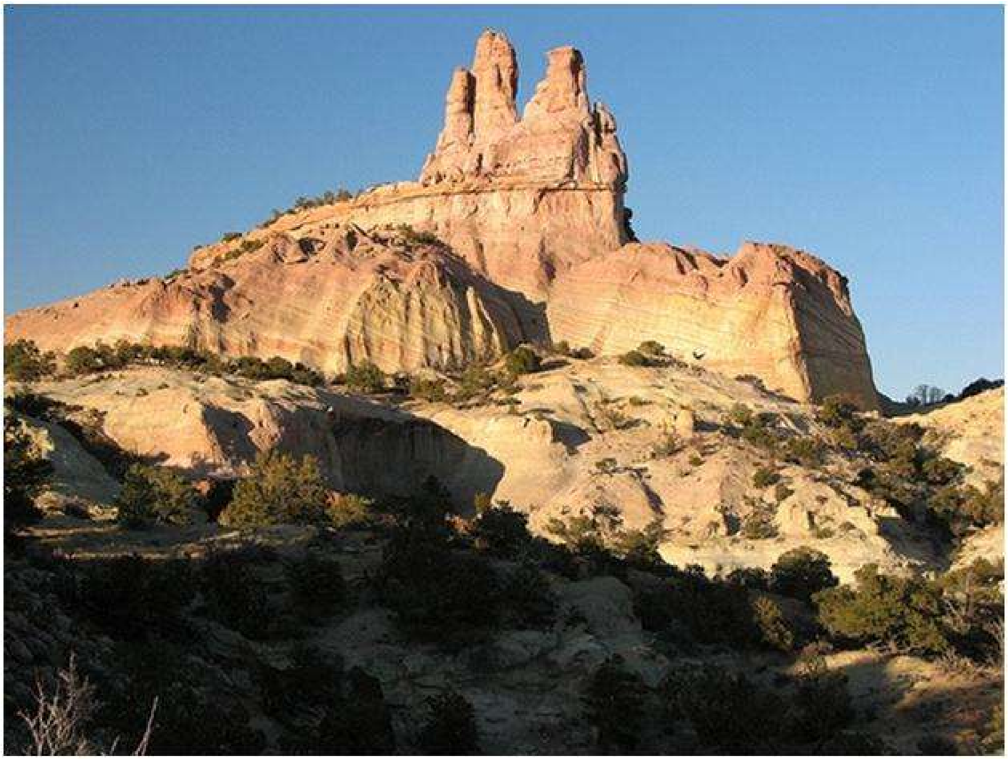
95% DRAFT

COVER SYSTEM DESIGN REPORT



~~10/31/2017~~02/26/201810/13/2019

Northeast Church Rock Site Closure

Prepared by:
Dwyer Engineering LLC
Stephen F Dwyer, PhD, PE
1813 Stagecoach Rd. SE
Albuquerque, NM 87123

Prepared for:
United Nuclear Corporation
475 Creamery Way
Exton, PA 19341

EXECUTIVE SUMMARY

The Removal Action (RA) referenced in the Administrative Settlement Agreement and Order on Consent for the United Nuclear Corporation Superfund Site and Northeast Church Rock (NECR) Mine Removal Site (AOC; USEPA, 2015) and described in the 2011 Action Memo (USEPA, 2011) and 2013 ROD (USEPA, 2013) calls for the excavation of approximately 1,000,000 cubic yards (cy) of mine waste from the Mine Site and placement at the Mill Site. Mine waste will be disposed of in a repository designed within the footprint of the existing tailings impoundment at the Mill Site. Disposal of waste at the Mill Site is contingent upon modification of the radioactive materials license issued by the U.S. Nuclear Regulatory Commission ("NRC") for the Mill Site.

The disposed of mine waste within the exiting tailings impoundment will be capped with a final cover system meeting applicable regulatory criteria and performance objectives. The final cover system referred to as an evapotranspiration (ET) cover is 4-ft thick (122 cm) composed of compacted cover soil overlain by a rock/soil admixture. The surface rock/soil admixture was designed to minimize erosion while providing a rooting medium for native vegetation as well as storage capacity for infiltrated precipitation. The overall profile provides adequate storage capacity to minimize flux through the cover and attenuate radon gas from the covered mine spoils below established performance criteria.

This report documents how the regulatory criteria and performance objectives have been satisfied with the cover design. The included documentation demonstrate the ability of the cover to provide adequate protection for a design life of 1000 years.

TABLE OF CONTENTS

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

ACAP	Alternative Cover Assessment Program
ALCD	Alternative Landfill Cover Demonstration
AOC	Agreement and Order on Consent
ARAR	Applicable or Relevant and Appropriate Requirement
ASTM	American Society for Testing and Materials
BGS	below ground surface
CFR	Code of Federal Regulations
cm	centimeter
cy	cubic yards
DOE	Department of Energy
DWYER	Dwyer Engineering, LLC
EE/CA	Engineering Evaluation/Cost Analysis
ET	evapotranspiration
EWERU	Engineering and Wind Erosion Research Unit
GCL	Geosynthetic Clay Liner
MDD	maximum dry density
Mill Site	Church Rock Mill Site
Mine Site	Northeast Church Rock Mine Site
MWH	Montgomery Watson Harza
NECR	Northeast Church Rock
NOAA	National Oceanic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
NRCS	Natural Resources Conservation Service
NTCRA	Non-Time Critical Removal Action
NWS	National Weather Service
PET	potential evapotranspiration
PMP	Probable Maximum Precipitation
PODR	Point of Diminishing Returns
PTW	principal threat waste
RA	Removal Action
RAO	Remedial Action Objective
ROD	Record of Decision
RAECOM	Radiation Attenuation Effectiveness and Cover Optimization with Moisture Effects
RUSLE	Revised Universal Soil Loss Equation
SA	Settlement Agreement Site
SOW	Statement of Work

ACRONYMS AND ABBREVIATIONS (CONTINUED)

USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USLE	Universal Soil Loss Equation
WEPS	Wind Erosion Prediction System
WEQ	Wind Erosion Equation

1.0 OVERVIEW OF DESIGN LOGIC

The Removal Action (RA) referenced in the Administrative Settlement Agreement and Order on Consent (AOC) and described in the 2011 Action Memo (USEPA, 2011) and 2013 Record of Decision (ROD; USEPA, 2013) calls for the excavation of approximately 1,000,000 cubic yards (cy) of mine waste from the Northeast Church Rock Mine Site (Mine Site) and placement at the Church Rock Mill Site (Mill Site). Mine waste will be disposed of in a repository designed within the footprint of the existing tailings impoundment at the Mill Site. These materials will then be capped with a final cover system, referred to as an evapotranspiration (ET) cover. The key regulatory performance criteria for the ET Cover system include:

- Maintain a design life of up to 1,000 years and at least 200 years.
- Minimize meteoric flux into the underlying mine waste (includes providing a rooting medium for native vegetation).
- Minimize erosion due to wind and runoff (up to the probably maximum precipitation event).
- Attenuate emanation of radon-222 from the mine waste to a rate of 20 pCi/m2s, average over the final cover surface.
- Design to accommodate minimum reliance on active maintenance.

This Design Report summarizes the design and analyses performed demonstrating that the recommended cover profile (1) meets the performance criteria and (2) will provide adequate protection for encapsulation of the mine spoils and underlying tailings materials for a design life of 1,000 years. The remainder of the report is structured as follows:

- Section 2 provides project background information.
- Section 3 provides the regulatory criteria and performance objectives for the cover design.
- Section 4 contains the erosion analysis and design incorporated into the final cover system.
- Section 5 summarizes the general cover profile development.
- Section 6, 7, and 8 contain the unsaturated modeling performed in support of the cover profile.
- Section 9 contains the cover's ability to mitigate radon flux through the cover.
- Section 10 summarizes the design logic and results.
- Appendices A and B include the specific input and output from the modeling simulations.

1.1 Erosion Protection

The Northeast Church Rock (NECR) site is located in an arid climate and exposed to erosion due to high-intensity precipitation events and significant wind. A key performance criterion for the cover system design is to provide for adequate erosion protection. The design event for evaluation of long-term erosional stability is the Probable Maximum Precipitation (PMP) based

on Nuclear Regulatory Commission (NRC) guidelines in NUREG-1623 (NRC, 2002). The designed cover system is capable of withstanding the windy conditions at the site as well as a rainfall intensity defined by the PMP event that is 6.5-inches for the 1-hour precipitation frequency [*Note: the PMP is significantly more conservative than the 2.96-inch value provided for the 1-hr precipitation frequency for a 1000 year period defined in the National Oceanic and Atmospheric Administration (NOAA) Atlas 14, Volume 1 (Bonnin, 2011)*].

The cover design is composed of two layers. The top layer is a uniform mixture of cover soil (67 percent by volume) with rock (33 percent by volume) referred to as a 'desert pavement'. This layer is designed to mitigate erosion by creating an armored surface with rock large enough to resist the erosive forces created during a PMP event. The bottom layer is composed of cover soil only. The overall cover thickness including both layers is a consistent 4 feet (122 cm).

Section 4 describes the design of the 'desert pavement' and analysis demonstrating the effectiveness of this layer. The admixture design is a function of the climate, soil, and cover surface geometry. The available cover soil borrow sources dictated the soil texture and thus fines content, while the geometry was optimized. The final geometry of the impoundment after placement of the mine spoils and cover system includes slopes generally less than 5 percent with slope lengths as long as 1,021 feet. In the design of the 'dessert pavement' layer, the smallest rock possible while still meeting the erosion requirements is preferred. Rock has no storage capacity, thus the overall thickness of cover is increased to overcome the loss of storage capacity from the addition of the rock. The rock to be used in the surface admixture layer or 'desert pavement' shall be durable to meet the 1,000-year design life requirement. This rock may not be readily available or may be expensive to acquire. Thus, the intent of this design is to maximize use of existing rock at the site meeting applicable durability requirements. Consequently, the thickness of the two layers varies (refer to Figure 13) depending on the location and respective slope length. The depth of rock/ soil admixture and rock size was varied: thinnest (14-inches thick with rock size of 1.5-inches) for top of slopes and gentle slopes; intermediate (18-inches thick with 2-inch rock) for middle of longer and/or steeper slope lengths; to thickest (27-inches thick with 3-inch rock) for bottom of longer and/or steeper slope lengths.

The resulting surface slopes meet guidance set forth in Dwyer et al. (1997) and NUREG-1623. The resulting surface was then analyzed utilizing the Revised Universal Soil Loss Equation (RUSLE) (USDA 1997) for surface water runoff induced soil loss and the Wind Erosion Prediction System or 'WEPS' (USDA 2010) for wind induced soil loss. The combined resulting estimated soil loss is significantly less than the USEPA (1991) recommended 2 tons/year/acre.

1.2 Applicable Data Supporting Effectiveness of ET Cover

Section 5 provides an overview of applicable field data and natural analogs that support the use of an ET Cover at the NECR site. The data includes applicable field data from a research project performed at Sandia National Laboratories (Dwyer 2003) that monitored test covers demonstrating the effectiveness of an ET Cover for the short-term. This data revealed that an ET Cover in a similar climate and elevation (foothills above Albuquerque, NM) with similar soil texture minimized flux through a 3.5-ft thick cover. Additional data included is a summary of applicable natural analogs that demonstrate the effectiveness of an ET Cover to minimize flux for the long-term. These natural analogs evaluated in a similar climate and elevation with similar soil texture, reveal that the typical long-term infiltration depth is about 2 feet. This is significantly less than the designed 4-ft thickness of the NECR cover.

1.3 Cover Depth Required to Minimize Flux

The final cover system contains two layers:

- A surface layer composed of a rock/soil admixture designed to mitigate erosion and enhance vegetation establishment.
- A bottom soil layer in conjunction with the surface layer contains adequate storage capacity to minimize flux due to meteoric water.

A series of computer simulations of the two-layered cover profile were performed to evaluate the myriad of variables to which the cover could be exposed during the 1,000-year performance period. The model geometry varied based on the respective rock/soil admixture design and depth described in Section 4. The computer sensitivity analyses evaluated possible climate change scenarios over this period of performance also considering information from the USEPA climate change website (https://www.epa.gov/climatechange). The full cover profile depth of 4 feet was shown to effectively minimize flux (in most cases reduce it to zero) for the multitude of scenarios modeled.

A key performance criterion of the cover system is effectiveness for up to 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years (40 CFR 192). The applicable field data and natural analogs described in Section 5 provide confidence that an ET Cover will effectively perform for this criterion. UNSAT-H, a one-dimensional, finite-difference computer program developed at the Pacific Northwest National Laboratory by Fayer and Jones (1990) was used to simulate the water balance of the cover profile (Fayer 2000). UNSAT-H simulates water flow through soils by solving Richards' equation and simulates heat flow by solving Fourier's heat conduction equation.

Over the required performance period of the cover system, the climate can change from dry to average to wet - the worst case for flux minimization being more precipitation. The cover soil hydraulic properties can change as can the vegetation. Myriad computer simulations were performed to evaluate each consideration varying one parameter at a time and then evaluating multiple changes. These parameters and boundary conditions are discussed below.

The input parameters utilized in the modeling effort included the envelope of variables possible over the 1,000-year performance period. Climate is critical and thus both typical and extreme climates scenarios were modeled. The climate was varied during the modeling simulations to include both the typical and worst case possibilities. Historical weather data for the Gallup, NM area and surrounding weather stations were evaluated from available historical data from 1897 to 2016. The average precipitation at the Gallup airport is about 11 inches per year (28 cm) per the Western Regional Climate Center (http://www.wrcc.dri.edu/). The typical model climate used an annual precipitation volume of 11.71 inches (29.74 cm) distributed as shown in Figure 14. The precipitation is highest during July and August (Figure 14) while the climate's demand for water, referred to as potential evapotranspiration (PET), is also highest during those months.

The most extreme climate year occurred in 1906 when the area received 23.8 inches (60.5 cm) of precipitation. This climate year was utilized as the most extreme weather in the computer simulations. This was not only the highest annual precipitation received on record, but the majority of the moisture came in March and April with significant moisture also received in February, November and December (Figure 15). Much of this moisture came as snow or less intense rainstorms compared to the typical summer monsoons that produce high intensity storms

and thus significant runoff. The worst case runoff event produced by the PMP was utilized for design of the surface admixture layer per Section 4. These months with high precipitation volume also had reduced PET due to their cooler temperatures, so this period was also the worst case infiltration climate that the site has experienced during recorded history. To add conservatism, 1906 was modeled back-to-back in all computer simulations. This is a series of events that is beyond anything known to occur at this site. Furthermore, the precipitation was applied during the computer simulations at a rate less than the infiltration rate. That is, the precipitation was applied slowly enough to allow for close to 100 percent infiltration, thus minimizing runoff. This added conservatism in the modeling effort given that much of the precipitation at the site runs off before it can infiltrate into the cover system.

Other input parameters critical to successful cover system performance during the 1,000-yr period include the cover soil texture, resulting hydraulic properties, and the vegetation. A number of potential cover soil borrow sources were investigated at the NECR site. The sources deemed adequate for cover soil include the north drainage area, the south drainage area, the east borrow, and the west borrow (Figure 11). Each borrow soil was evaluated in the computer simulations to verify its effectiveness and the cover depth required to minimize flux. Samples taken from the borrow sources were tested to determine their respective hydraulic properties. The hydraulic properties utilized in the UNSAT-H simulations required remolded samples from soil obtained in the drilling exercise performed as part of the pre-design studies effort (MWH 2014). These hydraulic properties were utilized as input parameters in the computer sensitivity analyses. These remolded soil samples and their respective hydraulic properties are representative of the expected as-built condition of the cover system. Thus these computer simulations utilizing these remolded values represent expected conditions for the short-term (less than 100 years).

A soil analog study of the potential borrow sources (Dwyer 2014) coincided with a vegetation analog study (Cedar Creek 2014) performed on the vegetation in various stages of maturation. Soil hydraulic properties change over time due to such things as soil pedogenesis, wet/dry cycles, and freeze/thaw cycles. In situ measurements of soil at multiple borrow sources were measured at multiple depths (surface, 1-ft, 2-ft, 3-ft and 4-ft). These soil data were utilized in computer simulations assumed to represent the long-term status of the soil.

Vegetation properties were also utilized in the computer simulations. The vegetation analogs studied represent a natural succession at the site (Cedar Creek 2014). The reclaimed community of vegetation represents vegetation in an area that has been disturbed and generally considered from a time period from seeding after construction completion up to about 50 years. The grassland community represents vegetation in an undisturbed setting and is assumed to represent the vegetation on the cover from a period of about 25 to 100 years after construction. The shrubland community represents vegetation in an undisturbed setting and is assumed to represent vegetation on the cover from a period of about 50 to 1,000 years. The effort to actually measure site parameters for soil and vegetation is not typically made for computer simulations of cover designs. Most cover design simply use generic values from the literature. However, extra effort was expended on this project to provide the best input parameters practical. Refer to Appendix A for details of these simulations.

Section 8 summarizes the sequenced long-term evaluation of the 4-ft cover overlying the mine spoils sequenced through time varying the vegetation and soil hydraulic properties (from constructed to long-term conditions) while evaluating possible typical and extreme climate

conditions. Each admixture design was separately evaluated (Figure 19); thus there was three sets of simulations for each parameter sensitivity analysis. The output showed that once vegetation is established, the net annual flux through the cover is zero. Refer to Appendix B for specifics of the simulations.

1.4 Radon Flux Evaluation

Section 9 provides an overview of the estimated radon release rate through the cover profile. The radon flux through the cover soil was calculated using the Radiation Attenuation Effectiveness and Cover Optimization with Moisture Effects (RAECOM) code, as described in (Rogers 1984a, 1984b). The model is used to perform one-dimensional, steady-state radon diffusion calculations for a multi-layer system. The computed radon flux for the cover profile is 11.37 pCi/m^2s (Table 19). This value is less than the maximum allowable value of 20 pCi/m^2s per 40 CFR 192.02.

2.0 BACKGROUND

The Mine and Mill Sites are located in close proximity to one another and approximately 16 miles northeast of Gallup, in McKinley County, New Mexico. The sites are temporarily being treated as one facility for purposes of the removal and remedial action, as described in the ROD (USEPA, 2013). The combined site is referred to as the "Settlement Agreement Site" (SA Site) in the AOC (USEPA, 2015). A summary of the site setting, history, and nature and extent of contamination is provided in the 2011 Action Memo (USEPA, 2011) and ROD (USEPA 2013).

An Engineering Evaluation/Cost Analysis (EE/CA) was prepared by the United States Environmental Protection Agency (USEPA), Region 9 to evaluate Non-Time- Critical Removal Action (NTCRA or "removal action") alternatives for soil and sediment (mine wastes) at the Mine Site. The site is a semi-arid climate at an elevation of about 7,000 feet above sea level. The vegetation is generally categorized as a pinyon-juniper landscape with shrubs and native grasses. The near surface soil is predominantly a clay loam.

The RA referenced in the AOC and described in the 2011 Action Memo (USEPA, 2011) and ROD (USEPA, 2013) is described in the first paragraph of Section 1. Disposal of waste at the Mill Site is contingent upon modification of the radioactive materials license issued by the NRC for the Mill Site.

The Selected Remedy addresses contaminated surface and subsurface soil from the Mine Site. Mine site waste with a radium 226 (Ra-226) concentration greater than 200 pCi/g and/or 500 mg/kg of total uranium is referred to as Principal Threat Waste (PTW), and will not be disposed of at the Mill Site.

The major components of the Selected Remedy are:

Excavation of Mine Waste. Waste from the Mine Site that contains concentrations of uranium and Ra-226 in excess of Action Levels established in the 2011 Action Memo (USEPA, 2011) will be excavated and transported offsite. Excavation at the Mine Site will continue until confirmation sample results from excavated areas are below the Action Levels established in 2011 Action Memo.

Repository Design. A repository to be designed at the Mill Site to contain mine waste from the Mine Site. The design will include an ET Cover over the repository to mitigate direct contact with the mine waste, limit infiltration of precipitation, and attenuate emanation of radon-222 from the mine waste.

Repository Construction. Construction of the repository is contingent on NRC approval of a license amendment to construct the repository for mine waste within the Mill Site Tailings Disposal Area. PTW will not be disposed of at the Mill Site, and will be transported from the Mine Site to an alternate disposal facility that will be selected during design.

3.0 PERFORMANCE OBJECTIVES & REGULATORY CRITERIA FOR COVER SYSTEM

The performance objectives and regulatory criteria for the cover system are summarized in Table 1. The cover system is an ET cover composed of natural earthen materials. The cover profile was designed to meet long-term performance objectives while visually blending into the natural aesthetics of the area.

The Performance Standards presented here are defined in the Action Memorandum: Request for a Non-Time-Critical Removal Action at the Northeast Church Rock Site (2011 Action Memo; USEPA, 2011), the ROD for the United Nuclear Corporation Site, (USEPA, 2013), and the AOC (USEPA, 2015) including the Statement of Work (SOW) attached as Appendix D to the AOC, and were developed to define attainment of the Removal Action and Remedial Action Objectives (RAOs) for the Selected Remedy. The Performance Standards include both general and specific standards applicable to the Selected Remedy work elements and associated work components. Table 1 presents performance standards related to the repository design and construction and explains how the design accomplishes these standards. Refer to Appendix G, Table G.2-1 of the 95% Design Report for the full set of performance standards related to the closure design.

Table 1. Performance Objectives and Regulatory Criteria for Cover System

Performance Standard Requirement Citation/ Regulation	Performance Standard	Discussion
10 CFR 61.23(g)	10 CFR 61.23(e). Standards for Issuance of a License. Refer to www.ecfr.gov.	The cover system incorporates only natural materials with indefinite design lives. The input parameters utilized in the design process took into account the 1000-year performance of the final cover system. See also Appendix G, Table G.2-1 of the 95% Design Report.
10 CFR 61.51(a)(c)	10 CFR 61.42. Refer to www.ecfr.gov.	The design includes an ET Cover with soil and rock admixture surface layer over the waste materials, which will be located within the restricted area of the existing tailings impoundment. The cover is designed to minimize flux through the cover due to meteoric precipitation. Surface features direct surface water drainage away from disposal units at velocities and gradients which will not result in significant erosion that will require ongoing active maintenance in the future. The mine spoils and ET Cover material are intended to be placed in a manner whereby a positive slope shall be maintained throughout the construction process and final design to allow runoff and disallow ponding on the materials.

Performance Standard Requirement Citation/ Regulation	Performance Standard	Discussion
2011 Action Memo, V.A.1., Bullet 1 – Repository Design	Design a repository for the contaminated material excavated and removed from the NECR Mine Site. Design specifications will comply with CERCLA requirements, specifically all ARARs. The design, at a minimum, will include a low permeability layer (liner) and a cap structure that will mitigate direct contact, limit water infiltration, and perform as a radon barrier.	Refer to Sections 6 and 7, which demonstrate the cover effectively minimizes flux. The design of the final cover system minimizes flux based on the Dwyer et al. (2007) Point of Diminishing Returns methodology and USEPA (2012). The design of the cover system mitigates erosion by the inclusion of rock into the surface layer effectively forming a 'desert pavement'. In addition the slopes and slope lengths were optimized to mitigate surface erosion. Refer to Section 3 for the design and erosion analysis that addresses this specific issue. The cover system also provides a rooting medium for native vegetation that limits erosion and serves to assist remove infiltrated water via transpiration. The cover system limits the release of radon to the atmosphere. Refer to Section 8 for the calculations and analysis that demonstrate compliance with the computed radon flux value less than the maximum allowable of 20 pCi/m^{2}s per 40 CFR 192.02. The repository liner is generally assumed to be the existing radon barrier from the original final cover system. This soil shall be reworked to minimize its saturated hydraulic conductivity. A groundwater analysis (Dwyer 2017) effectively showed the hydraulic conductivity at this liner have deposition of the mine spoils and final cover system is less than 1 x 10-7 cm/sec. The radon barrier (low-permeability layer is described in Appendix G of the 95% Design Report.
2011 Action Memo, Table A-1; 2013 ROD Table 1 and Sections 2.9.2 and 2.9.5	40 CFR 192 02(a) and 02(b). Standards for the Control of Residual Radioactive Materials from Inactive Uranium Processing Sites. Refer to www.ecfr.gov. – (a) Be effective for up to one thousand years, to the extent reasonably achievable, and, in any case, for at least 200 years, and,(b) Provide reasonable assurance that releases of radon-222 from residual radioactive material to the atmosphere will not: (1) Exceed an average release rate of 20 picocuries per square meter per second.	The final cover system is composed of only natural materials (soil and rock) that have indefinite performance lives. The profile was designed utilizing input parameters that demonstrate the cover will meet the performance objectives for a minimum of 1,000 years. Refer to Section 6 and 7 the effectiveness of the cover profile for the full design life. The cover system also limits the release of radon to the atmosphere. Refer to Section 8 for calculations and analysis that demonstrate compliance with the computed radon flux value less than the maximum allowable of 20 pCi/m^{2}s per 40 CFR 192.02.

Performance Standard Requirement Citation/ Regulation	Performance Standard	Discussion
2013 ROD, Section 1.4 – Repository Design	Design a repository at the UNC Site for the contaminated material excavated and removed from the NECR Site. Design specifications will comply with CERCLA requirements including all applicable or relevant and appropriate requirements (ARARs). The design will include a cap structure that will mitigate direct contact, limit water infiltration, and perform as a radon barrier. Final design will determine actual configurations of cap and liner structure and will be submitted as part of a license amendment request to the Nuclear Regulatory Commission (NRC).	The repository is designed for long-term stability and the design criteria used eliminate, to the extent practicable, the need for on-going maintenance. The cover system incorporates only natural materials with indefinite design lives. The input parameters utilized in the design process took into account the 1,000-year performance of the final cover system. The design includes a soil and rock cover over the waste materials, which will be located within the restricted area of the existing tailings impoundment. Refer to Section 3. The cover is designed to minimize flux through the cover due to meteoric precipitation. Refer to Sections 6 and 7. Surface features direct surface water drainage away from disposal units at velocities and gradients which will not result in significant erosion that will require ongoing active maintenance in the future. Refer to Section 3. The design of the repository (including placement of mine spoils and cover material) shall minimize water contact with waste during storage, contact of standing water with waste during disposal and contact of percolating or standing water with wastes after disposal. The construction drawings and specifications were prepared to mitigate the potential for storm water to be in contact with mine spoils during placement and limit the ability of significant infiltration into underlying materials. The modeling (see Sections 6 and 7) demonstrates that once the final cover system is in place, this cover will mitigate flux and thus reduce potential for meteoric water to impact underlying materials. See also Appendix G, Table G.2-1 of the 95% Design Report.
2013 ROD, Section 2.9.1, Bullet 3	Remediation Action Objectives • Prevent the migration of concentrations of contaminants located in the soil, mine waste, and tailings contained within the Tailings Disposal Area to ground water where the migration of those contaminants would result in ground water concentrations that exceed remediation goals established in EPA's 1988 ROD for the Ground Water	A groundwater analysis was performed of the final impoundment configuration, including placement of the mine spoils and final cover system, and submitted in *Tailings Consolidation and Groundwater Evaluation - 95% Design Draft.* (Dwyer 2017). The flux through the entire impoundment profile was compared to the flux through the similar existing profile without inclusion of the mine spoils or final cover system. Analysis results showed no significant increase of moisture

Performance Standard Requirement Citation/ Regulation	Performance Standard	Discussion
	Operable Unit (including any amendment), and, through this action, prevent human and ecological receptors from being exposed to ground water with concentrations of contaminants that exceed remediation goals established in the 1988 ROD, including any amendment.	release that could affect the underlying groundwater.
2013 ROD, Section 2.9.2, Bullet 1	Radionuclides and their daughter products in soil, mine waste, and tailings contained within the Tailings Disposal Area will not release radon-222 emissions from residual radioactive material to the atmosphere in exceedance of an average release rate of 20 picocuries per square meter per second (pCi/m^2s) 16 [40 CFR §§ 192.02(b)(1) and 192.32(b)(1)(ii)].	The placement of mine spoils within the impoundment combined with the final cover system demonstrates that the release of radon to the atmosphere will be less than 20 picocuries per square meter per second. Analysis (described in Section 8) demonstrates the calculated radon release rate to be less than 20 pCi/m2s.
2013 ROD, Section 2.9.2, Bullet 2	Radionuclides and their daughter products in soil, mine waste, and tailings contained within the Tailings Disposal Area will not release radon-222 emissions from residual radioactive material to the atmosphere that will increase the annual average concentration of radon-222 in air at or above any location outside the disposal site by more than one-half picocurie per liter [40 CFR § 192.02(b)(2)].	The placement of mine spoils within the impoundment combined with the final cover system demonstrates that the release of radon to the atmosphere will be less than 20 pCi/m2s . Modeling (refer to Section 8) demonstrates the calculated radon release rate to be less than 20 pCi/m2s . Also refer to: RTCS Row 469, EPA Comment G.7-7 App. G, Att 7, Table 1 Comment: 2013 ROD, Section 2.9.2 Bullet 2. Where are the calculations presented to satisfy the criteria that radon-222 emissions at the edge of the repository will not increase by more than 0.5 pCi/l? [40DFR 192.02(b)(2)] Response: Dwyer completed radon calculations through cover and the results are summarized in Section 8. Requirements in 40 CFR 192.02 (b) are satisfied because the requirements are an 'or' requirement (as opposed to an 'and' requirement).
2013 ROD, Section 2.9.2, Bullet 3	Remediation Goals • Migration of contaminants from the Tailings Disposal Area shall not result in ground water concentrations that exceed remediation goals established in EPA's 1988 ROD for the Ground Water Operable Unit, including any amendment.	A groundwater analysis (Dwyer 2017) of the flux through the entire impoundment profile was compared to the flux through the similar existing profile without inclusion of the mine spoils or final cover system. Analysis results show no significant increase of moisture release from the base of the alluvium beneath the existing fine tailings.
2013 ROD,	Cap design and cost estimates for	1) The final cover system is an ET Cover

Performance Standard Requirement Citation/ Regulation	Performance Standard	Discussion
Section 2.9.5 – Cap Design Criteria	Alternative 2 are based on the following elements: 1) The design includes a soil and rock cover over the waste materials, which will be located within the restricted area of the existing tailings impoundment. 2) The cover is designed to minimize flux through the cover due to meteoric precipitation. 3) Surface features direct surface water drainage away from disposal units at velocities and gradients which will not result in significant erosion that will require ongoing active maintenance in the future. 4) The design of the repository including placement of mine spoils and cover material shall minimize contact of water with waste during storage, contact of standing water with waste during disposal and contact of percolating or standing water with wastes after disposal.	composed of soil and rock located within the existing tailings impoundment 2) This report demonstrates the ET Cover demonstrates that flux due to meteoric precipitation is minimized 3) The mine spoils shall be placed to ensure runoff from the repository at a slope not to exceed 5 percent 4) Modeling summarized in this report demonstrate that the ET Cover on the mine spoils placed within the impoundment shall effectively minimize water contact due to meteoric precipitation.
2013 ROD, Section 2.9.5 – Cap Design Criteria, Bullet 1	Cap longevity designed for a minimum of 200 years with minimal maintenance and for effectiveness up to one thousand years, to the extent reasonably achievable [40 CFR §§ 192.02(a),192.32(b)(1)(i), and 264.111(a)]	The cap was designed to minimize flux of meteoric water into underlying materials (see Sections 6 and 7). It is designed to resist erosion (see Section 3). It is also designed to limit radon to within regulatory acceptable levels (see Section 8).
2013 ROD, Section 2.9.5 – Cap Design Criteria, Bullet 2	A sufficient clean (uncontaminated) soil layer to provide assurance that releases in the form of Radon-220 and -222 will not exceed an average release rate of 20 picocuries per meter squared per second [40 CFR §§ 192.02(b)(1) and 192.32(b)(1)(ii)], and will not increase the annual average concentration of radon-220 and -222 in air at or above any location outside the disposal site by more than one-half picocurie per liter [40 CFR § 192.02(b)(2)]	The placement of mine spoils within the impoundment combined with the final cover system demonstrates that the release of radon to the atmosphere will be less than 20 pCi/m2s . Modeling (see Section 8) shows a computed radon release rate of less than 20 pCi/m2s .
2013 ROD, Section 2.9.5 – Cap Design Criteria, Bullet 3	Cap construction to protect the mine waste, reduce the potential for leachate development, and prevent contaminated runoff by limiting infiltration of precipitation and by providing erosion protection and durability [40 CFR §§192.32(b)(1), 264.111(a), 264.111(b) 264.228(b)(1), 264.228(b)(3), and	The cap was designed to minimize flux of meteoric water into underlying materials (refer to Sections 6 and 7). The lack of significant flux through the final cover system eliminates the potential for leachate development. Section 3 summarizes the surface layer design and analysis intended to minimize erosion and soil loss. Rock used in the rock/soil admixture will

Performance Standard Requirement Citation/ Regulation	Performance Standard	Discussion
	264.228(b)(4)]	meet specified durability requirements intended to last for the 1,000-year design life of the cover system.
2013 ROD, Section 2.9.5 – Cap Design Criteria, Bullet 4	Cap slope, shape and drainage construction to ensure stability and minimize the effects of erosion, root intrusion, and animal destruction [40 CFR §§192.32(b)(1), 264.111(a), 264.111(b) 264.228(b)(1), 264.228(b)(3), and 264.228(b)(4)];	The repository is designed with top slopes of 2 to 5 percent to minimize the effects of soil loss due to runoff. The inclusion of a rock/soil admixture as the top layer of the cover system is intended to limit soil loss due to wind and water erosion. The admixture has also been shown to effectively maintain native vegetation.
2013 ROD, Section 2.9.5 – Cap Design Criteria, Bullet 6	the use of vegetation to emulate the structure, function, diversity, and dynamics of the native community to maximize resilience and sustainability	The cover system is designed to provide for a rooting medium for native vegetation. It is using locally available soil from engineer-approved borrow sources. The addition of a surface rock/soil admixture will also assist with the establishment and maturation of native vegetation. See also Appendix G, Table G.2-1 of the 95% Design Report.
2013 ROD, Section 2.9.5 – Cap Design Criteria, Bullet 7	Erosion modeling to determine effectiveness of cap design	The cap was designed to effectively minimize erosion. The slopes and slope lengths were designed to minimize erosion while enabling closure of a large volume of mine spoils. A rock/surface admixture is included in the cover profile that is intended to mitigate the formation of rill/gullies and limit soil loss due to both wind and water erosion. Section 3 summarizes the design and analysis performed related to erosion.
2013 ROD Table 1	10 CFR 40 Appendix A, Criterion 3. Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material From Ores Processed Primarily for Their Source Material Content. Refer to www.ecfr.gov.	The repository slopes have been optimized to limit the effects of erosion. Erosion protection design is included in Section 3.
2013 ROD Table 1	10 CFR 40 Appendix A, Criterion 5. Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material From Ores Processed Primarily for Their Source Material Content. Refer to www.ecfr.gov.	Criterion 5 is about a liner. This impoundment predated liner requirements. However, the repository includes a cover system designed to effectively minimize flux and limit the ability of meteoric water moving into underlying materials (see Criterion 6 below). Thus the potential impact to groundwater is not increased. Refer to Dwyer (2017).
2013 ROD Table	10 CFR 40 Appendix A, Criterion 6.	The cover was designed to minimize flux of

Performance Standard Requirement Citation/ Regulation	Performance Standard	Discussion
1	Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material From Ores Processed Primarily for Their Source Material Content. Refer to www.ecfr.gov.	meteoric water into underlying materials (refer to Sections 6 and 7). Because there is no flux through the final vegetated cover system, there will be no increase in leachate (see Section 3). Rock used in the rock/soil admixture will meet specified durability requirements intended to last for the 1,000-yr design life of the cover system (95% Design Report, Appendix H). Section 8 summarizes the analysis performed that shows the radon release rate will not exceed an average release rate of 20 pCi/m^{2}s [40 CFR §§ 192.02(b)(1) and 192.32(b)(1)(ii)], and will not increase the annual average concentration of radon-220 and -222 in air at or above any location outside the disposal site by more than one-half picocurie per liter [40 CFR § 192.02(b)(2)]. See also Appendix G, Table G.2-1 of the 95% Design Report.
2013 ROD Table 1	10 CFR 61.44. Refer to www.ecfr.gov.	The final cover system was designed to meet a 1,000-yr design life without appreciable maintenance. It utilized only natural materials (soil and rock). The analysis and design demonstrated that the cover will effectively perform for the design life. See also Appendix G, Table G.2-1 of the 95% Design Report.
2013 ROD Table 1	10 CFR 61 51(a)(1), 51(a)(4), 51(a)(5) and 51(a)(6). Refer to www.ecfr.gov.	The repository volume has been designed for the anticipated volume of material to be removed from the Mine Site. The repository is designed for long-term stability and the design criteria used eliminate, to the extent practicable, the need for on-going maintenance. The cover system incorporates only natural materials with indefinite design lives. The input parameters utilized in the design process took the 1,000-year performance of the final cover system into account. The design includes a soil and rock cover over the waste materials, which will be located within the restricted area of the existing tailings impoundment (refer to Section 3). The cover is designed to minimize flux through the cover due to meteoric precipitation (see Sections 6 and 7). Surface features direct surface water drainage away from disposal units at velocities and gradients designed to prevent significant

Performance Standard Requirement Citation/ Regulation	Performance Standard	Discussion
		erosion that would require ongoing active maintenance (refer to Section 3). The design of the repository (including placement of mine spoils and cover material) shall minimize water contact with waste during storage, disposal and following disposal (95% Design Report, Appendix I). The construction drawings and specifications were prepared to mitigate the potential for storm water to be in contact with mine spoils during placement and limit the ability of significant infiltration into underlying materials. The modeling (see Sections 6 and 7) demonstrates that once the final cover system is in place, this cover will mitigate flux and thus reduce potential for meteoric water to impact underlying materials. See also Appendix G, Table G.2-1 of the 95% Design Report.
2013 ROD Table 1 and Section 2.9.5 Cap Design, Bullets 1, 3, and 4	40 CFR 264.111(a). Refer to www.ecfr.gov.	See 95% Design Submittal, Appendix I regarding maintenance of the storm water control features around the repository. The repository volume has been designed for the anticipated volume of material to be removed from the Mine Site. The repository is designed for long-term stability and the design criteria used eliminate, to the extent practicable, the need for on-going maintenance. The cover system incorporates only natural materials with indefinite design lives. The input parameters utilized in the design process took the 1,000-yr performance of the final cover system into account. The design includes a soil and rock cover over the waste materials, which will be located within the restricted area of the existing tailings impoundment (refer to Section 3). The cover is designed to minimize flux through the cover due to meteoric precipitation (refer to Sections 6 and 7). Surface features direct surface water drainage away from disposal units at velocities and gradients which will not result in significant erosion that will require ongoing active maintenance in the future. Refer to Section 3 of this report. The design of the repository (including placement of mine spoils and cover material) shall minimize water contact with waste during

Performance Standard Requirement Citation/ Regulation	Performance Standard	Discussion
		storage, during disposal and following disposal. The construction drawings and specifications were prepared to mitigate the potential for storm water to be in contact with mine spoils during placement and limit the ability of significant infiltration into underlying materials. The modeling (see Sections 6 and 7) demonstrates that once the final cover system is in place, this cover will mitigate flux and thus reduce potential for meteoric water to impact underlying materials. See also Appendix G, Table G.2-1 of the 95% Design Report
2013 ROD, Table 1 and Section 2.9.5, Cap Design Criteria, Bullets 3 and 4	40 CFR 264.228(b)(4). Refer to www.ecfr.gov.	The cover system incorporates a rock/soil admixture that minimizes erosion due to surface water runoff and wind. The armament also mitigates the potential for rills and gullies. Section 3 provides a design summary and analysis that demonstrate erosion is minimized for the final cover system. See also Appendix G, Table G.2-1 of the 95% Design Report
2013 ROD Table 1 and Sections 2.9.2 and 2.9.5	40 CFR 192.32(b) (1). Refer to www.ecfr.gov. (2) The requirements of § 192.32(b)(1) shall not apply to any portion of a licensed and/or disposal site which contains a concentration of radium-226 in land, averaged over areas of 100 square meters, which, as a result of uranium byproduct material, does not exceed the background level by more than: (i) 5 picocuries per gram (pCi/g), averaged over the first 15 centimeters (cm) below the surface, and (ii) 15 pCi/g, averaged over 15 cm thick layers more than 15 cm below the surface	Radon flux performance objectives were demonstrated to be satisfied with the 4-ft thick ET Cover (refer to Section 9).
2015 AOC SOW, Paragraph 26 – Acceptance Criteria	For the part of the Tailings Disposal Area that is to contain the mine waste from the NECR Site and for the part of the current tailings cell that may be disturbed during implementation of the remedy, Respondents shall include, in their Design, detailed plans and specifications to meet and demonstrate compliance with Acceptance Criteria consistent with Section 5.1 of NUREG 1620.	The repository volume has been designed for the anticipated volume of material to be removed from the Mine Site. The repository is designed for long-term stability and the design criteria used eliminate, to the extent practicable, the need for on-going maintenance. The cover system incorporates only natural materials with indefinite design lives. The input parameters utilized in the design process account for the 1,000-yr performance of the final cover system.

Performance Standard Requirement Citation/ Regulation	Performance Standard	Discussion
		The design includes a soil and rock cover over the waste materials, which will be located within the restricted area of the existing tailings impoundment (refer to Section 3). The cover is designed to minimize flux due to meteoric precipitation (refer to Sections 6 and 7). Surface features direct surface water drainage away from disposal units at velocities and gradients that will not result in significant erosion requiring ongoing active maintenance (see Section 3). The design of the repository (including placement of mine spoils and cover material) shall minimize water contact with waste during storage, during disposal and following disposal. The construction drawings and specifications were prepared to mitigate the potential for storm water to be in contact with mine spoils during placement and limit the ability of significant infiltration into underlying materials. The modeling (see Sections 6 and 7) demonstrates that once the final cover system is in place, this cover will mitigate flux and thus reduce potential for meteoric water to impact underlying materials. See also Appendix G, Table G.2-1 of the 95% Design Report

4.0 EROSION

The performance objectives related to the ET Cover's ability to resist erosion are to reduce soil loss due to erosion to less than 2 tons/acre/year (USEPA 1991) and demonstrate the long-term stability of the cover surface (NRC, 2002). The cover surface layer was designed to satisfy these performance objectives.

The cover surface layer is composed of a mixture of rock and cover soil designed to mitigate the potential for rill or gully formation as well as minimize soil loss. This admixture design varies (rock size and depth) depending on the specific slope and slope length (Figure 13~~9~~). For example, the base of a long slope may have a large rock within the admixture and greater admixture thickness compared to the top of the slope. This erosion resistant admixture was designed consistent with guidance summarized in Dwyer et al. (2007) and USEPA (2012). The surface erosion admixture has been successfully deployed on multiple sites throughout the southwestern United States including an installation near San Mateo, NM on a uranium mine site closure. This site was closed in 2013 with an ET Cover similar to that proposed for the NECR site. Vegetation establishment on the cover exceeded performance requirements to have perennial plant coverage meet comparable undisturbed reference sites (Cedar Creek 2016). There has been no significant soil loss due to erosion nor any rill or gully formation on the cover system despite the site experiencing a beyond 100-year storm event (Cedar Creek 2016).

The following subsections summarize the design methods and calculations performed to develop a top layer. This top layer is composed of an admixture of rock and soil that is intended to form a 'desert pavement'. To ensure that the cover complies with NUREG-1623 and will behave as a desert pavement, two analyses were completed: the design of the rock/soil admixture per USEPA (2012) (Section 4.1) and an analysis of the long-term stability of the final slope as a rocky soil per NUREG-1623 (Section 4.2). The largest rock size as determined by the methodologies between that described in Section 4.1 and 4.2 governs and is summarized in Section 4.3, Tables 5 to 8. Finally, Section 4.4 summarizes the compliance of annual soil loss to less than 2 tons/acre/year as recommended by USEPA (1991).

4.1 DESIGN OF COVER SURFACE LAYER (ROCK/SOIL ADMIXTURE)

Rock/soil admixtures provide a proven means to minimize erosion while allowing for vegetation establishment without a significant reduction in evaporation (Waugh et al 1994, Dwyer 2003, Dwyer et al 2007). Erosion (Ligotke 1994) and water balance studies (Waugh 1994) suggest that moderate amounts of gravel mixed into the cover topsoil will control both water and wind erosion. As wind and water pass over the cover surface, some winnowing of fines from the admixture is expected, creating a vegetated erosion-resistant surface referred to as a “desert pavement”. The following rock/soil admixture design is for the final cover system's top surface where slopes are 5 percent or less.

4.1.1 DESIGN RAINFALL EVENT

The design event for evaluation of long-term erosional stability is the PMP based on NRC guidelines in NUREG-1623. This worst case storm event was used to design the surface admixture. The PMP, 1-hour precipitation value of 6.5-inches was utilized in the design and analysis. This PMP value was obtained from the most recent PMP study available (Applied Weather Associates, 2013). Results of this study supersede Hydrometeorological Report (HMR)

49 (Hansen et al. 1977). Definitions of PMP are found in most of the HMRs issued by the National Weather Service (NWS). The definition used in the most recently published HMR is "theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of the year" (HMR 59, p. 5).

The cover design life per 40 CFR 192(a) shall be effective for up to 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years. To appreciate the size of the PMP design event and for comparison purposes, the 1,000 return period (1-hour precipitation frequency) is 2.96 inches (7.52 cm) as determined using data supplied by the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) Hydrometerological Design Studies Center - NOAA Atlas 14, Volume 1 for Gallup, NM(Bonnin, 2011). The 1-hour time of concentration is generally considered conservative for any contributory area less than 50 acres (20 hectares) (Lindeburg 1989). It can be seen this 1,000 return period value is significantly less than the PMP value for the Church Rock, NM area that is 6.5-inches for the 1-hour precipitation frequency.

4.1.2 RUNOFF PREDICTION

The "rational method" was used to estimate runoff volumes. This method is commonly used in civil engineering applications and is a method recommended in DOE (1989) for design of cover systems for sites regulated by the Uranium Mill Tailings Radiation Control Act of 1978 (i.e., UMTRA sites) and NUREG-1623. The rational method is based on the assumption that rainfall occurs uniformly over the watershed at a constant intensity for duration equal to the time of concentration.

Using the rational method, the peak rate of runoff, (Q), in cubic feet per second (cfs) is given by the following expression [the runoff units are actually in acre-inches/hour but is commonly rounded to cfs]:

$$Q = C\ I\ A \qquad \textbf{Equation 1}$$

where:

C = Runoff coefficient (dimensionless) = 0.3 [Lindeburg 1989]

I = Rainfall intensity (in/hr) [Tables 3 and 4]

A = Surface area that contributes to runoff (acres) = $L^2/4$, [USEPA 2012, Dwyer et al 2007]

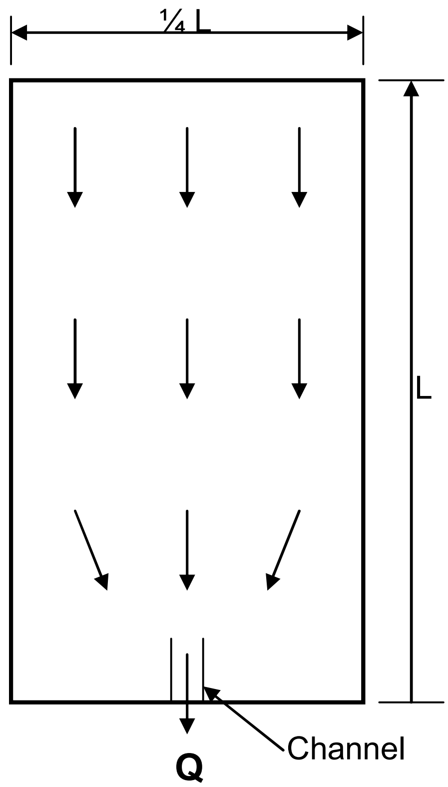


Figure 1. Contributory Area For Gully Formation

The time of concentration (t_c) was calculated based on the following equation (Brant & Oberman, 1975 per DOE 1989, p. 65):

$$t_c = C*(L/S*i^2)^{1/3}$$ **Equation 2**

where:

C = Coefficient = 1.0 bare area;

L = slope length (ft);

S = slope (ft/ft); and

i =rainfall intensity (in/hr) = 6.51 in/hr per PMP

Using the tabular values in Table 2 (DOE 1989), the percentage of rainfall intensity for a t_c of less than 1 hour can be determined.

Table 2. Incremental Rainfall Duration Percentage (DOE 1989, Table 4.1)

Rainfall Duration (RD) (min.)	Percentage of one-hour PMP (%)**
2.5	27.5
5	45
15	74
30	89
45	95
60	100

** % of one-hr PMP = RD/(0.089*RD + 0.0686)

The contributory surface area was calculated based on the assumed configuration shown in Figure 1 where L is the critical slope length [USEPA 2012, Dwyer et al. 2007]. Slopes and slope lengths were estimated from proposed contoured plans of the conceptual cover. Because most of the drainage areas from the cover were irregularly shaped, the slopes and slope lengths were estimated to match the area configuration described here.

