches/year
MDD = standard Proctor maximum dry density
K_{sat} = saturated vertical hydraulic conductivity
PET = potential evapotranspiration
LAI = leaf area index

FIGURES

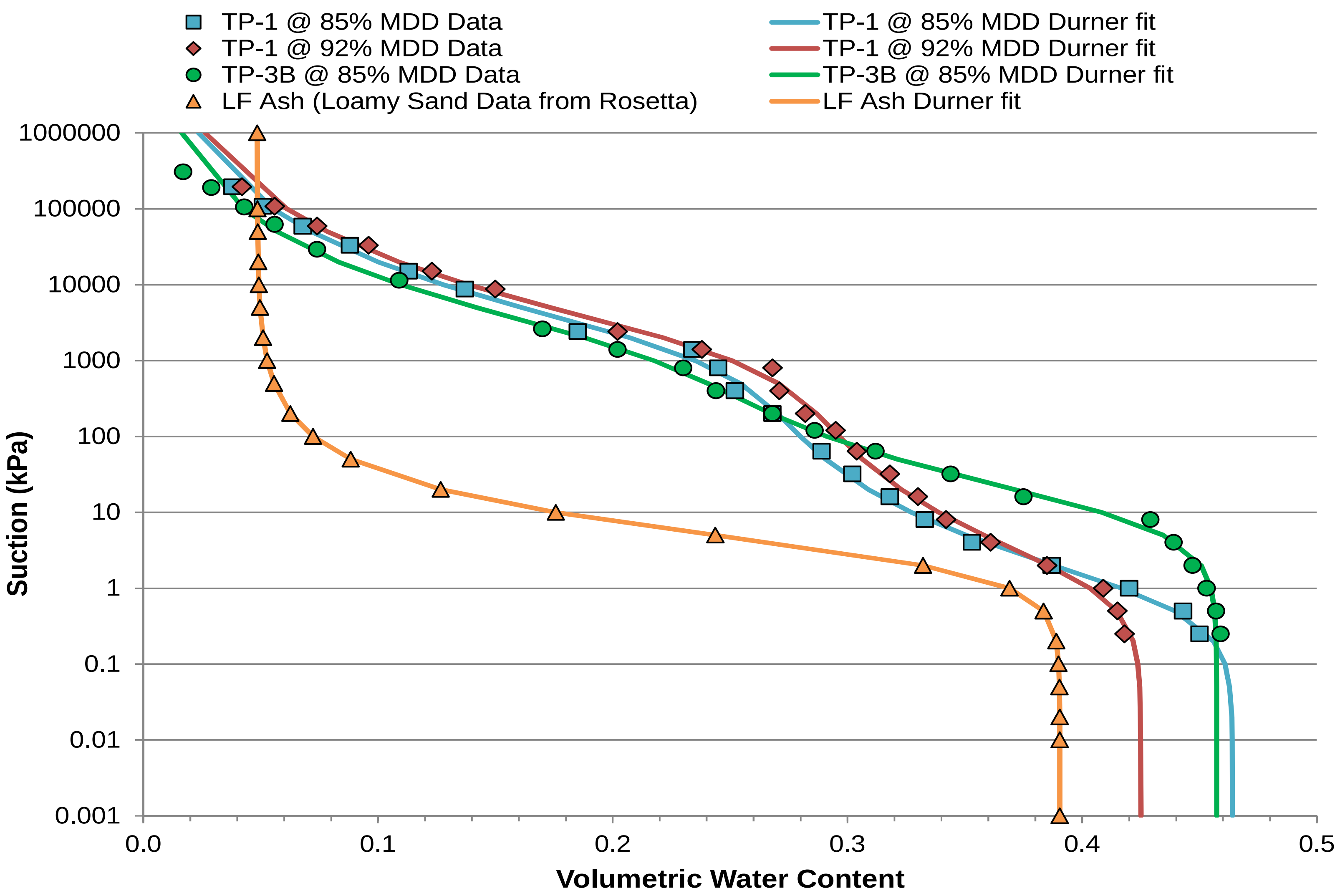