The rainfall one-hour intensity corresponding to the computed time of concentration (tc) is then computed as follows (DOE 1989, p. 66):

$$I = PMP_{(t_c)} x \frac{60}{t_c}$$ **Equation 3**

Table 3 summarizes the computations for the slope length intervals for the 5 percent slope while Table 4 summarizes those for the 2 percent slope length.

Table 3. Calculation of Rainfall Intensity for Slope of 5% with Slope Length of 1021-ft

C	L (ft)	S (%)	PMP (in/hr)	Tc (min)	Extrapolation[1]	I (in/hr)
1	1021	5.00%	6.51	7.839672	56.7%	28.228
1	1000	5.00%	6.51	7.785551	56.5%	28.327
1	900	5.00%	6.51	7.516867	55.5%	28.827
1	800	5.00%	6.51	7.227465	54.4%	29.385
1	700	5.00%	6.51	6.912822	53.1%	30.017
1	600	5.00%	6.51	6.566588	51.7%	30.746
1	525	5.00%	6.51	6.28072	50.4%	31.374
1	500	5.00%	6.51	6.179396	50.0%	31.603
1	400	5.00%	6.51	5.736443	47.9%	32.644
1	350	5.00%	6.51	5.48671	46.7%	33.262
1	300	5.00%	6.51	5.211904	45.3%	33.969
1	200	5.00%	6.51	4.553018	41.7%	35.795

[1] Extrapolation is the % of one-hr PMP = RD/(0.089*RD + 0.0686) [refer to Table 2]

Table 4. Calculation of Rainfall Intensity of 2% with Slope Length of 1000-ft

C	L (ft)	S (%)	PMP (in/hr)	Tc (min)	extrapolation[1]	I (in/hr)
1	1000	2.0%	6.51	10.567	65.0%	24.0158
1	900	2.0%	6.51	10.202	64.0%	24.5048
1	800	2.0%	6.51	9.809	62.9%	25.0542
1	700	2.0%	6.51	9.382	61.7%	25.6803
1	600	2.0%	6.51	8.912	60.3%	26.4064
1	500	2.0%	6.51	8.387	58.5%	27.2686
1	400	2.0%	6.51	7.786	56.5%	28.3266
1	350	2.0%	6.51	7.074	53.8%	29.6909
1	300	2.0%	6.51	6.179	50.0%	31.6028
1	200	2.0%	6.51	4.905	43.7%	34.7971

[1] Extrapolation is the % of one-hr PMP = RD/(0.089*RD + 0.0686) [refer to Table 2]

4.1.3 Channel Geometry

The channel geometry shown in Figure 2 is that assumed for gully formation.

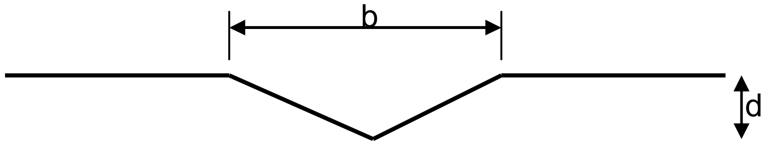


Figure 2. Channel Geometry

The geometry of the channel that forms is based on regression equations developed from analysis of a large number of channels (Simon, Li & Assoc. 1982). The channel width is given by:

$b = 37\ (Q_m^{0.38} / M^{0.39})$ **Equation 4**

where:

b = width of flow (ft)

Q_m = mean annual flow (cfs)

M = percentage of silts and clays in soils (38 percent for applicable borrow soil)

The average percentage of fines (silt and clay) from the available cover soil borrow sources is about 57 percent. (MWH 2014) This value can be reduced by the volume percentage of rock added to the soil that is 33 percent. The resulting 'M' value is thus 38 percent. The mean annual flow (Q_m) is assumed to be between 10 percent and 20 percent of the peak rate of runoff (Q) (Dwyer et al. 2007). In this case 10 percent was used.

For the given discharge point of geometry, the hydraulic depth (d_h), defined as the flow cross-sectional area divided by the width of water surface, is half of the gully depth (d).

For flows at the critical slope:

$b = 0.5\ F^{0.6}\ F_r^{-0.4} Q^{0.4}$ **Equation 5**

where:

F = width to depth ratio = b/dh

F_r = Froude Number ≈ 1.0

4.1.4 Incipient Particle Size

The incipient particle size is the particle that is on the brink of movement at the assumed conditions. Any increase in the erosional forces acting on the particle, due to an increase in velocity or slope, for example, will cause its movement. For construction purposes, the incipient particle size is assumed to be the D_{50} (50 percent of rock passing the given sieve size). The rock are sorted in one-dimensional sieves, thus the rock passing a 1-inch sieve can actually be 1-inch wide by 2-inches long and/or 2-inches deep. Thus converting the incipient particle size to the rock specified D_{50} value is conservative given the D_{50} rock will likely have a larger mass than the inferred incipient particle size. This incipient particle size (D_c) was calculated using the Shield's Equation:

$D_c = \tau/F_s(\gamma_s - \gamma)$ **Equation 6**

where:

τ = total average shear stress (pcf)

F_s = Shield's dimensionless shear stress = 0.047

γ_s = specific weight of soil (pcf) [168.5 pcf]

γ = water density = 62.4 pcf

The total average shear stress is given by:

$\tau = \gamma \text{ dh } S$ **Equation 7**

where:

S = slope (ft/ft)

dh = hydraulic depth (ft) = A/b (Figure 2)

4.1.5 Depth of Scour and Armoring Required

The incipient particle size defines the maximum size of particle that will be eroded for a given set of conditions. Material larger than the incipient particle size will not be displaced or eroded, and can form an armoring that will protect the surface from erosion by similar or lesser storm events.

The depth of scour (Y_s) to establish an armor layer is given by (Pemberton and Lara 1984):

$Y_s = Y_a [(1/P_c)-1]$ **Equation 8**

where:

Y_s = scour depth

Y_a = armor layer thickness

P_c = decimal fraction of material coarser than the incipient particle size

4.2 LONG-TERM STABILITY OF ROCKY SOIL COVER

The ET Cover surface admixture layer is analyzed below to satisfy NUREG-1623 requirements for a stable slope of an unprotected soil cover. The long-term stability of the top deck cover surface with the addition of the rock/soil admixture can be determined by the following equation (NUREG-1623):

$S_s^{7/6} = [65*t^{5/3}]/[P*L*F*n]$ **Equation 9**

where:

S_s = maximum stable slope (%)

t = 0.4*D_{75} (75% of rock passing the given sieve size)

P = rainfall intensity

L = slope length

F= 3 (NUREG-1623)

n = 0.03

If the maximum stable slope (S_s) is greater than or equal to the actual slope, the cover is stable. The D_{75} used in Equation 9 is conservatively assumed to equate to the D_{50} and Dc in the preceding set of calculations to design the surface admixture layer.

4.3 Rock/Soil Calculations

An excel spreadsheet was used to simultaneously solve the multiple equations. Section 4.3.1 presents calculated results for the rock/soil admixture for the 5 percent slope with total slope length of 1,021 feet. Section 4.3.2 presents calculated results for the rock/soil admixture for the 2 percent slope with total slope length of 1,000 feet.

Because the cover system rock requirement is substantial and the slope lengths are varied, admixture requirements was computed in intervals along the slope length. That is, the top of the slope has less erosive forces because the slope length is shorter than the bottom of the slope. Tables 5 to 8 summarize the analysis performed.

4.3.1 Admixture Design for Single Slope Length of 1,021 ft at 5 Percent Slope

Table 5 summarizes the admixture calculations following the method outlined in Section 4.1 while utilizing the intensity values (I) in Table 3. The critical particle size (Dc) and admixture depth are computed based on the slope length location along the 5 percent slope. For slope lengths 525 feet and longer, a 3-inch rock is required with a corresponding admixture depth of 27 inches. For a slope length of 350 feet to 525 feet, a 2-inch rock is required with a corresponding admixture depth of 18 inches. From the top of the slope to a slope length of 350 feet, a 1.5-inch rock is required with a corresponding admixture depth of 14 inches. All mixtures will be 33 percent rock to 67 percent soil by volume for the full admixture depth.

The largest Dc in the admixture design (summarized in Section 4.1) or long-term stable slope (per NUREG-1623) is included in Table 5. For slope lengths greater than 400 feet, the admixture design governed the Dc size. For slope lengths less than 400 feet, the Dc determined was based on NUREG-1623 requirements for a long-term stable slope.

Table 5. Admixture Design Summary

I (in/hr)	S (%)	Slope Length (ft)	A (acres)	Q (cfs)	Qm (cfs)	b (ft)	dH (in)	τ (psf)	Rock Size Dc (in)	use Rock Size Dc (in)	% gravel	Ya (in)	Ys (in)	Admix Depth (in)	Comment
28.2	5	1021	5.98	50.66	5.07	16.6	5.02	1.305	3.1	3.00	33%	9.0	18	27.0	
28.3	5	1000	5.74	48.77	4.88	16.4	4.94	1.285	3.1	3.00	33%	9.0	18	27.0	
28.8	5	900	4.65	40.20	4.02	15.2	4.56	1.186	2.9	3.00	33%	9.0	18	27.0	
29.4	5	800	3.67	32.38	3.24	14.0	4.17	1.084	2.6	3.00	33%	9.0	18	27.0	
30.0	5	700	2.81	25.32	2.53	12.7	3.77	0.980	2.4	3.00	33%	9.0	18	27.0	
30.7	5	600	2.07	19.06	1.91	11.4	3.35	0.871	2.1	3.00	33%	9.0	18	27.0	
31.4	5	525	1.58	14.90	1.49	10.4	3.02	0.786	1.9	2.00	33%	6.0	12	18.0	
31.6	5	500	1.43	13.60	1.36	10.1	2.91	0.758	1.8	2.00	33%	6.0	12	18.0	
32.6	5	400	0.92	8.99	0.90	8.6	2.46	0.638	1.5	2.00	33%	6.0	12	18.0	increased rock size per Section 4.2 (NUREG-1623) [1]
33.3	5	350	0.70	7.02	0.70	7.8	2.22	0.576	1.4	2.00	33%	6.0	12	18.0	increased rock size per Section 4.2 (NUREG-1623) [1]
34.0	5	300	0.52	5.26	0.53	7.0	1.97	0.512	1.2	1.50	33%	4.5	9	14.0	increased rock size per Section 4.2 (NUREG-1623) [1]
35.8	5	200	0.23	2.47	0.25	5.3	1.44	0.374	0.9	1.50	33%	4.5	9	14.0	increased rock size per Section 4.2 (NUREG-1623) [1]
38.8	5	100	0.06	0.67	0.07	3.2	0.84	0.218	0.5	1.50	33%	4.5	9	14.0	increased rock size per Section 4.2 (NUREG-1623) [1]

1 Values highlighted (slope lengths 100 to 400-ft) required an increase in Dc to meet NUREG-1623 requirements (Section 4.2). Refer to Table 6.

Table 6 summarizes the calculations to verify compliance with the long-term stability of a rocky soil slope per NUREG-1623 (Section 4.2). The slope lengths utilized in the calculations correspond to those from Table 5. The slope is 5 percent, consequently any calculation that computed a stable slope of greater than 5 percent with the particle size determined in Table 5 was acceptable. However, for slope lengths less than 400 feet, the Dc was increased in the computations to satisfy the long-term stability of a rocky soil slope per NUREG-1623.

Table 6. Long-Term Stability of Rocky Soil 5% Slope (NUREG 1623)

Rock Size (D75)	t	P	L	Calculated Ss	Comments
3.0	1.2	28.228	1021	5.5%	The calculated stable slope is greater than 5% (the slope to be built), therefore the Dc for rock size developed in Section 4.1 is more conservative
3.0	1.2	28.3266	1000	5.6%	The calculated stable slope is greater than 5% (the slope to be built), therefore the Dc for rock size developed in Section 4.1 is more conservativegreater than 5%, therefore the Dc for rock size developed in Section 4.1 is more conservative
3.0	1.2	28.8265	900	6.0%	The calculated stable slope is greater than 5% (the slope to be built), therefore the Dc for rock size developed in Section 4.1 is more conservativegreater than 5%, therefore the Dc for rock size developed in Section 4.1 is more conservative
3.0	1.2	29.3851	800	6.6%	The calculated stable slope is greater than 5% (the slope to be built), therefore the Dc for rock size developed in Section 4.1 is more conservativegreater than 5%, therefore the Dc for rock size developed in Section 4.1 is more conservative
3.0	1.2	30.0175	700	7.2%	The calculated stable slope is greater than 5% (the slope to be built), therefore the Dc for rock size developed in Section 4.1 is more conservativegreater than 5%, therefore the Dc for rock size developed in Section 4.1 is more conservative
3.0	1.2	30.7456	600	8.1%	The calculated stable slope is greater than 5% (the slope to be built), therefore the Dc for rock size developed in Section 4.1 is more conservativegreater than 5%, therefore the Dc for rock size developed in Section 4.1 is more conservative
2.0	0.8	31.3739	525	5.0%	The calculated stable slope is greater than 5% (the slope to be built), therefore the Dc for rock size developed in Section 4.1 is more conservativegreater than 5%, therefore the Dc for rock size developed in Section 4.1 is more conservative

Rock Size (D75)	t	P	L	Calculated Ss	Comments
2.0	0.8	31.6028	500	5.2%	The calculated stable slope is greater than 5% (the slope to be built), therefore the Dc for rock size developed in Section 4.1 is more conservative~~greater than 5%, therefore the Dc for rock size developed in Section 4.1 is more conservative~~
2.0	0.8	32.644	400	6.1%	As noted in Table 5, the rock size using this formula from NUREG-1623 governs for this slope length. The calculated stable slope is greater than 5% (the slope to be built), therefore the Dc for rock size developed in Section 4.1 is more conservative
2.0	0.8	33.2619	350	6.7%	As noted in Table 5, the rock size using this formula from NUREG-1623 governs for this slope ~~length .~~length. The calculated stable slope is greater than 5% (the slope to be built), therefore the Dc for rock size developed in Section 4.1 is more conservative
1.5	0.6	33.9694	300	5.0%	As noted in Table 5, the rock size using this formula from NUREG-1623 governs for this slope length. The calculated stable slope is greater than 5% (the slope to be built), therefore the Dc for rock size developed in Section 4.1 is more conservative
1.5	0.6	35.7948	200	6.7%	As noted in Table 5, the rock size using this formula from NUREG-1623 governs for this slope length. The calculated stable slope is greater than 5% (the slope to be built), therefore the Dc for rock size developed in Section 4.1 is more conservative
1.5	0.6	38.7645	100	11.4%	As noted in Table 5, the rock size using this formula from NUREG-1623 governs for this slope length. The calculated stable slope is greater than 5% (the slope to be built), therefore the Dc for rock size developed in Section 4.1 is more conservative

[1] Values highlighted (slope lengths less than 400 feet) required an increase in D_{75} from the Dc value computed using the methods outlined in Section 4.1 to meet NUREG-1623 requirements. Refer to Table 5.

4.3.2 Admixture Design for Single Slope Length of 1,000 ft at 2 Percent Slope

Table 7 provides a summary of the admixture calculations following the method in Section 4.1 while utilizing the intensity values (I) in Table 4. The critical particle size (Dc) and admixture depth are computed based on the slope length along the 2 percent slope. For all slope lengths, the long-term stability of a rocky soil slope (per NUREG-1623) determined the critical rock size

(Dc). All mixtures will be 33 percent rock to 67 percent soil by volume for the full admixture depth.

Table 7. Admixture Design Summary for Cover 2% Slope

I (in/hr)	S (%)	Slope Length (ft)	A (acres)	Q (cfs)	Qm (cfs)	b (ft)	dH (in)	τ (psf)	Dc (in)	use Dc (in)1,2	% Gravel	Ya (in)	Ys (in)	Admix Depth (in)	Comment
24.0	2	1000	5.739	41.35	4.13	15.36	4.61	0.480	1.2	1.5	33	4.5	9	14.0	increased rock size per Table 8. NUREG-1623
24.5	2	900	4.649	34.18	3.42	14.29	4.27	0.444	1.1	1.5	33	4.5	9	14.0	increased rock size per Table 8. NUREG-1623
25.1	2	800	3.673	27.61	2.76	13.17	3.90	0.406	1.0	1.5	33	4.5	9	14.0	increased rock size per Table 8. NUREG-1623
25.7	2	700	2.812	21.67	2.17	12.01	3.53	0.367	0.9	1.5	33	4.5	9	14.0	increased rock size per Table 8. NUREG-1623
26.4	2	600	2.066	16.37	1.64	10.80	3.15	0.327	0.8	1.5	33	4.5	9	14.0	increased rock size per Table 8. NUREG-1623
27.3	2	500	1.435	11.74	1.17	9.52	2.74	0.285	0.7	1.5	33	4.5	9	14.0	increased rock size per Table 8. NUREG-1623
28.3	2	400	0.918	7.80	0.78	8.15	2.32	0.241	0.6	1.5	33	4.5	9	14.0	increased rock size per Table 8. NUREG-1623
29.7	2	300	0.517	4.60	0.46	6.67	1.86	0.194	0.5	1.5	33	4.5	9	14.0	increased rock size per Table 8. NUREG-1623
31.6	2	200	0.230	2.18	0.22	5.02	1.37	0.142	0.3	1.5	33	4.5	9	14.0	increased rock size per Table 8. NUREG-1623
34.8	2	100	0.057	0.60	0.06	3.07	0.80	0.083	0.2	1.5[2]	33	4.5	9	14.0	

[1] Values highlighted (slope lengths 100 to 400 feet) required an increase in Dc to meet NUREG-1623 requirements. Refer to Table 6

[2] Adjusted the Dc to meet the available 1.5-inch rock on-site

Table 8 summarizes the calculations to verify compliance the long-term stability of a rocky soil slope per NUREG-1623. The slope lengths utilized in the calculations correspond to those from Table 7. For all slope lengths, the Dc was increased in the computations to satisfy the long-term stability of a rocky soil slope per NUREG-1623.

Table 8. Long-Term Stability of Rocky Soil 2% Slope (NUREG-1623)

D75[1]	t	P	L	Calculated Ss	Comments
1.5	0.6	24.0158	1000	2.4%	~~need to increase rock size per NUREG-1623~~ The calculated stable slope (Ss) is greater than the slope to be built of 2%, therefore OK
1.5	0.6	24.5048	900	2.6%	~~need to increase rock size per NUREG-1623~~ The calculated stable slope (Ss) is greater than the slope to be built of 2%, therefore OK~~greater than 2%, therefore OK~~
1.5	0.6	25.0542	800	2.8%	~~need to increase rock size per NUREG-1623~~ The calculated stable slope (Ss) is greater than the slope to be built of 2%, therefore OK~~greater than 2%, therefore OK~~
1.5	0.6	25.6803	700	3.1%	~~need to increase rock size per NUREG-1623~~ The calculated stable slope (Ss) is greater than the slope to be built of 2%, therefore OK~~greater than 2%, therefore OK~~
1.5	0.6	26.4064	600	3.4%	~~need to increase rock size per NUREG-1623~~ The calculated stable slope (Ss) is greater than the slope to be built of 2%, therefore OK~~greater than 2%, therefore OK~~
1.5	0.6	27.2686	500	3.9%	The calculated stable slope (Ss) is greater than the slope to be built of 2%, therefore OK~~need to increase rock size per NUREG-1623 greater than 2%, therefore OK~~
1.5	0.6	28.3266	400	4.6%	The calculated stable slope (Ss) is greater than the slope to be built of 2%, therefore OK~~need to increase rock size per NUREG-1623 greater than 2%, therefore OK~~
1.5	0.6	29.6909	300	5.6%	~~need to increase rock size per NUREG-1623~~ The calculated stable slope (Ss) is greater than the slope to be built of 2%, therefore OK~~greater than 2%, therefore OK~~
1.5	0.6	31.6028	200	7.5%	The calculated stable slope (Ss) is greater than the slope to be built of 2%, therefore OK~~need to increase rock size per NUREG-1623 greater than 2%, therefore OK~~
1.5~~[1]~~	0.6	34.7971	100	12.5%	The calculated stable slope (Ss) is greater than the slope to be built of 2%, therefore OK~~greater than 2%, therefore OK~~

[1] Adjusted the Dc to meet the available 1.5-inch rock on-site

4.4 SOIL LOSS

The soil loss computed utilizing the Revised Universal Soil Loss Equation (RUSLE) and the Wind Erosion Prediction System or 'WEPS' (USDA 2010) is included to satisfy the USEPA (1991) guidance limiting soil loss to less than 2 tons/acre/year. It is recognized that these tools were developed by the USDA to provide an approximation of soil loss on farmlands with very fine grained soils (USDA 1997, USDA 2010). However, it is a common means utilized to satisfy the soil loss requirement per USEPA (1991). It does not infer that the computed soil loss is an estimate of expected soil loss given that the cover system includes a top layer composed of a mixture of rock and gravel design to minimize soil loss. The rock size or incipient particle size defines the maximum size of particle that will be eroded for a given set of conditions. Material larger than the incipient particle size will not be displaced or eroded, and will form an armoring to protect the surface from further erosion from similar or lesser storm events.

4.4.1 Soil Loss Due to Surface Water Runoff

RUSLE represents a revision of the Universal Soil Loss Equation (USLE) technology in how the factor values in the equation are determined. RUSLE is explained in USDA Handbook 703, "Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)" (USDA 1997). The RUSLE is expressed as:

$A_s = R_e K (LS) C P_c$ **Equation 10**

Where:

A_s = average annual soil loss by sheet and rill erosion in tons per acre

R_e = rainfall energy/erosivity factor (dimensionless) --- see Figure 4

K = soil erodibility factor (dimensionless) --- see Figure 3

LS = slope length and steepness factor (dimensionless) -- --- see Figure 5

C = vegetative cover and management factor (dimensionless)

P_c = conservation support practice factor (dimensionless)

The following figures are derived from Agriculture Handbook 703 (USDA 1997).

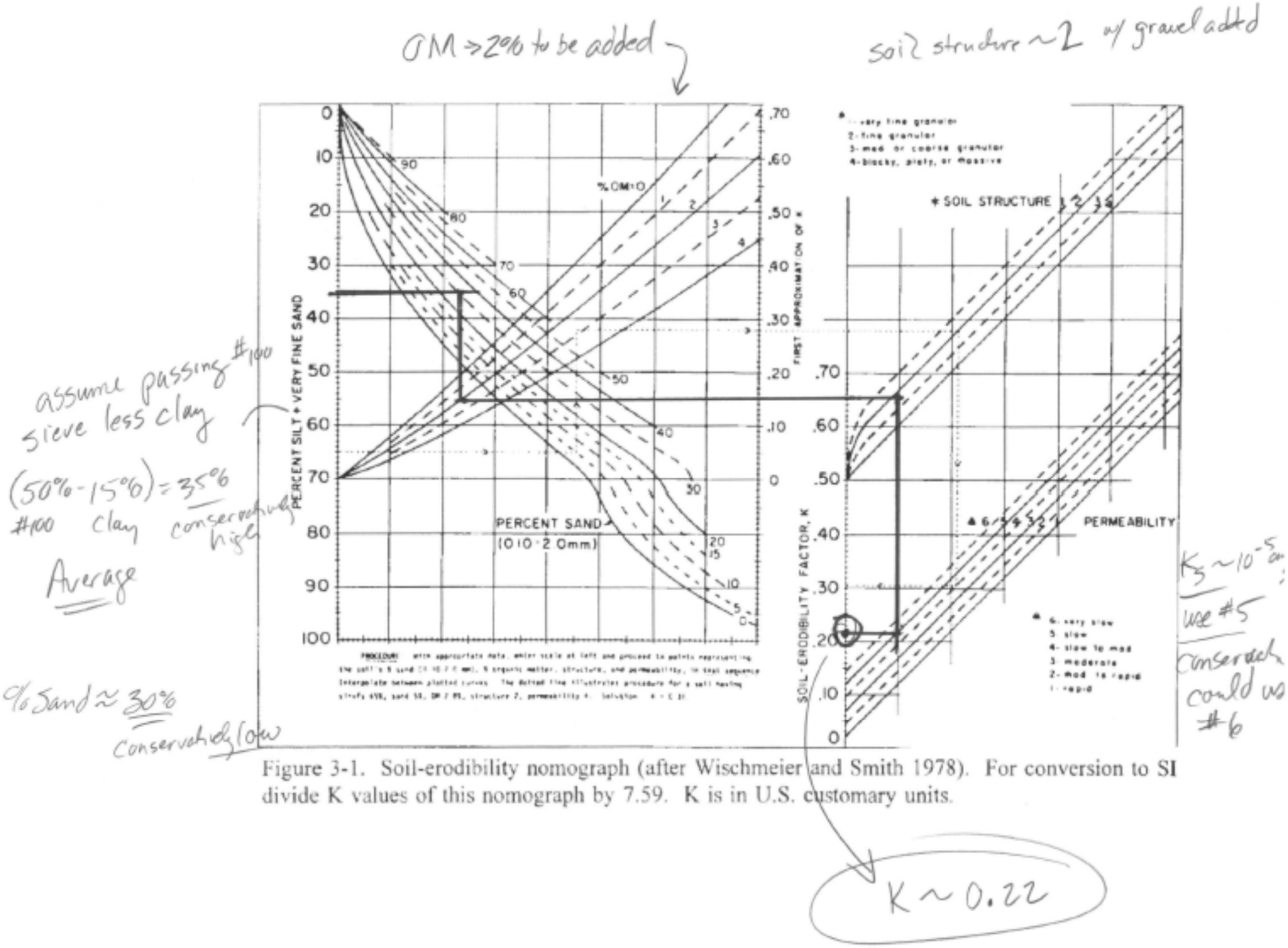


Figure 3-1. Soil-erodibility nomograph (after Wischmeier and Smith 1978). For conversion to SI divide K values of this nomograph by 7.59. K is in U.S. customary units.

Figure 3. RUSLE K Factor (USDA 1997)

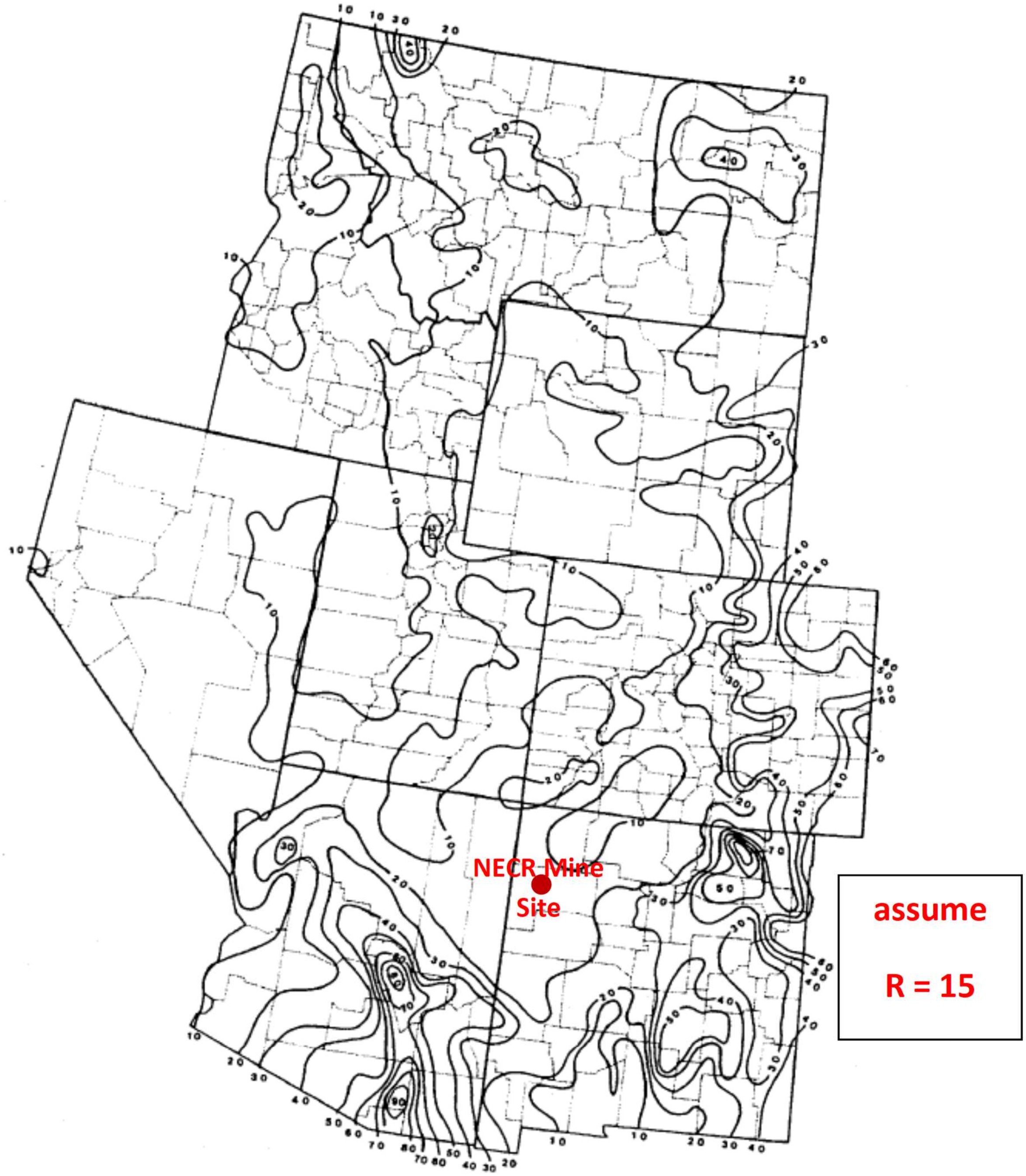


Figure 2-2. Isoerodent map of western United States. Units are hundreds ft·tonf·in(ac·h·yr)$^{-1}$.

Figure 4. RUSLE R Factor (USDA 1997)

assume = 1.10

Table 4-1.
Values for topographic factor, LS, for low ratio of rill to interrill erosion.[1]

Slope (%)	Horizontal slope length (ft) <3	6	9	12	15	25	50	75	100	150	200	250	300	400	600	800	1000
0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.5	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1.0	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.17	0.17
2.0	0.20	0.20	0.20	0.20	0.20	0.21	0.23	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.33	0.34	0.35
3.0	0.26	0.26	0.26	0.26	0.26	0.29	0.33	0.36	0.38	0.40	0.43	0.44	0.46	0.48	0.52	0.55	0.57
4.0	0.33	0.33	0.33	0.33	0.33	0.36	0.43	0.46	0.50	0.54	0.58	0.61	0.63	0.67	0.74	0.78	0.82
5.0	0.38	0.38	0.38	0.38	0.38	0.44	0.52	0.57	0.62	0.68	0.73	0.78	0.81	0.87	0.97	1.04	1.10
6.0	0.44	0.44	0.44	0.44	0.44	0.50	0.61	0.68	0.74	0.83	0.90	0.95	1.00	1.08	1.21	1.31	1.40
8.0	0.54	0.54	0.54	0.54	0.54	0.64	0.79	0.90	0.99	1.12	1.23	1.32	1.40	1.53	1.74	1.91	2.05
10.0	0.60	0.63	0.65	0.66	0.68	0.81	1.03	1.19	1.31	1.51	1.67	1.80	1.92	2.13	2.45	2.71	2.93
12.0	0.61	0.70	0.75	0.80	0.83	1.01	1.31	1.52	1.69	1.97	2.20	2.39	2.56	2.85	3.32	3.70	4.02
14.0	0.63	0.76	0.85	0.92	0.98	1.20	1.58	1.85	2.08	2.44	2.73	2.99	3.21	3.60	4.23	4.74	5.18
16.0	0.65	0.82	0.94	1.04	1.12	1.38	1.85	2.18	2.46	2.91	3.28	3.60	3.88	4.37	5.17	5.82	6.39
20.0	0.68	0.93	1.11	1.26	1.39	1.74	2.37	2.84	3.22	3.85	4.38	4.83	5.24	5.95	7.13	8.10	8.94
25.0	0.73	1.05	1.30	1.51	1.70	2.17	3.00	3.63	4.16	5.03	5.76	6.39	6.96	7.97	9.65	11.04	12.26
30.0	0.77	1.16	1.48	1.75	2.00	2.57	3.60	4.40	5.06	6.18	7.11	7.94	8.68	9.99	12.19	14.04	15.66
40.0	0.85	1.36	1.79	2.17	2.53	3.30	4.73	5.84	6.78	8.37	9.71	10.91	11.99	13.92	17.19	19.96	22.41
50.0	0.91	1.52	2.05	2.64	3.00	3.95	5.74	7.14	8.33	10.37	12.11	13.65	15.06	17.59	21.88	25.55	28.82
60.0	0.97	1.67	2.29	2.85	3.41	4.52	6.53	8.29	9.72	12.16	14.26	16.13	17.84	20.92	26.17	30.58	34.71

[1] Such as for rangeland and other consolidated soil conditions with cover (applicable to thawing soil where both interrill and rill erosion are significant).

Figure 5. RUSLE LS Factor (USDA 1997)

The RUSLE C factor (C = 0.16) was derived using the RUSLE2 software available through the USDA. The RUSLE P factor is 1 since no conservation support practice is utilized.

Solving for As = 15*0.22*1.10*0.16*1 = 0.58 tons/acre/year.

4.4.2 Soil Loss Due to Wind Erosion

The Wind Erosion Prediction System or 'WEPS' (USDA 2010) is a process-based, daily time-step, wind erosion simulation model. It represents the latest in wind erosion prediction technology and is designed to provide wind erosion soil loss estimates from cultivated, agricultural fields. WEPS 1.0 consists of the computer implementation of the WEPS science model with a graphical user interface designed to provide easy-to-use methods of entering inputs to the model and obtaining output reports. WEPS was developed by the Engineering and Wind Erosion Research Unit (EWERU) of the United States Department of Agriculture, Agricultural Research Service. The WEPS model is now recommended by the USDA in lieu of the previously used Wind Erosion Equation (WEQ).

WEPS is a model developed primarily for use by the USDA, Natural Resources Conservation Service (NRCS). As such, many capabilities of WEPS reflect the needs of NRCS for use in cultivated agricultural systems. However, WEPS has capabilities used in many other situations where wind affected soil movement is a problem.

The WEPS model is set up to determine wind erosion for agriculture fields and not necessarily a final cover system such as that described in this report. However, the gravel/soil admixture design is intended to mitigate soil loss due to water runoff and wind erosion (Dwyer et al. 2007, USEPA 2012).

Input for the WEPS inherent to the model include the local wind data generated by the USDA. The user defined input included selection of the area (State: New Mexico, County: McKinley, Latitude: 35.58N, Longitude: 108.26W, and Elevation: 6749-ft). User designated physical data included shape of region (circle) and size of area shown on output (Figure 6). The soil chosen was sandy loam (specific soil properties included within the software library of data). Other user defined input parameters for the WEPS model includes the volume percent of rock fragments in the soil (0.33 ft^3/ft^3), any barriers included to disrupt the wind (none chosen), and any management techniques to assist the soil resist erosion (none chosen).

Figure 6 represents the output from the computer simulation representing the final cover system for the NECR closure whereby the initial estimated wind erosion is about 0.2 tons/acre/year. This value is conservative given it was based on no lockage of wind by surrounding terrain or vegetation and no vegetation on the cover surface.

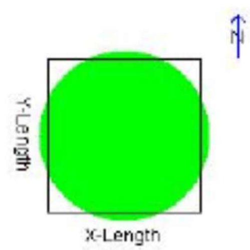
Run Summary

NRCS Natural Resources Conservation Service

NECR6

Run Date:	Wednesday, May 25, 2016, 08:54 PM		
Client Name:	UNC		
Farm No:	---	**Tract No:** ---	**Field No:** NECR - Imp
Run Location:	Runs		
Management:	NoCrop.man		
Soil:	Sandy_Loam_NA_100_SL.ifc		

Location Site Information



Field shape approximate

X-Length:	3190.3 ft
Y-Length:	3190.3 ft
Radius:	1799.9 ft
Area:	233.7 ac
Elevation:	6748.7 ft
Orientation:	0.0 °

Mode:	NRCS
Soil Loss Tolerance (T):	5.0 t/ac/yr
Site:	UNITED STATES NEW MEXICO MCKINLEY
Location:	35.58063° N, 108.26189° W
Cligen:	WINDOW ROCK
Windgen:	GALLUP MUNI/CLARKE

Erosion

Period	Crop/Residue	Gross Loss t/ac	Net Soil Loss From Field (t/ac) Total	Creep/Salt.	Suspen.	PM10
Rot. year: 1		0.2	0.2	0.1	0.2	Trace
Ave. Annual		0.2	0.2	0.1	0.2	Trace

SCI Summary

Soil Conditioning Index:	0.6	**SCI Subfactors**	
Energy Calculator:	0.0 gal diesel/ac	**OM:**	-0.03
Average Annual STIR:	0.0	**FO:**	1.00
Wind Erosion Soil Loss:	0.2 t/ac	**ER:**	0.91
Water Erosion Soil	0.0 t/ac		

Rotation Stir Energy

Date	Operation	Fuel	Stir	Energy Btu/ac	Cost USD/ac
Jan 01, 01	Add Non-Crop Mulch	Diesel	0.0	0	0.00
		Total / ac		0	0.00
		Total	0.0	0	0.00

Figure 6. Soil Loss due to Wind Erosion per WEPS (USDA 2010)

Since the annual soil loss of both wind and surface water is 0.78 tons/acre/year, which is less than 2 tons/acre/year, the performance criteria (USEPA 1991) is satisfied.

5.0 APPLICABILITY OF ET COVER AS FINAL COVER SYSTEM FOR NECR

This report describes an ET Cover System capable of meeting the stated performance objectives described in Section 3.0. The applicability of the ET cover for short and long-term at the site is based on the combination of the following:

1. Natural analog studies described in Section 5.1
2. Applicable field data described in Section 5.2

Natural analogs are a useful tool for evaluation of the long-term performance of a soil profile. Natural analog studies (Section 5.1) performed at the investigated potential borrow sources for cover material for the NECR project revealed that the effective maximum penetration depth of precipitation for typical climatic conditions is less than 2 feet (61 cm). These findings are consistent with other similar sites (Dwyer et al. 2007). Calcium carbonate and gypsum were identified in significant concentrations at a depth of about 18 inches (45 cm) revealing that these salts generally precipitated out at this maximum soil depth. A nearby site with similar elevation and climate revealed pronounced calcium carbonate horizons exist at a depth of about 2 feet (61 cm) reinforcing the typical infiltration depth (Figure 8). Furthermore, the majority of native vegetation roots were found to be limited to this upper 18 inches (45 cm) of soil reinforcing that this is the typical maximum depth of precipitation infiltration for the Mine Site conditions.

Applicable field data of cover systems are useful for evaluating the short-term effectiveness of a cover profile. A summary of applicable field data (Section 5.2) demonstrated an ET Cover is equivalent to a thicker prescriptive cover containing a clay barrier layer and geosynthetic membrane at this site (Dwyer 2003). The ET Cover will also provide more stability and longer-term performance than a cover depending on a product with a limited lifespan such as a geomembrane.

5.1 NATURAL ANALOGS EVALUATION

Analog studies involve the use of logical analogy to investigate natural and archaeological occurrences of materials, conditions, or processes similar to those known or predicted to occur in some part of the engineered cover system (Waugh 1994). Conventional engineering approaches for designing cover systems often fail to fully consider ecological processes. Natural ecosystems effective at capturing and or redistributing materials in the environment have evolved over millions of years. Consequently, when contaminants are introduced into the environment, ecosystem processes begin to influence the distribution and transport of these materials, just as they influence the distribution and transport of nutrients that occur naturally in ecosystems (Hakonson et al., 1992). As the ecological status of the cover changes, so will performance factors such as water infiltration, water retention, ET, soil erosion, gas diffusion, and biointrusion. The objective is to design the cover so that subsequent ecological change will enhance and preserve the encapsulating system. Consideration of natural analogs were included in the cover design by disclosing which properties are effective in a given environment and what processes may lead to possible failure.

An objective for designing a cover for the NECR site, given the longevity requirements for radionuclides, is to accommodate long-term environmental processes while requiring as little

maintenance as possible. The performance of any cover will change as the environmental setting inevitably evolves in response to natural processes. Understanding how environmental conditions may change is crucial to designing, constructing, and maintaining long-term cover systems. Effective modeling and performance assessment require scenarios based on both current and possible future environmental settings. Natural analog studies help identify and evaluate likely changes in environmental processes that may influence cover performance; processes that cannot be addressed with short-term field tests or existing numerical models (Waugh et al. 1994).

The natural analog study (Dwyer 1997, Waugh and Smith 1997) involved assessment of the effectiveness of undisturbed native soil profiles on or near the NECR site. This allowed for an evaluation of the typical maximum depth of infiltration. The depth of vegetation roots (Figure 7) from native grasses and shrubs were noted as well as the depth of calcium carbonate deposits or formation of a caliche layer. Soils in semiarid and arid regions commonly have carbonate-rich horizons at some depth below the surface. The origin of carbonate horizons involves carbonate-bicarbonate equilibria (Birkeland 1984), as shown by the following reactions:

$$CO_2 + H_2O$$

$$\uparrow\downarrow$$

$$CaCO_3 + H_2CO_3 \Leftrightarrow Ca^{2+} + 2HCO_3^-$$

Carbon dioxide partial pressures in soil air are 10 to more than 100 times that in the atmosphere; this decreases the pH, which, in turn, increases $CaCO_3$ solubility. The partial pressure of CO_2 is high as a result of CO_2 produced by root and microorganism respiration and organic matter decomposition. Thus, the highest CO_2 partial pressure are associated with the A horizon located near the surface, with values diminishing down to the base of the zone of roots. In arid and semi-arid regions, the quantity of water leaching through the soil is also generally greater near the surface than at depth. Thus, as the water moves vertically through the soil, the Ca^+ and HCO^{3-} content might increase to the point of saturation. Combining the effects of high CO_2 partial pressure and downward-percolating water, we might visualize the formation of a $CaCO_3$-rich horizon as follows: in the upper soil zone, Ca^{2+} is present by the leaching of calcium-bearing minerals. Due to plant growth and biological activity, CO_2 partial pressure is high and forms carbonic acid upon contact with calcium-bearing water. Percolating water carries Ca^{2+} and HCO_3^- ions downward in the profile. $CaCO_3$ precipitation as a caliche horizon takes place by some combination of decreasing CO_2 partial pressure (i.e. less carbonic acid production) below the zone of rooting and major biological activity and/or the progressive increase in Ca^{2+} and HCO_3^- concentrations with depth as the water is lost by ET. The position (depth) of the $CaCO_3^-$ bearing horizon is therefore related to the depth that precipitation infiltrates before it is removed by ET.

The concentrations of salts found dramatically increased in concentrations (Figure 8) at about 2 feet (61 cm) below ground surface (BGS) revealing that this is the typical maximum infiltration depth for precipitation. Extreme infiltration events could potentially move deeper than this, but as the area dried this moisture would likely move back up in the profile and be removed via ET. The moisture being drawn upward after an extreme infiltration event is a consequence of the energy gradients produced by the site-specific extreme climatic demand for water or PET as illustrated in Figures 14 and 15. This is another advantage of ET covers: they allow for moisture

beneath a cover profile to move up and be removed from the profile via ET. A site in the foothills east of Albuquerque, NM (about 100 miles east of the NECR site) with similar vegetation, climate, and elevation shows a distinct interface between topsoil and calcium carbonate (Figure 8).

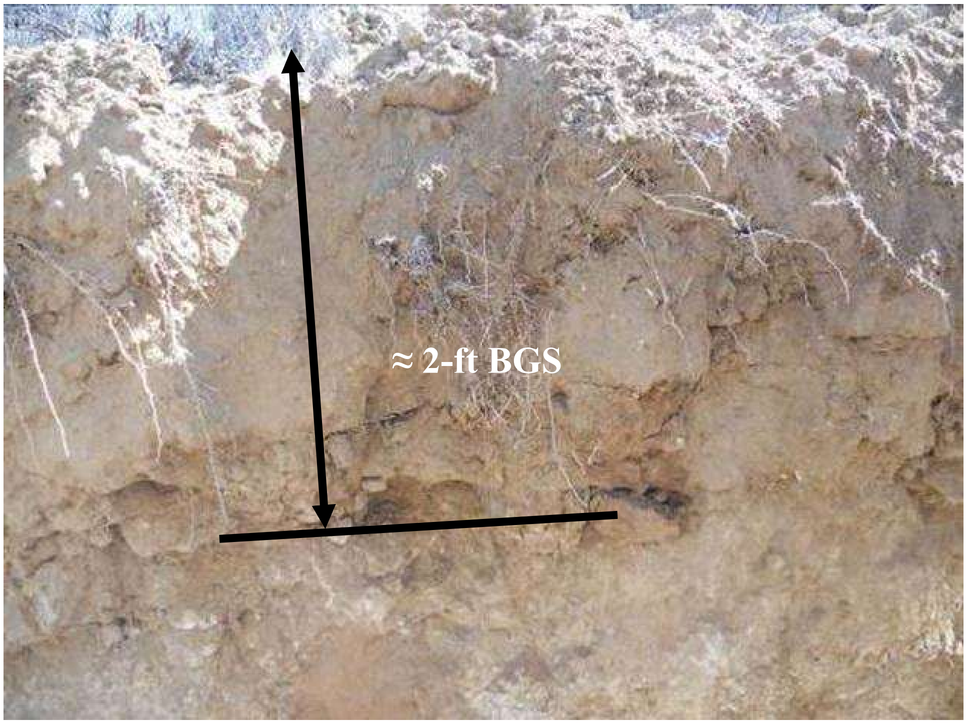


Figure 7. Root Depth @ 2-FT - NECR East Borrow Site

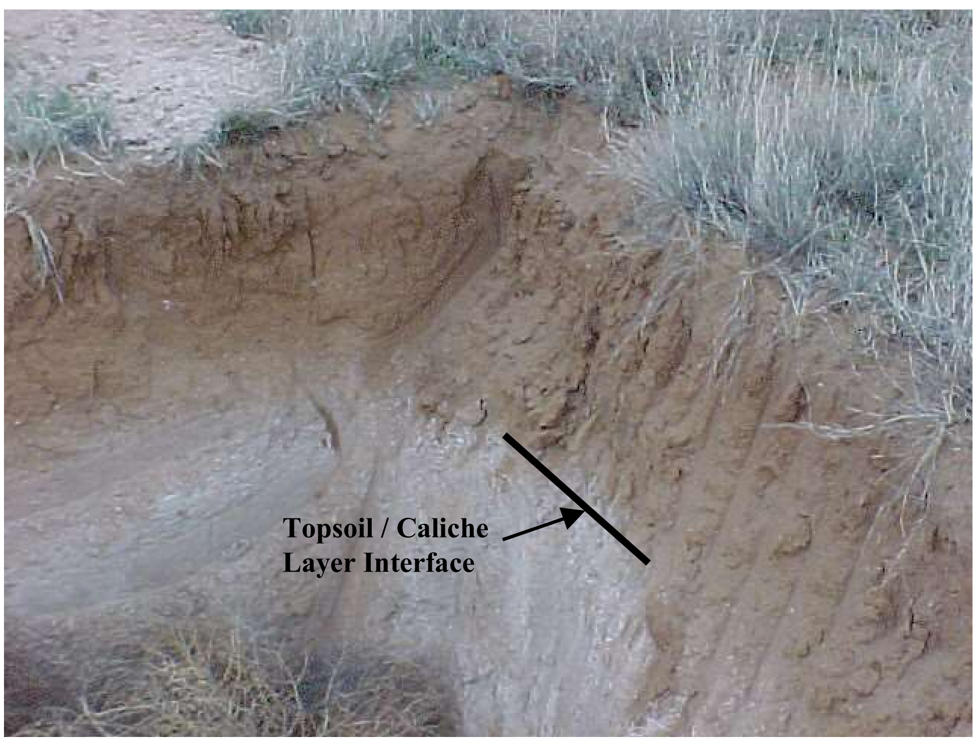


Figure 8. CaCO3/Soil Interface at Shallow Depth at site near Albuquerque, NM

5.2 RESEARCH AND FIELD DATA THAT SUPPORT THE USE OF AN ET COVER AT NECR

Myriad sites throughout the United States have been permitted for alternative cover systems based on applicable field data. Applicable field data is available on the USEPA web site (http://www.clu-in.org/download/remed/epa542f03015.pdf#search='evapotranspiration%20epa%20fact%20sheet); the USEPA's Alternative Cover Assessment Program (ACAP) web site (ftp://ftp.dri.edu/pub/ACAP/); and USEPA Technology Innovation web site (http://cluin.org/products/altcovers/).

One of the most widely used data sets is that from a large-scale demonstration performed at Sandia National Laboratory in Albuquerque, NM. This site has a similar climate, vegetation and soil textures as the NECR site. This project evaluated alternative covers side-by-side with prescriptive cover profiles (Dwyer 2003). This study was referred to as the Alternative Landfill Cover Demonstration (ALCD). There were six cover designs tested in this demonstration project: two baseline cover profiles (prescriptive RCRA Subtitle 'D' and Subtitle 'C' covers respectively) and four alternative cover designs (an ET Cover, two different Capillary Barrier System designs, and a cover featuring a Geosynthetic Clay Liner (GCL)). This study was endorsed by the Western Governors Association and was reviewed annually during its monitoring phase for its technical merit by a consortium of regulators and technical experts.

The demonstration allowed for testing of the cover profiles under both ambient and stressed conditions. During stress tests of the cover profiles, water was evenly applied to the plots to evaluate the subsequent water balance variables for each cover profile. Extreme summer events were simulated such as severe thunderstorms as well as winter and spring events such as large snow falls and expedited melting of snow during low transpiration periods.

The results showed that a well-designed ET Cover composed of 3.5 feet (107 cm) of native soil performed as well as or better than a prescriptive cover over 5-ft-thick (152 cm) containing a 2-ft-thick (61 cm) clay barrier layer and geomembrane (Figures 9 and 10). Because the RCRA Subtitle C soil barrier layer showed and increasing moisture buildup (Dwyer 2003) and the geomembrane has a limited design life. The ET Cover should significantly outperform this cover over the long-term. The moisture content continued to build within the Subtitle C clay barrier layer beneath the geomembrane due to leakage through the minimal flaws in the membrane (typical of a membrane installed with good quality control) while not allowing removal due to ET (this is not shown in the graphics below). The ET Cover profile produced zero flux after vegetation was well established.

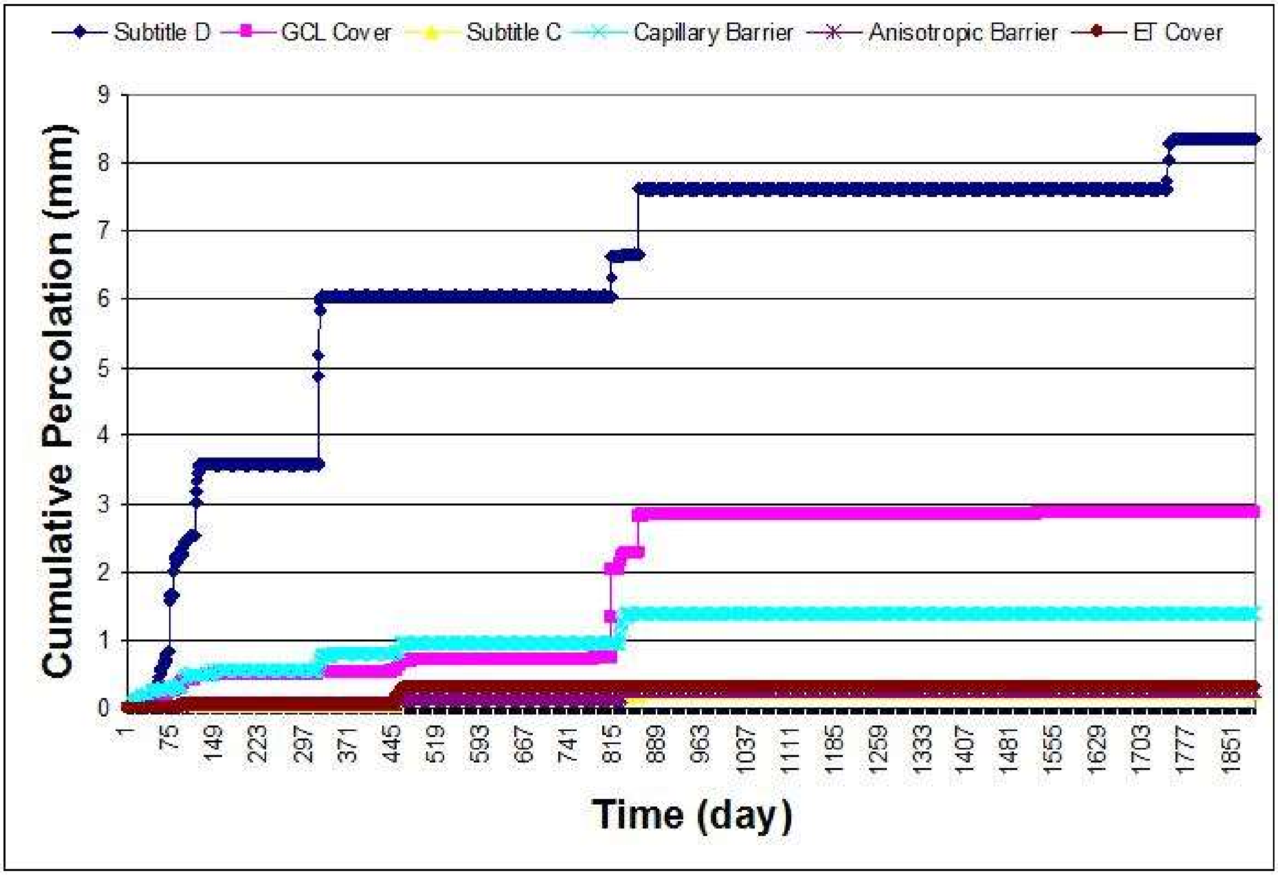
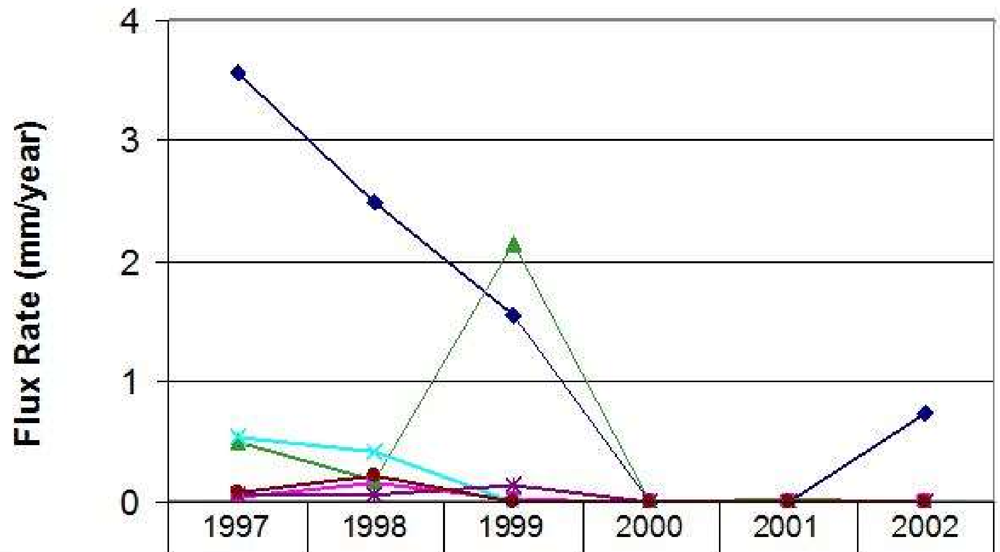


Figure 9. Sandia National Lab. Results: Cumulative Percolation for the Six Test Covers (Dwyer 2003)



	1997	1998	1999	2000	2001	2002
Subtitle D	3.56447	2.47911	1.56115	0.00000	0.00000	0.73966
Subtitle C	0.04131	0.15161	0.01756	0.00000	0.00000	0.00000
GCL Cover	0.50628	0.18831	2.15408	0.00018	0.02091	0.00000
Capillary Barrier	0.54412	0.40907	0.00000	0.00008	0.00002	0.00005
Anisotropic Barrier	0.05135	0.06888	0.13937	0.00035	0.00047	0.00021
ET Cover	0.07546	0.21837	0.00538	0.00002	0.00000	0.00000

Figure 10. Sandia National Lab. Results: Annual Flux for the Six Test Covers (Dwyer 2003)

6.0 UNSATURATED MODELING OF COVER SYSTEM

The previous section summarized data supporting the effectiveness of an ET Cover in both the short-term with the applicable field data and in the long-term with the natural analogs evaluation. This section provides an overview of modeling performed in support of the profile design for the final cover system.

Modeling was performed to determine an ET cover profile that minimizes flux given the myriad of input parameters (cover soil and vegetation data) and historical climate data for the site. Unsaturated flow modeling of a cover profile is useful to develop a minimum cover thickness and evaluate the cover profile subjected to a variety of conditions as well as input and boundary sensitivities (Dwyer et al. 2007, USEPA 2012).

6.1 OVERVIEW OF UNSAT-H

Historically, HELP (Schroeder et al., 1994) was utilized to predict water balance in landfill systems including the final cover. However, it is now recognized that this software has its limitations (ITRC 2003). Software more applicable for the analyses of water flow within an alternative earthen cover system is based on the Richard's Equation (ITRC 2003). One of the most common software (ITRC 2003) based on the Richard's equation is UNSAT-H (Fayer 2000). This unsaturated modeling software was designed specifically for earthen covers. It has been recommended for use on alternative earthen covers in the ITRC (2003) design guidance documents. Consequently, UNSAT-H was used on this project.

UNSAT-H has been used to design recent alternative earthen covers (Dwyer 2003). UNSAT-H is a one-dimensional, finite-difference computer program developed at the Pacific Northwest National Laboratory by Fayer and Jones (1990). UNSAT-H can be used to simulate the water balance of earthen covers as well as soil heat flow (Fayer 2000). UNSAT-H simulates water flow through soils by solving Richards' equation and simulates heat flow by solving Fourier's heat conduction equation.

A schematic illustration showing how UNSAT-H computes the water balance is shown in Figure 11. UNSAT-H separates precipitation falling on an earthen cover into infiltration and overland flow. The quantity of water that infiltrates depends on the infiltration capacity of the soil profile immediately prior to rainfall (e.g., total available porosity). Thus, the fraction of precipitation shed as overland flow depends on saturated and unsaturated hydraulic conductivities of the soils characteristic of the final cover. If the rate of precipitation exceeds the soil's infiltration capacity, the extra water is shed as surface runoff. UNSAT-H does not consider absorption and interception of water by the plant canopy, or the effect of slope and slope-length when computing surface runoff. This allows conservative infiltration and percolation estimates since cover systems are generally sloped to encourage runoff.

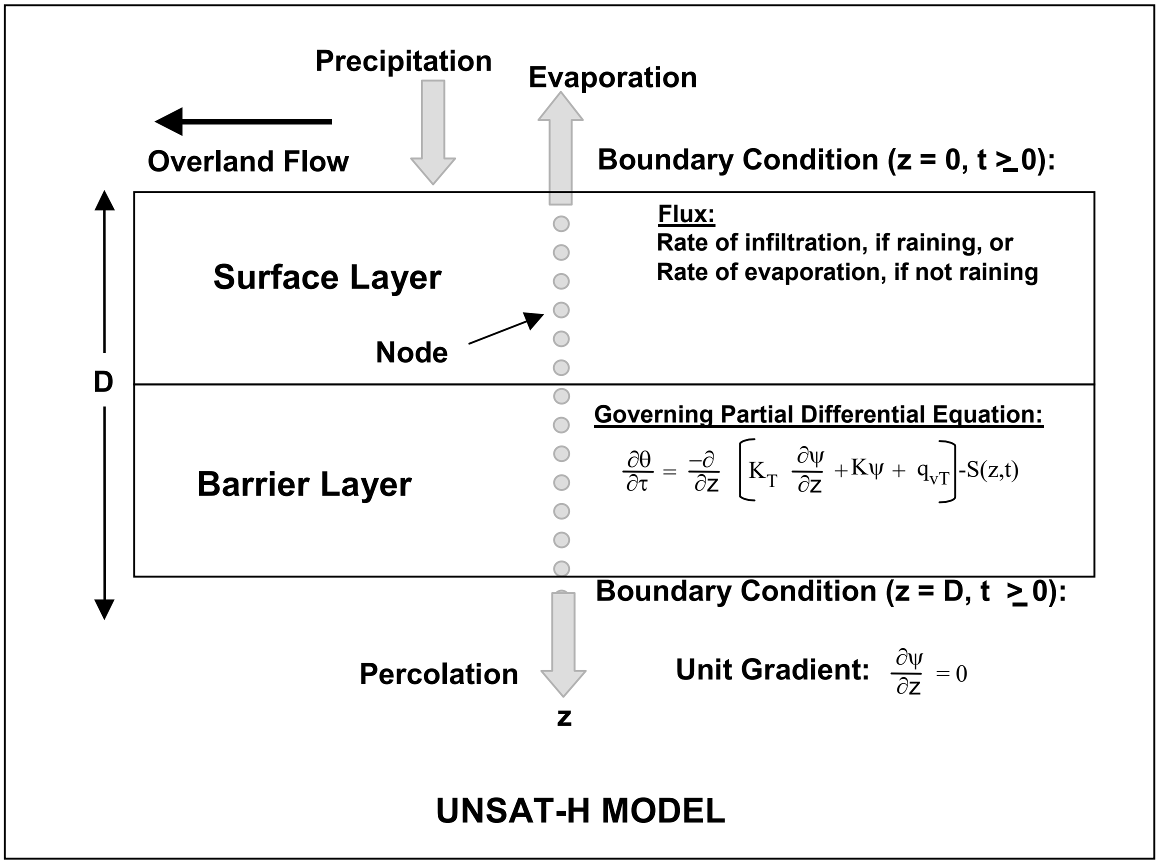


Figure 11. Schematic Representation of Water Balance Computation by UNSAT-H

Water infiltrating a soil profile during an UNSAT-H simulation moves upward or downward as a consequence of gravity and matric potential gradients. Evaporation from the cover surface is computed using Fick's law. Water removal by transpiration of plants is treated as a sink term in Richards' equation. The upper boundary condition includes daily potential evapotranspiration (PET) and precipitation values. PET is a measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration assuming no control on water supply. Actual evapotranspiration (ET) is the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration.~~Potential evapotranspiration (PET) is computed from the daily wind speed, relative humidity, net solar radiation, and daily minimum and maximum air temperatures using a modified form of Penman's equation given by Doorenbos and Pruitt (1977).~~ Soil water storage is computed by integrating the water content profile. Flux from the lower boundary is via percolation. UNSAT-H, being a one-dimensional program, does not compute lateral drainage.

6.2 UNSAT-H INPUT PARAMETERS

Input parameters utilized in the computer simulations with UNSAT-H for the ET cover were developed based on field and laboratory measurements, values from the literature, and expert opinion. Parameter descriptions are in Sections 6.3 to 6.7.

The development of the final cover system utilizing unsaturated flow modeling was performed in a stepped approach. An extensive set of sensitivity analyses were performed to determine a minimum cover thickness. The sensitivity analyses evaluated potential input parameters and climate scenarios expected over the performance period of the cover system. The input parameters evaluated included the potential cover soil borrow sources, variability of the cover soil over time, variability in vegetation, and variability in cover profiles (surface erosion protection layer composed of rock and soil). The upper boundary condition or climate was also evaluated from typical to extreme wet conditions.

There are three different rock/soil admixture designs depending on the slope and slope length. Refer to Figure 13 for geometry of the admixture designs and Section 4 for the analysis.

Multiple potential local borrow sources were evaluated for cover soil. As described in the Pre-Design Studies Report (MWH 2014), there were five borrow areas evaluated for cover soil: (1) the North Drainage Borrow Area; (2) the South Drainage Borrow Area; (3) Dilco Hill Borrow Area; (4) East Borrow Area; and (5) West Borrow Area (Figure 12).

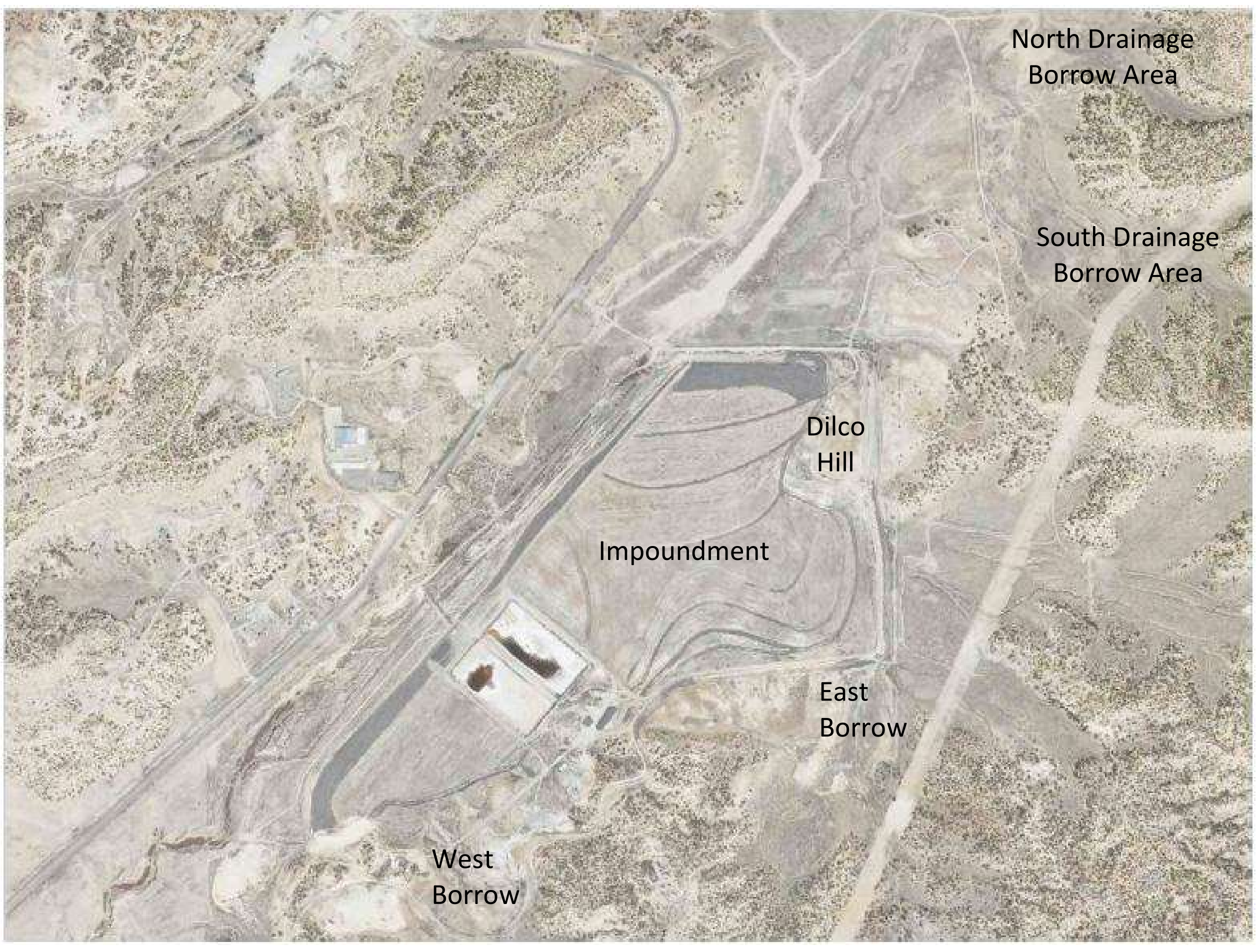


Figure 12. Cover Soil Borrow Areas

Soils were excavated from each borrow area and tested for geotechnical and hydraulic properties. The remolded laboratory measurements yielded soil results that would exist as the soil is

installed; that is, the remolded samples represent the hydraulic status of the soils in the short- to intermediate-term.

Soil pedogenic processes can alter the soil hydraulic properties over a longer time period. Consequently, an analog study was performed whereby the cover soil borrow sources were measured in situ to measure the long-term hydraulic properties of potential soil borrow sources (Dwyer 2014). A tension infiltrometer was utilized to measure the moisture characteristic curve and saturated hydraulic conductivity for the North Drainage Area, South Drainage area and East Borrow areas. The Dilco Hill area was not evaluated largely since it is not a likely borrow area and the East and West borrow areas have similar soil textures in a disturbed setting. Furthermore, the soil analog study was planned to coincide with the vegetation analog study performed at the site (Cedar Creek 2014).

6.3 MODEL GEOMETRY

The model geometry was based on the expected depth of the cover system. The nodal spacing was set at a range narrow enough to accurately represent the modeled cover profile. The erosion analysis and subsequent surface erosion protection layer was performed and optimized whereby there are three different cover profiles changing from the top of the slope toward the base of the slopes (refer to Section 4). In general, the top of the slope will have a top erosion protection layer composed of rock mixed with soil to a depth of 14 inches. The middle of the longer slope lengths will be composed of a top erosion protection layer composed of rock mixed with soil to a depth of 18 inches. While the base of the longer slopes will have a top surface layer composed of rock mixed with soil to a depth of 27 inches. The rock sizing varies from the top to bottom of the long 5 percent slope as follows: 1.5-inch diameter, 2-inch diameter, and 3-inches diameter, respectively. All admixture profiles contain 33 percent rock to 67 percent soil by volume. Cover profiles are 4-feet-thick. Cover soil beneath this erosion protection surface layer is from engineer-approved borrow sources. The mixed soil is from the same engineer-approved borrow sources. The rock is from engineer-approved on-site stockpiles or engineer-approved vendors meeting cover design durability requirements. Figure 13 shows a general summary of the profiles modeled.

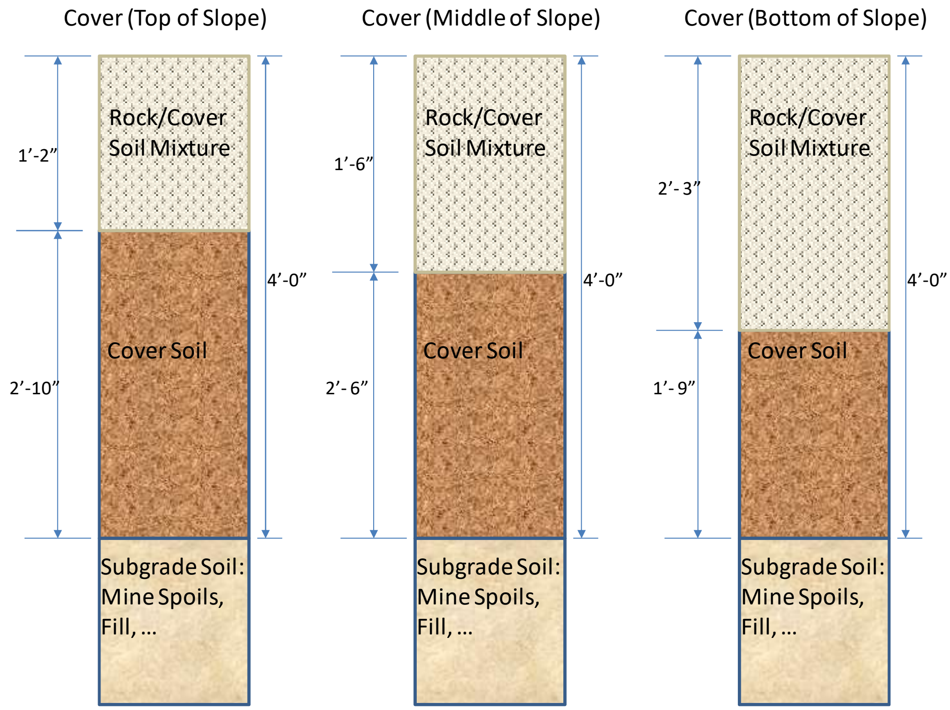


Figure 13. Cover Profiles

6.4 BOUNDARY CONDITIONS

Historical weather data for the Gallup, NM area and surrounding weather stations were evaluated from 1897 to 2016. Weather from Ft. Wingate, NM was utilized as the upper boundary condition due to its proximity and similar elevation to the Mill Site. Boundary conditions used to evaluate the modeled profiles included both typical climatic data and extreme conditions.

The average precipitation for the NECR area is about 11 inches per year (28 cm) (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nmgalf). Weather information from 1949 (Ft. Wingate, NM weather station) was utilized as the simulated "typical year" with an annual precipitation volume of 11.71-inches (29.74 cm). This typical climate year had just above the average annual precipitation volume (11.71-in compared to the average of 11-in/yr) and was distributed throughout the year as shown in Figure 14.

For every month of the year, the climate's demand for water (PET) far exceeds the actual supply of water (precipitation) (Figure 14). The climate's annual demand for water referred to as potential evapotranspiration (PET) is 83.4 inches (211.74 cm) or about 6.5 times more than the actual supply of water (precipitation). Consequently a "store and release" cover designed to take advantage of variances between the water demand and actual water supply (such as an ET cover) is well suited for the NECR site.

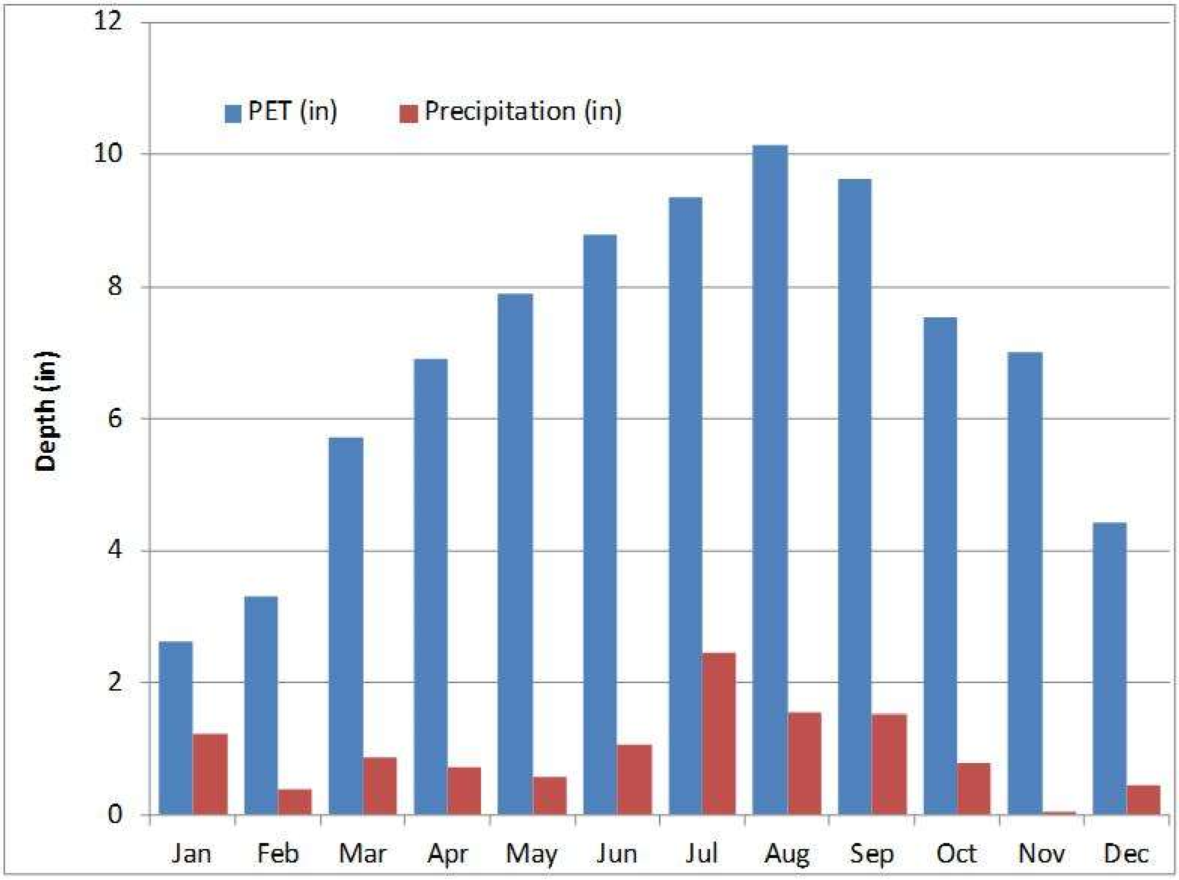


Figure 14. Typical Climate: Monthly Precip. Vs. Pet for Ft. Wingate, NM

Because the design requires long-term effectiveness, extreme climate conditions were also evaluated. The wettest year on record for the NECR area was 1906 (Ft. Wingate, NM weather station) and produced almost double the average annual precipitation volume (23.8 inches, or 60.5 cm). Furthermore, much of this moisture came as snow from January to April and October to December. This is a period in the modeling when PET is low and transpiration of moisture through vegetation is minimized or completely ceased. The monthly distribution of precipitation and PET are presented in Figure 15 for this wettest year on record. The wettest year was modeled two years in a row to add conservatism to the analyses. To add additional conservatism, the precipitation was applied at a rate slow enough to essentially force 100 percent infiltration (reduced runoff to zero or near zero), since much of the precipitation received at the NECR site runs off in high intensity storms. Erosion analysis (Section 4) utilized the PMP defined 1-hour event for calculation of surface runoff

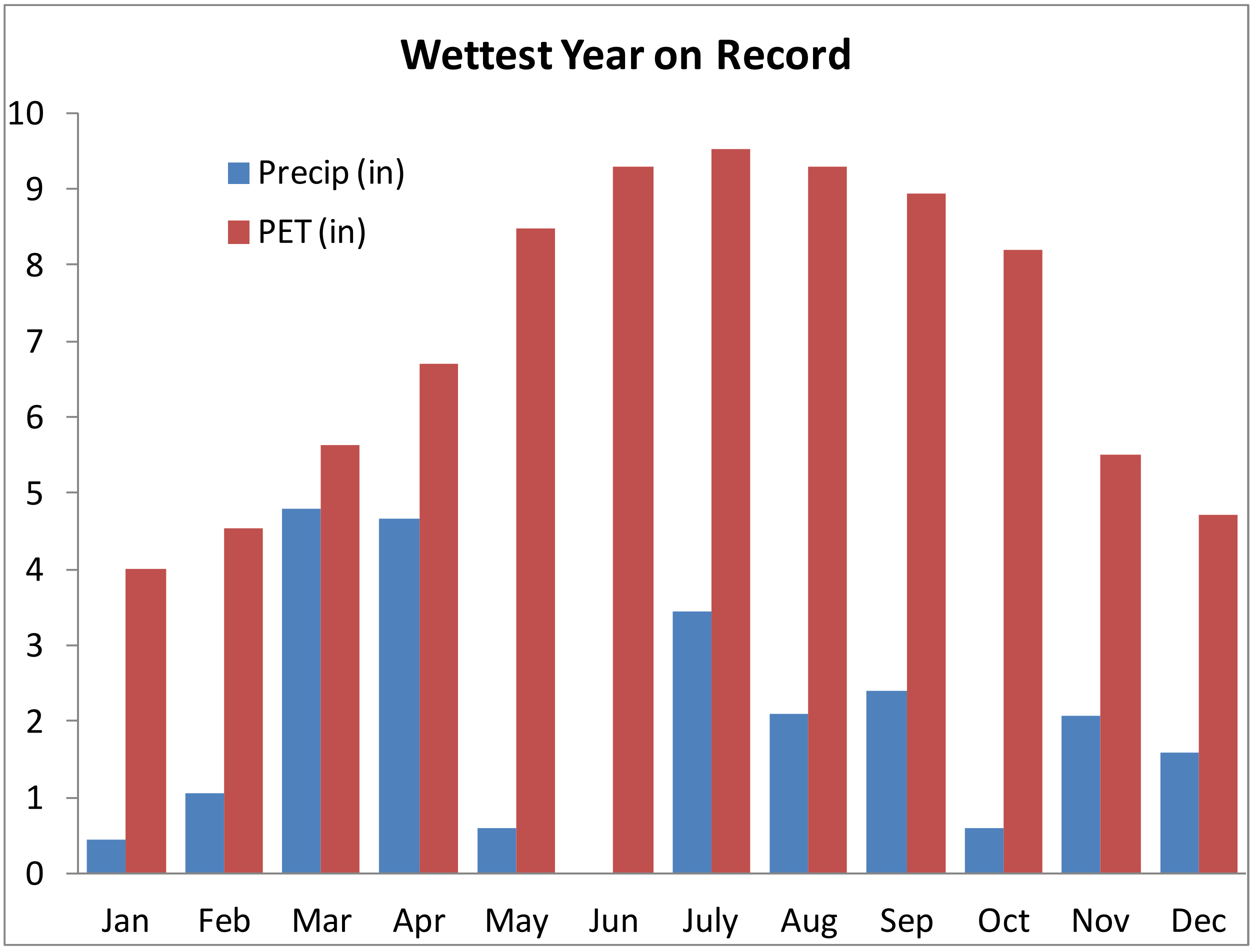


Figure 15. Wettest Year on Record Climate: Monthly Precip. Vs. Pet for Ft. Wingate, NM

Water flow across the surface and lower boundary of the cover profile of interest is determined by boundary condition specifications. For infiltration events, the upper boundary was conservatively set to a maximum hourly flux for these computer simulations of 0.4 inches (1 cm) per hour that minimized runoff (zero in most cases) while maximizing infiltration. This is conservative because precipitation at the site generally comes from high-intensity storms where much of the precipitation will runoff without infiltrating into the cover profile.

The UNSAT-H program partitions PET into potential evaporation (E_p) and potential transpiration (T_p). Potential evaporation is estimated or derived from daily weather parameters (Fayer 2000). Potential transpiration is calculated using a function (Equation 11) based on the value of the assigned leaf area index (LAI) and an equation developed by Ritchie and Burnett (1971) as follows:

$$T_p = PET\ [a + b(LAI)^c] \quad \text{where } d \leq LAI \leq e \qquad \textbf{Equation 11}$$

where:

a,b,c,d, and e are fitting parameters

a = 0.0, b = 0.52, and c = 0.5, d = 0.1, and e = 2.7 (Fayer 2000)

The maximum and minimum daily temperatures, daily precipitation values and site latitude were input parameters used to calculate PET (Samani and Pessarkli, 1986). The Samani method used to calculate PET correlates well with the Penman method utilized within UNSAT-H (Samani and Pessarkli, 1986). The UNSAT-H program then partitioned the daily PET values into E_p and T_p. T_p was calculated using a function shown in Equation 11.

Two separate files were written for each year modeled: one file represented the daily PET values and the other file consisted of the daily precipitation values.

The lower boundary condition was a unit gradient. With the unit gradient, the calculated drainage flux depends on the hydraulic conductivity of the lower boundary node. The unit gradient corresponded to gravity-induced drainage and was most appropriate because drainage was not impeded. The base of the modeled profile was placed well below transient activity and in relative steady state conditions to ensure that the unit gradient bottom boundary condition used did not affect the output for the cover system.

6.5 VEGETATION DATA

Vegetation will generally increase ET from the cover because a plant's matric potential or suction can be orders of magnitude higher than that of the soil (Figure 16).

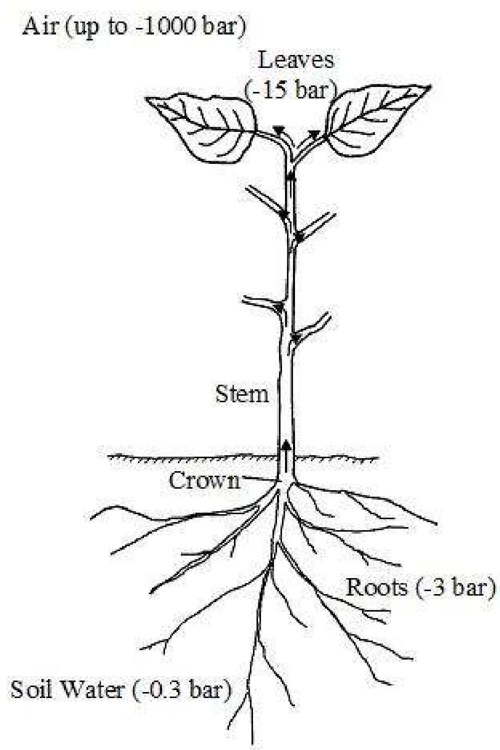


Figure 16. Typical Soil-Plant-Atmosphere Water Potential Variation (Hillel 1998)

The input parameters representing vegetation include the LAI, rooting depth and density, root growth rate, suction head values corresponding to the wilting point, head corresponding to the water content below which plant transpiration starts to decrease, and a head value corresponding to the water content above which plants do not transpire because of anaerobic conditions were defined. The onset and termination of the growing season for the site are defined in terms of Julian days. The maximum rooting depth is based on expected vegetation characteristics. The root length density (RLD) is assumed to follow an exponential function such as that defined in Equation 12:

$$RLD = a \exp(-bz) + c \qquad \textbf{Equation 12}$$

where:

a,b, and c are fitting parameters

z = depth below surface

The cover profiles (Figure 13) were modeled with vegetation on the surface. They were also modeled without any vegetation.

Cedar Creek performed an analog study of the native vegetation at the NECR site both in a disturbed setting and an undisturbed setting (Cedar Creek 2014). This study was utilized in the modeling to develop input parameters related to vegetation. The following rooting parameters (Table 9) were utilized when vegetation was included in the model (Cedar Creek 2014).

Table 9. Rooting Parameters (Cedar Creek 2014)

Parameter	Reclaimed Analog	Grass Analog	Shrub Analog
a	556.28	0.34	0.43
b	-0.0000054	-0.072	-0.034
c	-555.92	0.14	0.078

Other vegetation parameters including the LAI, percent bare area utilized, and maximum rooting depths for the respective vegetation used in a computer simulation are summarized in Table 10.

Table 10. Vegetation Parameters (Cedar Creek 2014)

Parameter	Reclaim Analog	Grass Analog	Shrub Analog
LAI	0.91	0.64	0.52
% Bare Area	52.3%	64.9%	75.2%
Root Length	147 cm	142 cm	155 cm

The vegetation analogs studied represent a natural succession at the site (Cedar Creek 2014). The reclaimed community of vegetation represents vegetation in a disturbed area and generally considered from seeding upon construction completion up to about 50 years. The grassland community represents undisturbed vegetation and is assumed to represent vegetation on the cover from about 25 to 100 years after construction. The shrubland community represents

vegetation in an undisturbed setting and is assumed to represent vegetation on the cover from about 50 to 1,000 years.

In the modeling simulations that included vegetation, the onset and termination of the growing season for the site were Julian days 63 and 343, respectively. This is determined from the typical climate conditions for the NECR site and the respective growing degree days presented in Figure 17. The growing degree days were computed (Samani and Pessaraki 1986) for the typical year. The LAI was transitioned from 0 to the full LAI starting with Julian day 63 to 170. Day 171 through 266, the full LAI was utilized. The LAI was then transitioned down from the full LAI to 0 from Julian day 267 to 343. This was conservative since it is realistic that plants can transpire longer than indicated at this site.

The UNSAT-H model adjusts the full LAI based on the percent bare area of vegetation. For example, for a shrub vegetation with an LAI of 0.52 and a percent bare area of 75.2 percent, the LAI is reduced to 0.752 * 0.52 = 0.39.

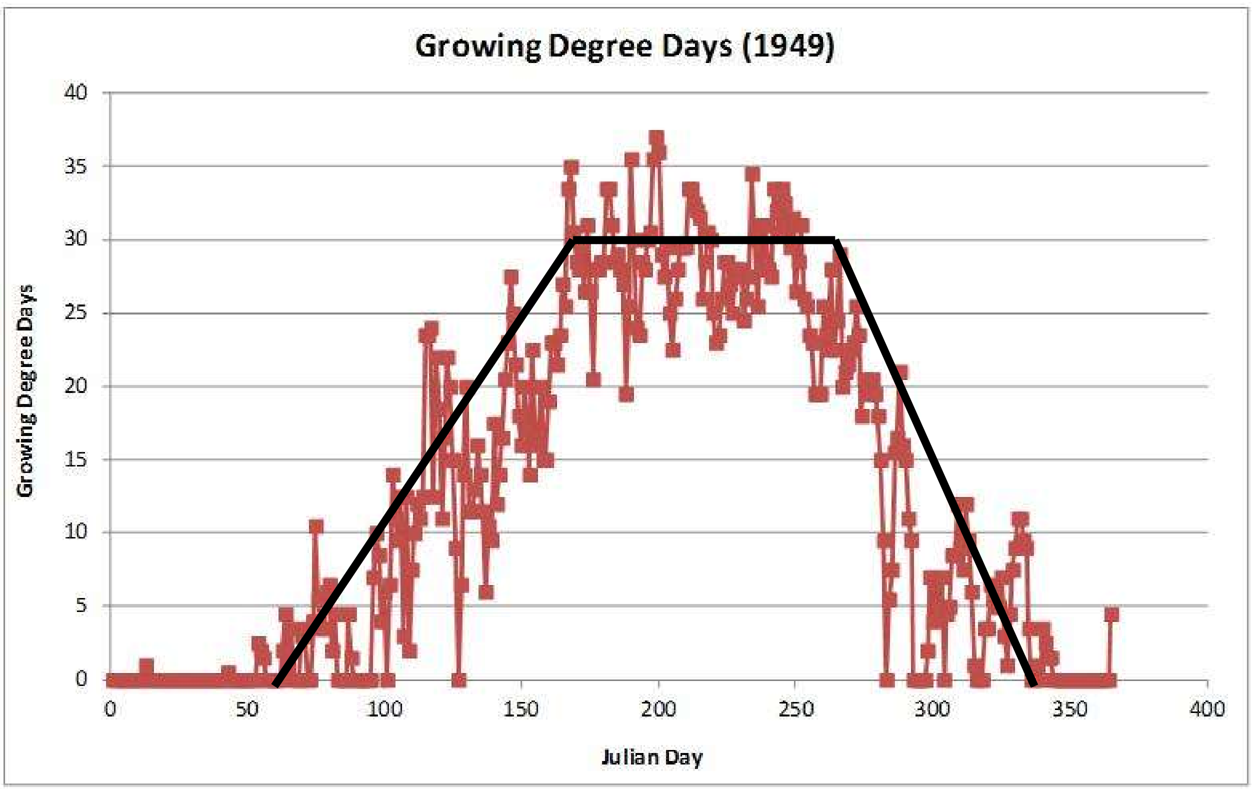


Figure 17. Leaf Area Index Transition during the Year

For computer simulations that do not include vegetation, the transpiration is set at zero. That is, all moisture removed from the profile upward is solely by evaporation.

6.6 SOIL PROPERTIES RELATED TO VEGETATION

Suction head values corresponding to the wilting point, head corresponding to the water content below which plant transpiration starts to decrease, and a head value corresponding to the water

content above which plants do not transpire because of anaerobic conditions were defined. Matric potential or suction heads are generally written as positive numbers, but in reality are negative values. Consequently, the higher the value - the greater the soil suction.

Not all of the water stored in the soil can be removed via transpiration. Vegetation is generally assumed to reduce the soil moisture content to the permanent wilting point. The wilting point for these computer simulations was set at 40,000 cm for reclaimed vegetation and grassland and 70,000 for shrubland vegetation (Fayer and Walters 1995). This was conservatively used although some shrubs near the site could remove water from the soil to a suction of 100,000 cm (Hillel 1998). Evaporation from the soil surface can further reduce the soil moisture below the wilting point toward the residual saturation, which is the water content at an infinite matric potential. The head corresponding to the water content below which plant transpiration starts to decrease was defined as 32.2 feet (1000 cm) (Fayer and Walters 1995, Fayer 2000). The head value corresponding to the water content above which plants do not transpire because of anaerobic conditions was defined at 4 inches (30 cm) (Fayer and Walters 1995).

6.7 SOIL PROPERTIES

Soil mechanical and hydraulic properties were obtained from laboratory testing of multiple soil samples collected at various potential borrow sources (MWH 2014). There are multiple potential borrow sources for cover soil (Figure 12~~1~~). Additionally, the top layer or rock/soil admixture of the cover profile has three different designs depending on where on the slope it is located. The upper admixture is composed of the mixture of rock and cover soil. In addition, the cover soil directly below the upper rock/soil admixture will be composed of soil from the same borrow source.

The hydraulic properties of the borrow soils modeled were obtained from laboratory testing of the various soil textures at a prescribed density of 90 percent of the maximum dry density (ASTM, 2012). This density approximately equates to the natural density of the borrow soils in their undisturbed setting. Because the density of the soil will migrate towards this natural density setting, it is warranted to install it as close to this density as possible. Therefore, the construction specifications for installation of the cover soil will require the installed density of the cover soil to be 90 percent of its maximum dry density (MDD) with a small tolerance allowance (+/- 5 pcf of MDD). The hydraulic properties of the remolded samples are assumed to represent the soil as it is installed in the field.

The top admixture layer have rock mixed into it at a volumetric ratio of 33 percent rock to 67 percent soil. The mixture of rock into the soil effectively alters its hydraulic properties. Consequently, the hydraulic properties were adjusted for the admixture layer (ASTM, 2007). Equation 13 was used to adjust the saturated hydraulic conductivity based on the addition of rock (Peck and Watson 1979).

$$K_b = [K_s * 2(1 - V_r)]/(2 + V_r) \qquad \textbf{Equation 13}$$

$$where: K_b = saturated\ hydraulic\ conductivty, bulk$$

$$K_s = saturated\ hydraulic\ conductivty, soil$$

$$V_r = volume\ of\ rock$$

For the computer simulations, the calculated bulk saturated hydraulic conductivity was then increased an order of magnitude in the top foot of the modeled cover system (14 inches for the admixture that is 14 inches deep) to account for dynamic processes such as freeze/thaw cycles, wet/dry cycles, and biointrusion. This added conservatism in the modeling results. This corresponds with findings from the soil analog studied at the site whereby soils in undisturbed settings have a saturated hydraulic conductivity of about one order of magnitude higher than the lower portions of the soil profile (Dwyer 2014).

The moisture retention data for the cover soil was also adjusted to reflect the addition of the rock in the surface admixture layer. The actual volumetric moisture content versus soil suction measurements made in the laboratory were utilized as the basis. Each respective measured volumetric moisture content was lowered per Equation 14 [ASTM 2007 and Bouwer & Rice 1984].

$$\theta_b = (1 - V_r)\theta_s \qquad \textbf{Equation 14}$$

$$where: \theta_b = bulk\ volumetric\ moisture\ content$$

$$\theta_s = \text{saturated}\ volumetric\ moisture\ content$$

$$V_r = volume\ of\ rock$$

The Mualem conductivity function was used to describe the unsaturated hydraulic conductivity of the soils (van Genuchten et al. 1991). The van Genuchten ‘m’ parameter for this function is assumed to be‘1-1/n’; ‘n’ being one of the established van Genuchten parameters. The initial soil conditions were expressed in terms of suction head values that correspond to the average moisture content between each soil layer’s field capacity and permanent wilting point determined from each respective soil layer’s moisture characteristic curve.

A summary of the soil input parameters for the UNSAT-H simulations are summarized in Table 11. The respective borrow soil properties adjusted for the addition of 33 percent by volume rock for the top admixture layer is summarized in Table 12. The van Genuchten parameters were developed from the laboratory soil measurements (soil suction versus moisture content) using the RETC software (van Genuchten et al. 1991).

Table 11. Borrow Cover Soil Laboratory Measured Soil Properties

Borrow	Sample ID	Soil Type	Volume (cy)	K_s (cm/sec @ 90%)	Van Genuchten parameters			
					Θ_s (vol.)	Θ_r (vol.)	alpha	n
West Borrow	WB-B1-06	Sandy Loam	100000	2.10E-04	0.4951	0	0.0484	1.2943
East Borrow	EB-B6-03	Sandy Loam	50000	2.90E-05	0.5093	0	0.0140	1.2689
Dilco Hill	DH-B1-03	Sandy Loam	5000	2.50E-04	0.6281	0	0.0298	1.4159

Borrow	Sample ID	Soil Type	Volume (cy)	K_s (cm/sec @ 90%)	Van Genuchten parameters			
					Θ_s (vol.)	Θ_r (vol.)	alpha	n
South Drainage	SB-B4-01	Sandy Loam	170000	7.40E-05	0.5191	0	0.0373	1.2243
North Drainage	NB-B2-04	Sandy Loam	80000	7.50E-05	0.4563	0	0.0084	1.4721

Table 12. Adjusted Borrow Soil Laboratory Measured Soil Properties for 33% Rock by Volume

Borrow	K_s (cm/sec @ 90%)	Van Genuchten parameters			
		Θ_s (vol.)	Θ_r (vol.)	alpha	n
West Borrow	1.21E-04	0.3317	0	0.0484	1.2943
East Borrow	1.67E-05	0.3412	0	0.0140	1.2689
Dilco Hill	1.44E-04	0.4208	0	0.0298	1.4159
South Drainage	4.26E-05	0.3478	0	0.0373	1.2243
North Drainage	4.31E-05	0.3057	0	0.0084	1.4721

Soil hydraulic properties vary with time, as a result of soil pedogenic processes. As the ecological status of the cover matures and changes, so will performance factors such as water infiltration, water retention, ET, soil erosion, gas diffusion, and biointrusion (Dwyer 2003). Because changes in soil hydraulic properties are expected over time, and these changes will affect water movement within the cover, the cover profiles were also evaluated utilizing soil properties after dynamic ecosystem changes have altered the hydraulic properties of the soil profiles. Refer to the Natural Analog Study of cover soil borrow sources (Dwyer 2014).

A summary of the Natural Analog Study (Dwyer 2014) soil input parameters for the UNSAT-H simulation are summarized in Table 13. These soil properties are assumed to be the long-term values. The respective borrow soil properties adjusted for the addition of 33 percent by volume rock for the top admixture layer is summarized in Table 14.