Figure A-1

Soil Water Characteristic Curves for Infiltration Model Soil Layers

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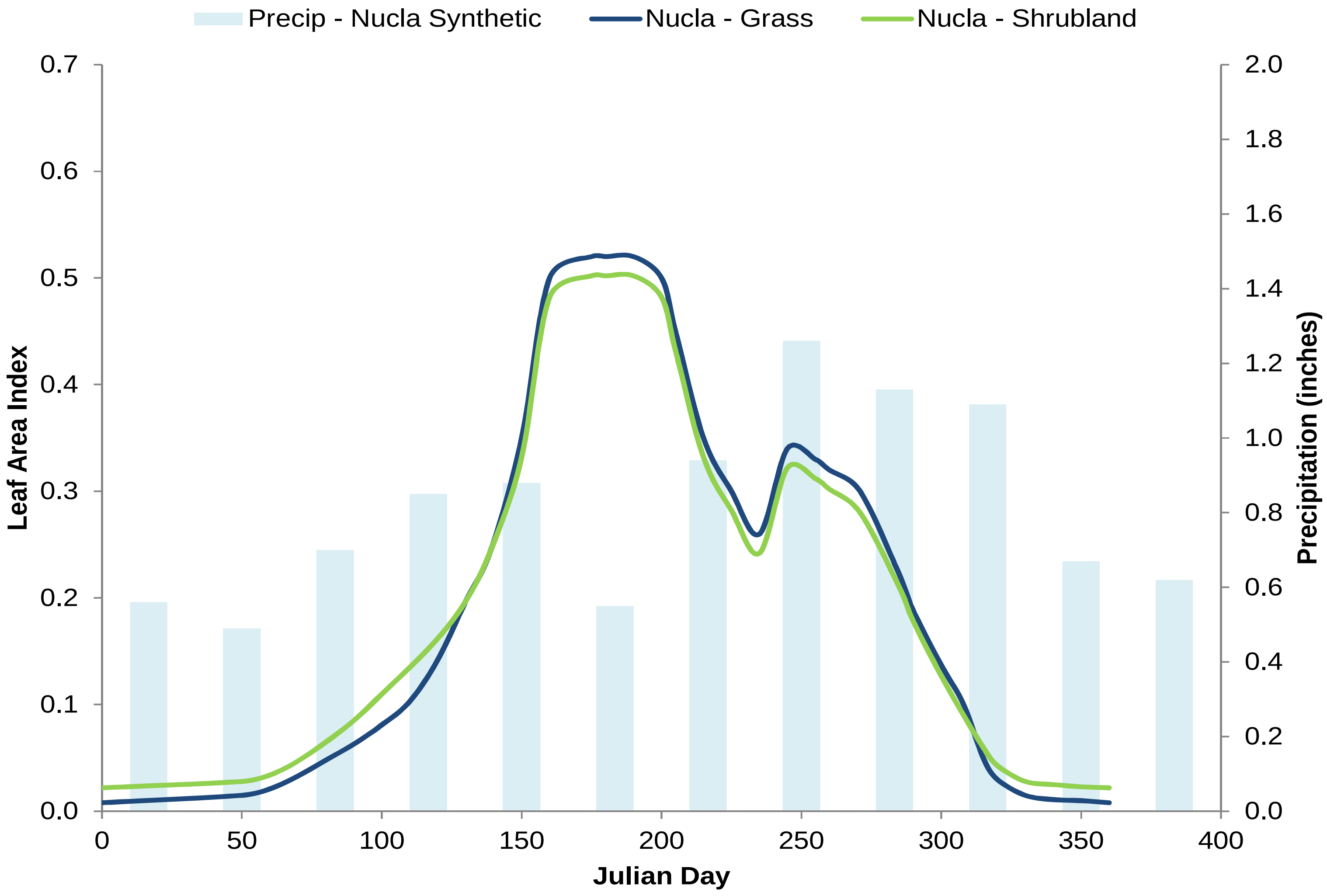