Table 13. Soil Hydraulic Properties Measured In Situ with Tension Infiltrometer

Borrow	Depth	Van Genuchten parameters				Ks (cm/sec)
		Θ_s (vol.)	Θ_r (vol.)	α (1/cm)	n	
North Drainage Borrow	top foot	0.43057	0	0.00902	1.47081	3.70E-04
	rest	0.423809	0	0.008851	1.445759	6.96667E-05
South Drainage Borrow	top foot	0.458069	0	0.016946	1.30539	2.12E-04
	rest	0.478611	0	0.01685	1.316409	5.30E-05
East Borrow	top foot	0.48835	0	0.014612	1.256892	2.15E-04

Borrow	Depth	Van Genuchten parameters				Ks (cm/sec)
		Θ_s (vol.)	Θ_r (vol.)	α (1/cm)	n	
	rest	0.492587	0	0.014538	1.289946	3.40E-05

Table 14. Tension Infiltrometer Measured Soil Hydraulic Properties Adjusted for Addition of 33% Gravel

Borrow	Depth	Van Genuchten parameters				K_s (cm/sec)
		Θ_s (vol.)	Θ_r (vol.)	α (1/cm)	n	
North Drainage Borrow	top foot	0.288482	0	0.00902	1.47081	2.13E-04
	rest	0.283952	0	0.008851	1.445759	4.01E-05
South Drainage Borrow	top foot	0.306906	0	0.016946	1.30539	1.22E-04
	rest	0.32067	0	0.01685	1.316409	3.05E-05
East Borrow	top foot	0.327195	0	0.014612	1.256892	1.24E-04
	rest	0.330033	0	0.014538	1.289946	1.96E-05

The subgrade soil used in the profile beneath the ET cover was that measured from the mine spoils using sample TT-205-GT1 remolded to 90 percent of the maximum dry density per ASTM (2012).

Table 15. Mine Spoils Measured Soil Hydraulic Properties

Sample	Depth	Van Genuchten parameters				K_s (cm/sec)
		Θ_s (vol.)	Θ_r (vol.)	α (1/cm)	n	
TT-205-GT1	all	0.3774	0	0.0525	1.2338	2.2E-04

7.0 UNSAT-H SENSITIVITY ANALYSES

Modeling was performed to evaluate ET cover profiles utilizing native soil and vegetation parameters described in Section 6 as well as variability in climate data for the site. The sensitivity analyses were performed to assess the range of potential input parameters and climatic scenarios expected over the long-term performance period of the final cover system and to demonstrate the cover system's ability to meet the performance objectives.

Soil hydraulic parameters were assessed for the potential borrow sources for cover soil (South Drainage Borrow Area, North Drainage Borrow Area, East Borrow, and West Borrow). The hydraulic soil parameters were evaluated based on the remolded values measured in the laboratory (MWH 2014) that are assumed to represent short-term conditions as well as the soil values measured in undisturbed area of the respective borrow sources in situ to assess the condition of the soils long-term (Dwyer 2014).

The various stages of vegetation were evaluated in the sensitivity analyses including no vegetation, reclaimed vegetation, grassland vegetation, and shrubland vegetation. These vegetation stages represent a natural succession at the site (Cedar Creek 2014) and are described in Section 6.5.

The cover profile variances were also evaluated based on the profiles depicted in Figure 13. The profiles include an admixture top surface consisting of 33 percent rock to 67 percent soil by volume with rock 1.5-inches in diameter mixed to a depth of 14 inches; with rock 2-inches in diameter mixed to a depth of 18 inches; and with rock 3-inches in diameter mixed to a depth of 27 inches. Directly underneath each admixture is the respective cover soil from the same borrow source without the mixture of rock.

Finally, sensitivity to climate variation was evaluated whereby both typical and extreme conditions were modeled. The typical climate year used to evaluate the cover performance was weather from 1949 with an annual precipitation volume of 11.71-inches (29.74 cm). The Ft. Wingate weather data set also had the most extreme weather with the wettest year on record in 1906 with an annual precipitation volume of 23.8-inches (60.5 cm). Much of that moisture came as snow from January to April and October to December. In this period of the modeling the PET is low and transpiration of moisture through vegetation is minimized or completely ceased (refer to Section 6.4).

Table 15 summarizes the simulations performed in the cover profile sensitivity analyses. Refer to Appendix A for details and specifics of the input and output for each simulation.

Table 16. Summary of Computer Simulations in the Cover Profile Sensitivity Analyses

Simulation Series	Cover Profile/Model Geometry	Input Parameters utilized in respective Sensitivity Analysis				
		Rock Size in Surface Admixture (D50)	Soil Borrow Source	Cover Soil Hydraulic Property Measurement	Vegetation Stage	Climate
Series A	14-in surface admixture over 34-in cover soil	1.5-inch	East Borrow	Remolded (EB-B6-03)	No vegetation	Typical & two consecutive years of wettest year on record

Simulation Series	Cover Profile/Model Geometry	Input Parameters utilized in respective Sensitivity Analysis				
		Rock Size in Surface Admixture (D50)	Soil Borrow Source	Cover Soil Hydraulic Property Measurement	Vegetation Stage	Climate
	14-in surface admixture over 34-in cover soil	1.5-inch	North Drainage Borrow	Remolded (NB-B2-04)	No vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	South Drainage Borrow	Remolded (SB-B4-01)	No vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	West Borrow	Remolded (WB-B1-06)	No vegetation	Typical & two consecutive years of wettest year on record
Series B	18-in surface admixture over 34-in cover soil	2-inch	East Borrow	Remolded (EB-B6-03)	No vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	North Drainage Borrow	Remolded (NB-B2-04)	No vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	South Drainage Borrow	Remolded (SB-B4-01)	No vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	West Borrow	Remolded (WB-B1-06)	No vegetation	Typical & two consecutive years of wettest year on record
Series C	27-in surface admixture over 34-in cover soil	3-inch	East Borrow	Remolded (EB-B6-03)	No vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	North Drainage Borrow	Remolded (NB-B2-04)	No vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	South Drainage Borrow	Remolded (SB-B4-01)	No vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	West Borrow	Remolded (WB-B1-06)	No vegetation	Typical & two consecutive years of wettest year on record

Simulation Series	Cover Profile/Model Geometry	Input Parameters utilized in respective Sensitivity Analysis				
		Rock Size in Surface Admixture (D50)	Soil Borrow Source	Cover Soil Hydraulic Property Measurement	Vegetation Stage	Climate
Series D	14-in surface admixture over 34-in cover soil	1.5-inch	East Borrow	Remolded (EB-B6-03)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	North Drainage Borrow	Remolded (NB-B2-04)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	South Drainage Borrow	Remolded (SB-B4-01)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	West Borrow	Remolded (WB-B1-06)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
Series E	18-in surface admixture over 34-in cover soil	2-inch	East Borrow	Remolded (EB-B6-03)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	North Drainage Borrow	Remolded (NB-B2-04)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	South Drainage Borrow	Remolded (SB-B4-01)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	West Borrow	Remolded (WB-B1-06)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
Series F	27-in surface admixture over 34-in cover soil	3-inch	East Borrow	Remolded (EB-B6-03)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	North Drainage Borrow	Remolded (NB-B2-04)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	South Drainage Borrow	Remolded (SB-B4-01)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record

Simulation Series	Cover Profile/Model Geometry	Input Parameters utilized in respective Sensitivity Analysis				
		Rock Size in Surface Admixture (D50)	Soil Borrow Source	Cover Soil Hydraulic Property Measurement	Vegetation Stage	Climate
	27-in surface admixture over 34-in cover soil	3-inch	West Borrow	Remolded (WB-B1-06)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
Series G	14-in surface admixture over 34-in cover soil	1.5-inch	East Borrow	Remolded (EB-B6-03)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	North Drainage Borrow	Remolded (NB-B2-04)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	South Drainage Borrow	Remolded (SB-B4-01)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	West Borrow	Remolded (WB-B1-06)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
Series H	18-in surface admixture over 34-in cover soil	2-inch	East Borrow	Remolded (EB-B6-03)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	North Drainage Borrow	Remolded (NB-B2-04)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	South Drainage Borrow	Remolded (SB-B4-01)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	West Borrow	Remolded (WB-B1-06)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
Series I	27-in surface admixture over 34-in cover soil	3-inch	East Borrow	Remolded (EB-B6-03)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	North Drainage Borrow	Remolded (NB-B2-04)	Grassland Vegetation	Typical & two consecutive years of wettest year on record

Simulation Series	Cover Profile/Model Geometry	Input Parameters utilized in respective Sensitivity Analysis				
		Rock Size in Surface Admixture (D50)	Soil Borrow Source	Cover Soil Hydraulic Property Measurement	Vegetation Stage	Climate
	27-in surface admixture over 34-in cover soil	3-inch	South Drainage Borrow	Remolded (SB-B4-01)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	West Borrow	Remolded (WB-B1-06)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
Series J	14-in surface admixture over 34-in cover soil	1.5-inch	East Borrow	Remolded (EB-B6-03)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	North Drainage Borrow	Remolded (NB-B2-04)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	South Drainage Borrow	Remolded (SB-B4-01)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	West Borrow	Remolded (WB-B1-06)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
Series K	18-in surface admixture over 34-in cover soil	2-inch	East Borrow	Remolded (EB-B6-03)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	North Drainage Borrow	Remolded (NB-B2-04)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	South Drainage Borrow	Remolded (SB-B4-01)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	West Borrow	Remolded (WB-B1-06)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
Series L	27-in surface admixture over 34-in cover soil	3-inch	East Borrow	Remolded (EB-B6-03)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record

Simulation Series	Cover Profile/Model Geometry	Input Parameters utilized in respective Sensitivity Analysis				
		Rock Size in Surface Admixture (D50)	Soil Borrow Source	Cover Soil Hydraulic Property Measurement	Vegetation Stage	Climate
	27-in surface admixture over 34-in cover soil	3-inch	North Drainage Borrow	Remolded (NB-B2-04)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	South Drainage Borrow	Remolded (SB-B4-01)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	West Borrow	Remolded (WB-B1-06)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
Series M	14-in surface admixture over 34-in cover soil	1.5-inch	East Borrow	In Situ (Dwyer 2014)	No Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	North Drainage Borrow	In Situ (Dwyer 2014)	No Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	South Drainage Borrow	In Situ (Dwyer 2014)	No Vegetation	Typical & two consecutive years of wettest year on record
Series N	18-in surface admixture over 34-in cover soil	2-inch	East Borrow	In Situ (Dwyer 2014)	No Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	North Drainage Borrow	In Situ (Dwyer 2014)	No Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	South Drainage Borrow	In Situ (Dwyer 2014)	No Vegetation	Typical & two consecutive years of wettest year on record
Series O	27-in surface admixture over 34-in cover soil	3-inch	East Borrow	In Situ (Dwyer 2014)	No Vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	North Drainage Borrow	In Situ (Dwyer 2014)	No Vegetation	Typical & two consecutive years of wettest year on record

Simulation Series	Cover Profile/Model Geometry	Input Parameters utilized in respective Sensitivity Analysis				
		Rock Size in Surface Admixture (D50)	Soil Borrow Source	Cover Soil Hydraulic Property Measurement	Vegetation Stage	Climate
	27-in surface admixture over 34-in cover soil	3-inch	South Drainage Borrow	In Situ (Dwyer 2014)	No Vegetation	Typical & two consecutive years of wettest year on record
Series P	14-in surface admixture over 34-in cover soil	1.5-inch	East Borrow	In Situ (Dwyer 2014)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	North Drainage Borrow	In Situ (Dwyer 2014)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	South Drainage Borrow	In Situ (Dwyer 2014)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
Series Q	18-in surface admixture over 34-in cover soil	2-inch	East Borrow	In Situ (Dwyer 2014)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	North Drainage Borrow	In Situ (Dwyer 2014)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	South Drainage Borrow	In Situ (Dwyer 2014)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
Series R	27-in surface admixture over 34-in cover soil	3-inch	East Borrow	In Situ (Dwyer 2014)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	North Drainage Borrow	In Situ (Dwyer 2014)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	South Drainage Borrow	In Situ (Dwyer 2014)	Reclaimed Vegetation	Typical & two consecutive years of wettest year on record
Series S	14-in surface admixture over 34-in cover soil	1.5-inch	East Borrow	In Situ (Dwyer 2014)	Grassland Vegetation	Typical & two consecutive years of wettest year on record

Simulation Series	Cover Profile/Model Geometry	Input Parameters utilized in respective Sensitivity Analysis				
		Rock Size in Surface Admixture (D50)	Soil Borrow Source	Cover Soil Hydraulic Property Measurement	Vegetation Stage	Climate
	14-in surface admixture over 34-in cover soil	1.5-inch	North Drainage Borrow	In Situ (Dwyer 2014)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	South Drainage Borrow	In Situ (Dwyer 2014)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
Series T	18-in surface admixture over 34-in cover soil	2-inch	East Borrow	In Situ (Dwyer 2014)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	North Drainage Borrow	In Situ (Dwyer 2014)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	South Drainage Borrow	In Situ (Dwyer 2014)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
Series U	27-in surface admixture over 34-in cover soil	3-inch	East Borrow	In Situ (Dwyer 2014)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	North Drainage Borrow	In Situ (Dwyer 2014)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	South Drainage Borrow	In Situ (Dwyer 2014)	Grassland Vegetation	Typical & two consecutive years of wettest year on record
Series V	14-in surface admixture over 34-in cover soil	1.5-inch	East Borrow	In Situ (Dwyer 2014)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	North Drainage Borrow	In Situ (Dwyer 2014)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
	14-in surface admixture over 34-in cover soil	1.5-inch	South Drainage Borrow	In Situ (Dwyer 2014)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record

Simulation Series	Cover Profile/Model Geometry	Input Parameters utilized in respective Sensitivity Analysis				
		Rock Size in Surface Admixture (D50)	Soil Borrow Source	Cover Soil Hydraulic Property Measurement	Vegetation Stage	Climate
Series W	18-in surface admixture over 34-in cover soil	2-inch	East Borrow	In Situ (Dwyer 2014)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	North Drainage Borrow	In Situ (Dwyer 2014)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
	18-in surface admixture over 34-in cover soil	2-inch	South Drainage Borrow	In Situ (Dwyer 2014)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
Series X	27-in surface admixture over 34-in cover soil	3-inch	East Borrow	In Situ (Dwyer 2014)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	North Drainage Borrow	In Situ (Dwyer 2014)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record
	27-in surface admixture over 34-in cover soil	3-inch	South Drainage Borrow	In Situ (Dwyer 2014)	Shrubland Vegetation	Typical & two consecutive years of wettest year on record

Although the varied input parameters such as soil, vegetation and cover profile geometry showed some sensitivity, the most sensitive item was the climatic variation. The Point of Diminishing Returns (PODR) method (Dwyer et al. 2007, USEPA 2011) utilizes modeling to calculate the cover thickness required to effectively minimize flux through the cover. That is, at the PODR, an additional inch of soil will no longer enhance the cover's performance. Based on the PODR method (Dwyer et al. 2007, EPA 2011), the outcome predicted a cover thickness of less than 2 feet for typical weather conditions for all soil, vegetation input parameters and cover profiles. For the wettest year on record, the PODR was produced at a depth of about 3 feet for all soil, vegetation input parameters and cover profiles. The PODR was less than 4 feet for a climate scenario that is beyond anything experienced in recorded history with the wettest year on record (much of the moisture is received in the winter months where PET is at its lowest) occurs in consecutive years. Refer to Figure 18 for the worst case graphic of the sensitivity analyses performed.

The input parameters were varied one at a time to evaluate their respective change on the calculated output. The recommended cover thickness is 4 feet based on analyses that demonstrated the cover has adequate storage capacity to withstand the worst-case scenarios expected over the 1,000-year performance period combined with some expected soil loss due to

erosion (limited due to rock/soil admixture). That is, no annual net percolation will pass through the vegetated cover system even in the worst case scenario.

The worst case graphic results from the series of simulations from the sensitivity analyses is shown in Figure 18. The PODR is achieved within the proposed cover profile. The results of simulations, including output graphics, are included in Appendix A.

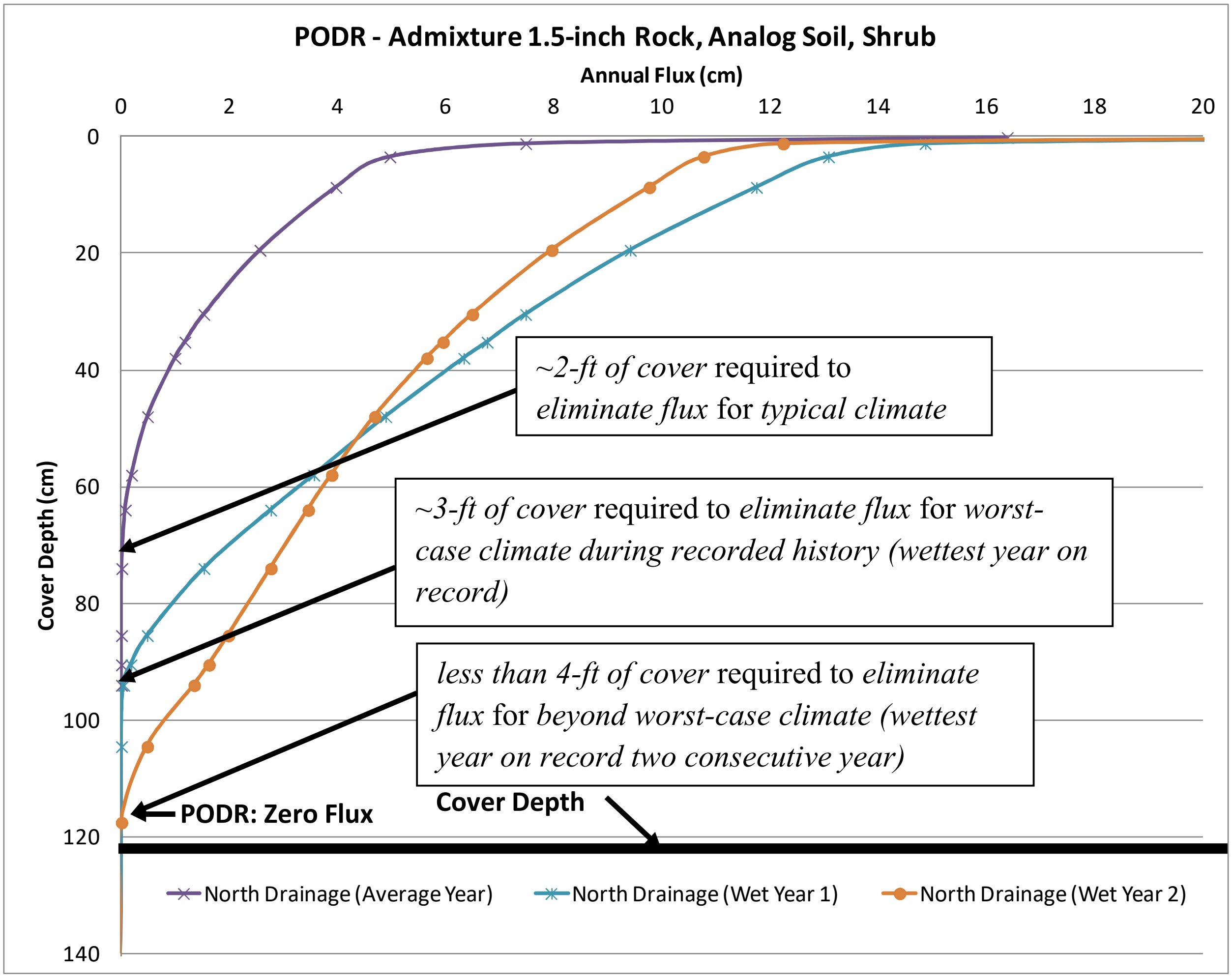


Figure 18. Worst Case Infiltration for Vegetated Cover System from Sensitivity Analyses

8.0 LONG-TERM SIMULATIONS

8.1 Long-Term Simulations Input Data

After the sensitivity analyses were performed as described in Section 7, the resulting cover profiles (Figure 13) were modeled to represent the long-term performance of the given profiles.

The long-term evaluation of the 4 foot cover profiles (Figure 13) overlying the mine spoils simulated the potential changes through the 1,000-year performance period, varying the vegetation and soil hydraulic properties as they evolve. Typical and extreme climate conditions are included. Each admixture (1.5-in diameter rock mixed with soil to 14-inch depth, 2-inch rock mixed with soil to 18-inch depth, and 3-inch diameter rock mixed with soil to a 27-inch depth - the remaining cover is soil from same borrow source) was separately evaluated (Figure 13), thus there were three sets of long-term simulations completed each in four stages.

The UNSAT-H software cannot alter input parameters after initiation of a given simulation. Consequently, the long-term evaluations were calculated in multiple stages, where the output from earlier time steps were used as input for subsequent time steps. That is, for each long-term evaluation, the initial simulation with an initial set of input parameters was performed for a specified period of time and set of climatic conditions. The last day of the last year of that initial simulation output, specifically the matric potential values for each node from the previous simulation, was then used as the initial soil conditions for the subsequent simulation with the altered input parameters (Figure 19). For example, the *final* soil suction values for each node in the model geometry for the 'initial' stage was used as the starting conditions for the next 'short-term' stage.

There was no vegetation included in the 'initial' stage, but vegetation was included in subsequent stages (Cedar Creek 2014). The long-term simulations were performed in four stages: the 'initial' stage, followed by the 'short-term' stage, followed by the 'intermediate' stage, and finally the 'long-term' stage (Figure 19). The initial stage consisted of 3 years of typical or average climate with no vegetation. The short-term stage, intermediate stage, and long-term stage all consisted of 20 years of average to extreme climatic data. Thus the whole long-term simulation is 63 years. The extreme climate data was the wettest year on record run consecutively sandwiched by typical climatic data. There were no dry climatic years included in any of the simulations. All precipitation in the weather files was conservatively set to allow for 100 percent or close to 100 percent infiltration, thus minimizing runoff.

Time	Initial	Short-Term	Intermediate	Long-Term
Vegetation	None	Disturbed (Reclaimed)	Grassland	Shrubland
Soil	Remolded (Lab Measured)	Remolded (Lab Measured)	Remolded (Lab Measured)	Undisturbed (In Situ Measured)
Climate	Typical	Typical and Extreme	Typical and Extreme	Typical and Extreme
No. of Years Modeled	3	20	20	20

Figure 19. Input based on Design Life for Computer Simulations

The first stage (initial time) of the long-term simulations, in the respective series for each admixture design assumed from the time of construction completion out three years with no vegetation. The soil from the south drainage borrow area was used since it is the largest borrow source. The soil hydraulic input parameters from different borrow sources showed minimal variation in the predicted PODR for the cover profiles from the sensitivity analyses described in Section 7. The remolded values for the soil hydraulic properties based on laboratory measurements (refer to Section 6) were used in the 'initial' stage. These soil properties were also the soil input parameters for the short- to intermediate- time periods. No vegetation is assumed for the 'initial' stage for a period of 3 years with average weather conditions. It is highly likely that vegetation will begin to emerge the first year and continue to expand into the second and third years, but to be conservative; absolutely no vegetation (and thus no transpiration) is included during the 'initial' model stage. Average weather conditions were assumed because dry conditions would obviously yield no flux and wet conditions would yield vegetation. The moisture condition (matric potential for each node in the model geometry) at the end of the third year, was used as the initial moisture conditions (matric potential for each node in the new model geometry) for the next 'short-term' stage.

The second stage (short-term time) of the long-term simulations in the respective series for each admixture included vegetation from the reclaimed vegetation analog (Cedar Creek 2014). The reclaimed community of vegetation represents vegetation in a disturbed area and generally considered from shortly after seeding upon construction completion up to about 50 years (Cedar Creek 2014). The soil input parameters and geometries from the first stage of simulations was consistent with this stage of simulations. Typical climate conditions were used for ten consecutive years followed by the wettest year on record two years in a row, followed by eight more years of typical climate conditions. This is conservative given the fact that the wettest year on record appears in two consecutive years every twenty years and that there are no dry years included in the analysis. The wettest years run consecutively is assumed to be the worst case infiltration event the site is likely to see. The moisture condition (matric potential for each node in the model geometry) at the end of the last year of the respective 'short-term' stage for each admixture design, was used as the initial moisture conditions (matric potential for each node in the new model geometry) for the next 'intermediate' stage.

The third stage of the long-term simulations (intermediate time) in the respective series for each admixture included vegetation from the grassland vegetation analog (Cedar Creek 2014). The grassland community represents undisturbed vegetation and is assumed to represents the vegetation on the cover from about 25 to 100 years after construction (Cedar Creek 2014). The soil input parameters and geometries from the 'short-term' stage was consistent with this 'intermediate' stage. Typical climate conditions were used for ten consecutive years followed by the wettest year on record two years in a row, followed by eight more years of typical climate conditions. The wettest years run consecutively is assumed to be the worst case infiltration events the site is likely to see. The moisture condition (matric potential for each node in the model geometry) at the end of the last year of each respective 'intermediate' stage for each admixture design, was used as the initial moisture conditions (matric potential for each node in the new model geometry) for the next 'long-term' stage.

The fourth stage of the long-term simulations (long-term time) in the respective series for each admixture included vegetation from the shrubland vegetation analog (Cedar Creek 2014). The shrubland community represents undisturbed vegetation and is assumed to represent vegetation on the cover from about 50 to 1,000 years (Cedar Creek 2014). The geometries from the 'intermediate' stage was consistent with this 'long-term' stage. The soil input parameters were changed to that from the soil analog data obtained from the South Drainage Borrow Area that represent an undisturbed soil structure or the long-term status of the soil (Dwyer 2014). Typical climate conditions were used for ten consecutive years followed by the wettest year on record two years in a row, followed by eight more years of typical climate conditions. The wettest years run consecutively is assumed to be the worst case infiltration events the site is likely to see.

8.2 Long-Term Simulations Results

A detailed description of each computer simulation performed with input parameters and respective output including graphics is included in Appendix B. The long-term simulations performed were for the cover profile with the 14-inch-deep surface admixture layer (Figure 13). This profile was used because it was the worst case profile requiring the deepest PODR to minimize flux compared to the other admixture depths. The PODR or depth where flux is minimized at just over 2-ft is easily achieved within the recommended cover profile depth. This despite the climate utilized in the long-term simulation included the wettest year on record in consecutive years run every twenty years. That is, during this 63 year simulation, the wettest year on record occurred six times. Figure 21 shows that a drying trend is established and will continue until relative steady state is achieved (Dwyer 2017). Consequently, modeling the profile for any longer would not produce additional useful data.

For years 1, 2, and 3 (no vegetation), there was a de minims amount of flux estimated but the PODR was reached at a shallow depth (Figure 20). All flux values through the vegetated cover for all subsequent years was zero.

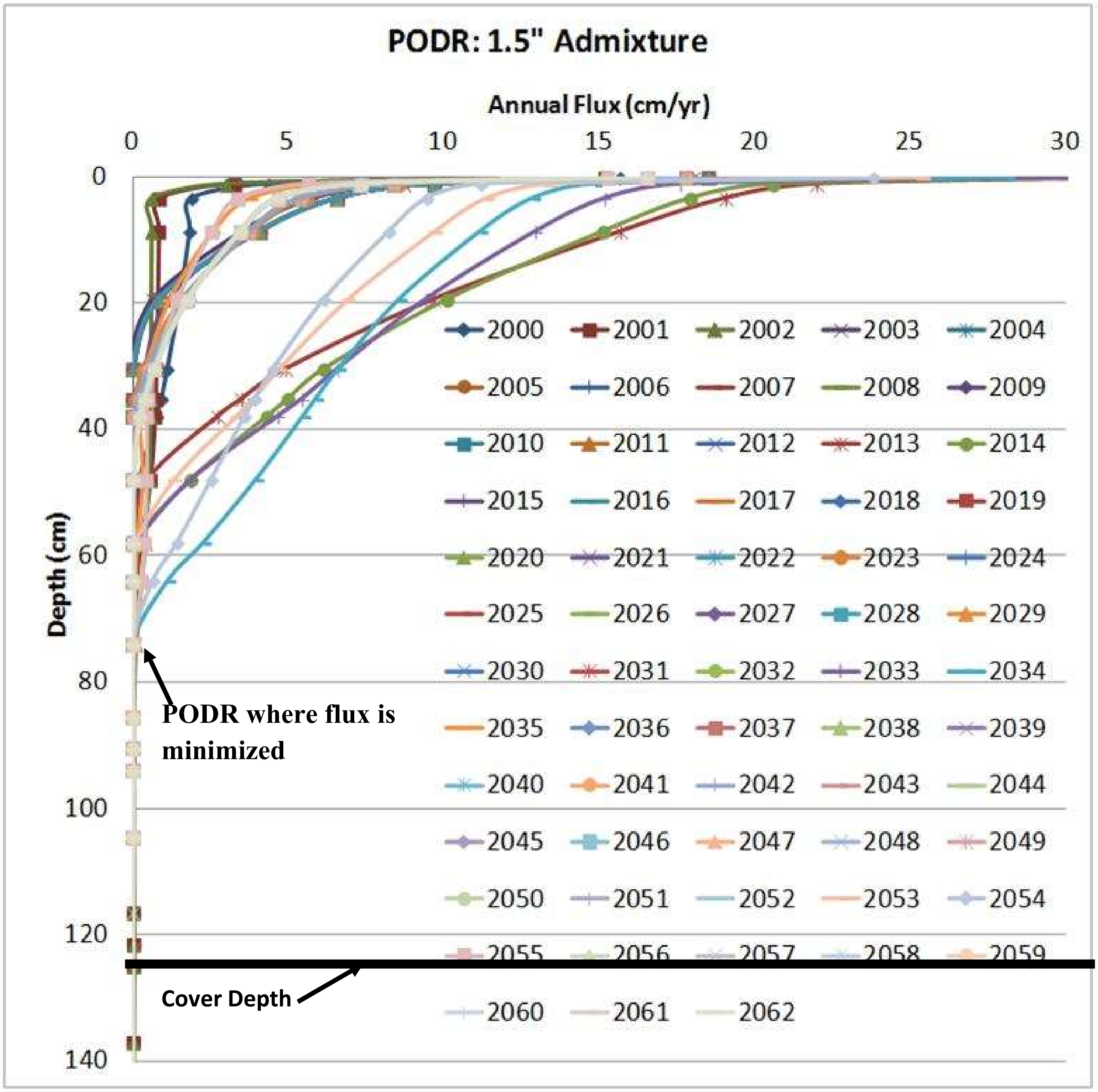


Figure 20. PODR for Long-Term Simulation, 14-inch deep Surface Layer

8.3 Long-Term Simulations Results for Profile B8

Another set of long-term simulations was performed of Profile B8 corresponding to the consolidation and unsaturated flow analysis described in Dwyer (2017). Profile B8* was modeled because it is the only cross section that included fully saturated tailings due to consolidation resulting from placement of the mine spoils and ET cover on the impoundment (Dwyer 2017). This set of simulations included placement of the ET cover over the placed mine spoils over the existing profile including the consolidated tailings. This analysis is to demonstrate that under the most conservative conditions, the cover and underlying mine spoils

will not cause moisture build-up on the underlying radon barrier/liner …. Details of this analyses are included in *Tailings Consolidation and Groundwater Evaluation - 95% Design (*Dwyer 2017).

Suction values within the profile modeled that included the installed moisture condition of all of the mine spoils and ET cover at the suction value corresponding to the respective optimum moisture content (ASTM. 2012) are shown in Figure 21. The optimum moisture content is the wettest condition that the materials will be placed. Per the design specifications, any wetter condition will require removal of the material and drying it or reworking the soil to dry it in place. No material will be placed on top of a wet layer of soil until that underlying soil lift meets the specified conditions. Mine spoils are placed directly on the existing cover/radon barrier less the removal of the existing surface riprap that will be utilized elsewhere in the project.

At the request of the regulatory agencies, another sensitivity analysis was performed similar to that described above; however, the mine spoils and ET cover were all installed 3 percent wet of the optimum moisture content per ASTM D698 (ASTM, 2012). This moisture is beyond that allowed in the design specifications but was included to evaluate the sensitive nature of moisture included in the mine spoils and ET cover during placement. The results are similar to those shown in Figure 21. That is, the moisture content of the installed mine spoils and ET cover will not cause moisture build-up on the underlying radon barrier/liner while the radon barrier/liner continues to dry similarly to that shown in Figure 21.

Figure 21 shows that even though the mine spoils initial suction value is very wet, it quickly dries and continues to dry during the full simulation (middle of mine spoils). The base of the mine spoils and adjacent radon barrier suction values move toward a steady state condition (equal suction values) and then eventually all layers show a drying trend for the duration of the long-term simulation. This drying trend will continue until a steady state condition is reached at a greater suction value than the end of this simulation. This is because no net flux will pass through the vegetated cover system; the initial conditions are the wettest conditions and the profile will only dry as time passes.

Figure 21 illustrates that there is no moisture buildup on the existing radon/barrier and thus no potential for future seepage through the barrier. Dwyer (2017) describes this analysis and results. Dwyer (2017) further illustrates that the wettest condition of the profile modeled is the initial condition and that the profile continues to dry while approaching steady state conditions.

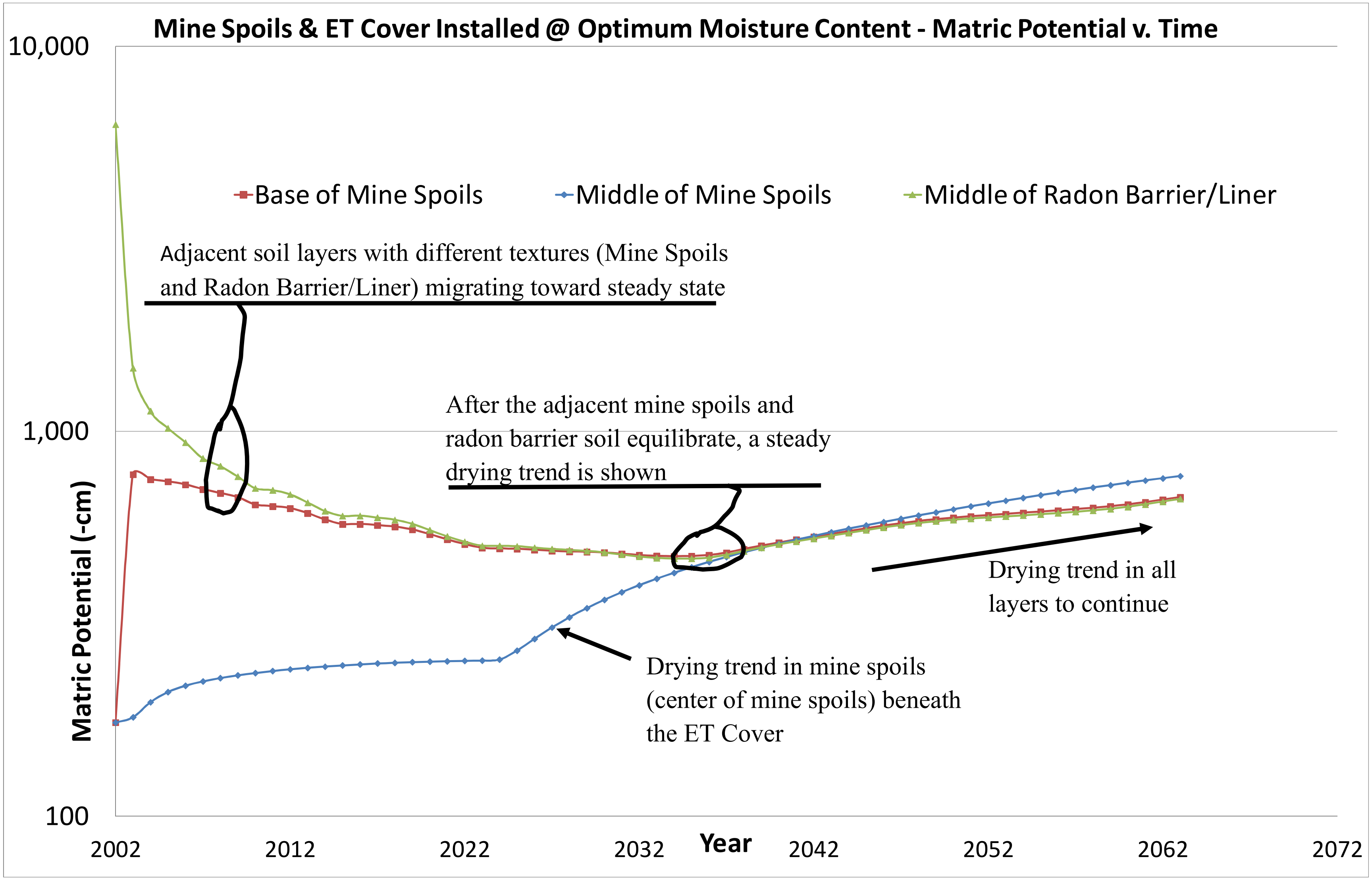


Figure 21. Suction Values for Specified Profile Depth vs. Time

9.0 RADON ATTENUATION

Federal regulations limiting radon releases to the atmosphere are contained in 40 CFR §192.02. The regulations are also typically applied as an ARAR to DOE sites undergoing remediation. These regulations require that release of 222Rn to the atmosphere not exceed: (i) an average release rate of 20 pCi/m^2s; ***or*** (ii) increase the annual average concentration of 222Rn in the air at or above any location outside of the disposal site by more than one-half picocurie per liter.

The ET cover soil functions as an effective barrier to gas diffusion, air-filled voids in the soil have to be discontinuous. Gas diffuses slowly through wet soils that contain only occasional, unconnected air bubbles. The ET cover system was evaluated for its ability to limit radon flux (NRC 1989, NRC 2003). The radon flux through the ET cover soil was calculated using the Uranium Mill Tailings Cover Calculator (http://www.wise-uranium.org/ctc.html) that is a clone of the RAECOM code, as described in (Rogers 1984a, 1984b). It performs one-dimensional, steady-state radon diffusion calculations for a multi-layer system.

9.1 Input Data for Radon Flux Modeling

- Layer Data: The profile was modeled with a bottom layer of mine spoils capped with a two layered ET Cover system. The ET Cover profile is 4 feet (1.22 m) thick. The top layer is a 27-inch (69 cm) layer of rock and soil mixed at a ratio of 33 percent rock to 67 percent soil by volume. Of the three admixture designs, this is the most conservative given it has the thickest admixture region that has a reduced porosity and fines content. The bottom layer of the cover is all soil 21-inches thick (53 cm). The mine spoils was assumed to be 5 m thick (NRC, 1989, Section C 1.1.1).

  NUREG Guide 3.64: 'Section C 1.1.1 Layer Thicknesses'

  > *The thickness of the tailings source, xt, will be determined from the applicant's estimates of total tailings production and areal extent of the pile. Because a tailings thickness greater than about 100-200 cm is effectively equivalent to an infinitely thick radon source, a value of xt = 500 cm represents an equivalent infinitely thick tailings source of radon that may be used in the absence of more specific smaller values.*

  Thus, 500 cm is the maximum thickness to be used for tailings in the RADON model. Refer to Table 18 for a layer by layer description of parameters.

- Ra-226 Activity Concentration [pCi/g]: Activity concentration of Radium-226 in each respective layer. The Ra-226 activity concentration for the mine waste rock was a weighted average of that measured in the field. The RA-226 concentration used for the entire 5 m depth of waste rock was 29.7 pCi/g (Table 17). A value of zero was assumed for the cover material since it is constructed of clean cover soil for an engineer approved borrow source (NRC, 1989, Section C 1.1.4).

Table 17. Radium-226 Concentrations in Mine Spoils (provided by Stantec)

	Average Values (pCi/g)	Average of 75th Percentile Values (pCi/g)	Average of 90th Percentile Values (pCi/g)	Total Volumes (CY)
Area 1 - Vent Holes 3 and 8	7.6	2.4	3.5	14,764
Area 2 - Boneyard and NEMSA	21.0	26.7	28.5	50,535
Area 3 - Road, Sandfill 2, Sandfill 3, NECR-2	10.1	11.4	12.2	223,080
Area 4 - North of Pond 3	5.8	5.2	10.0	18,148
Area 5 - TPH Stockpile	9.5	9.6	23.4	30,000
Area 7 - Sandfill 1	35.5	50.5	59.5	35,506
Area 6 - Sediment Pad	74.9	86.3	91.1	56,646
Area 8 - NECR-1	21.8	24.2	28.7	361,382
Area 8 - NECR-1 Step out Material	9.5	9.6	23.4	130,000
Area 11 - TPH Stockpile Area	7.5	9.8	11.5	16,290
Area 9 - Pond 1	60.8	85.2	94.9	44,634
Area 10 - Pond 2	8.0	10.2	11.5	18,948
Area 12 - Pond 3	6.7	7.1	7.3	22,375
Area 13 - Drainage near Highway	7.5	6.5	24.9	41,937
Weighted Average by Volume	**20.5**	**24.0**	**29.7**	

Table 18. Radon Flux Input Parameters

Layer No.	Thickness [m]	Ra-226 Activity Conc. [pCi/g]	Ra-226 Emanat	Porosity	Moisture [dry wt_%]	Rn-222 Diff. Coeff - - *calculated* [m2/s]
Mine Spoils	5	29.7	0.35	0.3774	6	2.253E-06
Bottom Layer of Cover	0.53	0	0.35	0.5216	5.87	3.604E-06
Top Layer (Admixture) of Cover	0.69	0	0.35	0.34945	3.93	2.535E-06

- **Rn-222 Emanation Fraction** is a fraction of the total amount of radon-222 produced by radium decay that escapes from the soil particles and gets into the pores of the soil. It depends on the soil material and the moisture content. It varies over a range of 0.1 - 0.4 or more; typical values are in the range of 0.2 - 0.3. A value of 0.35 was used [NRC 1989, NRC, 2003]

- **Porosity** is the ratio of the pore volume (air- and water-filled) to the total volume of the soil. Refer to Table 18 for the porosity values for each layer. The numerical average value of porosities for the borrow soils listed in Table 11 was used for layer 2. The average value of porosities for the admixture for borrow sources listed in Table 12 was used. The porosity for Sample TT-205-GT1 considered to be typical for the mine spoils was used.
- **Moisture Contents [dry wt_%]** is the percentage of water weight to dry soil weight. The average in situ moisture content for the mine spoils was 8 percent. The average optimum moisture content for the mine spoils is about 12 percent. An initial and long-term moisture content of 6 percent was used for the mine spoils (NRC 1989). NRC (1989) notes that 6 percent represents the lower bound for moisture in western soils and is typically used as a default value for the long term water content of tailings. The average measured gravimetric moisture content for the cover soil borrow sources evaluated was 6.3 percent. However, following guidance in NRC (1989) the average volumetric moisture content associated with the soil samples summarized in Table 11 based on their respective wilting point (soil suction value of 15 bars or 15,000 cm) is 8.41 percent. This converts to a gravimetric moisture content of 5.87 percent utilizing the average dry bulk density of 89.5 pounds per cubic foot for these soil samples. Utilizing the moisture retention data summarized in Table 12, this gravimetric moisture content is reduced to 3.93 percent for the surface admixture layer based on the addition of 33 percent rock. Thus the most conservative values were used: moisture contents of 6 percent was utilized for the mine spoils, 5.87 percent for the bottom cover soil layer, and 3.93 percent for the surface cover admixture layer.
- **Rn-222 Effective Diffusion Coefficient [m^2/s]** defined from Fick's equation as the ratio of the diffusive flux density of radon activity across the pore area to the gradient of the radon activity concentration in the pore or interstitial space. This value was calculated in the model based on the assigned input parameters identified above.

9.2 Output for Radon Flux Modeling

The computed radon flux was **<u>13.73 pCi/m²s</u>** (Table 19). This value is less than the maximum allowable of 20 pCi/m^2s per 40 CFR 192.02.

Table 19. Radon Flux Calculation Output

Layer No.	Thickness [m]	Exit Flux [pCi/m2s]	Exit Conc. [pCi/L]	MIC
Mine Spoils	5	24.99	15.85E+03	0.802
Bottom of Cover	0.53	16.52	11.92E+03	0.892
Top Admixture Layer of Cover	0.69	13.73	0	0.854

10.0 SUMMARY OF RESULTS

The design methods and calculations demonstrate that the recommended cover design (Figure 13) will meet the objectives of performance for 1,000-years to include limiting meteoric flux into the underlying mine waste, minimize erosion, provide a rooting medium for native vegetation, and attenuate emanation of radon-222 from the mine waste. This conclusion is based on erosion computations, moisture flux modeling, and radon emanation calculations, and which are summarized in the following subsections.

10.1 Erosion Protection

The cover is composed of two layers. The top layer is a rock/soil admixture referred to as a 'desert pavement'. This layer is designed to mitigate erosion by adding rock to the engineer-approved cover soil. This surface layer satisfies NUREG 1623 (NRC, 2002) for the long-term stability of a rocky soil cover. The overall cover thickness including both layers will be a consistent 4 feet (122 m) while the thickness surface admixture (refer to Figure 13) depends on the location and respective slope length. The bottom layer is composed of cover soil only.

The surface desert pavement is a mixture of 33 percent rock to 67 percent soil by volume. For a slope of 5 percent, the admixture top layer contains D_{50} rock of 1.5 inches mixed with soil to a depth of 14 inches for the upper 300 feet of the slope length. From a slope length of 300 to 600 feet, the rock size was increased to 2 inches while the depth of the admixture was increased to 18 inches. Finally, for slope lengths longer than 600 feet with a 5 percent slope, the rock size was increased to 3 inches while the admixture depth was increased to 27 inches.

For slopes of 2 percent, the 1.5-inch rock admixture at a depth of 14 inches was adequate for the full 1,000 ft slope length. The resulting surface slopes meet requirements set forth in Dwyer et al. (1997) and NRC (2002).

The resulting surface was then analyzed utilizing the RUSLE (USDA 1997) for surface water runoff induced soil loss and the WEPS (USDA 2010) for wind induced soil loss. The combined resulting estimated soil loss is significantly less than the USEPA (1991) recommended 2 tons/year/acre.

10.2 Modeling of Cover System

Section 7 summarized the sensitivity analyses evaluating myriad input parameters demonstrating the 4-ft-thick cover system's effectiveness for the 1,000-year performance period. The modeling output provided in Appendix A and B revealed that for typical climatic conditions, a 2-ft cover thickness minimized flux due to precipitation. A cover thickness less than 4 feet effectively minimized flux even while applying the wettest year on record in two consecutive years. This scenario includes the wettest year where much of this precipitation occurred in the winter and early spring and late fall where PET is low and then doubled it by running the year back-to-back to provide conservatism in the design and analysis. The analyses revealed that the 4-ft vegetated ET cover will produce no flux no matter the combination of input parameters possible for the 1,000-year performance period. There was minimal difference in prediction of the PODR for the cover profile from the myriad input parameters modeled including cover soil and vegetation. The most sensitive item was the climate comparing typical to the extreme wet conditions (two consecutive wettest years on record). The 4-ft cover depth is the thickness of soil with the

required storage capacity needed to minimize flux based on the application of the wettest year on record with close to 100 percent infiltration two years in a row. This climatic scenario is beyond anything seen at the site in recorded history and beyond anything likely to occur at the site. The combination of this climatic data and slow application rate to force nearly 100 percent infiltration while minimizing runoff created the worst case infiltration design scenario.

The regulatory agencies requested an additional set of sensitivity analyses be performed of the cover profiles without any vegetation for an extended period of time. The results of this analyses is contained in Appendix C. The results show that a de minims amount of flux is produced but the PODR and thus performance objective to minimize flux is satisfied well within the 4-ft profile. It should be noted that this de minims flux is many orders of magnitude less than the flux through the existing cover on the impoundment (Dwyer 2017).

10.3 Radon Flux

Section 9 provided an overview of the estimated radon release rate through the cover profile. The radon flux through the cover soil was calculated using the RAECOM code, as described in (Rogers 1984a, 1984b). It performs one-dimensional, steady-state radon diffusion calculations for a multi-layer system. The top layer is a 27-inch-thick (69 cm) layer of rock and soil mixed at a ratio of 1 rock to 2 soil by volume. Of the three admixture designs, this is the most conservative given it has the thickest admixture region that has a reduced porosity and fines content. The bottom layer of the cover is a 21-inch-thick (53 cm) soil layer. The mine spoils was assumed to be 5 meters thick (NRC, 1989, Section 1.1.1). The computed radon flux was 13.73 pCi/m^2s (Table 19). This value is less than the maximum allowable of 20 pCi/m^2s per 40 CFR 192.02.

11.0 REFERENCES

1. Applied Weather Associates. 2013. Probable Maximum Precipitation Study for Arizona. July.
2. American Society for Testing and Materials (ASTM), 2007. Standard Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles. ASTM D4718.
3. American Society for Testing and Materials (ASTM), 2012. Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3)). ASTM D698. May 1.
4. Birkeland, P. W. 1984. Soils and Geomorphology, in Oxford University Press, pp. 138-140.
5. Bonnin, G., D. Martin, B. Lin, T. Parzybok, M. Tekta, and D. Riley, 2011. Precipitation-Frequency Atlas of the United States, Volume 1, Version 5.0: Semiarid Southwest (Arizona, Southeast California, Nevada, New Mexico, Utah). NOAA Atlas 14.
6. Bouwer H. and R. Rice, 1984. Hydraulic Properties of Stony Vadose Zones. Ground Water, 22 (6) (1984), pp. 696–705
7. Cedar Creek Associates. 2016. San Mateo Project 2016 Year 4 Revegetation Evaluation Report. December.
8. Cedar Creek Associates. 2014. Vegetation Characterization and Biointrusion Surveys Church Rock Mill Site. July.
9. Doorenbos, J. and W.O. Pruitt. 1977. Guidelines for prediction crop water requirements. FAO Irrig. and Drain. Paper No. 24, 2nd ed., FAO Rome, Italy.
10. Dwyer, S.F., 1997. "Large-Scale Field Study of Landfill Covers at Sandia National Laboratories," in Conference Proceedings: Landfill Capping in the Semi-Arid West: Problems, Perspectives, and Solutions, T.D. Reynolds and R.C. Morris, eds., held in Grand Teton National Park, Wyoming, May 1997, pp. 87–107.
11. Dwyer, SF, R Rager, J Hopkins. 2007. Cover System Design Guidance and Requirements Document. Los Alamos National Laboratory report LA-UR-06-4715.
12. Dwyer, SF. 2003. Water Balance Measurements and Computer Simulations of Landfill Closures. PhD Dissertation. University of New Mexico, Albuquerque, NM.
13. Dwyer, SF. 2014. Natural Analog Study of Cover Soil Borrow Sources Using a Tension Infiltrometer. Northeast Churchrock Mine, Gallup, NM. August 20.
14. Dwyer, SF. 2017. Tailings Consolidation and Groundwater Evaluation - 95% Design Draft. May.
15. Fayer, M. J., and T. L. Jones. 1990. UNSAT-H version 2.0: Unsaturated soil water and heat flow model. PNL-6779, Pacific Northwest Laboratory, Richland, WA.
16. Fayer, M.J. 2000. UNSAT-H Version 3.0: Unsaturated Soil Water and Heat Flow Model, Theory, User Manual, and Examples. Pacific Northwest Laboratory, Richland, WA.
17. Fayer, MJ and TB Walters. 1995. Estimated Recharge Rates at the Hanford Site. PNL-10285, Pacific Northwest Laboratory, Richland, WA.

18. Hakonson, T.E. and L.J. Lane. 1992. The role of physical process in the transport of man-made radionuclides in arid ecosystems. R. M. Harrison (ed.) In: Biogeochemical Pathways of Artificial Radionuclides, John Wiley & Sons.

19. Hansen, E.M., F.K. Schwarz, and J.T Reidel, 1977: Probable Maximum Precipitation Estimates. Colorado River and Great Basin Drainages. Hydrometeorological Report No. 49, NWS, NOAA, U.S. Department of Commerce, Silver Spring, Md, 161 pp.

20. Hillel, D. 1998. Environmental Soil Physics. Academic Press, San Diego, CA.

21. ITRC. 2003. Technical and Regulatory Guidance for Design, Installation, and Monitoring of Alternative Final Landfill Covers. Interstate Technology and Regulatory Council, Alternative Landfill Technologies Team, Washington DC.

22. Ligotke, M. W. 1994. Control of Eolian Soil Erosion from Waste-Site Surface Barriers, in In-Situ Remediation: Scientific Basis for Current and Future Technologies, edited by G. W. Gee, G. W. and N. R. Wing, Battelle Press, Richland, Washington, pp. 545-559.

23. Lindeburg, M. (editor) 1989. Civil Engineering Reference Manual, 5th ed. Professional Publications, Belmont, CA.

24. MWH. 2014. Pre-Design Studies Northeast Church Rock Mine Site Removal Action/Church Rock Mill Site. October 31.

25. Peck, A.J., and J.D. Watson. 1979. Hydraulic Conductivity and Flow in Non-uniform Soil. In Workshop on Soil Physics and Field Heterogeneity. CSIRO Division of Environmental Mechanics, Canberra, Australia.

26. Pemberton, E. L. and Lara, J. M., 1984, Computing degradation and local scour: U.S. Bureau of Reclamation, Technical Guideline, 48 p.

27. Ritchie, J.T., and E. Burnett. (1971). Dryland Evaporative Flux in a Semi-humid Climate, 2, Plant Influences. Agron. J. 63:56-62.

28. Rogers and Associates Engineering (1984a). “Radon Attenuation Effectiveness and Cover Optimization with Moisture Effects (RAECOM),” computer program, U.S. Nuclear Regulatory Commission, Washington, DC.

29. Rogers and Associates Engineering (1984b). “Radon Attenuation Handbook for Uranium Mill Tailings Cover System,” NUREG/CR-3533, U.S. Nuclear Regulatory Commission, Washington, DC.

30. Samani, Z. A. and M.Pessarakli, 1986: Estimating Potential Crop Evapotranspiration with Minimum Data in Arizona, Transactions of the ASAE Vol. 29, No. 2, pp. 522-524.

31. Schroeder, P., C. Lloyd and P. Zappi. 1994. The Hydrologic Evaluation of Landfill Performance (HELP) Model User’s Guide for Version 3.0. U.S. Environmental Protection Agency, EPA/600/R-94/168a, Cincinnati, OH.

32. Simon, Li & Associates. 1982. Engineering Analysis of Fluvial Systems, Ft. Collins, CO.

33. U.S. Department of Energy (DOE), 1989. Technical Approach Document Revision II, UMTRA–DOE/AL 050425.0002, Albuquerque Operations Office, Albuquerque, New Mexico.

34. U.S. Environmental Protection Agency (USEPA) Region 6, 1988. Record of Decision, United Nuclear Corporation, Groundwater Operable Unit, McKinley County, New Mexico. September.

35. U.S. Environmental Protection Agency (USEPA), 1991. Environmental Protection Agency, Seminar Publication: Design and Construction of RCRA/CERCLA Final Covers. EPA/625/4-91/025.

36. U.S. Environmental Protection Agency (USEPA), Region 6 and Region 9, 2015. Administrative Settlement Agreement and Order on Consent for Design and Cost Recovery. April 27.

37. U.S. Environmental Protection Agency (USEPA), Region 6 and Region 9, 2011. Action Memorandum: Request for a Non-Time-Critical Removal Action at the Northeast Church Rock Site, McKinley County, New Mexico, Pinedale Chapter of the Navajo Nation. September 29.

38. U.S. Environmental Protection Agency (USEPA), 2012. Closing Small tribal Landfills and Open Dumps. How to Design Environmentally Safe Covers Including Additional Design Guidance for Arid Regions. EPA Design Guidance EPA-909-R-11-007.

39. U.S. Environmental Protection Agency (USEPA), Region 6, 2013. Record of Decision, United Nuclear Corporation Site, McKinley County, New Mexico. March 29.

40. U.S. Nuclear Regulatory Commission (NRC), 1989. Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers, Regulatory Guide 3.64.

41. U.S. Nuclear Regulatory Commission (NRC), 2002. Design of Erosion Protection for Long-term Stabilization. NUREG-1623, September.

42. U.S. Nuclear Regulatory Commission (NRC), 2003. Standard Review Plan for the Review of a Reclamation Plan for Mill Tailings Sites Under Title II of the Uranium Mill Tailings Radiation Control Act of 1978. Final Report. NUREG-1620, Rev. 1. June.

43. United States Department of Agriculture (USDA). 1997. Agriculture Handbook 703. Predicting Soil Erosion by water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). US Department of Agriculture Handbook 703.

44. United States Department of Agriculture (USDA). 2010. The Wind Erosion Prediction System. Wind Erosion Research Unit, Manhattan, Kansas. March.

45. Van Genuchten, M.Th., F.J. Leij, and S.R. Yates. 1991. The RETC code for quantifying the hydraulic functions of unsaturated soils.

46. Waugh, W. J., K. L. Peterson, S. O. Link, B. N. Bjornstad, and G. W. Gee, 1994. Natural Analogs of the Long-term Performance of Engineered Covers, p. 379-409 In Gee, G. W. and N. R. Wing, editors, 1994, In-Situ Remediation, Scientific Basis for Current and Future Technologies, Part 1, The Thirty-Third Hanford Symposium on Health and the Environment, November 7-11, 1994, Battelle Press, Richland, Washington.

47. Waugh, W. Joseph, 1994. Paleoclimatic Data Application: Long-Term Performance of Uranium Mill Tailings Repositories. Workshop Proceedings: Climate Change in the Four Corners and Adjacent Regions, September 12-14, 1994 in Grand Junction, CO.

48. Waugh, W.J., and G.M. Smith. 1997. Effects of root intrusion at the Burrell, Pennsylvania, Uranium Mill Tailings Disposal Site. GJO-97-5-TAR, GJO-LTSM-4.

APPENDIX A

MODELING SENSITIVITY ANALYSES OF COVER SYSTEM

FIGURES

TABLES

Modeling was performed to evaluate ET Cover profiles utilizing native soil and vegetation parameters as well as variability in climate data for the site. The sensitivity analyses were performed to assess the range of potential input parameters and climatic scenarios expected over the full long-term performance period of the final cover system; and to demonstrate the cover system's ability to meet the applicable performance objectives. The following subsections summarize each of the sensitivity analyses performed with respective results.

A.1 SIMULATION SERIES A

The first set of computer simulations involved evaluating the borrow area with the remolded samples / laboratory measured soil values without any vegetation and incorporating the 1.5-inch diameter (D50) rock admixture that is 14-inches deep. Beneath the admixture is cover soil from the same borrow source. The top 14-inches had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

In Sections A.1.1 to A.1.4, Tables 1 to 4 contains the annual water balance variables for the initial five years after construction without any vegetation for the cover soil borrow sources (north drainage borrow area, south drainage borrow area, east borrow and west borrow). The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 1 presents a graphical summary of the Series A computer simulations of flux (cm/yr) versus depth (cm) for all five years modeled for each borrow soil. This depth of cover soil where flux is minimized is referred to as the Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' (PODR) is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. It can be seen that the annual net flux is effectively minimized at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover be minimized.

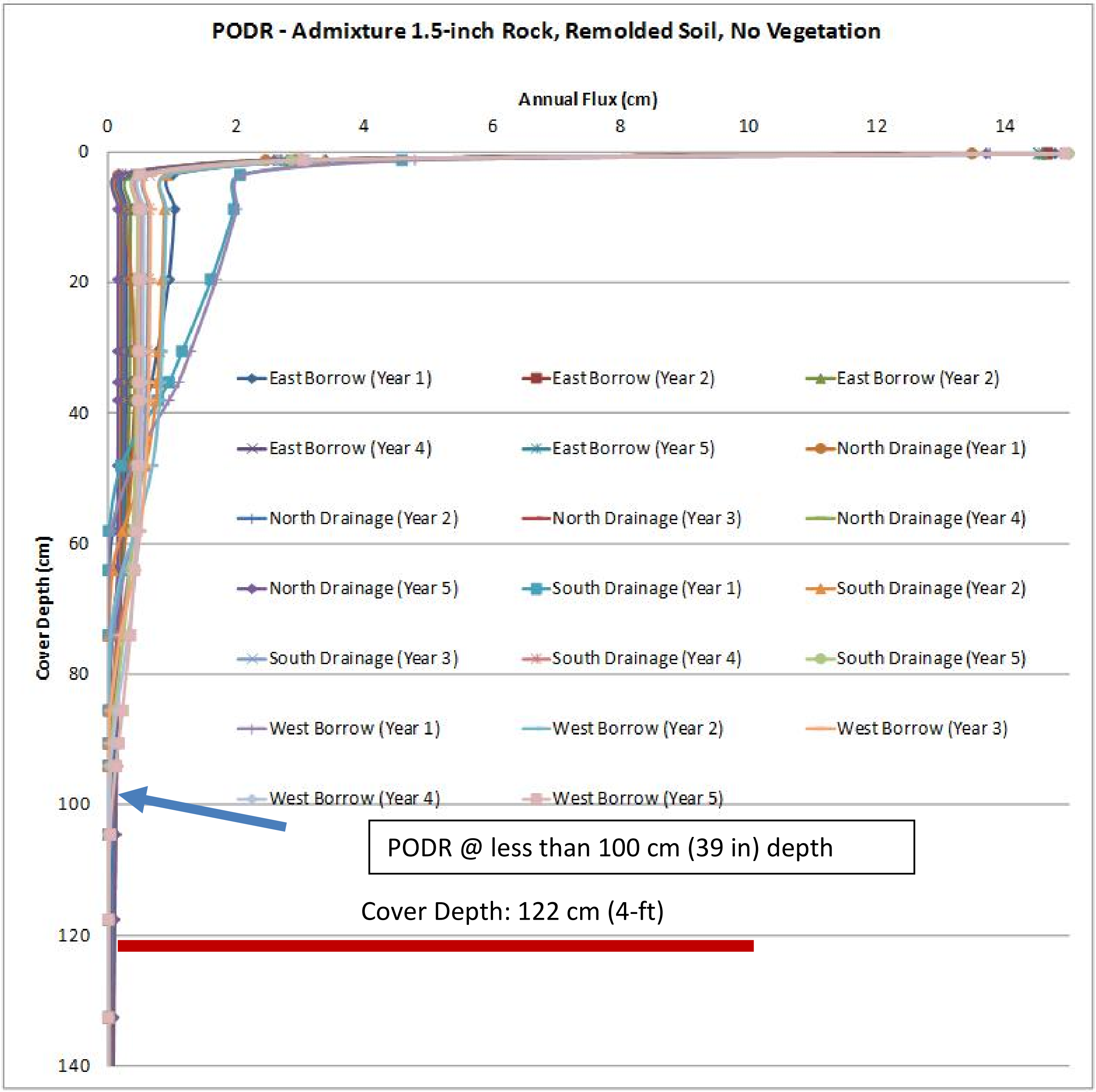


Figure 22. Flux (cm/yr) v. Depth (cm) for Simulation Series A

A.1.1 1.5-INCH ADMIXTURE 14-IN DEEP, EAST BORROW, NO VEGETATION

Simulation 1 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the east borrow area, with no vegetation.

Table 20. Simulation 1 Results (East Borrow, No Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0 cm	28.777 cm	0.235 cm	2.66E-03 cm
Average Year #2	29.743 cm	211.744 cm	0 cm	29.050 cm	0.241 cm	2.69E-03 cm
Average Year #3	29.743 cm	211.744 cm	0 cm	29.174 cm	0.243cm	4.02E-03 cm
Average Year #4	29.743 cm	211.744 cm	0 cm	29.233 cm	0.246 cm	9.68E-03 cm
Average Year #5	29.743 cm	211.744 cm	0 cm	29.272 cm	0.244 cm	2.00E-02 cm

A.1.2 1.5-INCH ADMIXTURE 14-IN DEEP, NORTH DRAINAGE BORROW, NO VEGETATION

Simulation 2 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with no vegetation.

Table 21. Simulation 2 Results (North Drainage Borrow, No Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	29.806 cm	0	1.41E-02 cm
Average Year #2	29.743 cm	211.744 cm	0	29.531 cm	0	5.09E-02 cm
Average Year #3	29.743 cm	211.744 cm	0	29.581 cm	0	7.87E-02 cm
Average Year #4	29.743 cm	211.744 cm	0	29.610 cm	0	9.08E-02 cm
Average Year #5	29.743 cm	211.744 cm	0	29.628 cm	0	9.55E-02 cm

A.1.3 1.5-INCH ADMIXTURE 14-IN DEEP, SOUTH DRAINAGE BORROW, NO VEGETATION

Simulation 3 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with no vegetation.

Table 22. Simulation 3 Results (South Drainage Borrow, No Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	27.893 cm	0	6.21E-04 cm
Average Year #2	29.743 cm	211.744 cm	0	28.874 cm	0	6.20E-04 cm
Average Year #3	29.743 cm	211.744 cm	0	29.127 cm	0	6.20E-04 cm
Average Year #4	29.743 cm	211.744 cm	0	29.236 cm	0	6.25E-04 cm
Average Year #5	29.743 cm	211.744 cm	0	29.305 cm	0	7.08E-04 cm

A.1.4 1.5-INCH ADMIXTURE 14-IN DEEP, WEST BORROW, NO VEGETATION

Simulation 4 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with no vegetation.

Table 23. Simulation 4 Results (West Borrow, No Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	27.814 cm	0.001 cm	5.98E-04 cm
Average Year #2	29.743 cm	211.744 cm	0	28.873 cm	0.001 cm	5.96E-04 cm

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #3	29.743 cm	211.744 cm	0	29.111 cm	0.001 cm	5.97E-04 cm
Average Year #4	29.743 cm	211.744 cm	0	29.222 cm	0.001 cm	6.71E-04 cm
Average Year #5	29.743 cm	211.744 cm	0	29.289 cm	0.001 cm	1.59E-03 cm

A.2 SIMULATION SERIES B

The next set of computer simulations involved evaluating the borrow sources with the laboratory measured soil values with no vegetation and incorporating the 2-inch diameter (D50) rock admixture that is 18-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

In Sections A.2.1 to A.2.4, Tables 4 to 8 contains the annual water balance variables for the initial five years after construction with no vegetation for borrow source, respectively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 2 presents a graphical summary of the Series B computer simulations of flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. It can be seen that the annual net flux is effectively minimized at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

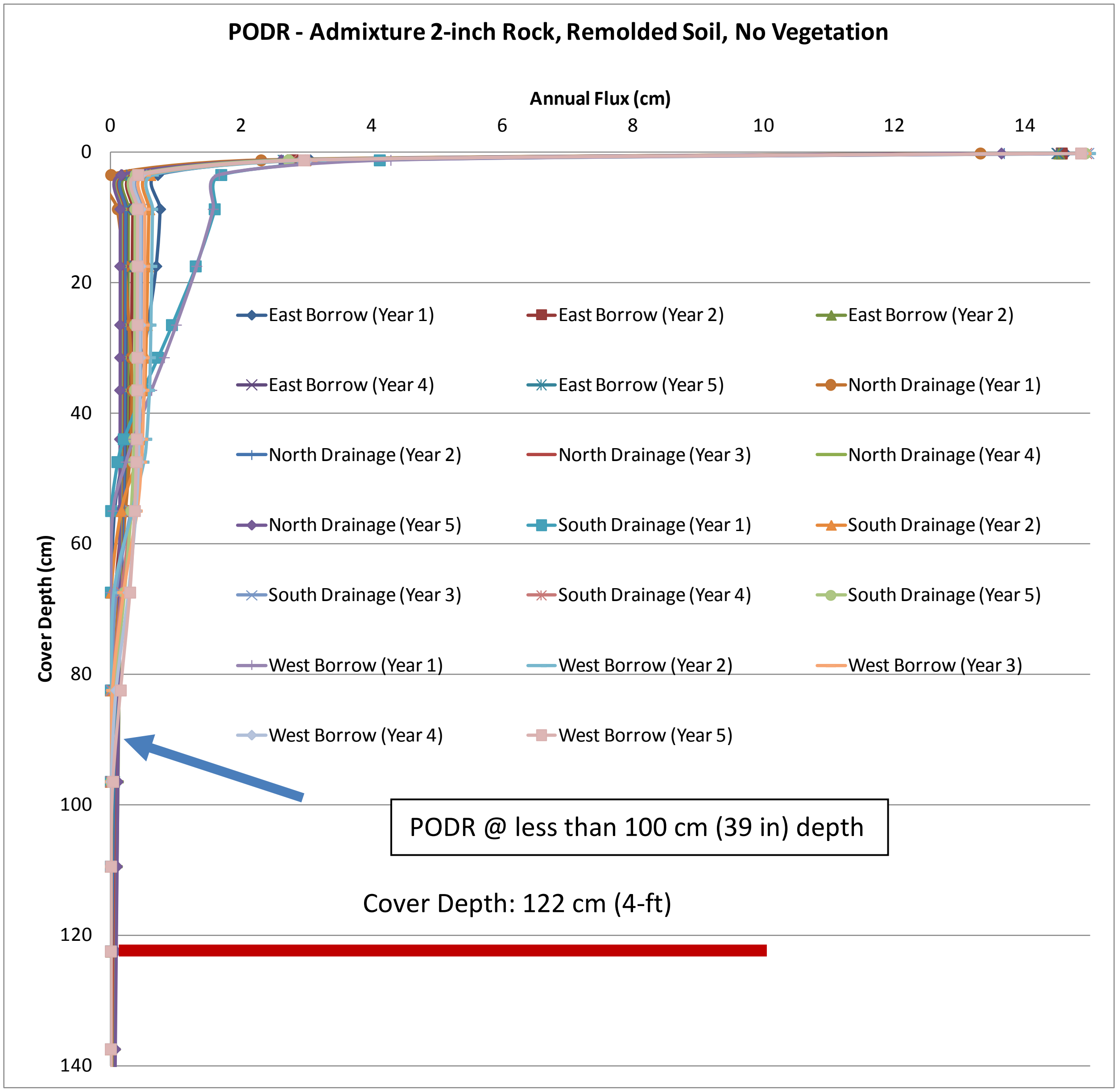


Figure 23. Flux (cm/yr) v. Depth (cm) for Simulation Series B

A.2.1 2-INCH ADMIXTURE 18-IN DEEP, EAST BORROW, NO VEGETATION

Simulation 5 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the east borrow area, with no vegetation.

Table 24. Simulation 5 Results (East Borrow, No Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0 cm	29.055 cm	0.239 cm	2.66E-03 cm
Average Year #2	29.743 cm	211.744 cm	0 cm	29.193 cm	0.243 cm	2.67E-03 cm
Average Year #3	29.743 cm	211.744 cm	0 cm	29.254 cm	0.244 cm	3.37E-03 cm
Average Year #4	29.743 cm	211.744 cm	0 cm	29.289 cm	0.243 cm	6.54E-03 cm
Average Year #5	29.743 cm	211.744 cm	0 cm	29.312 cm	0.244 cm	1.28E-02 cm

A.2.2 2-INCH ADMIXTURE 18-IN DEEP, NORTH DRAINAGE BORROW, NO VEGETATION

Simulation 6 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with no vegetation.

Table 25. Simulation 6 Results (North Drainage Borrow, No Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	29.968 cm	0	1.35E-02 cm
Average Year #2	29.743 cm	211.744 cm	0	29.566 cm	0	3.94E-02 cm
Average Year #3	29.743 cm	211.744 cm	0	29.601 cm	0	6.31E-02 cm
Average Year #4	29.743 cm	211.744 cm	0	29.623 cm	0	7.58E-02 cm
Average Year #5	29.743 cm	211.744 cm	0	29.638 cm	0	8.20E-02 cm

A.2.3 2-INCH ADMIXTURE 18-IN DEEP, SOUTH DRAINAGE BORROW, NO VEGETATION

Simulation 7 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with no vegetation.

Table 26. Simulation 7 Results (South Drainage Borrow, No Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	28.225 cm	0	6.21E-04 cm
Average Year #2	29.743 cm	211.744 cm	0	29.152 cm	0	6.20E-04 cm
Average Year #3	29.743 cm	211.744 cm	0	29.275 cm	0	6.20E-04 cm
Average Year #4	29.743 cm	211.744 cm	0	29.329 cm	0	6.22E-04 cm
Average Year #5	29.743 cm	211.744 cm	0	29.366 cm	0	6.54E-04 cm

A.2.4 2-INCH ADMIXTURE 18-IN DEEP, WEST BORROW, NO VEGETATION

Simulation 8 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with no vegetation.

Table 27. Simulation 4 Results (West Borrow, No Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	28.251 cm	0.001 cm	5.98E-04 cm
Average Year #2	29.743 cm	211.744 cm	0	29.148 cm	0.001 cm	5.96E-04 cm

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #3	29.743 cm	211.744 cm	0	29.262 cm	0.001 cm	5.97E-04 cm
Average Year #4	29.743 cm	211.744 cm	0	29.323 cm	0.001 cm	6.71E-04 cm
Average Year #5	29.743 cm	211.744 cm	0	29.364 cm	0.001 cm	1.59E-03 cm

A.3 SIMULATION SERIES C

The next set of computer simulations involved evaluating the borrow area with the laboratory measured soil values with no vegetation and incorporating the 3-inch diameter (D50) rock admixture that is 27-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

In Sections A.3.1 to A.3.4, Tables 9 to 12 contains the annual water balance variables for the initial five years after construction with no vegetation for borrow source, respectively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 3 presents a graphical summary of the Series C computer simulations of flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The ‘point of diminishing returns’ is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. It can be seen that the annual net flux is effectively minimized at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover be minimized.

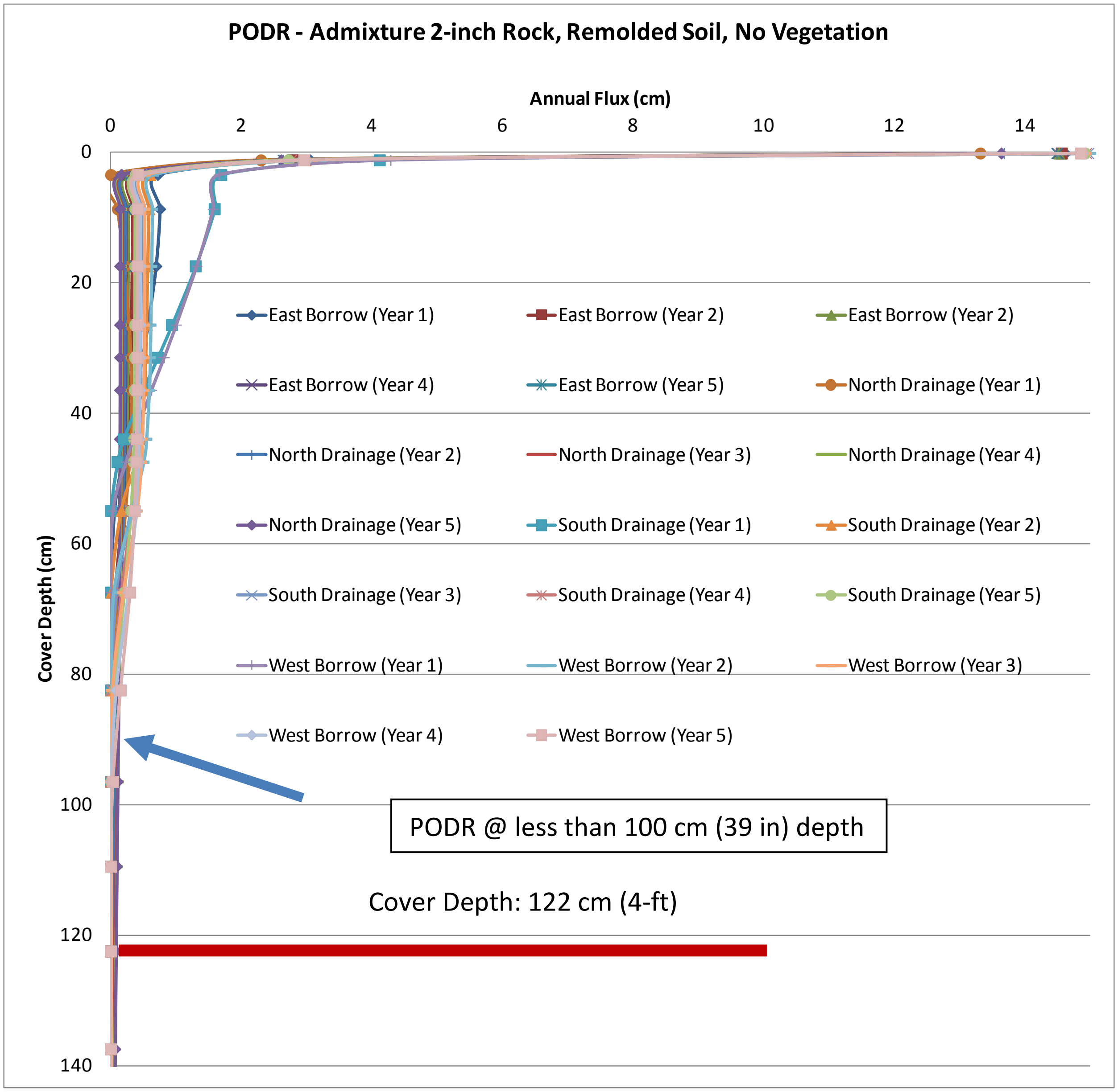


Figure 24. Flux (cm/yr) v. Depth (cm) for Simulation Series C

A.3.1 3-INCH ADMIXTURE 27-IN DEEP, EAST BORROW, NO VEGETATION

Simulation 9 included the input parameters described in Section 5. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the east borrow area, with no vegetation.

Table 28. Simulation 9 Results (East Borrow, No Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0 cm	29.057 cm	0.239 cm	2.66E-03 cm
Average Year #2	29.743 cm	211.744 cm	0 cm	29.231 cm	0.244 cm	2.66E-03 cm
Average Year #3	29.743 cm	211.744 cm	0 cm	29.309 cm	0.244 cm	3.22E-03 cm
Average Year #4	29.743 cm	211.744 cm	0 cm	29.340 cm	0.245 cm	6.04E-03 cm
Average Year #5	29.743 cm	211.744 cm	0 cm	29.358 cm	0.245 cm	1.17E-02 cm

A.3.2 3-INCH ADMIXTURE 27-IN DEEP, NORTH DRAINAGE BORROW, NO VEGETATION

Simulation 10 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with no vegetation.

Table 29. Simulation 10 Results (North Drainage Borrow, No Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	30.013 cm	0	1.32E-02 cm
Average Year #2	29.743 cm	211.744 cm	0	29.611 cm	0	3.63E-02 cm
Average Year #3	29.743 cm	211.744 cm	0	29.634 cm	0	5.67E-02 cm
Average Year #4	29.743 cm	211.744 cm	0	29.648 cm	0	6.75E-02 cm
Average Year #5	29.743 cm	211.744 cm	0	29.658 cm	0	7.30E-02 cm

A.3.3 3-INCH ADMIXTURE 27-IN DEEP, SOUTH DRAINAGE BORROW, NO VEGETATION

Simulation 11 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with no vegetation.

Table 30. Simulation 11 Results (South Drainage Borrow, No Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	28.224 cm	0	6.21E-04 cm
Average Year #2	29.743 cm	211.744 cm	0	29.179 cm	0	6.20E-04 cm
Average Year #3	29.743 cm	211.744 cm	0	29.343 cm	0	6.20E-04 cm
Average Year #4	29.743 cm	211.744 cm	0	29.413 cm	0	6.21E-04 cm
Average Year #5	29.743 cm	211.744 cm	0	29.451 cm	0	6.46E-04 cm

A.3.4 3-INCH ADMIXTURE 27-IN DEEP, WEST BORROW, NO VEGETATION

Simulation 12 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with no vegetation.

Table 31. Simulation 12 Results (West Borrow, No Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	28.252 cm	0.001 cm	5.98E-04 cm
Average Year #2	29.743 cm	211.744 cm	0	29.212 cm	0.001 cm	5.96E-04 cm

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #3	29.743 cm	211.744 cm	0	29.363 cm	0.001 cm	5.96E-04 cm
Average Year #4	29.743 cm	211.744 cm	0	29.426 cm	0.001 cm	6.18E-04 cm
Average Year #5	29.743 cm	211.744 cm	0	29.458 cm	0.001 cm	8.93E-04 cm

A.4 SIMULATION SERIES D

The next set of computer simulations involved evaluating the borrow area with the laboratory measured soil values with reclaimed vegetation and incorporating the 1.5-inch diameter (D50) rock admixture that is 14-inches deep. Beneath the admixture is cover soil from the same borrow source. The top 14-inches had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.4.1 to A.4.4, Tables 13 to 16 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 4 presents a graphical summary of the Series D computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The ‘point of diminishing returns’ is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover be minimized.

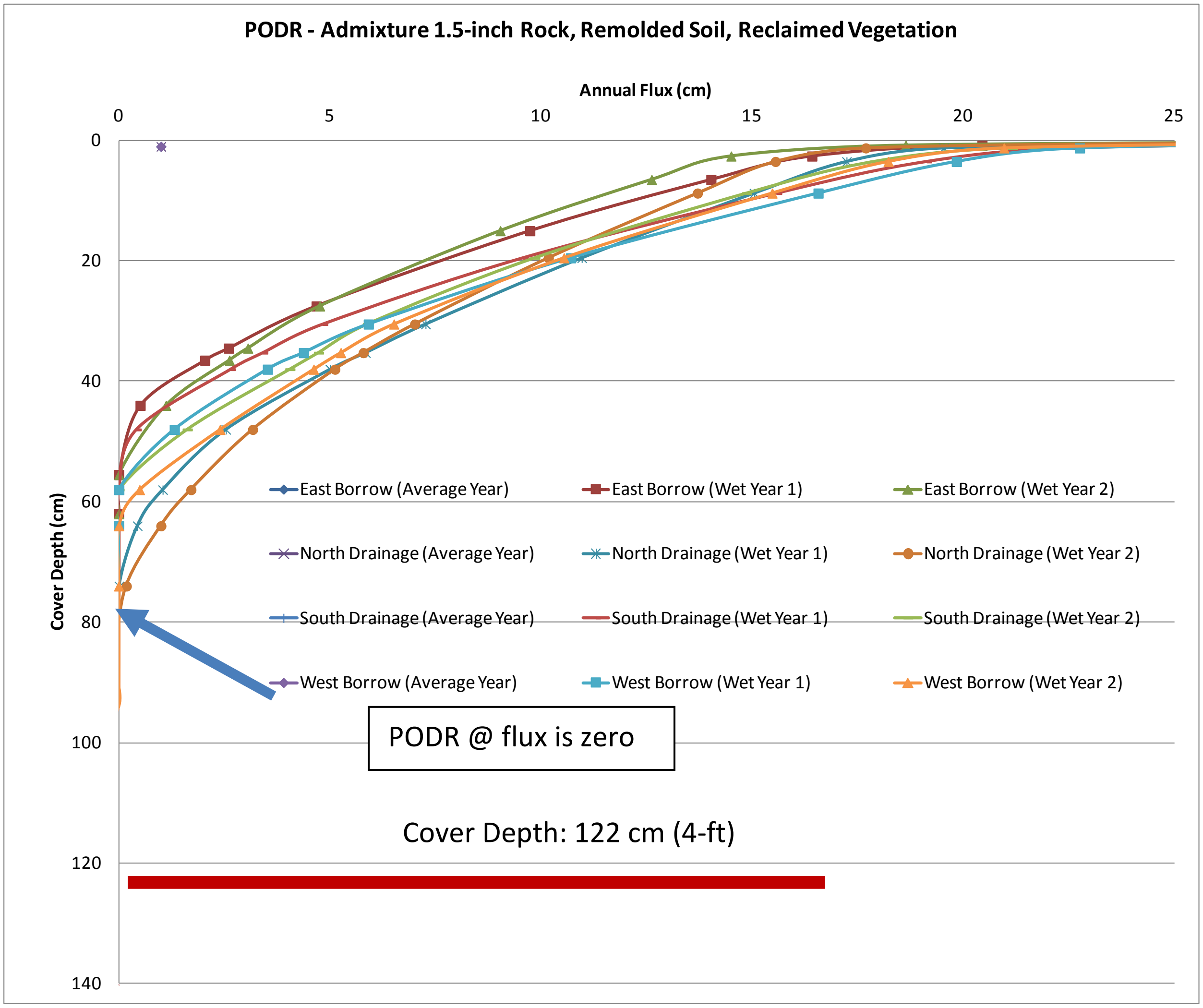


Figure 25. Flux (cm/yr) v. Depth (cm) for Simulation Series D

A.4.1 1.5-INCH ADMIXTURE 14-IN DEEP, EAST BORROW, RECLAIMED VEGETATION

Simulation 13 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the east borrow area, with reclaimed vegetation.

Table 32. Simulation 13 Results (East Borrow, Reclaimed Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.777 cm	23.136 cm	0.201 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	13.201 cm	39.348 cm	4.113 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	14.289 cm	41.261 cm	4.172 cm	0 cm

A.4.2 1.5-INCH ADMIXTURE 14-IN DEEP, NORTH DRAINAGE BORROW, RECLAIMED VEGETATION

Simulation 14 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with reclaimed vegetation.

Table 33. Simulation 14 Results (North Drainage Borrow, Reclaimed Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.814 cm	22.658 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	14.700 cm	42.402 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	15.809 cm	44.178 cm	0 cm	0 cm

A.4.3 1.5-INCH ADMIXTURE 14-IN DEEP, SOUTH DRAINAGE BORROW, RECLAIMED VEGETATION

Simulation 15 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with reclaimed vegetation.

Table 34. Simulation 15 Results (South Drainage Borrow, Reclaimed Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.308 cm	22.646 cm	0.025 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	16.091 cm	39.035 cm	0.805 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	17.919 cm	41.125 cm	0.122 cm	0 cm

A.4.4 1.5-INCH ADMIXTURE 14-IN DEEP, WEST BORROW, RECLAIMED VEGETATION

Simulation 16 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with reclaimed vegetation.

Table 35. Simulation 16 Results (West Borrow, Reclaimed Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.943 cm	22.091 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	17.138 cm	39.248 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	18.600 cm	41.048 cm	0 cm	0 cm

A.5 SIMULATION SERIES E

The next set of computer simulations involved evaluating the borrow area with the laboratory measured soil values with reclaimed vegetation and incorporating the 2-inch diameter (D50) rock admixture that is 18-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.5.1 to A.5.4, Tables 17 to 20 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; (6) calculated percolation; and (7) water stored in the modeled soil profile.

Figure 5 presents a graphical summary of the Series E computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover be minimized.

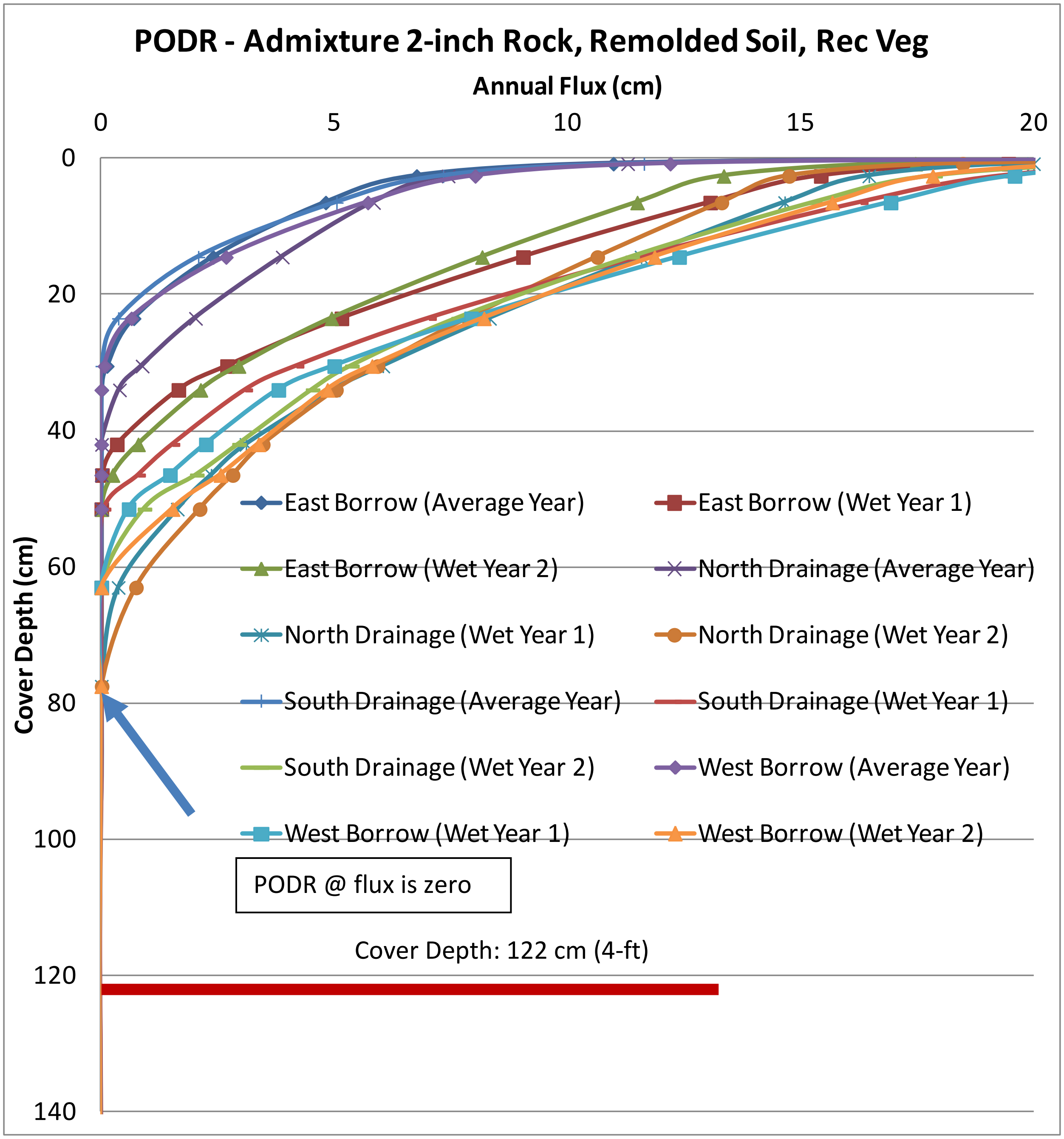


Figure 26. Flux (cm/yr) v. Depth (cm) for Simulation Series E

A.5.1 2-INCH ADMIXTURE 18-IN DEEP, EAST BORROW, RECLAIMED VEGETATION

Simulation 17 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the east borrow area, with reclaimed vegetation.

Table 36. Simulation 17 Results (East Borrow, Reclaimed Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.526 cm	23.161 cm	0.204 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	13.091 cm	40.254 cm	4.194 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	13.863 cm	42.314 cm	4.281 cm	0 cm

A.5.2 2-INCH ADMIXTURE 18-IN DEEP, NORTH DRAINAGE BORROW, RECLAIMED VEGETATION

Simulation 18 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with reclaimed vegetation.

Table 37. Simulation 18 Results (North Drainage Borrow, Reclaimed Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	7.102 cm	22.841 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	14.292 cm	43.699 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	15.066 cm	45.379 cm	0 cm	0 cm

A.5.3 2-INCH ADMIXTURE 18-IN DEEP, SOUTH DRAINAGE BORROW, RECLAIMED VEGETATION

Simulation 19 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with reclaimed vegetation.

Table 38. Simulation 19 Results (South Drainage Borrow, Reclaimed Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	7.179 cm	22.664 cm	0.026 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	16.268 cm	40.156 cm	0.349 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	17.910 cm	41.949 cm	0.136 cm	0 cm

A.5.4 2-INCH ADMIXTURE 18-IN DEEP, WEST BORROW, RECLAIMED VEGETATION

Simulation 20 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with reclaimed vegetation.

Table 39. Simulation 20 Results (West Borrow, Reclaimed Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	7.748 cm	22.099 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	16.967 cm	40.263 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	18.333 cm	42.053 cm	0 cm	0 cm

A.6 SIMULATION SERIES F

The next set of computer simulations involved evaluating the borrow area with the laboratory measured soil values with reclaimed vegetation and incorporating the 3-inch diameter (D50) rock admixture that is 27-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.6.1 to A.6.4, Tables 21 to 24 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 6 presents a graphical summary of the Series F computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover be minimized.

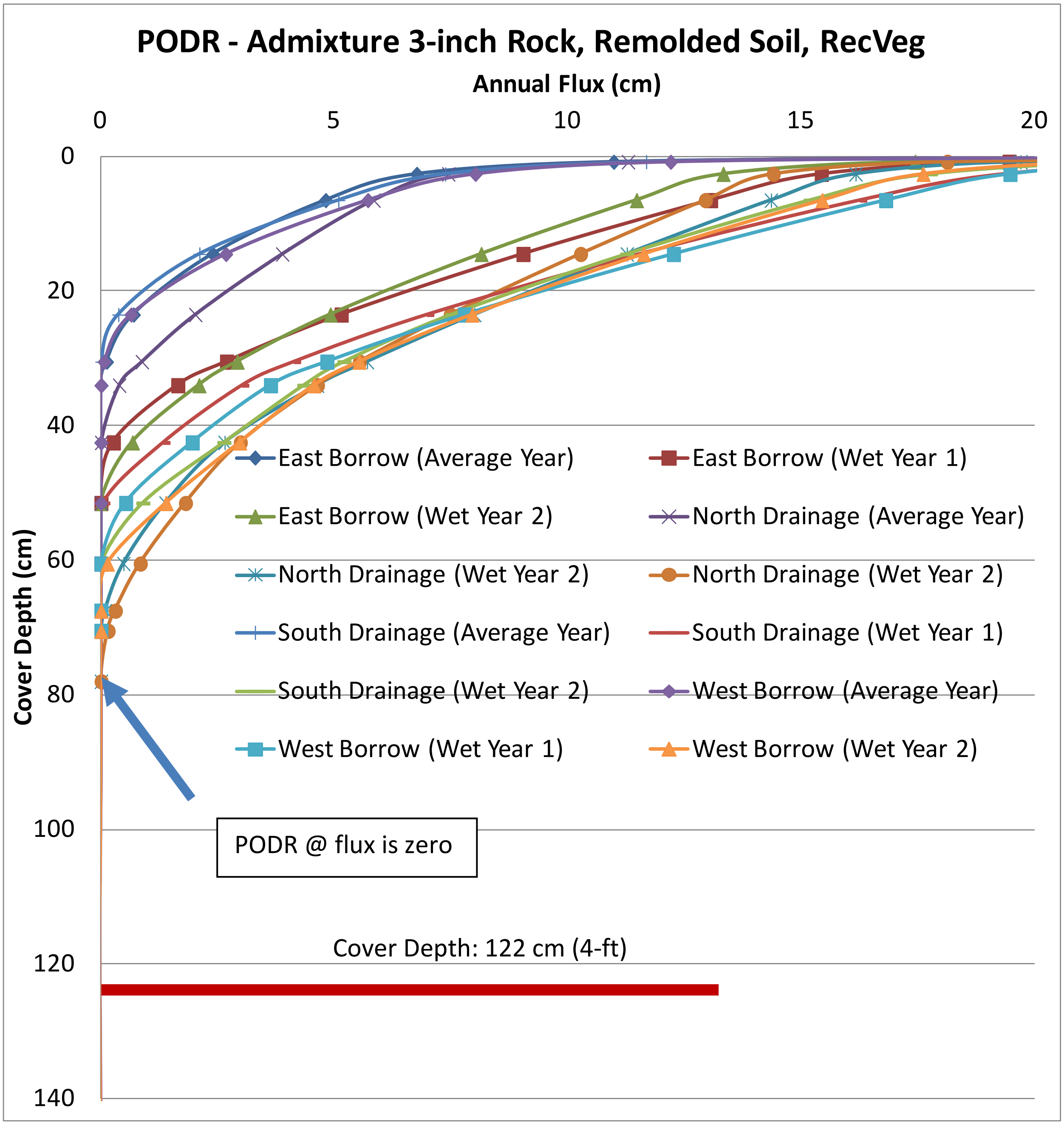


Figure 27. Flux (cm/yr) v. Depth (cm) for Simulation Series F

A.6.1 3-INCH ADMIXTURE 27-IN DEEP, EAST BORROW, RECLAIMED VEGETATION

Simulation 21 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the east borrow area, with reclaimed vegetation.

Table 40. Simulation 21 Results (East Borrow, Reclaimed Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.526 cm	23.161 cm	0.204 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	13.096 cm	40.256 cm	4.193 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	13.860 cm	42.303 cm	4.313 cm	0 cm

A.6.2 3-INCH ADMIXTURE 27-IN DEEP, NORTH DRAINAGE BORROW, RECLAIMED VEGETATION

Simulation 22 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with reclaimed vegetation.

Table 41. Simulation 22 Results (North Drainage Borrow, Reclaimed Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	7.102 cm	22.839 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	14.157 cm	43.994 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	14.768 cm	45.724 cm	0 cm	0 cm

A.6.3 3-INCH ADMIXTURE 27-IN DEEP, SOUTH DRAINAGE BORROW, RECLAIMED VEGETATION

Simulation 23 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with reclaimed vegetation.

Table 42. Simulation 23 Results (South Drainage Borrow, Reclaimed Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	7.219 cm	22.690 cm	0.026 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	16.288 cm	40.204 cm	0.345 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	17.876 cm	42.102 cm	0.134 cm	0 cm

A.6.4 3-INCH ADMIXTURE 27-IN DEEP, WEST BORROW, RECLAIMED VEGETATION

Simulation 24 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with reclaimed vegetation.

Table 43. Simulation 24 Results (West Borrow, Reclaimed Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	7.748 cm	22.099 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	16.911 cm	40.377 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	18.170 cm	42.271 cm	0 cm	0 cm

A.7 SIMULATION SERIES G

The next set of computer simulations involved evaluating the borrow area with the laboratory measured soil values with grassland vegetation and incorporating the 1.5-inch diameter (D50) rock admixture that is 14-inches deep. Beneath the admixture is cover soil from the same borrow source. The top 14-inches had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections 6.7.1 to 6.7.4, Tables 25 to 28 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 7 presents a graphical summary of the Series G computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The ‘point of diminishing returns’ is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover be minimized.