Figure A-2

Leaf Area Index for Nucla Grass and Shrubland

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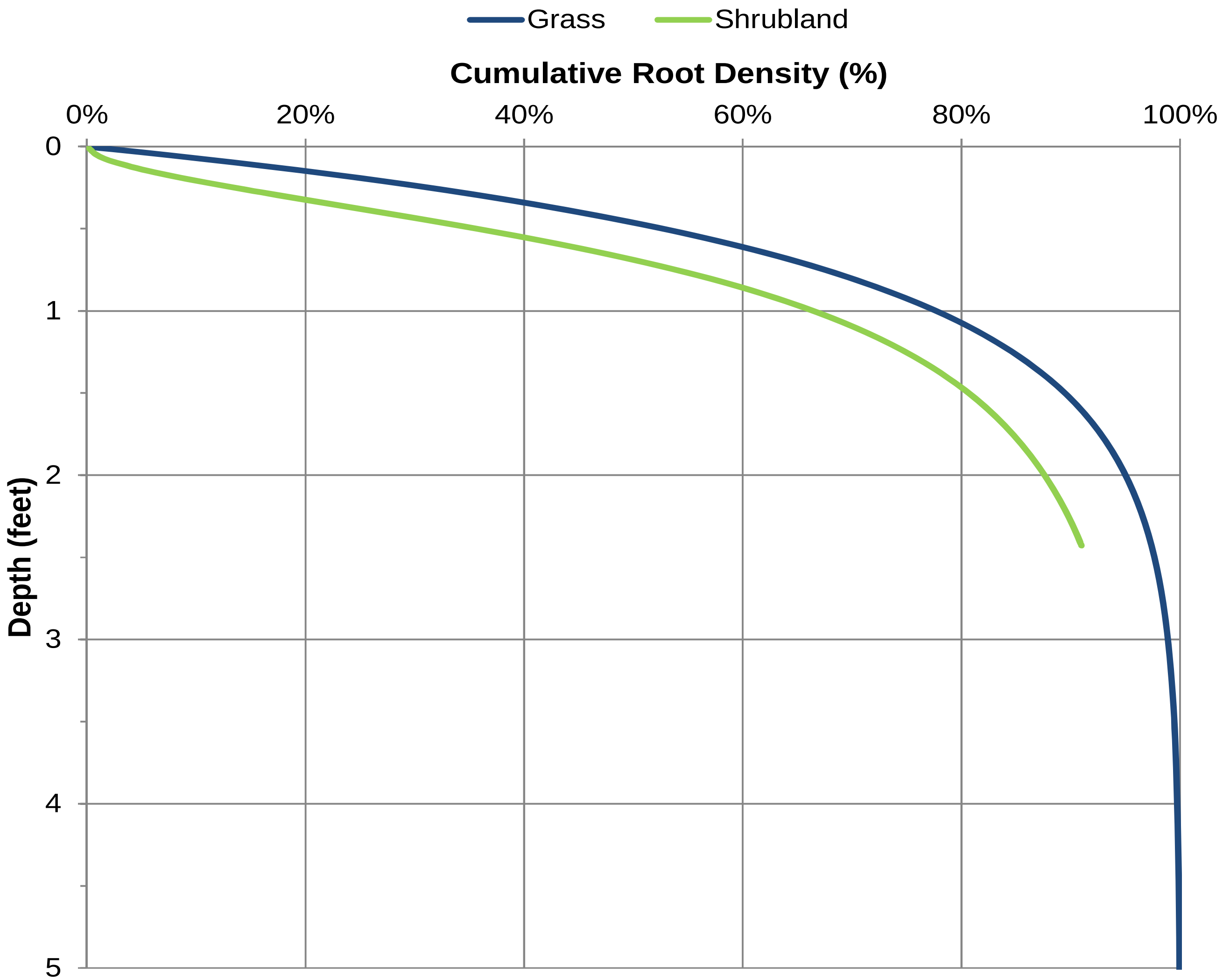