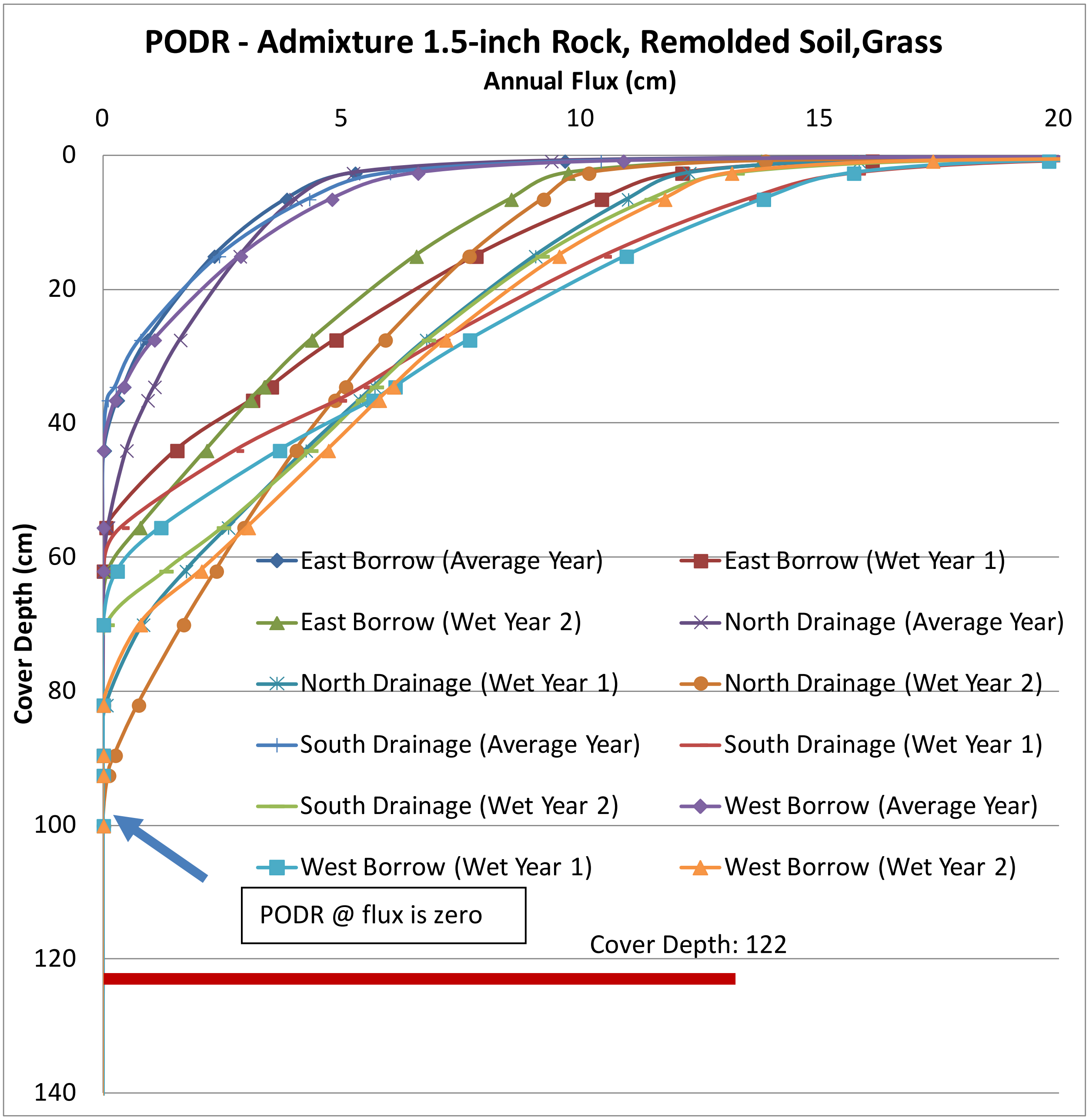


Figure 28. Flux (cm/yr) v. Depth (cm) for Simulation Series G

A.7.1 1.5-INCH ADMIXTURE 14-IN DEEP, EAST BORROW, GRASSLAND VEGETATION

Simulation 25 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the east borrow area, with grassland vegetation.

Table 44. Simulation 25 Results (East Borrow, Grassland Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.057 cm	24.639 cm	0.200 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	8.583 cm	43.561 cm	4.259 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	9.559 cm	45.885 cm	4.368 cm	0 cm

A.7.2 1.5-INCH ADMIXTURE 14-IN DEEP, NORTH DRAINAGE BORROW, GRASSLAND VEGETATION

Simulation 26 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with grassland vegetation.

Table 45. Simulation 26 Results (North Drainage Borrow, Grassland Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	4.979 cm	24.968 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	8.830 cm	47.888 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	9.933 cm	49.959 cm	0 cm	0 cm

A.7.3 1.5-INCH ADMIXTURE 14-IN DEEP, SOUTH DRAINAGE BORROW, GRASSLAND VEGETATION

Simulation 27 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with grassland vegetation.

Table 46. Simulation 27 Results (South Drainage Borrow, Grassland Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.806 cm	24.047 cm	0.012 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	10.314 cm	43.728 cm	0.242 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	11.873 cm	46.472 cm	0.095 cm	0 cm

A.7.4 1.5-INCH ADMIXTURE 14-IN DEEP, WEST BORROW, GRASSLAND VEGETATION

Simulation 28 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with grassland vegetation.

Table 47. Simulation 28 Results (West Borrow, Grassland Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.243 cm	23.603 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	10.981 cm	44.152 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	12.562 cm	46.714 cm	0 cm	0 cm

A.8 SIMULATION SERIES H

The next set of computer simulations involved evaluating the borrow area with the laboratory measured soil values with grassland vegetation and incorporating the 2-inch diameter (D50) rock admixture that is 18-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.8.1 to A.8.4, Tables 29 to 32 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 8 presents a graphical summary of the Series H computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

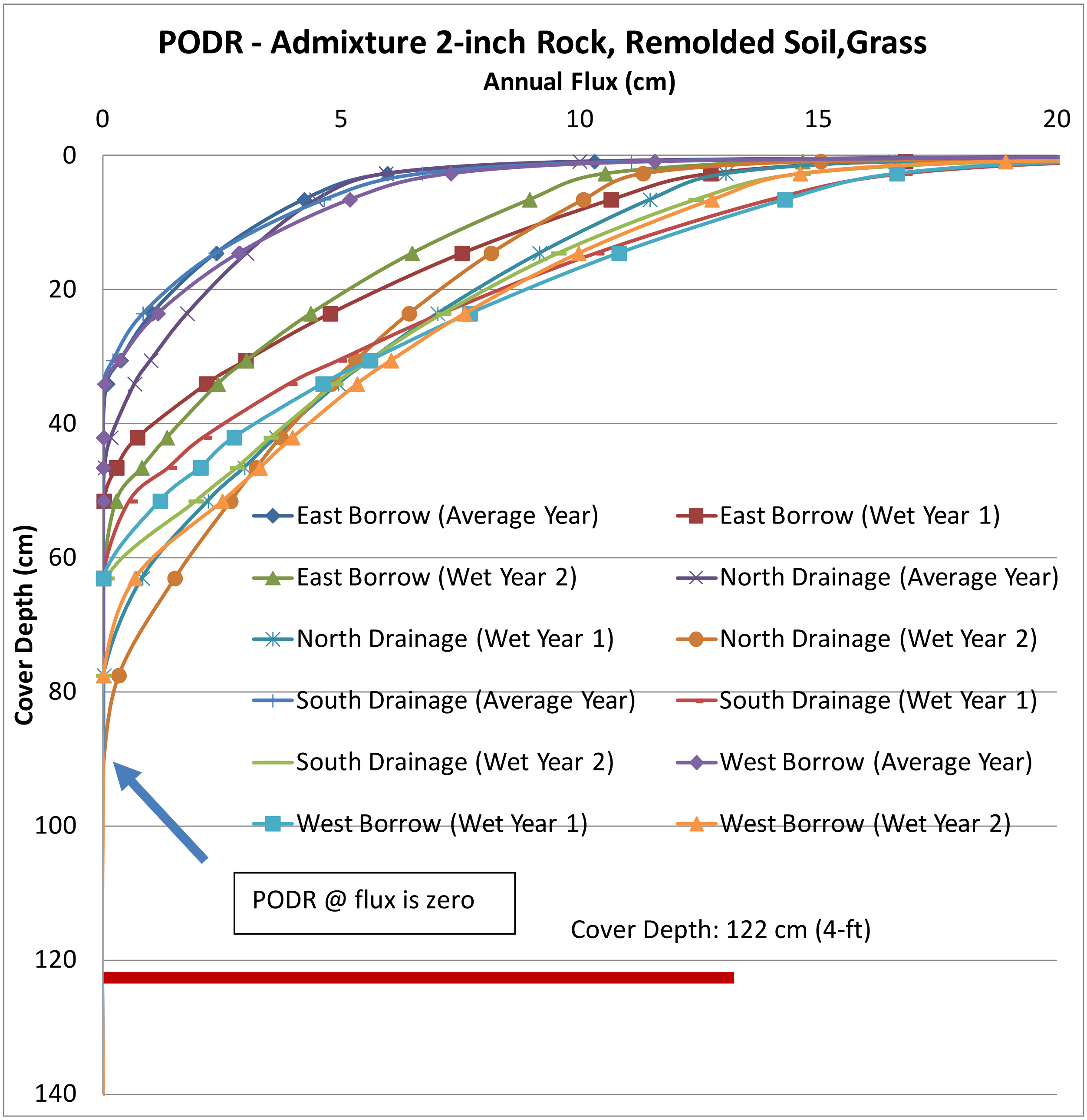


Figure 29. Flux (cm/yr) v. Depth (cm) for Simulation Series H

A.8.1 2-INCH ADMIXTURE 18-IN DEEP, EAST BORROW, GRASSLAND VEGETATION

Simulation 29 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the east borrow area, with grassland vegetation.

Table 48. Simulation 29 Results (East Borrow, Grassland Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.757 cm	23.937 cm	0.197 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	10.128 cm	42.847cm	4.238 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	10.875 cm	45.030 cm	4.335 cm	0 cm

A.8.2 2-INCH ADMIXTURE 18-IN DEEP, NORTH DRAINAGE BORROW, GRASSLAND VEGETATION

Simulation 30 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with grassland vegetation.

Table 49. Simulation 30 Results (North Drainage Borrow, Grassland Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.668 cm	24.276 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	10.445 cm	47.033 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	11.450 cm	48.739 cm	0 cm	0 cm

A.8.3 2-INCH ADMIXTURE 18-IN DEEP, SOUTH DRAINAGE BORROW, GRASSLAND VEGETATION

Simulation 31 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with grassland vegetation.

Table 50. Simulation 31 Results (South Drainage Borrow, Grassland Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.537 cm	23.339 cm	0.015 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	12.742 cm	42.692 cm	0.161 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	14.264 cm	44.795 cm	0.266 cm	0 cm

A.8.4 2-INCH ADMIXTURE 18-IN DEEP, WEST BORROW, GRASSLAND VEGETATION

Simulation 32 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with grassland vegetation.

Table 51. Simulation 32 Results (West Borrow, Grassland Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	7.015 cm	22.831 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	13.338 cm	43.102 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	14.828 cm	45.161 cm	0 cm	0 cm

A.9 SIMULATION SERIES I

The next set of computer simulations involved evaluating the borrow area with the laboratory measured soil values with grassland vegetation and incorporating the 3-inch diameter (D50) rock admixture that is 27-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.9.1 to A.9.4, Tables 33 to 36 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 9 presents a graphical summary of the Series I computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

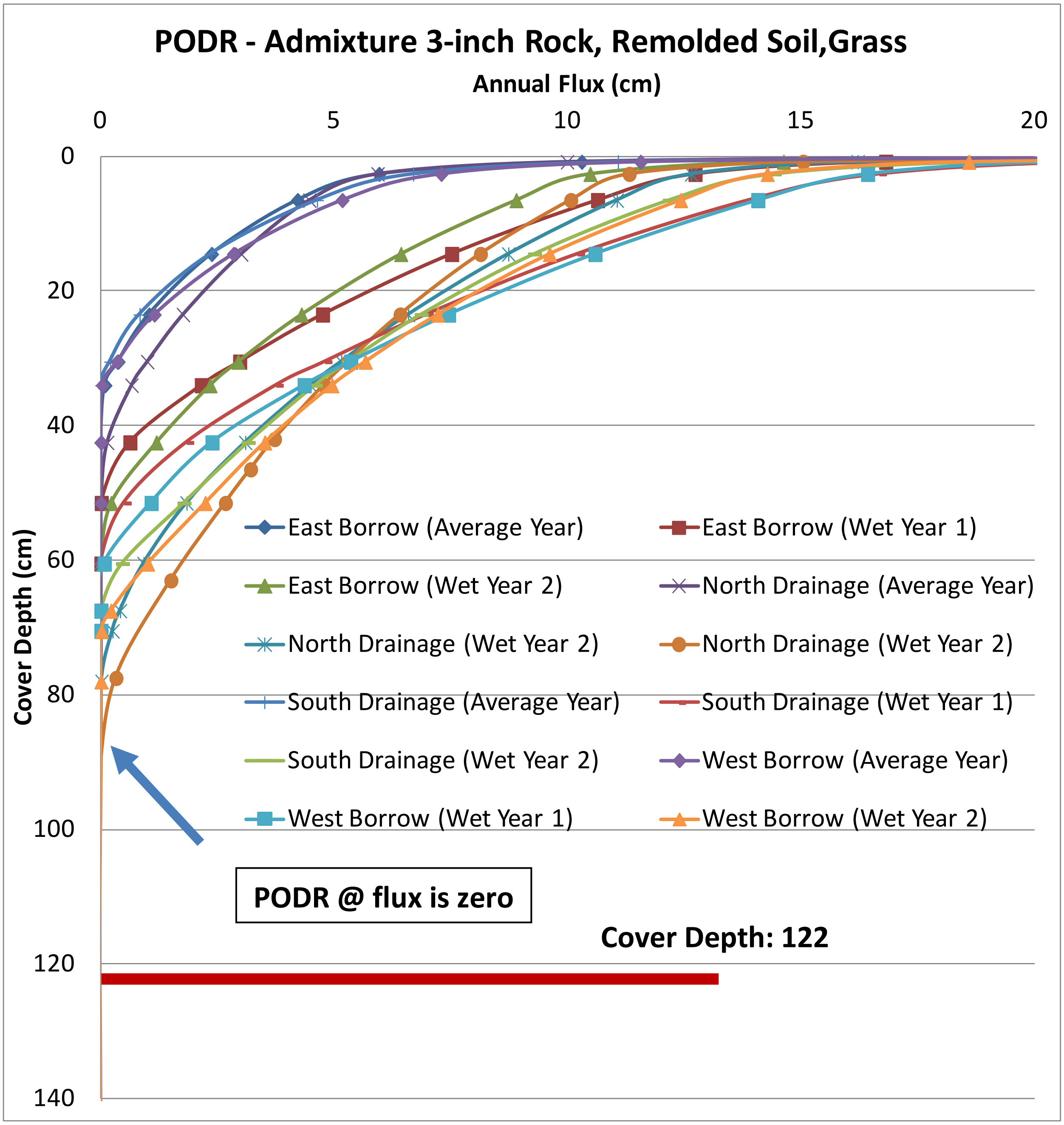


Figure 30. Flux (cm/yr) v. Depth (cm) for Simulation Series I

A.9.1 3-INCH ADMIXTURE 27-IN DEEP, EAST BORROW, GRASSLAND VEGETATION

Simulation 33 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the east borrow area, with grassland vegetation.

Table 52. Simulation 33 Results (East Borrow, Grassland Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.757 cm	23.937 cm	0.197 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	10.168 cm	42.874 cm	4.216 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	10.940 cm	45.057 cm	4.347 cm	0 cm

A.9.2 3-INCH ADMIXTURE 27-IN DEEP, NORTH DRAINAGE BORROW, GRASSLAND VEGETATION

Simulation 34 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with grassland vegetation.

Table 53. Simulation 34 Results (North Drainage Borrow, Grassland Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.667 cm	24.277 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	10.425 cm	47.431 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	11.150 cm	49.180 cm	0 cm	0 cm

A.9.3 3-INCH ADMIXTURE 27-IN DEEP, SOUTH DRAINAGE BORROW, GRASSLAND VEGETATION

Simulation 35 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with grassland vegetation.

Table 54. Simulation 35 Results (South Drainage Borrow, Grassland Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.542 cm	23.341 cm	0.016 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	12.828 cm	42.799 cm	0.155 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	14.336 cm	45.024 cm	0.268 cm	0 cm

A.9.4 3-INCH ADMIXTURE 27-IN DEEP, WEST BORROW, GRASSLAND VEGETATION

Simulation 36 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with grassland vegetation.

Table 55. Simulation 36 Results (West Borrow, Grassland Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	7.016 cm	22.831 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	13.395 cm	43.304 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	14.753 cm	45.486 cm	0 cm	0 cm

A.10 SIMULATION SERIES J

The next set of computer simulations involved evaluating the borrow area with the laboratory measured soil values with shrubland vegetation and incorporating the 1.5-inch diameter (D50) rock admixture that is 14-inches deep. Beneath the admixture is cover soil from the same borrow source. The top 14-inches had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.10.1 to A.10.4, Tables 37 to 40 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 10 presents a graphical summary of the Series J computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The ‘point of diminishing returns’ is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

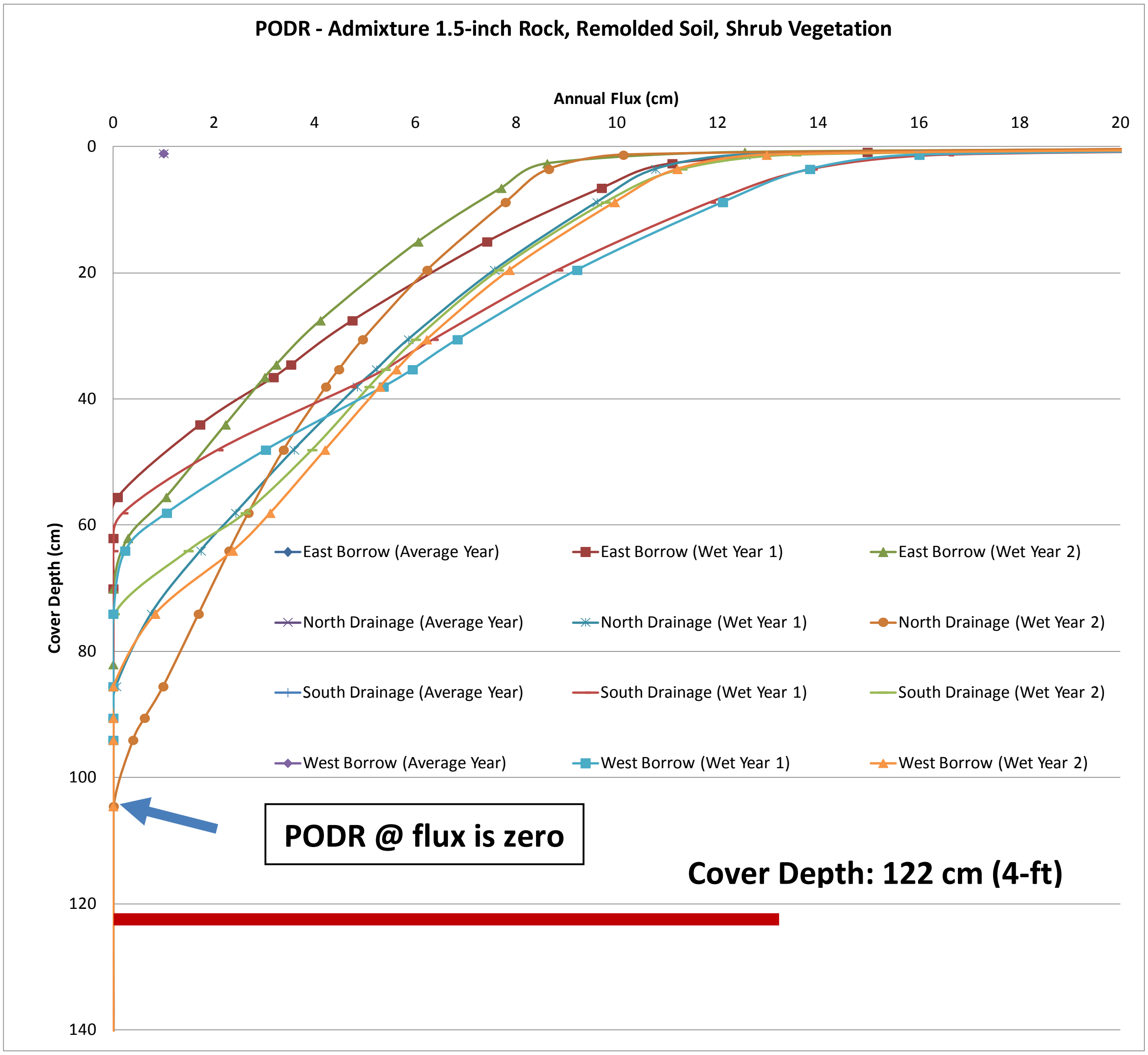


Figure 31. Flux (cm/yr) v. Depth (cm) for Simulation Series J

A.10.1 1.5-INCH ADMIXTURE 14-IN DEEP, EAST BORROW, SHRUBLAND VEGETATION

Simulation 37 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the east borrow area, with shrubland vegetation.

Table 56. Simulation 37 Results (East Borrow, Shrubland Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	4.779 cm	25.083 cm	0.201 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	7.344 cm	44.645 cm	4.273 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	8.073 cm	47.070 cm	4.381 cm	0 cm

A.10.2 1.5-INCH ADMIXTURE 14-IN DEEP, NORTH DRAINAGE BORROW, SHRUBLAND VEGETATION

Simulation 38 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with shrubland vegetation.

Table 57. Simulation 38 Results (North Drainage Borrow, Shrubland Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	4.578 cm	25.463 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	7.269 cm	49.076 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	8.056 cm	51.288 cm	0 cm	0 cm

A.10.3 1.5-INCH ADMIXTURE 14-IN DEEP, SOUTH DRAINAGE BORROW, SHRUBLAND VEGETATION

Simulation 39 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with shrubland vegetation.

Table 58. Simulation 39 Results (South Drainage Borrow, Shrubland Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.386 cm	24.567 cm	0.010 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	8.383 cm	45.140 cm	0.196 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	9.396 cm	48.077 cm	0.098 cm	0 cm

A.10.4 1.5-INCH ADMIXTURE 14-IN DEEP, WEST BORROW, SHRUBLAND VEGETATION

Simulation 40 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with shrubland vegetation.

Table 59. Simulation 40 Results (West Borrow, Shrubland Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.713 cm	24.181 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	8.826 cm	45.654 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	9.856 cm	48.459 cm	0 cm	0 cm

A.11 SIMULATION SERIES K

The next set of computer simulations involved evaluating the borrow area with the laboratory measured soil values with shrubland vegetation and incorporating the 2-inch diameter (D50) rock admixture that is 18-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.11.1 to A.11.4, Tables 41 to 44 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 11 presents a graphical summary of the Series K computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

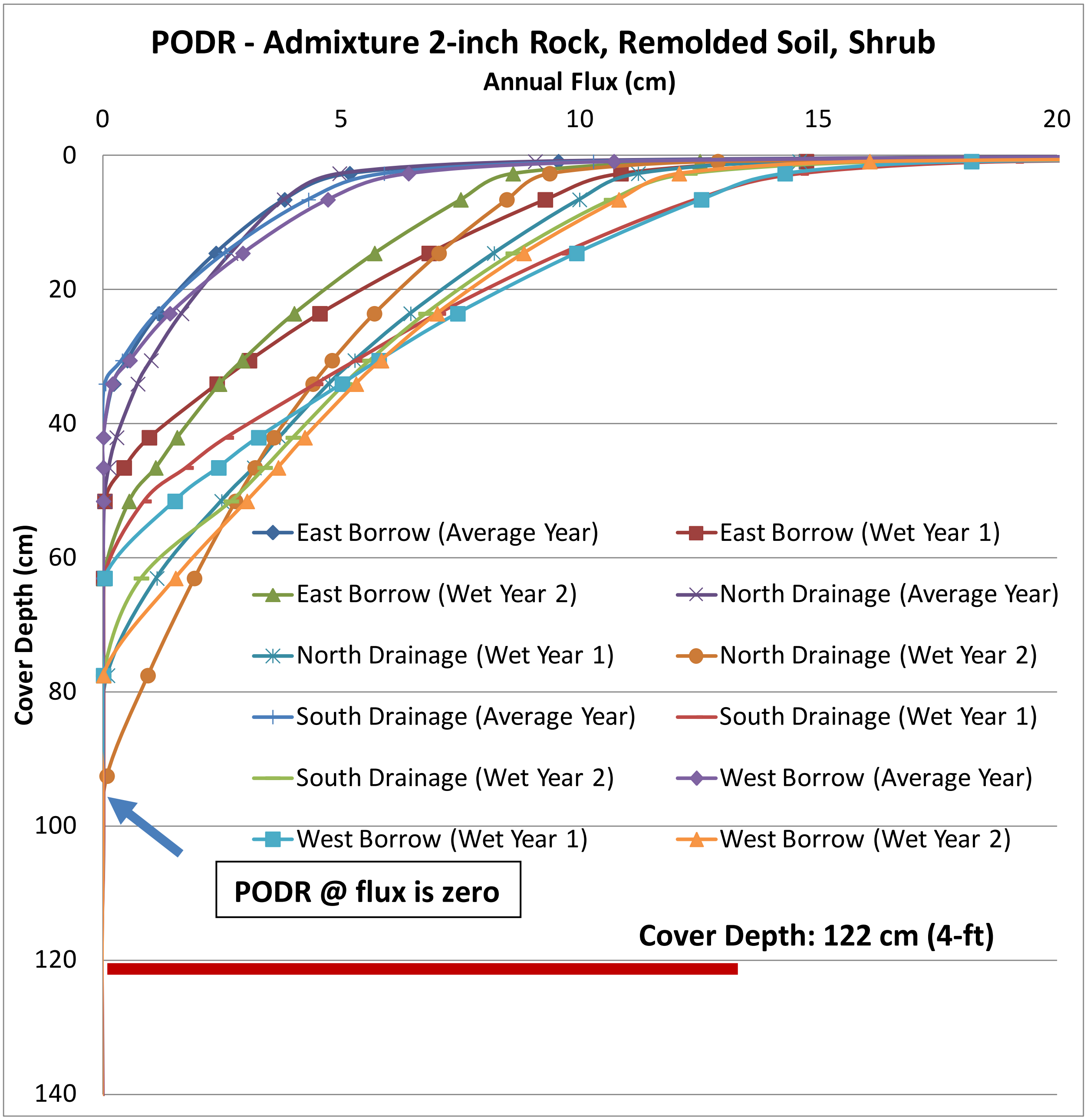


Figure 32. Flux (cm/yr) v. Depth (cm) for Simulation Series K

A.11.1 2-INCH ADMIXTURE 18-IN DEEP, EAST BORROW, SHRUBLAND VEGETATION

Simulation 41 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the east borrow area, with shrubland vegetation.

Table 60. Simulation 41 Results (East Borrow, Shrubland Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	4.974 cm	24.770 cm	0.201 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	7.857 cm	44.850 cm	4.296 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	8.469 cm	47.023 cm	4.452 cm	0 cm

A.11.2 2-INCH ADMIXTURE 18-IN DEEP, NORTH DRAINAGE BORROW, SHRUBLAND VEGETATION

Simulation 42 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with shrubland vegetation.

Table 61. Simulation 42 Results (North Drainage Borrow, Shrubland Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	4.719 cm	25.262 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	7.824 cm	49.024 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	8.682 cm	50.851 cm	0 cm	0 cm

A.11.3 2-INCH ADMIXTURE 18-IN DEEP, SOUTH DRAINAGE BORROW, SHRUBLAND VEGETATION

Simulation 43 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with shrubland vegetation.

Table 62. Simulation 43 Results (South Drainage Borrow, Shrubland Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.682 cm	24.209 cm	0.013 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	9.519 cm	45.150 cm	0.106 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	10.651 cm	47.464 cm	0.311 cm	0 cm

A.11.4 2-INCH ADMIXTURE 18-IN DEEP, WEST BORROW, SHRUBLAND VEGETATION

Simulation 44 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with shrubland vegetation.

Table 63. Simulation 44 Results (West Borrow, Shrubland Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.050 cm	23.819 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	9.968 cm	45.666 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	11.108 cm	47.916 cm	0 cm	0 cm

A.12 SIMULATION SERIES L

The next set of computer simulations involved evaluating the borrow area with the laboratory measured soil values with shrubland vegetation and incorporating the 3-inch diameter (D50) rock admixture that is 27-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.12.1 to A.12.4, Tables 45 to 48 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 12 presents a graphical summary of the Series L computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

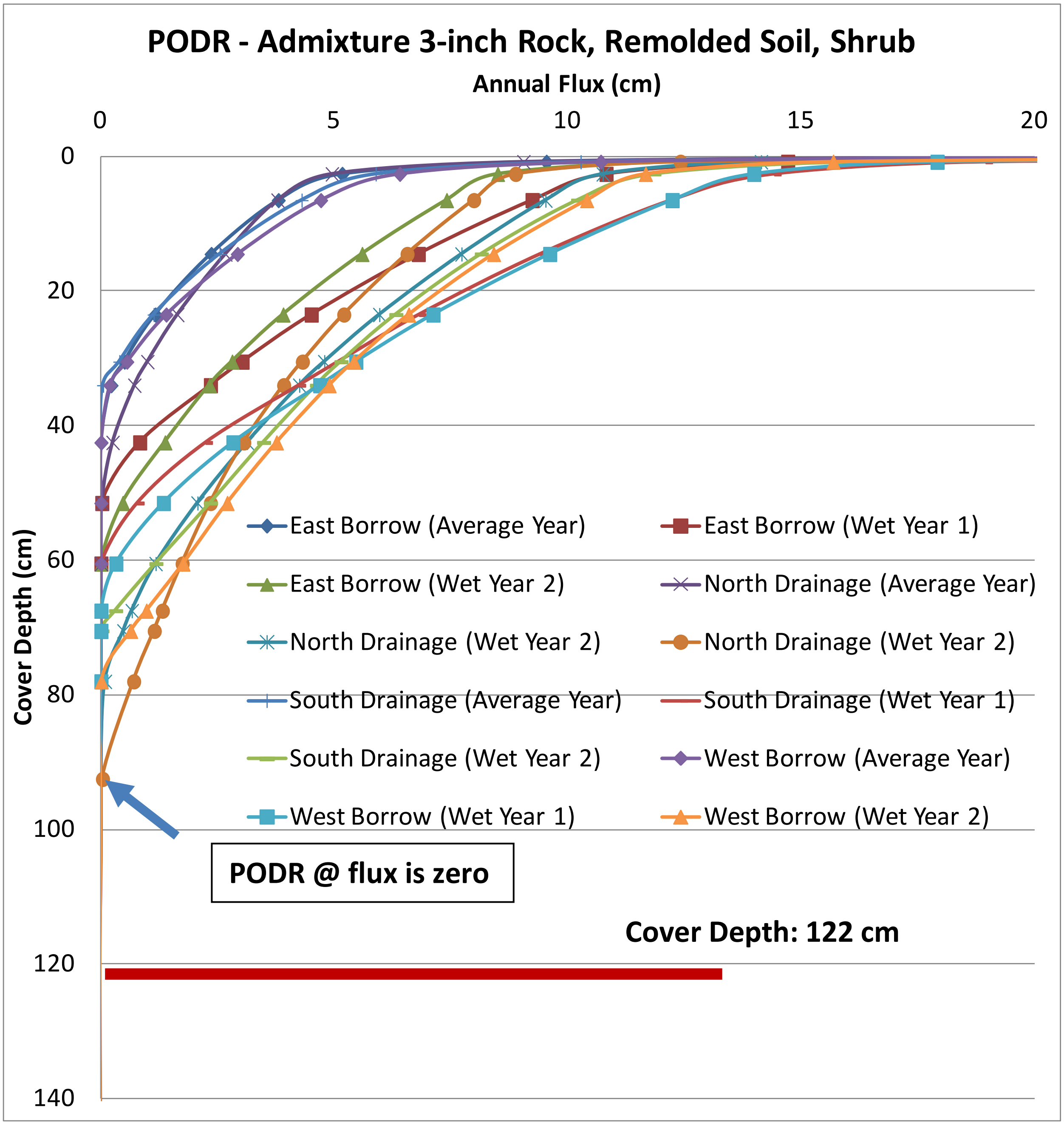


Figure 33. Flux (cm/yr) v. Depth (cm) for Simulation Series L

A.12.1 3-INCH ADMIXTURE 27-IN DEEP, EAST BORROW, SHRUBLAND VEGETATION

Simulation 45 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the east borrow area, with shrubland vegetation.

Table 64. Simulation 45 Results (East Borrow, Shrubland Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	4.968 cm	24.769 cm	0.201 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	7.900 cm	44.875 cm	4.295 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	8.565 cm	47.078 cm	4.483 cm	0 cm

A.12.2 3-INCH ADMIXTURE 27-IN DEEP, NORTH DRAINAGE BORROW, SHRUBLAND VEGETATION

Simulation 46 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with shrubland vegetation.

Table 65. Simulation 46 Results (North Drainage Borrow, Shrubland Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	4.712 cm	25.266 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	7.869 cm	49.476 cm	0 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	8.514 cm	51.318 cm	0 cm	0 cm

A.12.3 3-INCH ADMIXTURE 27-IN DEEP, SOUTH DRAINAGE BORROW, SHRUBLAND VEGETATION

Simulation 47 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with shrubland vegetation.

Table 66. Simulation 47 Results (South Drainage Borrow, Shrubland Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.678 cm	24.206 cm	0.012 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	9.616 cm	45.324 cm	0.104 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	10.770 cm	47.769 cm	0.319 cm	0 cm

A.12.4 3-INCH ADMIXTURE 27-IN DEEP, WEST BORROW, SHRUBLAND VEGETATION

Simulation 48 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, remolded laboratory measured soil from the north drainage borrow area, with shrubland vegetation.

Table 67. Simulation 48 Results (West Borrow, Shrubland Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.048 cm	23.819 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	10.087 cm	45.959 cm	0 cm	0 cm

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Wet Year #2	60.350 cm	215.456 cm	11.179 cm	48.306 cm	0 cm	0 cm

A.13 SIMULATION SERIES M

The next set of computer simulations involved evaluating the borrow area with the in situ measured (Dwyer 2014) soil values with no vegetation and incorporating the 1.5-inch diameter (D50) rock admixture that is 14-inches deep. Beneath the admixture is cover soil from the same borrow source. The top 14-inches had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

In Sections A.13.1 to A.13.3, Tables 49 to 51 contains the annual water balance variables for the initial five years after construction with no vegetation for borrow source, respectively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 13 presents a graphical summary of the Series M computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' (PODR) is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. It can be seen that the annual net flux is effectively minimized at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

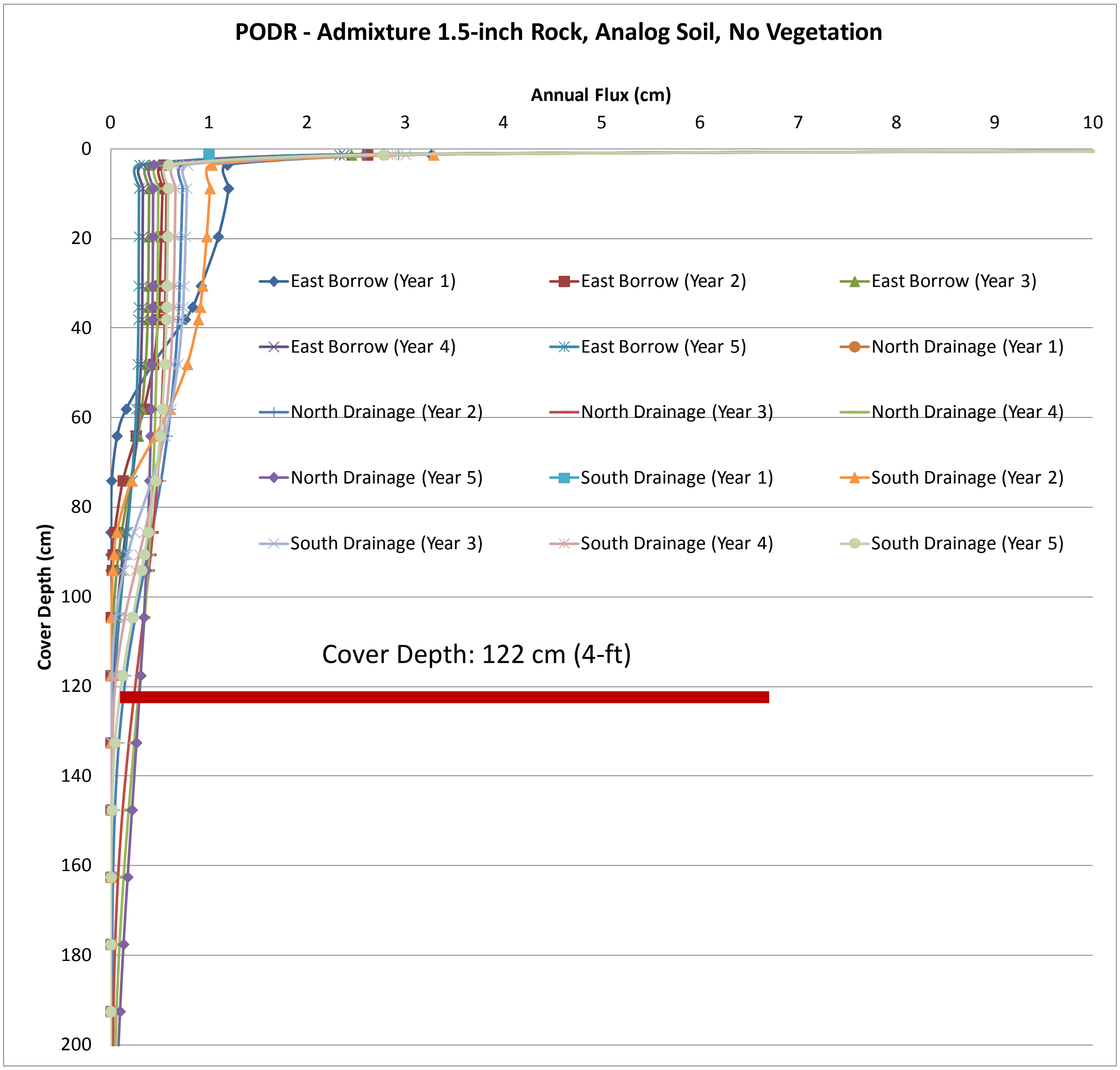


Figure 34. Flux (cm/yr) v. Depth (cm) for Simulation Series M

A.13.1 1.5-INCH ADMIXTURE 14-IN DEEP, EAST BORROW, NO VEGETATION

Simulation 50 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the east borrow area, with no vegetation.

Table 68. Simulation 50 Results (East Borrow, No Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0 cm	28.791 cm	0	2.66E-03 cm
Average Year #2	29.743 cm	211.744 cm	0 cm	29.253 cm	0	2.79E-03 cm
Average Year #3	29.743 cm	211.744 cm	0 cm	29.386 cm	0	5.93E-03 cm
Average Year #4	29.743 cm	211.744 cm	0 cm	29.450 cm	0	1.69E-02 cm
Average Year #5	29.743 cm	211.744 cm	0 cm	29.491 cm	0	3.40 E-02 cm

A.13.2 1.5-INCH ADMIXTURE 14-IN DEEP, NORTH DRAINAGE BORROW, NO VEGETATION

Simulation 51 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, , in situ measured soil (Dwyer 2014) from the north drainage borrow area, with no vegetation.

Table 69. Simulation 51 Results (North Drainage Borrow, No Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	28.693 cm	0	1.57 E-02 cm
Average Year #2	29.743 cm	211.744 cm	0	29.054 cm	0	1.29E-01 cm
Average Year #3	29.743 cm	211.744 cm	0	29.213 cm	0	2.38E-01 cm
Average Year #4	29.743 cm	211.744 cm	0	29.296 cm	0	2.81E-01 cm

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #5	29.743 cm	211.744 cm	0	29.349 cm	0	2.93E-01 cm

A.13.3 1.5-INCH ADMIXTURE 14-IN DEEP, SOUTH DRAINAGE BORROW, NO VEGETATION

Simulation 52 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the south drainage borrow area, with no vegetation.

Table 70. Simulation 52 Results (South Drainage Borrow, No Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	27.029 cm	0	2.43E-03 cm
Average Year #2	29.743 cm	211.744 cm	0	27.703 cm	0	2.58E-03 cm
Average Year #3	29.743 cm	211.744 cm	0	27.931 cm	0	8.18E-03 cm
Average Year #4	29.743 cm	211.744 cm	0	28.051 cm	0	3.70E-02 cm
Average Year #5	29.743 cm	211.744 cm	0	28.122 cm	0	9.18E-02 cm

A.14 SIMULATION SERIES N

The next set of computer simulations involved evaluating the borrow area with the in situ measured (Dwyer 2014) soil values with no vegetation and incorporating the 2-inch diameter (D50) rock admixture that is 18-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

In Sections A.14.1 to A.14.3, Tables 52 to 54 contains the annual water balance variables for the initial five years after construction with no vegetation for borrow source, respectively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 14 presents a graphical summary of the Series N computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' (PODR) is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. It can be seen that the annual net flux is effectively minimized at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

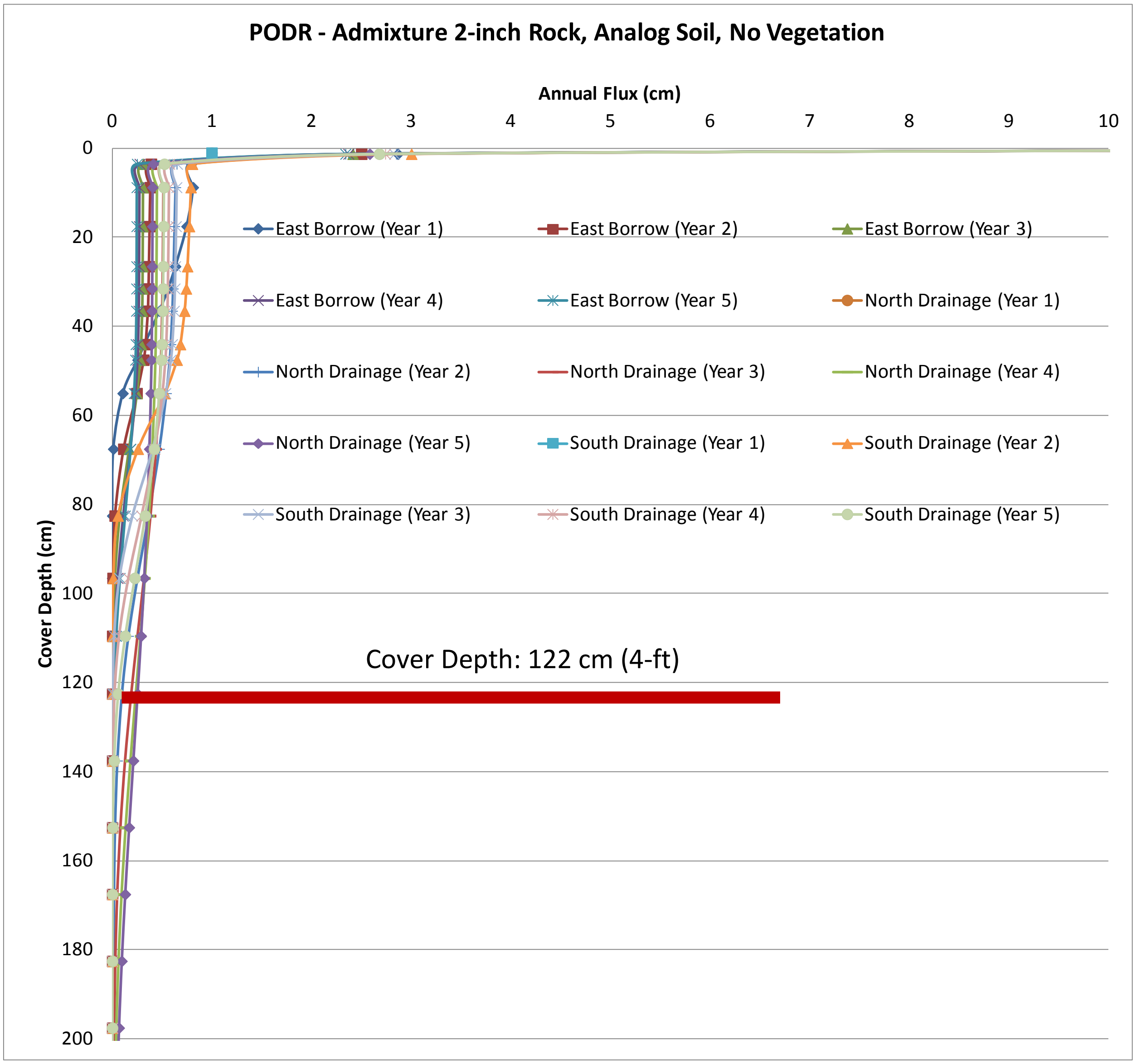


Figure 35. Flux (cm/yr) v. Depth (cm) for Simulation Series N

A.14.1 2-INCH ADMIXTURE 18-IN DEEP, EAST BORROW, NO VEGETATION

Simulation 53 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the east borrow area, with no vegetation.

Table 71. Simulation 53 Results (East Borrow, No Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0 cm	29.189 cm	0	2.66E-03 cm
Average Year #2	29.743 cm	211.744 cm	0 cm	29.402 cm	0	2.70E-03 cm
Average Year #3	29.743 cm	211.744 cm	0 cm	29.469 cm	0	4.10E-03 cm
Average Year #4	29.743 cm	211.744 cm	0 cm	29.506 cm	0	9.55E-03 cm
Average Year #5	29.743 cm	211.744 cm	0 cm	29.533 cm	0	1.91E-02 cm

A.14.2 2-INCH ADMIXTURE 18-IN DEEP, NORTH DRAINAGE BORROW, NO VEGETATION

Simulation 54 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, , in situ measured soil (Dwyer 2014) from the north drainage borrow area, with no vegetation.

Table 72. Simulation 54 Results (North Drainage Borrow, No Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	28.992 cm	0	1.41 E-02 cm
Average Year #2	29.743 cm	211.744 cm	0	29.152 cm	0	9.82E-02 cm
Average Year #3	29.743 cm	211.744 cm	0	29.268 cm	0	1.91E-01 cm
Average Year #4	29.743 cm	211.744 cm	0	29.333 cm	0	2.37E-01 cm

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #5	29.743 cm	211.744 cm	0	29.376 cm	0	2.56E-01 cm

A.14.3 2-INCH ADMIXTURE 18-IN DEEP, SOUTH DRAINAGE BORROW, NO VEGETATION

Simulation 55 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the south drainage borrow area, with no vegetation.

Table 73. Simulation 55 Results (South Drainage Borrow, No Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	27.298 cm	0	2.43E-03 cm
Average Year #2	29.743 cm	211.744 cm	0	27.926 cm	0	2.52E-03 cm
Average Year #3	29.743 cm	211.744 cm	0	28.063 cm	0	5.97E-03 cm
Average Year #4	29.743 cm	211.744 cm	0	28.137 cm	0	2.38E-02 cm
Average Year #5	29.743 cm	211.744 cm	0	28.189 cm	0	6.05E-02 cm

A.15 SIMULATION SERIES O

The next set of computer simulations involved evaluating the borrow area with the in situ measured (Dwyer 2014) soil values with no vegetation and incorporating the 3-inch diameter (D50) rock admixture that is 27-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

In Sections A.15.1 to A.15.3, Tables 55 to 57 contains the annual water balance variables for the initial five years after construction with no vegetation for borrow source, respectively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 15 presents a graphical summary of the Series O computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' (PODR) is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. It can be seen that the annual net flux is effectively minimized at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

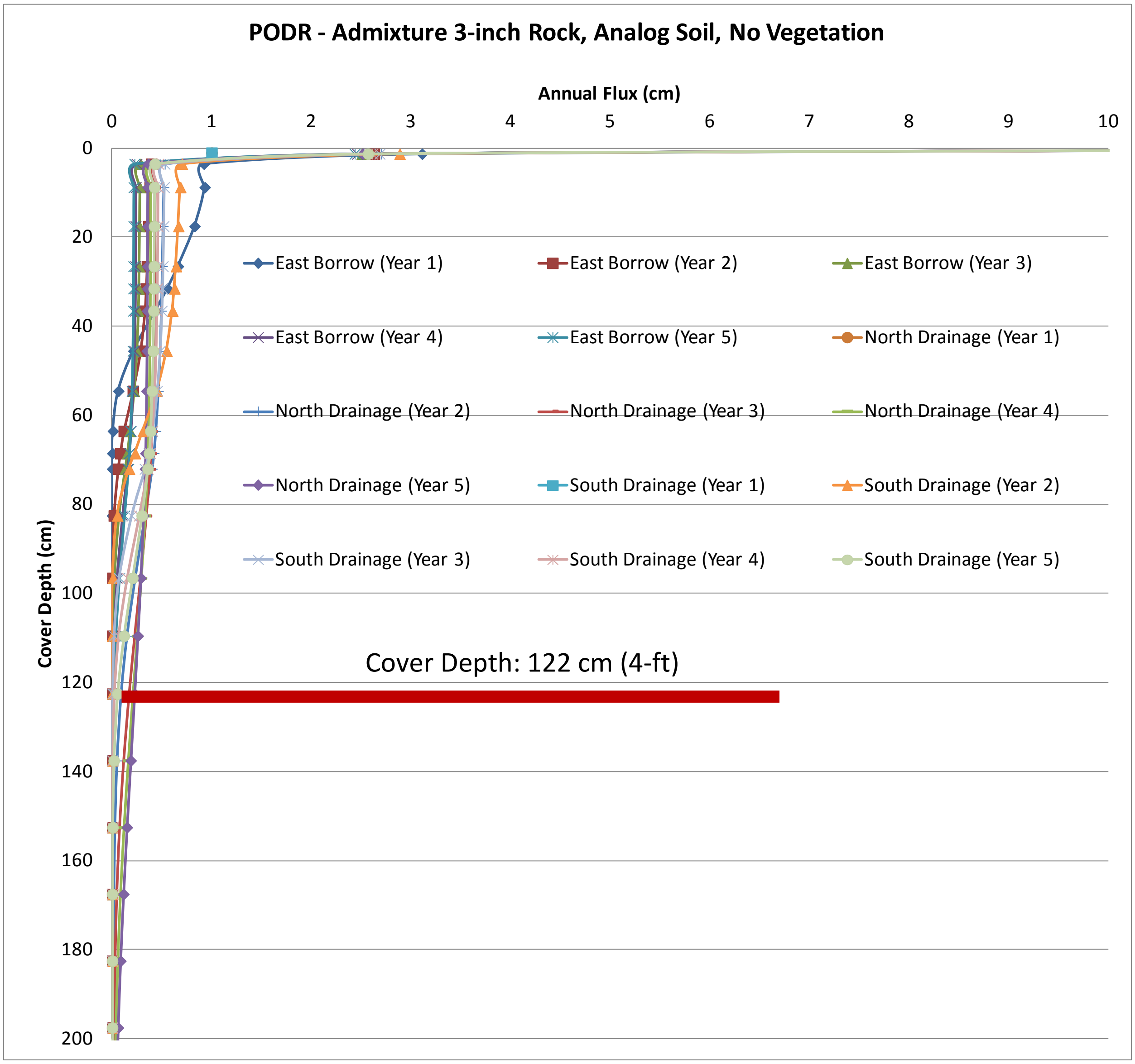


Figure 36. Flux (cm/yr) v. Depth (cm) for Simulation Series O

A.15.1 3-INCH ADMIXTURE 27-IN DEEP, EAST BORROW, NO VEGETATION

Simulation 56 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the east borrow area, with no vegetation.

Table 74. Simulation 56 Results (East Borrow, No Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0 cm	27.914 cm	0	2.66E-03 cm
Average Year #2	29.743 cm	211.744 cm	0 cm	28.227 cm	0	2.70E-03 cm
Average Year #3	29.743 cm	211.744 cm	0 cm	28.323 cm	0	3.58E-03 cm
Average Year #4	29.743 cm	211.744 cm	0 cm	28.361 cm	0	8.10E-03 cm
Average Year #5	29.743 cm	211.744 cm	0 cm	28.380 cm	0	1.70E-02 cm

A.15.2 3-INCH ADMIXTURE 27-IN DEEP, NORTH DRAINAGE BORROW, NO VEGETATION

Simulation 57 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, , in situ measured soil (Dwyer 2014) from the north drainage borrow area, with no vegetation.

Table 75. Simulation 57 Results (North Drainage Borrow, No Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	29.096 cm	0	1.37E-02 cm
Average Year #2	29.743 cm	211.744 cm	0	29.271 cm	0	9.02E-02 cm
Average Year #3	29.743 cm	211.744 cm	0	29.351 cm	0	1.71E-01 cm
Average Year #4	29.743 cm	211.744 cm	0	29.395 cm	0	2.10E-01 cm
Average Year #5	29.743 cm	211.744 cm	0	29.426 cm	0	2.27E-01 cm

A.15.3 3-INCH ADMIXTURE 27-IN DEEP, SOUTH DRAINAGE BORROW, NO VEGETATION

Simulation 58 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the south drainage borrow area, with no vegetation.

Table 76. Simulation 58 Results (South Drainage Borrow, No Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year #1	29.743 cm	211.744 cm	0	27.309 cm	0	2.43E-03 cm
Average Year #2	29.743 cm	211.744 cm	0	28.023 cm	0	2.50E-03 cm
Average Year #3	29.743 cm	211.744 cm	0	28.182 cm	0	5.70E-03 cm
Average Year #4	29.743 cm	211.744 cm	0	28.245 cm	0	2.25E-02 cm
Average Year #5	29.743 cm	211.744 cm	0	28.280 cm	0	5.54E-02 cm

A.16 SIMULATION SERIES P

The next set of computer simulations involved evaluating the borrow area with the in situ measured soil values (Dwyer 2014) with reclaimed vegetation and incorporating the 1.5-inch diameter (D50) rock admixture that is 14-inches deep. Beneath the admixture is cover soil from the same borrow source. The top 14-inches had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.16.1 to A.16.3, Tables 58 to 60 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 16 presents a graphical summary of the Series P computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

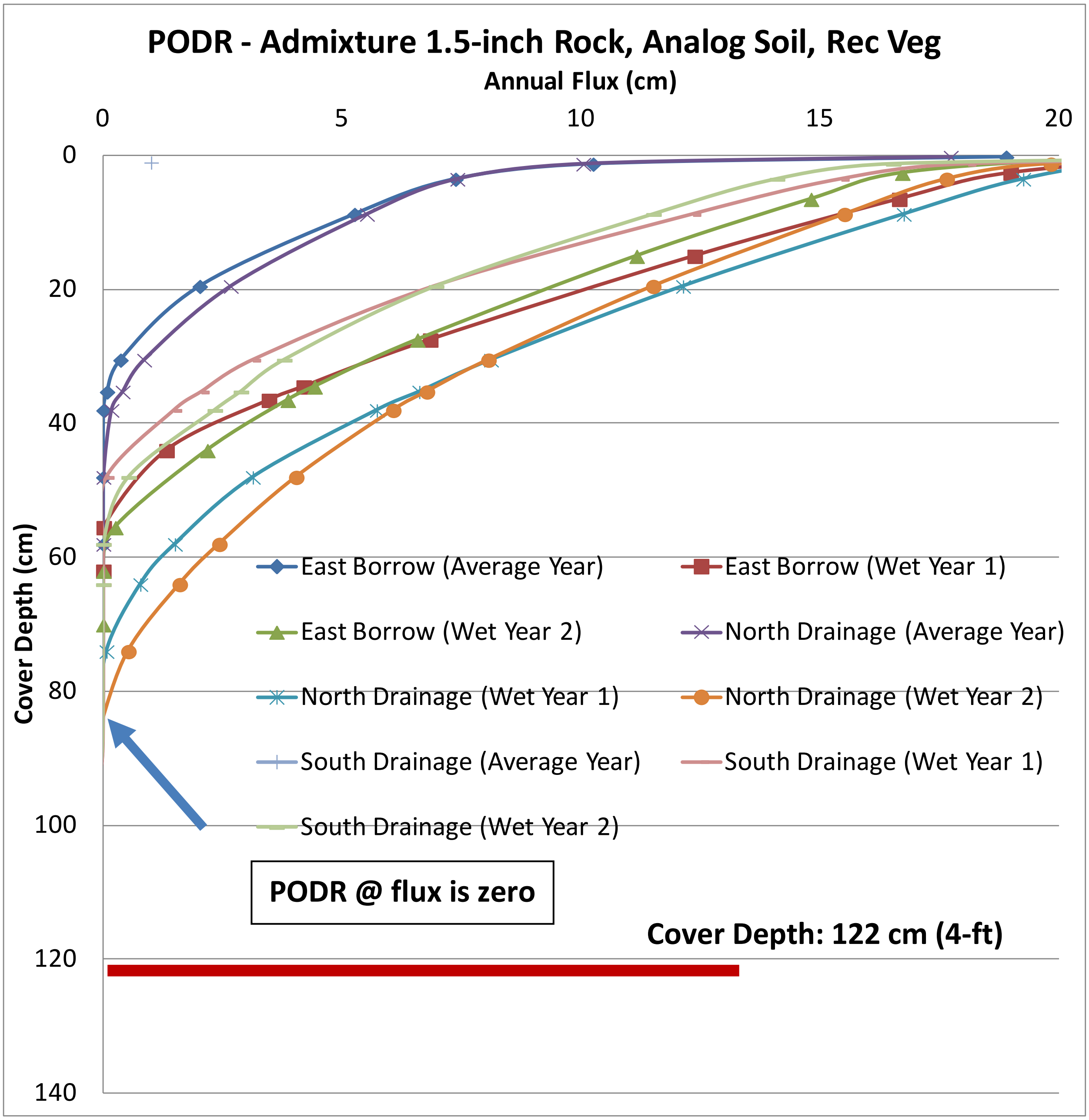


Figure 37. Flux (cm/yr) v. Depth (cm) for Simulation Series P

A.16.1 1.5-INCH ADMIXTURE 14-IN DEEP, EAST BORROW, RECLAIMED VEGETATION

Simulation 59 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the east borrow area, with reclaimed vegetation.

Table 77. Simulation 59 Results (East Borrow, Reclaimed Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	7.159 cm	21.954 cm	0.022 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	15.302 cm	39.575 cm	1.258 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	16.545 cm	41.830 cm	1.344 cm	0 cm

A.16.2 1.5-INCH ADMIXTURE 14-IN DEEP, NORTH DRAINAGE BORROW, RECLAIMED VEGETATION

Simulation 60 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, , in situ measured soil (Dwyer 2014) from the north drainage borrow area, with reclaimed vegetation.

Table 78. Simulation 60 Results (North Drainage Borrow, Reclaimed Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	7.291 cm	22.159 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	16.549 cm	40.184 cm	0.038 cm	0 cm

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Wet Year #2	60.350 cm	215.456 cm	17.977 cm	41.891 cm	0.045 cm	0 cm

A.16.3 1.5-INCH ADMIXTURE 14-IN DEEP, SOUTH DRAINAGE BORROW, RECLAIMED VEGETATION

Simulation 61 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, , in situ measured soil (Dwyer 2014) from the north drainage borrow area, with reclaimed vegetation.

Table 79. Simulation 61 Results (South Drainage Borrow, Reclaimed Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.187 cm	21.995 cm	0.963 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	13.294 cm	36.213 cm	7.443 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	14.539 cm	37.707 cm	7.518 cm	0 cm

A.17 SIMULATION SERIES Q

The next set of computer simulations involved evaluating the borrow area with the in situ measured soil values (Dwyer 2014) with reclaimed vegetation and incorporating the 2-inch diameter (D50) rock admixture that is 18-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.17.1 to A.17.3, Tables 61 to 63 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 17 presents a graphical summary of the Series Q computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

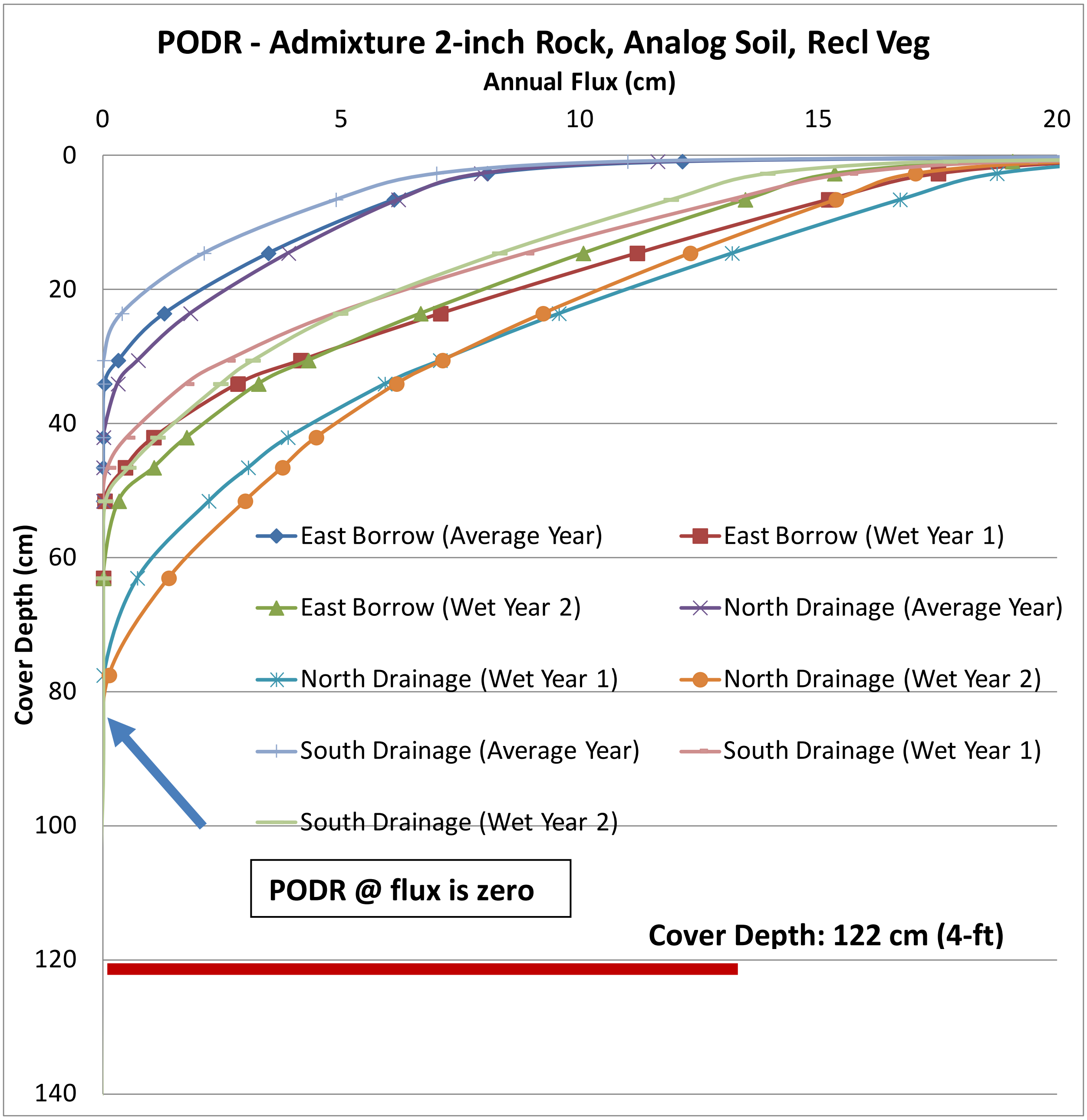


Figure 38. Flux (cm/yr) v. Depth (cm) for Simulation Series Q

A.17.1 2-INCH ADMIXTURE 18-IN DEEP, EAST BORROW, RECLAIMED VEGETATION

Simulation 62 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the east borrow area, with reclaimed vegetation.

Table 80. Simulation 62 Results (East Borrow, Reclaimed Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	7.922 cm	21.947 cm	0.020 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	14.966 cm	40.900 cm	1.402 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	15.872 cm	43.025 cm	1.532 cm	0 cm

A.17.2 2-INCH ADMIXTURE 18-IN DEEP, NORTH DRAINAGE BORROW, RECLAIMED VEGETATION

Simulation 63 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, , in situ measured soil (Dwyer 2014) from the north drainage borrow area, with reclaimed vegetation.

Table 81. Simulation 63 Results (North Drainage Borrow, Reclaimed Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	7.724 cm	22.211 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	16.257 cm	41.277 cm	0.031 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	17.377 cm	42.971 cm	0.041 cm	0 cm

A.17.3 2-INCH ADMIXTURE 18-IN DEEP, SOUTH DRAINAGE BORROW, RECLAIMED VEGETATION

Simulation 64 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, , in situ measured soil (Dwyer 2014) from the north drainage borrow area, with reclaimed vegetation.

Table 82. Simulation 64 Results (South Drainage Borrow, Reclaimed Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.900 cm	22.015 cm	0.960 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	13.544 cm	36.680 cm	7.456 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	14.503 cm	38.347 cm	7.591 cm	0 cm

A.18 SIMULATION SERIES R

The next set of computer simulations involved evaluating the borrow area with the in situ measured soil values (Dwyer 2014) with reclaimed vegetation and incorporating the 3-inch diameter (D50) rock admixture that is 27-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.18.1 to A.18.3, Tables 64 to 66 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 18 presents a graphical summary of the Series R computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

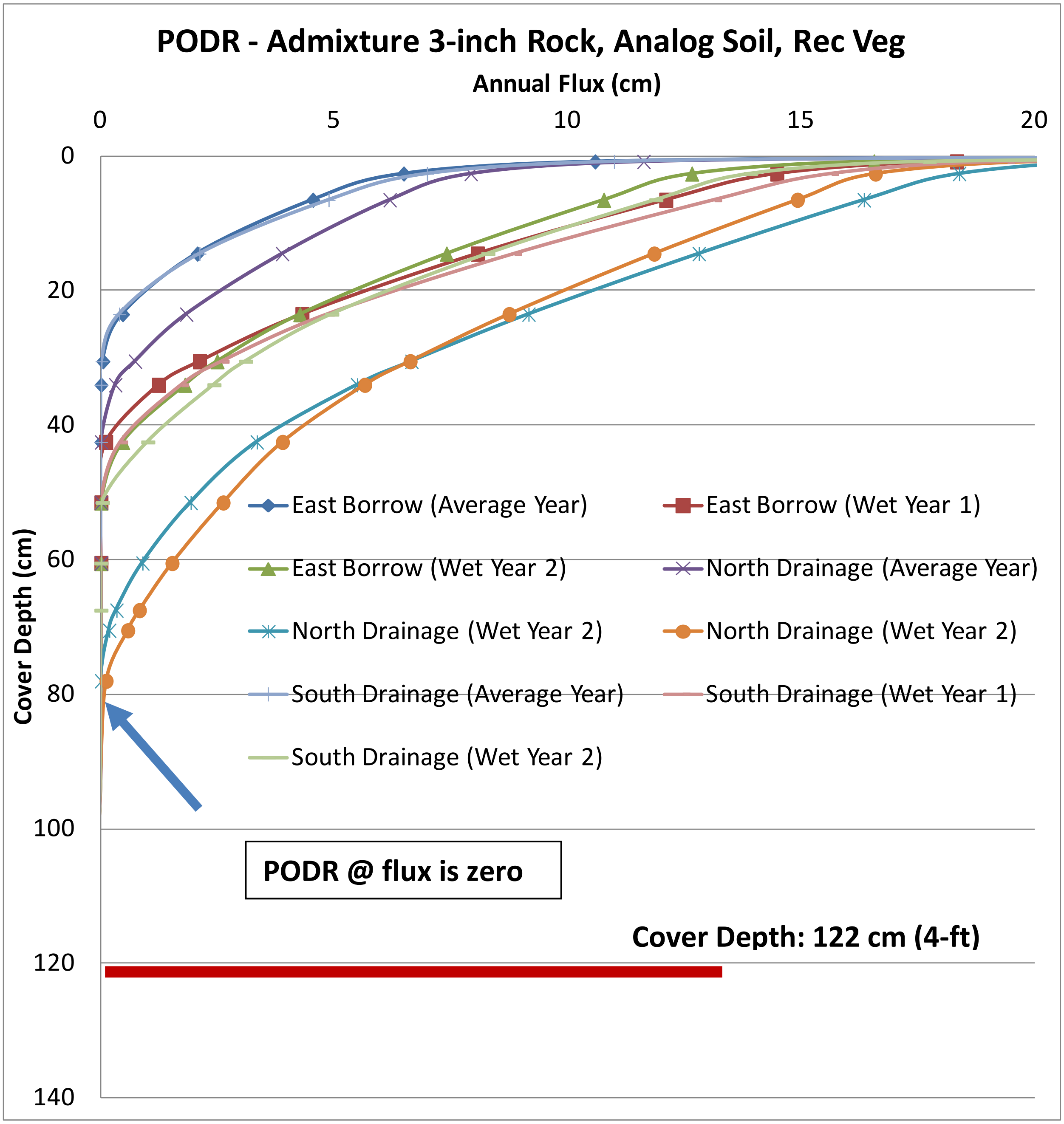


Figure 39. Flux (cm/yr) v. Depth (cm) for Simulation Series R

A.18.1 3-INCH ADMIXTURE 27-IN DEEP, EAST BORROW, RECLAIMED VEGETATION

Simulation 65 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the east borrow area, with reclaimed vegetation.

Table 83. Simulation 65 Results (East Borrow, Reclaimed Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	7.922 cm	21.947 cm	0.020 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	14.966 cm	40.900 cm	1.402 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	15.872 cm	43.025 cm	1.532 cm	0 cm

A.18.2 3-INCH ADMIXTURE 27-IN DEEP, NORTH DRAINAGE BORROW, RECLAIMED VEGETATION

Simulation 66 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, , in situ measured soil (Dwyer 2014) from the north drainage borrow area, with reclaimed vegetation.

Table 84. Simulation 66 Results (North Drainage Borrow, Reclaimed Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	7.724 cm	22.211 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	16.257 cm	41.277 cm	0.031 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	17.377 cm	42.971 cm	0.041 cm	0 cm

A.18.3 3-INCH ADMIXTURE 27-IN DEEP, SOUTH DRAINAGE BORROW, RECLAIMED VEGETATION

Simulation 67 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, , in situ measured soil (Dwyer 2014) from the north drainage borrow area, with reclaimed vegetation.

Table 85. Simulation 67 Results (South Drainage Borrow, Reclaimed Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.900 cm	22.015 cm	0.960 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	13.544 cm	36.680 cm	7.456 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	14.503 cm	38.347 cm	7.591 cm	0 cm

A.19 SIMULATION SERIES S

The next set of computer simulations involved evaluating the borrow area with the in situ measured soil values (Dwyer 2014) with grassland vegetation and incorporating the 1.5-inch diameter (D50) rock admixture that is 14-inches deep. Beneath the admixture is cover soil from the same borrow source. The top 14-inches had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.19.1 to A.19.3, Tables 66 to 68 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 19 presents a graphical summary of the Series S computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

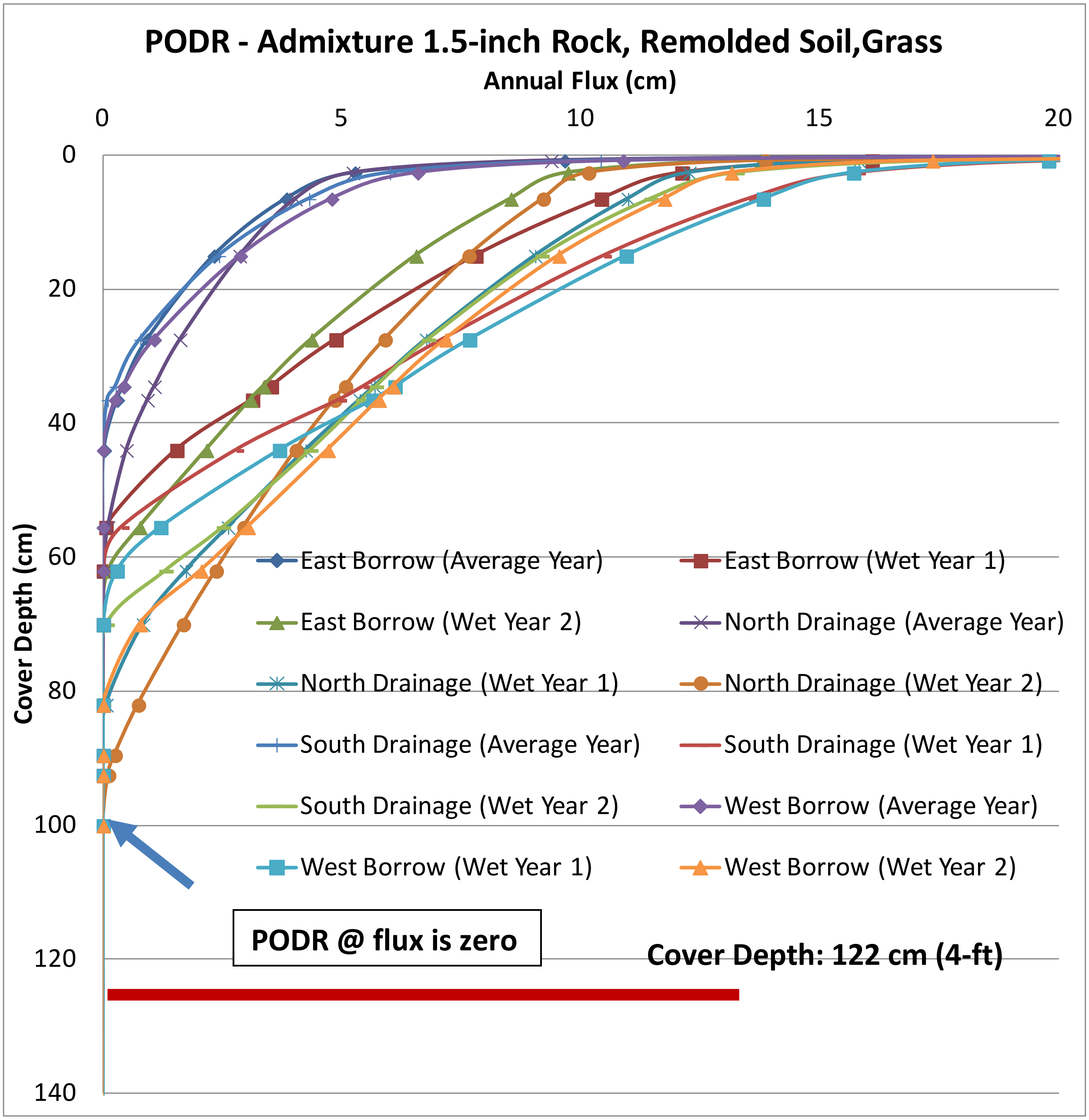


Figure 40. Flux (cm/yr) v. Depth (cm) for Simulation Series S

A.19.1 1.5-INCH ADMIXTURE 14-IN DEEP, EAST BORROW, GRASSLAND VEGETATION

Simulation 68 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the east borrow area, with grassland vegetation.

Table 86. Simulation 68 Results (East Borrow, Grassland Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.087 cm	23.806 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	9.467 cm	45.430 cm	1.365 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	10.484 cm	47.874 cm	1.439 cm	0 cm

A.19.2 1.5-INCH ADMIXTURE 14-IN DEEP, NORTH DRAINAGE BORROW, GRASSLAND VEGETATION

Simulation 69 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the north drainage borrow area, with grassland vegetation.

Table 87. Simulation 69 Results (North Drainage Borrow, Grassland Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.778 cm	24.161 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	10.522 cm	45.285 cm	0.044 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	12.101 cm	47.479 cm	0.055 cm	0 cm

A.19.3 1.5-INCH ADMIXTURE 14-IN DEEP, SOUTH DRAINAGE BORROW, GRASSLAND VEGETATION

Simulation 70 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the north drainage borrow area, with grassland vegetation.

Table 88. Simulation 70 Results (South Drainage Borrow, Grassland Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.53 cm	23.379 cm	0.968 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	9.175 cm	39.551 cm	7.604 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	10.481 cm	41.461 cm	7.721 cm	0 cm

A.20 SIMULATION SERIES T

The next set of computer simulations involved evaluating the borrow area with the in situ measured soil values (Dwyer 2014) with grassland vegetation and incorporating the 2-inch diameter (D50) rock admixture that is 18-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.20.1 to A.20.3, Tables 70 to 72 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 20 presents a graphical summary of the Series T computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The ‘point of diminishing returns’ is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

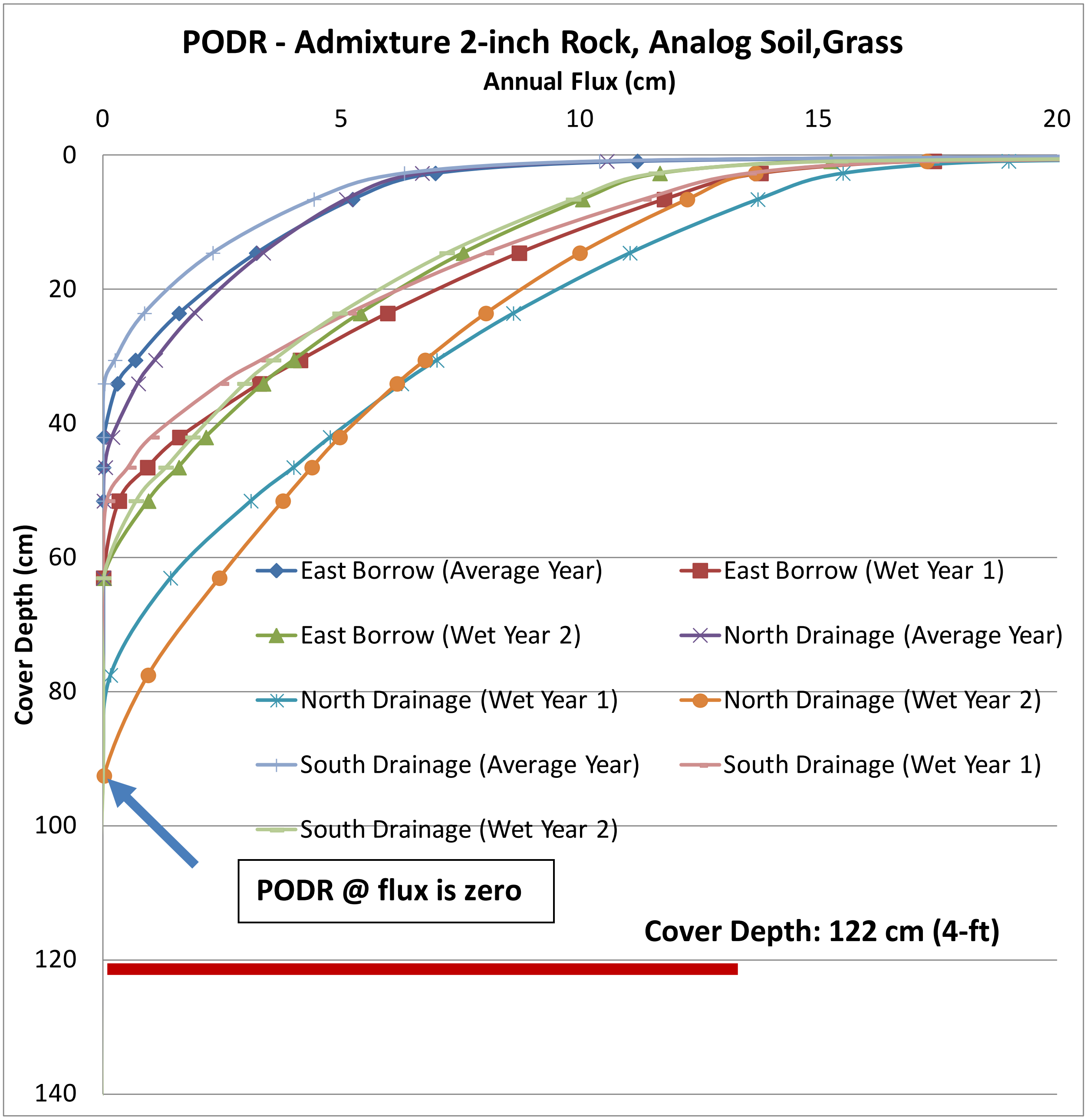


Figure 41. Flux (cm/yr) v. Depth (cm) for Simulation Series T

A.20.1 2-INCH ADMIXTURE 18-IN DEEP, EAST BORROW, GRASSLAND VEGETATION

Simulation 71 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the east borrow area, with grassland vegetation.

Table 89. Simulation 71 Results (East Borrow, Grassland Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.915 cm	22.973 cm	0.001 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	11.181 cm	44.454 cm	1.493 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	12.030 cm	46.557 cm	1.592 cm	0 cm

A.20.2 2-INCH ADMIXTURE 18-IN DEEP, NORTH DRAINAGE BORROW, GRASSLAND VEGETATION

Simulation 72 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the north drainage borrow area, with grassland vegetation.

Table 90. Simulation 72 Results (North Drainage Borrow, Grassland Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.537 cm	23.397 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	12.380 cm	44.400 cm	0.036 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	13.800 cm	46.216 cm	0.046 cm	0 cm

A.20.3 2-INCH ADMIXTURE 18-IN DEEP, SOUTH DRAINAGE BORROW, GRASSLAND VEGETATION

Simulation 73 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the north drainage borrow area, with grassland vegetation.

Table 91. Simulation 73 Results (South Drainage Borrow, Grassland Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.236 cm	22.673 cm	0.968 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	10.927 cm	38.684 cm	7.525 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	11.948 cm	40.547 cm	7.678 cm	0 cm

A.21 SIMULATION SERIES U

The next set of computer simulations involved evaluating the borrow area with the in situ measured soil values (Dwyer 2014) with grassland vegetation and incorporating the 3-inch diameter (D50) rock admixture that is 27-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.21.1 to A.21.3, Tables 73 to 75 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 21 presents a graphical summary of the Series U computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

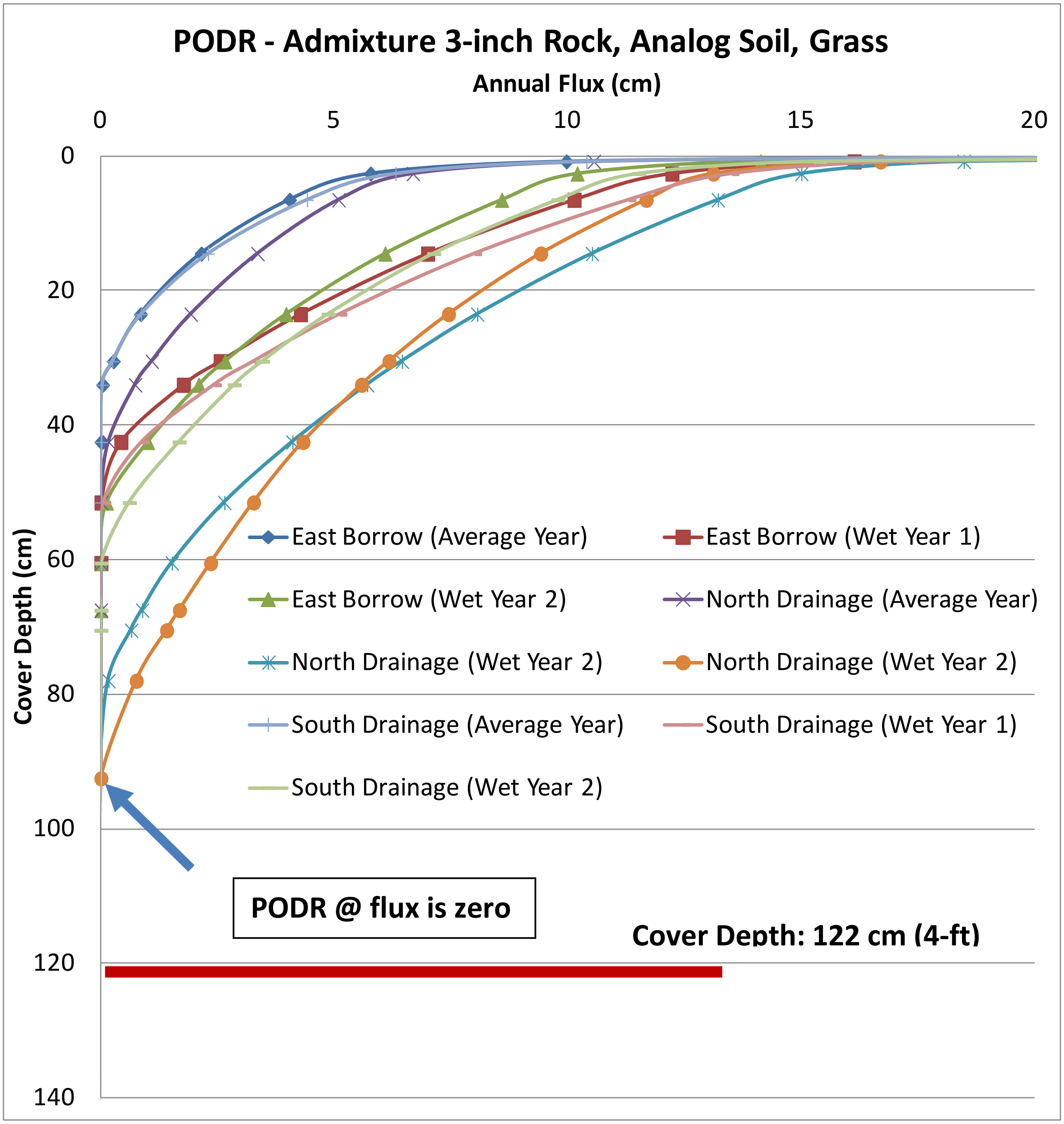


Figure 42. Flux (cm/yr) v. Depth (cm) for Simulation Series U

A.21.1 3-INCH ADMIXTURE 27-IN DEEP, EAST BORROW, GRASSLAND VEGETATION

Simulation 74 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the east borrow area, with grassland vegetation.

Table 92. Simulation 74 Results (East Borrow, Grassland Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.664 cm	23.176 cm	1.044 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	9.871 cm	39.547 cm	8.015 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	10.675 cm	41.550 cm	8.119 cm	0 cm

A.21.2 3-INCH ADMIXTURE 27-IN DEEP, NORTH DRAINAGE BORROW, GRASSLAND VEGETATION

Simulation 75 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the north drainage borrow area, with grassland vegetation.

Table 93. Simulation 75 Results (North Drainage Borrow, Grassland Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.537 cm	23.397 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	12.321 cm	44.892 cm	0.036 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	13.401 cm	46.767 cm	0.046 cm	0 cm

A.21.3 3-INCH ADMIXTURE 27-IN DEEP, SOUTH DRAINAGE BORROW, GRASSLAND VEGETATION

Simulation 76 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the north drainage borrow area, with grassland vegetation.

Table 94. Simulation 76 Results (South Drainage Borrow, Grassland Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	6.236 cm	22.673 cm	0.967 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	10.987 cm	38.703 cm	7.524 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	12.026 cm	40.609 cm	7.677 cm	0 cm

A.22 SIMULATION SERIES V

The next set of computer simulations involved evaluating the borrow area with the in situ measured soil values (Dwyer 2014) with shrubland vegetation and incorporating the 1.5-inch diameter (D50) rock admixture that is 14-inches deep. Beneath the admixture is cover soil from the same borrow source. The top 14-inches had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.22.1 to A.22.3, Tables 77 to 79 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 22 presents a graphical summary of the Series V computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

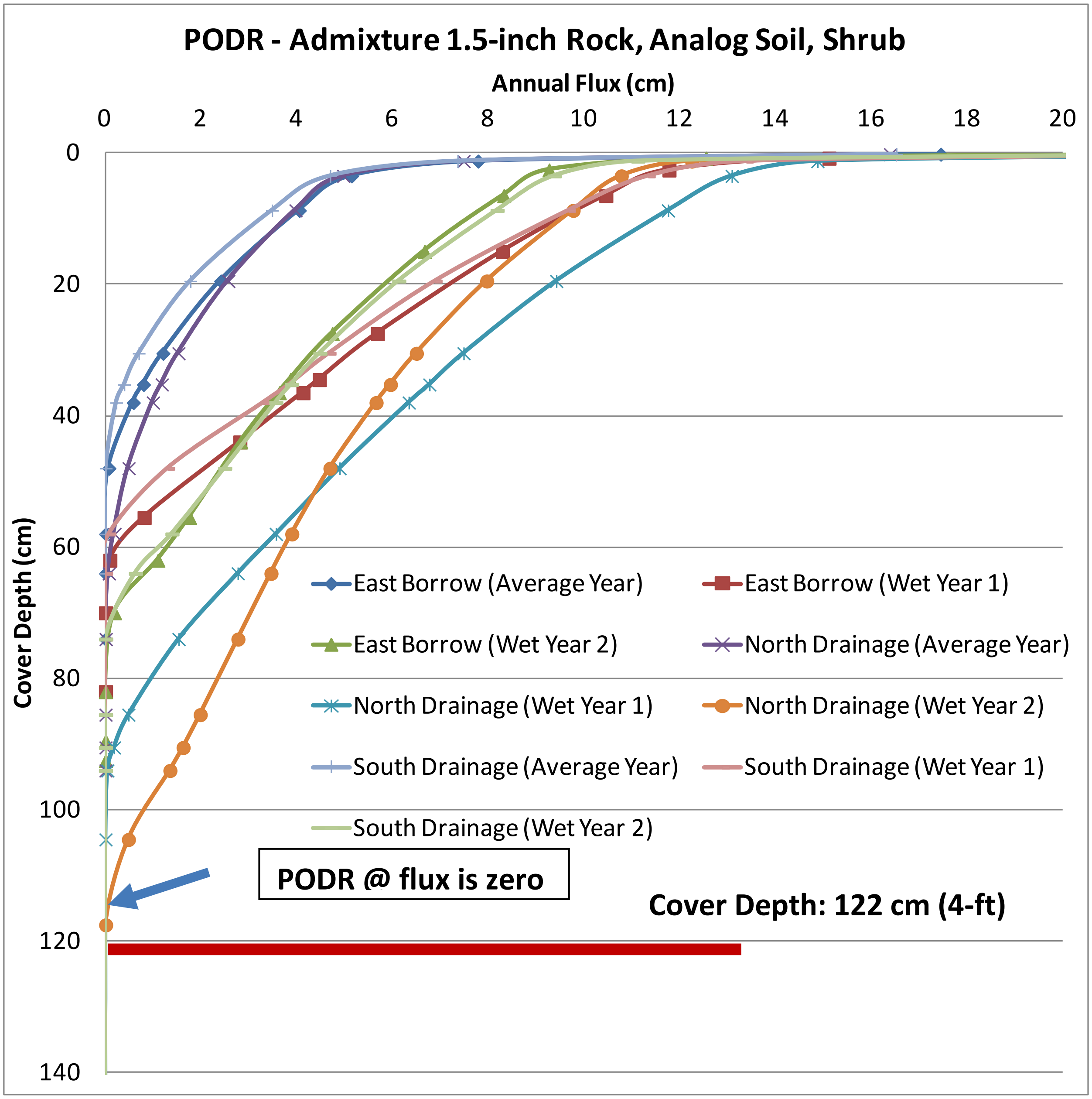


Figure 43. Flux (cm/yr) v. Depth (cm) for Simulation Series V

A.22.1 1.5-INCH ADMIXTURE 14-IN DEEP, EAST BORROW, SHRUBLAND VEGETATION

Simulation 77 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the east borrow area, with shrubland vegetation.

Table 95. Simulation 77 Results (East Borrow, Grassland Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.637 cm	24.385 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	7.948 cm	46.842 cm	1.361 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	8.669 cm	49.338 cm	1.443 cm	0 cm

A.22.2 1.5-INCH ADMIXTURE 14-IN DEEP, NORTH DRAINAGE BORROW, SHRUBLAND VEGETATION

Simulation 78 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the north drainage borrow area, with shrubland vegetation.

Table 96. Simulation 78 Results (North Drainage Borrow, Grassland Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.316 cm	24.705 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	8.568 cm	46.619 cm	0.045 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	9.679 cm	49.025 cm	0.057 cm	0 cm

A.22.3 1.5-INCH ADMIXTURE 14-IN DEEP, SOUTH DRAINAGE BORROW, SHRUBLAND VEGETATION

Simulation 79 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 1.5-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the north drainage borrow area, with shrubland vegetation.

Table 97. Simulation 79 Results (South Drainage Borrow, Grassland Vegetation, 14-in Deep/1.5-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.139 cm	23.871 cm	0.969 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	7.782 cm	40.568 cm	7.648 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	8.774 cm	42.614 cm	7.769 cm	0 cm

A.23 SIMULATION SERIES W

The next set of computer simulations involved evaluating the borrow area with the in situ measured soil values (Dwyer 2014) with shrubland vegetation and incorporating the 2-inch diameter (D50) rock admixture that is 18-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.23.1 to A.23.3, Tables 79 to 81 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 23 presents a graphical summary of the Series W computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The ‘point of diminishing returns’ is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

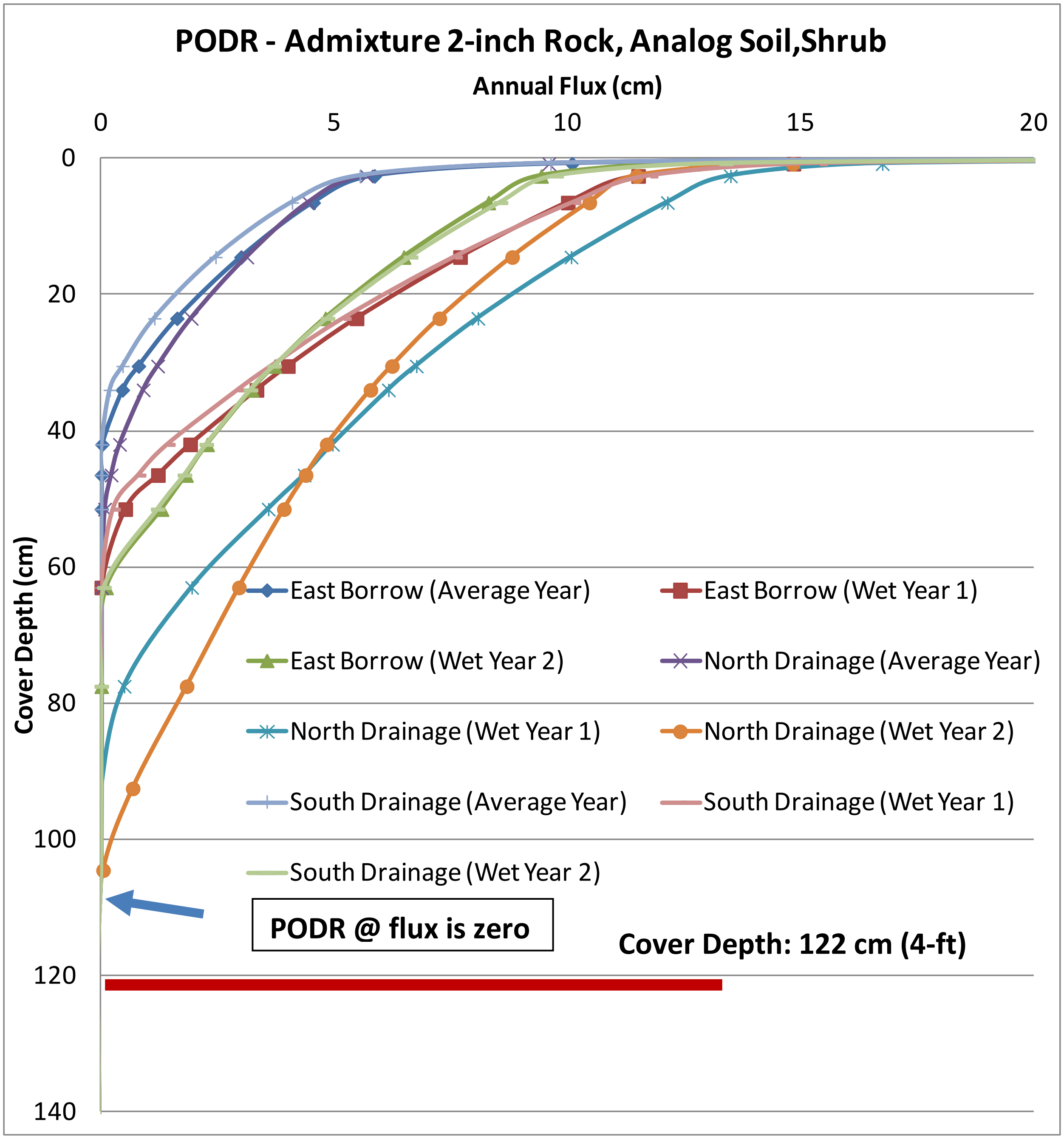


Figure 44. Flux (cm/yr) v. Depth (cm) for Simulation Series W

A.23.1 2-INCH ADMIXTURE 18-IN DEEP, EAST BORROW, SHRUBLAND VEGETATION

Simulation 80 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the east borrow area, with shrubland vegetation.

Table 98. Simulation 80 Results (East Borrow, Grassland Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.812 cm	24.122 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	8.490 cm	46.901 cm	1.528 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	9.179 cm	49.983 cm	1.617 cm	0 cm

A.23.2 2-INCH ADMIXTURE 18-IN DEEP, NORTH DRAINAGE BORROW, SHRUBLAND VEGETATION

Simulation 81 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the north drainage borrow area, with shrubland vegetation.

Table 99. Simulation 81 Results (North Drainage Borrow, Grassland Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.338 cm	24.430 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	9.272 cm	46.588 cm	0.038 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	10.455 cm	48.586 cm	0.049 cm	0 cm

A.23.3 2-INCH ADMIXTURE 18-IN DEEP, SOUTH DRAINAGE BORROW, SHRUBLAND VEGETATION

Simulation 82 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 2-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the north drainage borrow area, with shrubland vegetation.