Figure A-3

Grass and Shrubland Cumulative Root Distribution

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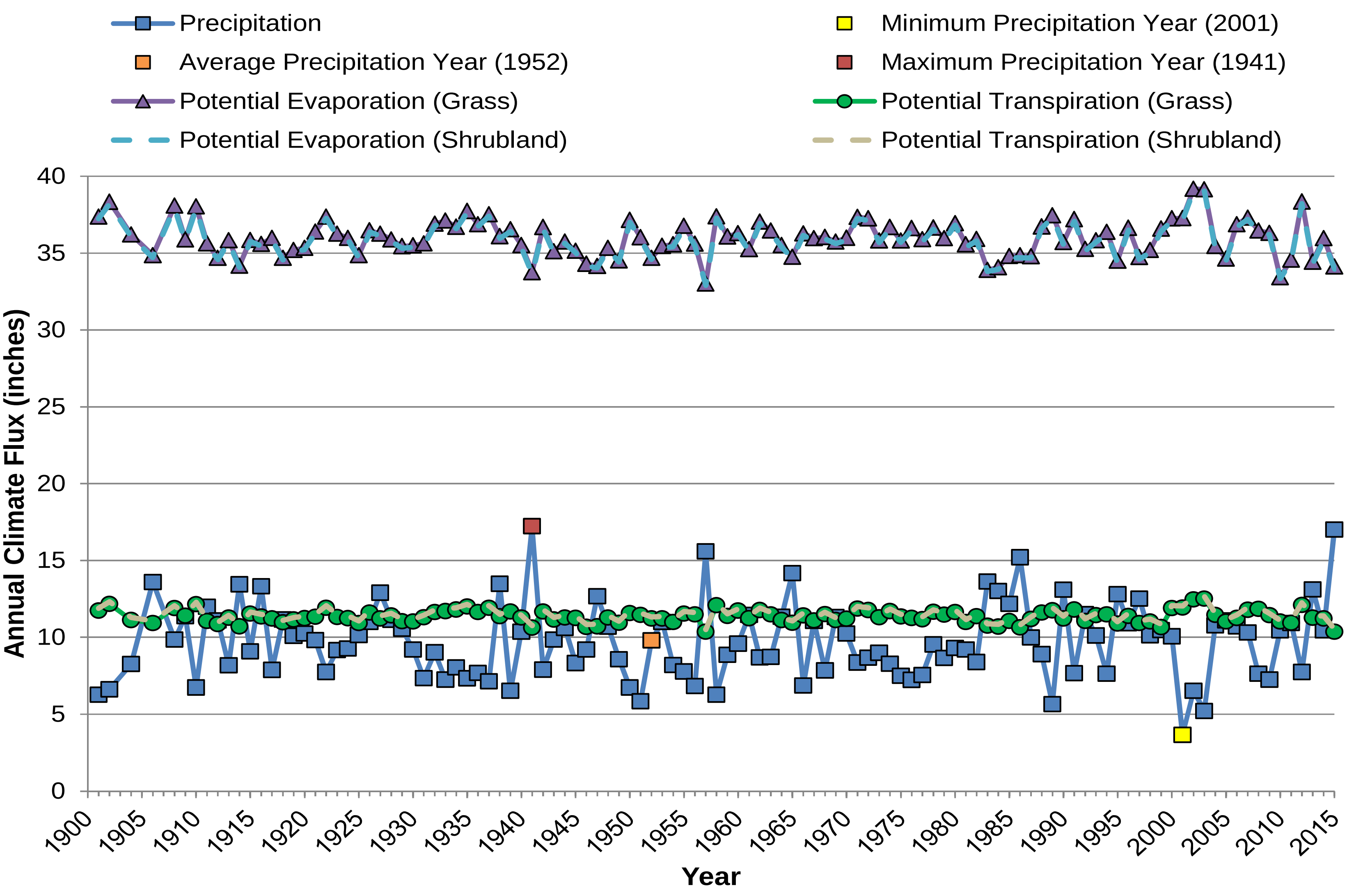

Figure A-4

Annual Precipitation, Potential Evaporation, and Potential Transpiration for Infiltration Model

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Africa	+ 27 11 254 4800
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North America	+ 1 800 275 3281
South America	+ 56 2 2616 2000

solutions@golder.com
www.golder.com

Golder Associates Inc.
44 Union Boulevard, Suite 300
Lakewood, Colorado 80228
Tel: (303) 980-0540
Fax: (303) 985-2080

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