Table 100. Simulation 82 Results (South Drainage Borrow, Grassland Vegetation, 18-in Deep/2-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.418 cm	23.520 cm	0.973 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	8.536 cm	40.526 cm	7.643 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	9.426 cm	42.502 cm	7.768 cm	0 cm

A.24 SIMULATION SERIES X

The next set of computer simulations involved evaluating the borrow area with the in situ measured soil values (Dwyer 2014) with shrubland vegetation and incorporating the 3-inch diameter (D50) rock admixture that is 27-inches deep. Beneath the admixture is cover soil from the same borrow source. The top foot had the saturated hydraulic conductivity increased by an order of magnitude to account for effects such as roots and freeze/thaw action on the soil. This order of magnitude increase to about a foot deep is consistent with soil measurements made in situ (Dwyer 2014).

These computer simulations involved running 10 average years in a row to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record modeled back to back. In Sections A.24.1 to A.24.3, Tables 82 to 84 contains the annual water balance variables for the tenth year of the average consecutive modeled years and the two wettest years on record modeled consecutively. The following water balance variables are summarized for each year: (1) applied precipitation; (2) applied potential evapotranspiration (PET); (3) calculated transpiration; (4) calculated evaporation; (5) calculated runoff; and (6) calculated percolation.

Figure 24 presents a graphical summary of the Series X computer simulations flux (cm/yr) versus depth (cm) for each year of each simulation. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). The 'point of diminishing returns' is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. For all of these simulations the flux is actually zero at a depth less than the 4-ft cover thickness. Thus 40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 are satisfied in that flux through the cover is minimized.

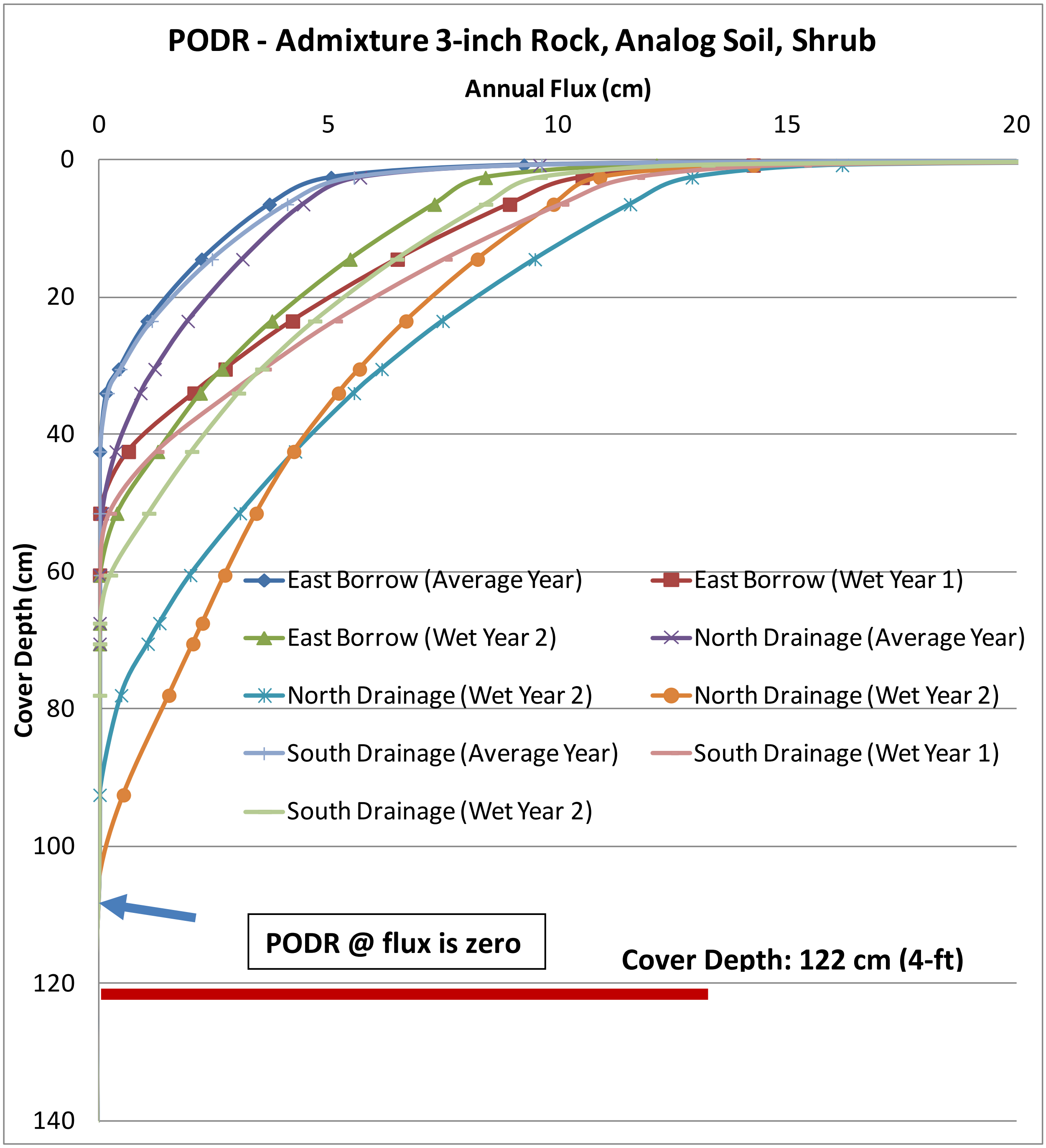


Figure 45. Flux (cm/yr) v. Depth (cm) for Simulation Series X

A.24.1 3-INCH ADMIXTURE 27-IN DEEP, EAST BORROW, SHRUBLAND VEGETATION

Simulation 83 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the east borrow area, with shrubland vegetation.

Table 101. Simulation 83 Results (East Borrow, Grassland Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	4.912 cm	23.952 cm	1.062 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	7.775 cm	41.336 cm	8.109 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	8.491 cm	43.442 cm	8.196 cm	0 cm

A.24.2 3-INCH ADMIXTURE 27-IN DEEP, NORTH DRAINAGE BORROW, SHRUBLAND VEGETATION

Simulation 84 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the north drainage borrow area, with shrubland vegetation.

Table 102. Simulation 84 Results (North Drainage Borrow, Grassland Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.530 cm	24.435 cm	0 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	9.291 cm	47.150 cm	0.038 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	10.231 cm	49.151 cm	0.050 cm	0 cm

A.24.3 3-INCH ADMIXTURE 27-IN DEEP, SOUTH DRAINAGE BORROW, SHRUBLAND VEGETATION

Simulation 85 included the input parameters described in Section 6. Specifically, this simulation included an admixture with 33% rock to 67% soil by volume with 3-inch diameter D50 rock, in situ measured soil (Dwyer 2014) from the north drainage borrow area, with shrubland vegetation.

Table 103. Simulation 85 Results (South Drainage Borrow, Grassland Vegetation, 27-in Deep/3-in Dia. Rock Admixture)

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation @ 4ft BGS
Average Year	29.743 cm	211.744 cm	5.415 cm	23.520 cm	0.973 cm	0 cm
Wet Year #1	60.350 cm	215.456 cm	8.618 cm	40.568 cm	7.648 cm	0 cm
Wet Year #2	60.350 cm	215.456 cm	9.555 cm	42.631 cm	7.776 cm	0 cm

APPENDIX B

LONG-TERM MODELING SIMULATIONS OF COVER PROFILES

FIGURES

The long-term evaluation of the 4-ft cover profiles overlying the mine spoils simulated the potential changes through time, varying the vegetation and soil hydraulic properties as they evolve. Typical and extreme climate conditions are included. Each admixture (1.5-in diameter rock mixed with soil to 14-inch depth, 2-inch rock mixed with soil to 18-inch depth, and 3-inch diameter rock mixed with soil to a 27-inch depth - the remainder of the cover is cover soil from same borrow source) was separately evaluated, thus there was three sets of long-term simulations completed in four stages.

B.1 1.5-INCH, 14-IN DEEP ADMIXTURE

40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 require that flux through the cover be minimized. The ‘point of diminishing returns’ (PODR) is defined as the depth at which flux is effectively minimized. That is, the PODR occurs at a depth whereby an additional increment of soil will no longer significantly reduce the flux. This depth of cover soil where flux is minimized is referred to as the Dwyer (et al 2007) Point of Diminishing Returns Method. Figure 1 contains all computer simulations years included for the cover geometry that included the top surface admixture to a depth of 14-inches. Figure 1 shows that the PODR is reached at a depth of about 85 cm (about 33-in) for the long-term set of simulations that included a profile with the admixture top surface of 1.5-inch rock mixed with soil at a ratio of 33% to 67% by volume with the cover soil from the south drainage borrow area to a depth of 14-inches. The remainder of the profile included the same cover soil to a depth of 4-ft (122 cm) with mine spoils beneath this.

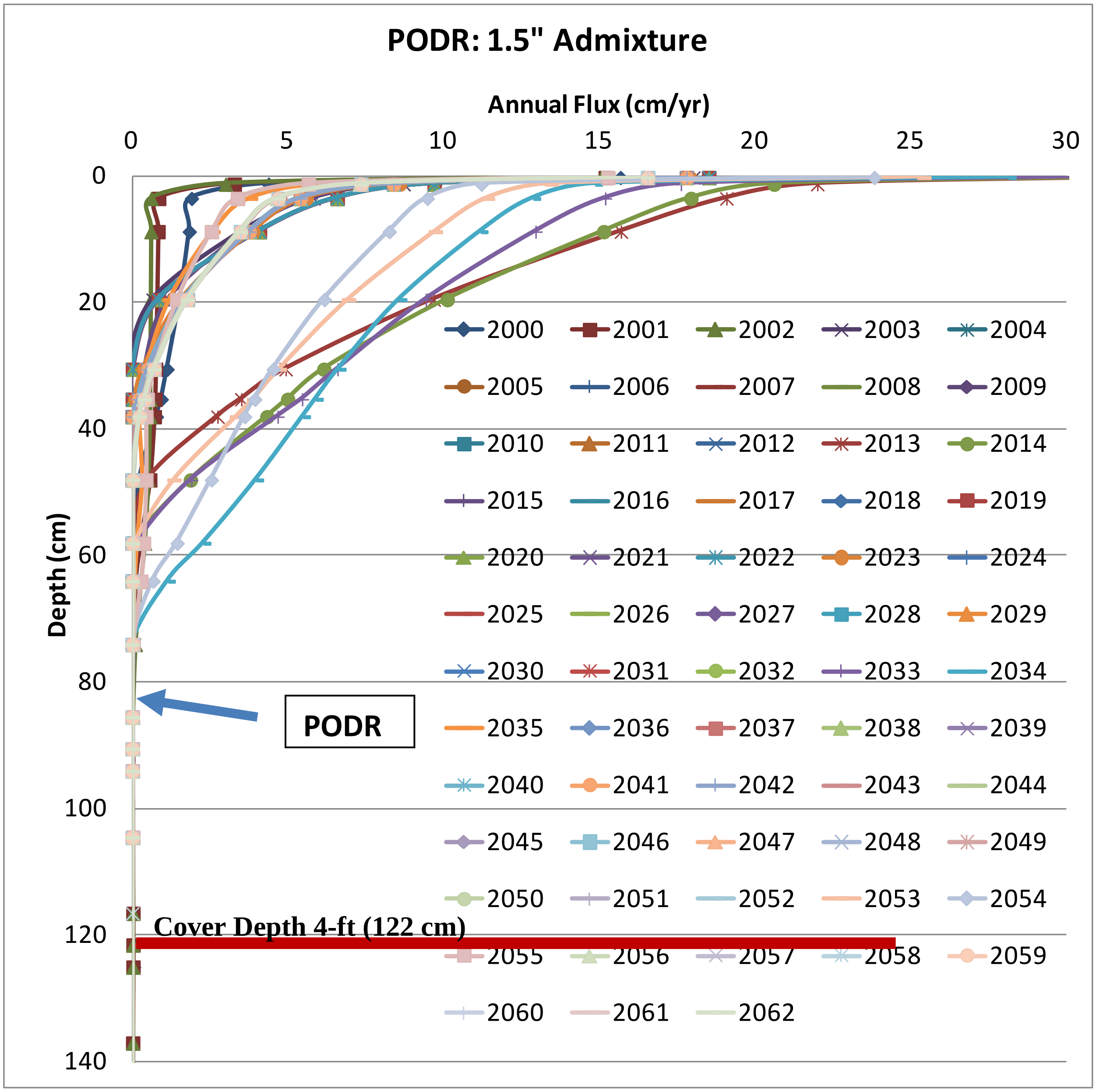


Figure 46. PODR for Long-Term Simulation with 1.5"Rock, 14" Deep Admixture in Profile

B.1.1 INITIAL TIME PERIOD OF LONG-TERM SIMULATION: NO VEGETATION

Figure 2 includes the three years from the 'initial' stage of the long-term simulation for the 4-ft cover profile with a 14-inch deep surface admixture layer. Figure 2 shows that the PODR is reached at a depth of about 85 cm (about 33-in) for the initial stage (no vegetation) of the long-term set of simulations. The annual flux at this PODR is about 1E-03 cm/year. This flux is likely a result of the lower boundary condition (unit gradient) placed on the model profile.

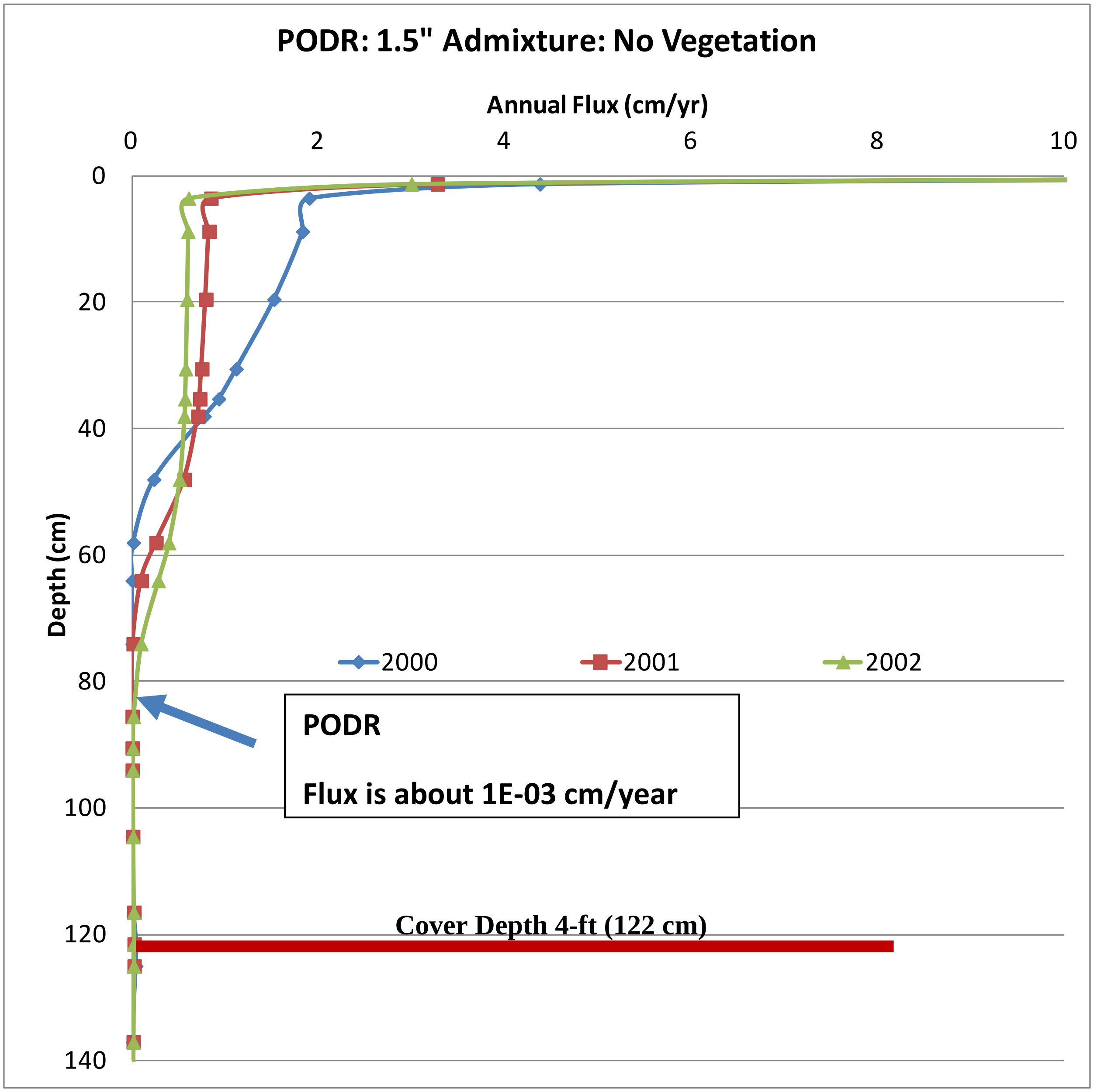


Figure 47. PODR for Initial Stage (No Vegetation) of Long-Term Simulation with 1.5", 14" Deep Admixture

B.1.2 SHORT-TERM TIME PERIOD OF LONG-TERM SIMULATION: RECLAIMED / DISTURBED VEGETATION

Figure 3 includes the twenty years from the 'short-term' stage of the long-term simulation for the 4-ft cover profile with a 14-inch deep surface admixture layer. Figure 3 shows that the PODR is reached at a depth of about 72-cm (28-in) for the short-term stage of the long-term set of simulations. The annual flux at this PODR is zero.

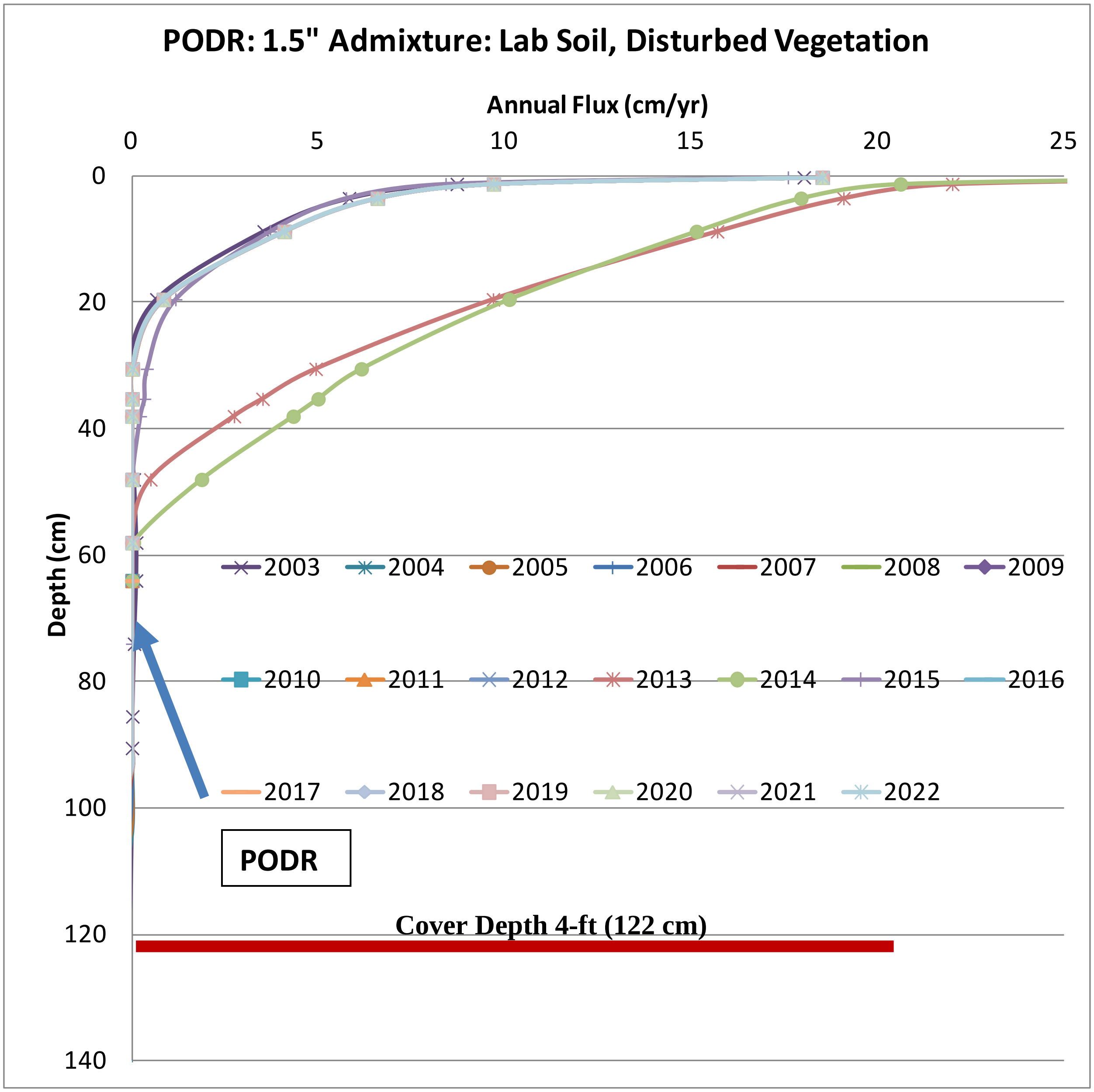


Figure 48. PODR for Short-Term Stage (Disturbed Vegetation) of Long-Term Simulation with 1.5", 14" Deep Admixture

B.1.3 INTERMEDIATE-TERM TIME PERIOD OF LONG-TERM SIMULATION: GRASSLAND VEGETATION

Figure 4 includes the twenty years from the 'intermediate' stage of the long-term simulation for the 4-ft cover profile with a 14-inch deep surface admixture layer. Figure 4 shows that the PODR is reached at a depth of about 107-cm (42-in) for the intermediate-term stage of the long-term set of simulations. The annual flux at this PODR is zero. The wet climate did not produce the deepest

PODR, rather it was produced during an average climate year. The deepest PODR occurs in the average years following the two consecutive wet years. Those two wet years allowed more infiltration into the profile and although it did not make it to the base of the cover, it slowly moved downward until the upward energy gradients overcame gravity and pulled the moisture back up.

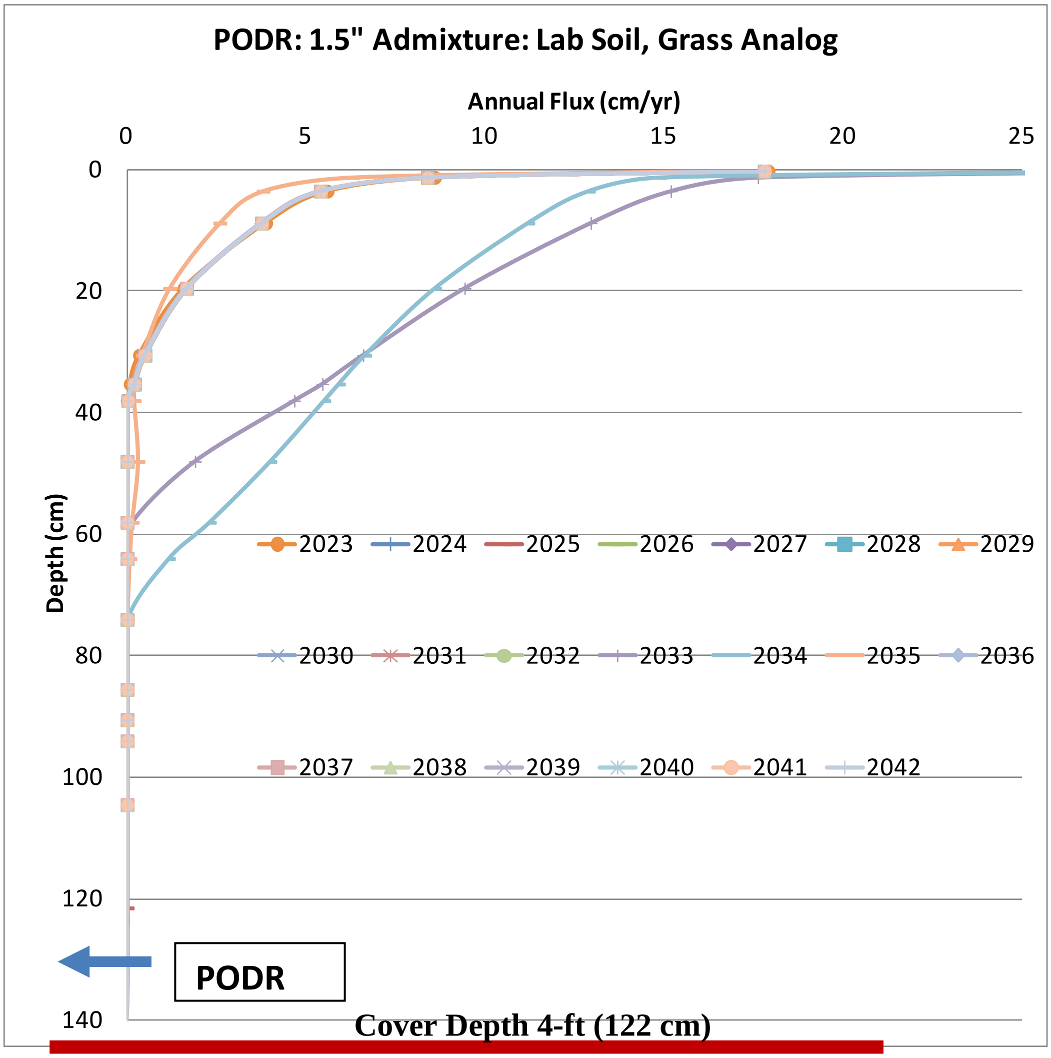


Figure 49. PODR for Intermediate-Term Stage (Grass Vegetation) of Long-Term Simulation with 1.5", 14" Deep Admixture

B.1.4 LONG-TERM TIME PERIOD OF LONG-TERM SIMULATION: SHRUBLAND VEGETATION

Figure 5 includes the twenty years from the 'long-term' stage of the long-term simulation for the 4-ft cover profile with a 14-inch deep surface admixture layer. Figure 5 shows that the PODR is reached at a depth of about 115-cm (45-in) for the long-term stage of the long-term set of simulations. The annual flux at this PODR is zero. The wet climate did not produce the deepest PODR, rather it was produced during an average climate year. The deepest PODR occurs in the

average years following the two consecutive wet years. Those two wet years allowed more infiltration into the profile and although it did not make it to the base of the cover, it slowly moved downward until the upward energy gradients overcame gravity and pulled the moisture back up.

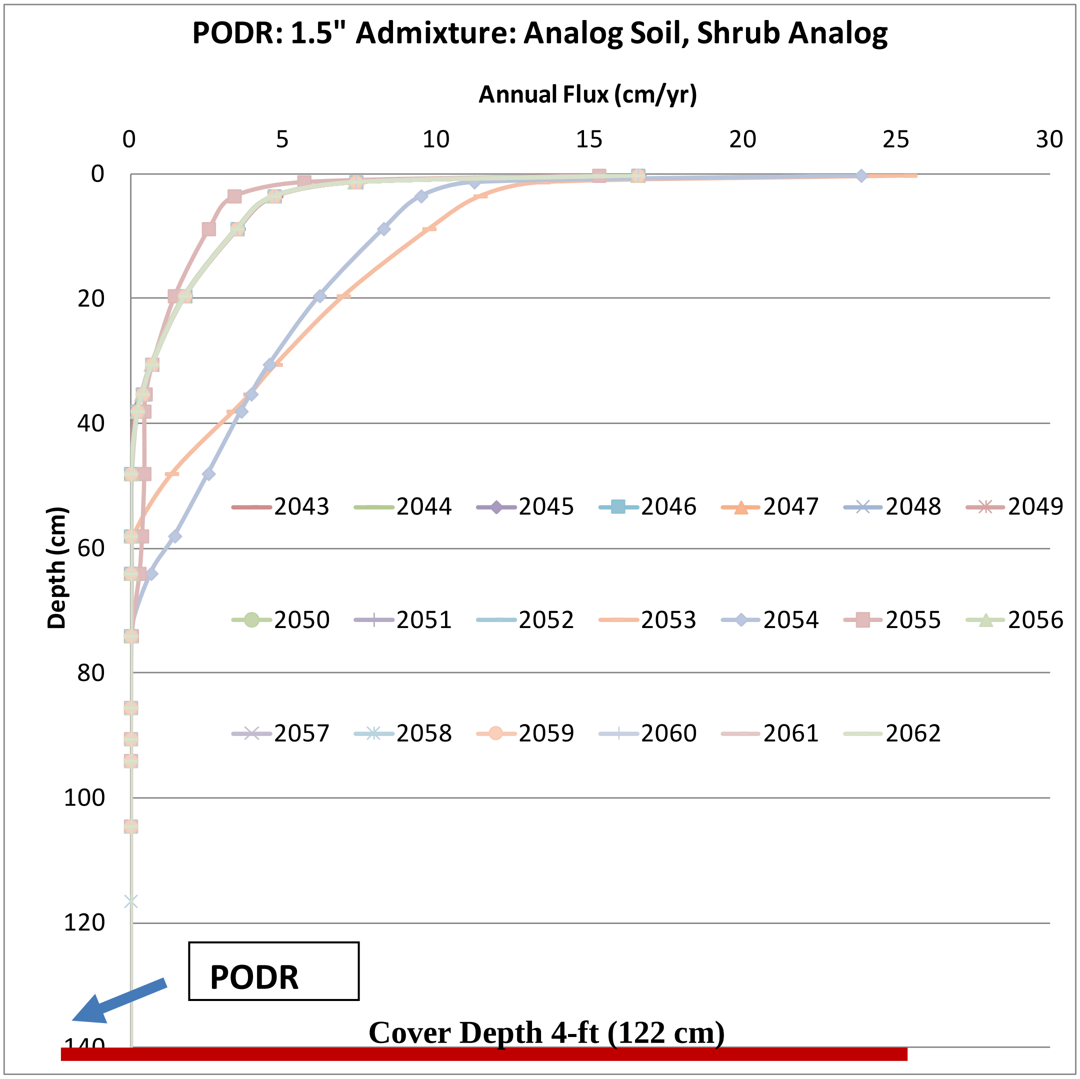


Figure 50. PODR for Long-Term Stage (Shrub Vegetation) of Long-Term Simulation with 1.5", 14" Deep Admixture

B.2 2-INCH, 18-IN DEEP ADMIXTURE

40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 require that flux through the cover be minimized. The 'point of diminishing returns' (PODR) is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. This depth of cover soil where flux is minimized is referred to as the Dwyer (et al 2007) Point of Diminishing Returns Method. Figure 6 contains all computer simulations years included for the cover geometry that included the top surface admixture to a

depth of 18-inches. Figure 6 shows that the PODR is reached at a depth less than 122 cm (4-ft) for the long-term set of simulations that included a profile with the admixture top surface of 2-inch rock mixed with soil at a ratio of 33% to 67% by volume with the cover soil from the south drainage borrow area to a depth of 18-inches. The remainder of the profile included the same cover soil to a depth of 4-ft (122 cm) with mine spoils beneath this.

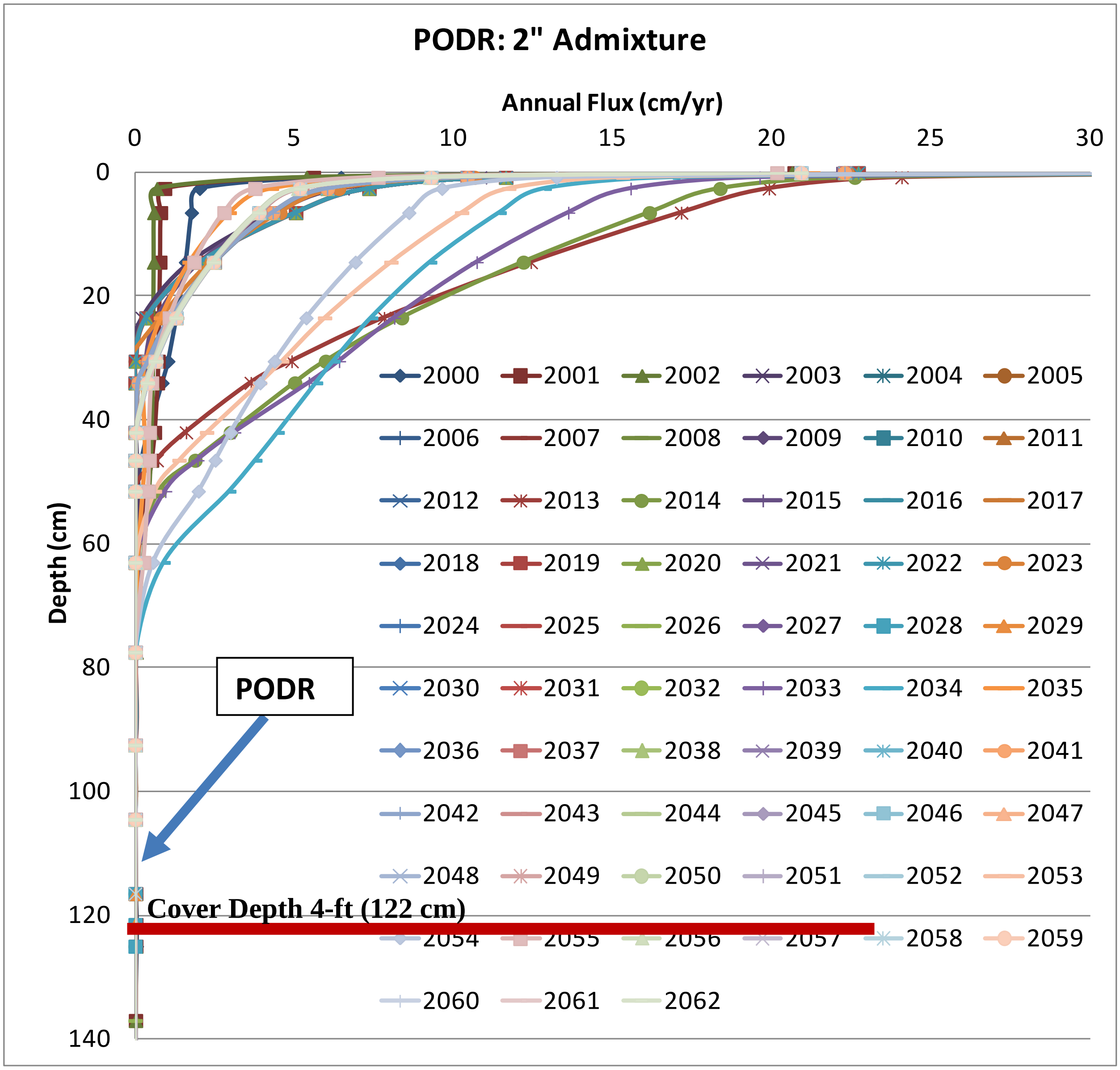


Figure 51. PODR for Long-Term Simulation with 2"Rock, 18" Deep Admixture in Profile

B.2.1 INITIAL TIME PERIOD OF LONG-TERM SIMULATION: NO VEGETATION

Figure 7 includes the three years from the 'initial' stage of the long-term simulation for the 4-ft cover profile with a 18-inch deep surface admixture layer. Figure 7 shows that the PODR is reached at a depth of about 85 cm (about 33-in) for the initial stage (no vegetation) of the long-term set of simulations. The annual flux at this PODR is about 1E-03 cm/year. This flux is likely a result of the lower boundary condition (unit gradient) placed on the model profile.

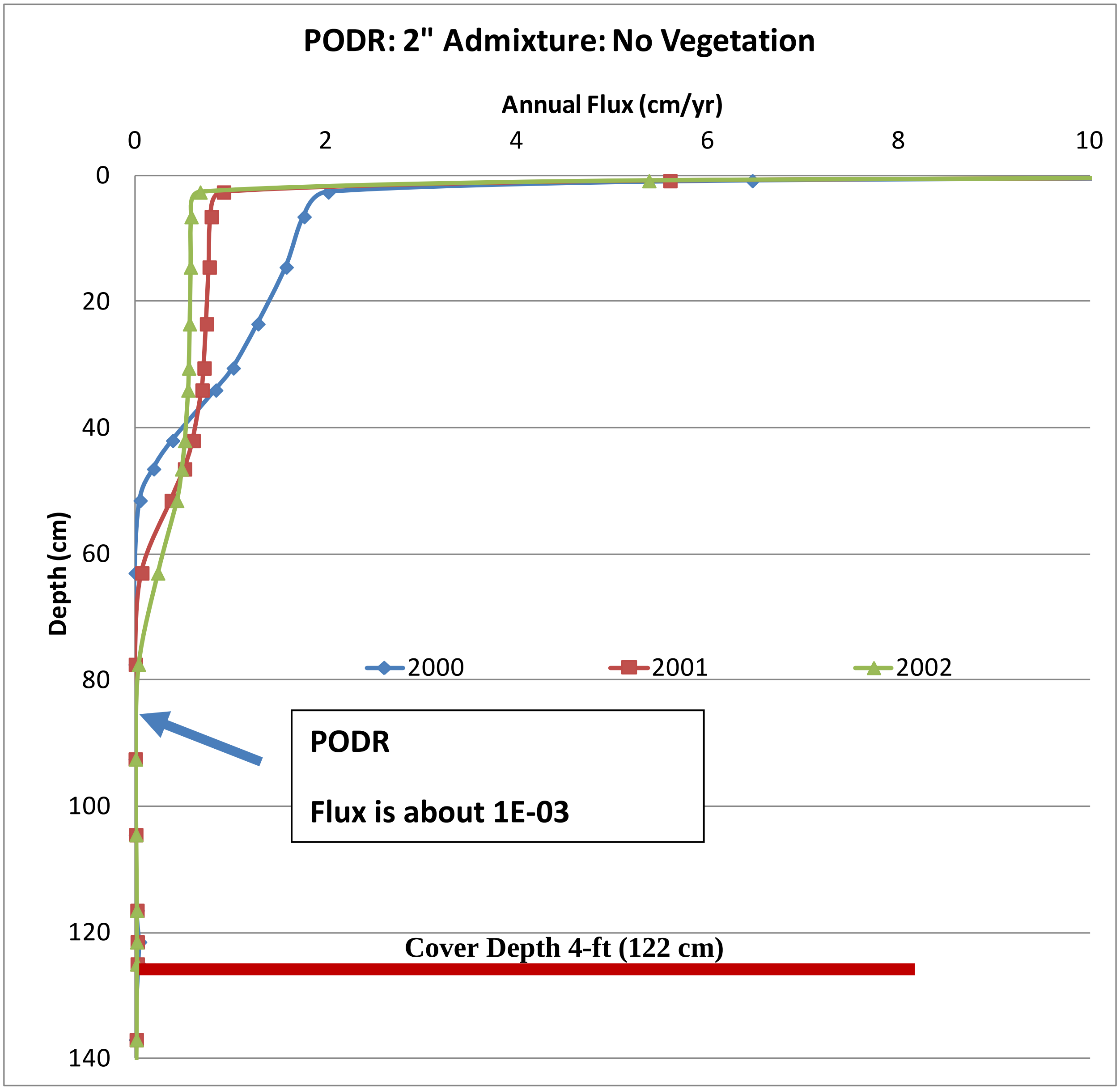


Figure 52. PODR for Initial Stage (No Vegetation) of Long-Term Simulation with 2", 18" Deep Admixture

B.2.2 SHORT-TERM TIME PERIOD OF LONG-TERM SIMULATION: RECLAIMED / DISTURBED VEGETATION

Figure 8 includes the twenty years from the 'short-term' stage of the long-term simulation for the 4-ft cover profile with a 18-inch deep surface admixture layer. Figure 8 shows that the PODR is reached at a depth of about 75-cm (30-in) for the short-term stage of the long-term set of simulations. The annual flux at this PODR is zero.

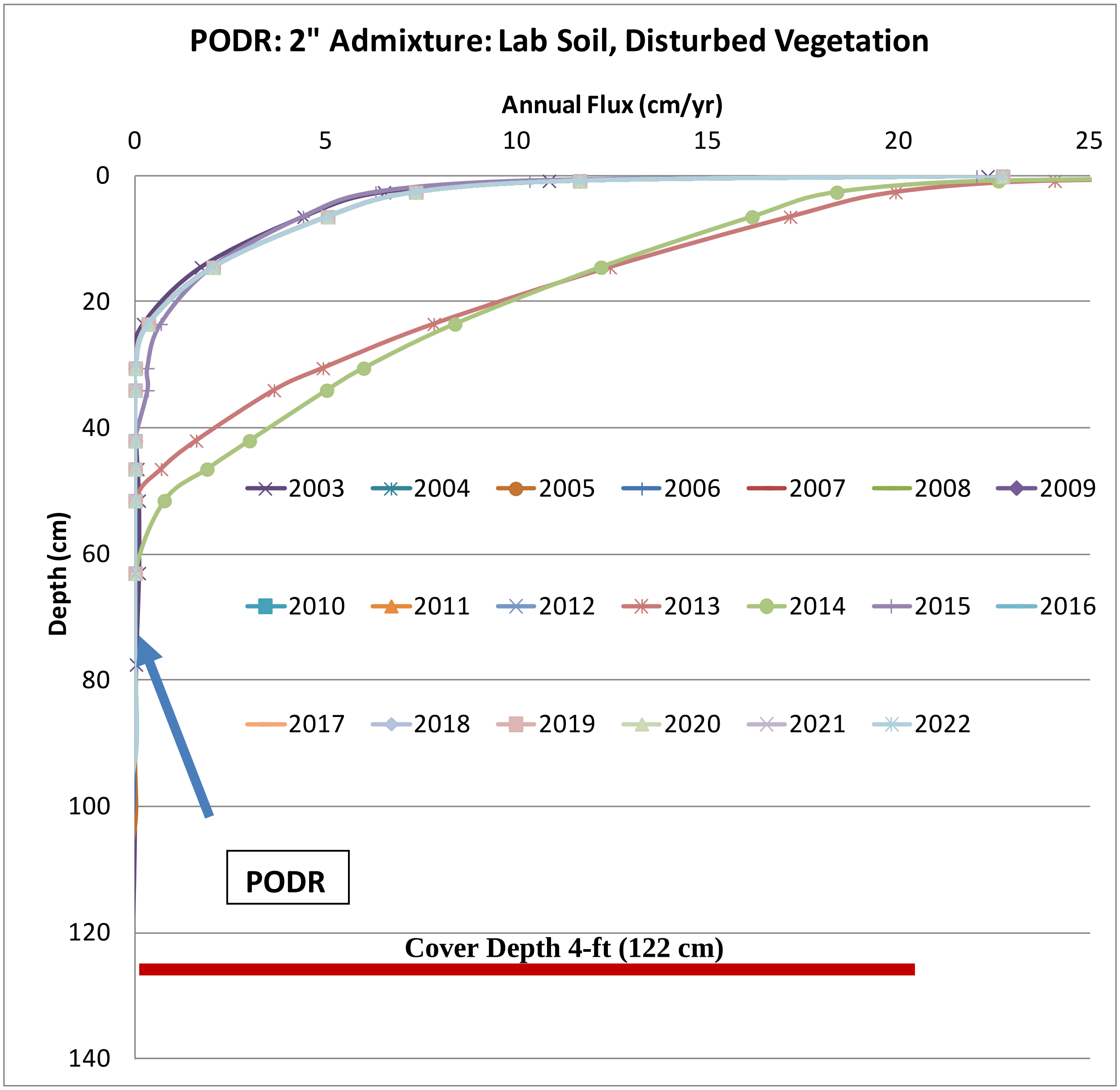


Figure 53. PODR for Short-Term Stage (Disturbed Vegetation) of Long-Term Simulation with 2", 18" Deep Admixture

B.2.3 INTERMEDIATE-TERM TIME PERIOD OF LONG-TERM SIMULATION: GRASSLAND VEGETATION

Figure 9 includes the twenty years from the 'intermediate' stage of the long-term simulation for the 4-ft cover profile with a 18-inch deep surface admixture layer. Figure 9 shows that the PODR is reached at a depth of about 122-cm (4-ft) for the intermediate-term stage of the long-term set of simulations. The annual flux at this PODR is zero. The wet climate did not produce the deepest PODR, rather it was produced during an average climate year. The deepest PODR occurs in the average years following the two consecutive wet years. Those two wet years allowed more infiltration into the profile and although it did not make it to the base of the cover, it slowly moved downward until the upward energy gradients overcame gravity and pulled the moisture back up.

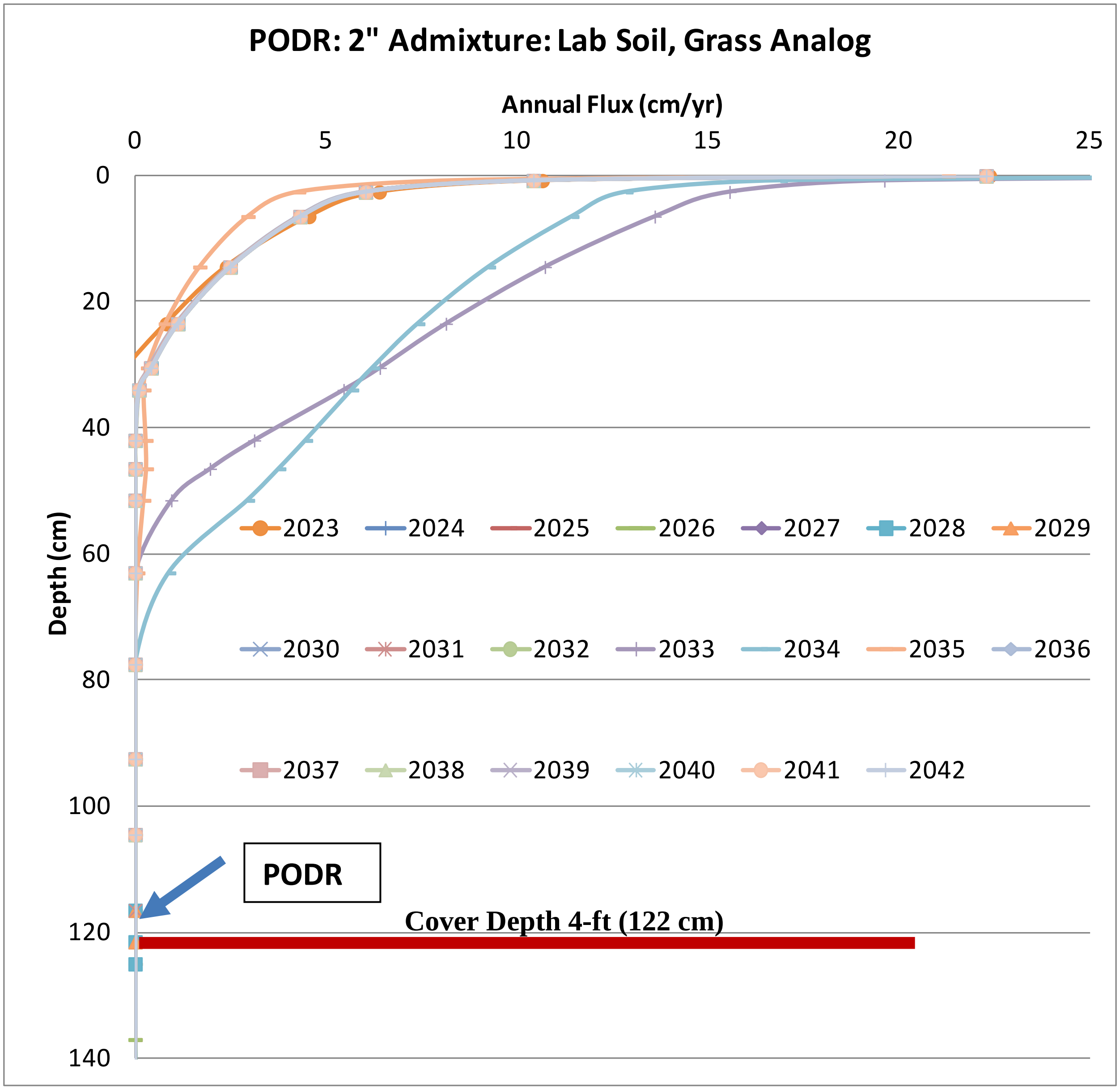


Figure 54. PODR for Intermediate-Term Stage (Grass Vegetation) of Long-Term Simulation with 2", 18" Deep Admixture

B.2.4 LONG-TERM TIME PERIOD OF LONG-TERM SIMULATION: SHRUBLAND VEGETATION

Figure 10 includes the twenty years from the 'long-term' stage of the long-term simulation for the 4-ft cover profile with a 18-inch deep surface admixture layer. Figure 10 shows that the PODR is reached at a depth of about 115-cm (45-in) for the long-term stage of the long-term set of simulations. The annual flux at this PODR is zero. The wet climate did not produce the deepest PODR, rather it was produced during an average climate year. The deepest PODR occurs in the average years following the two consecutive wet years. Those two wet years allowed more infiltration into the profile and although it did not make it to the base of the cover, it slowly moved downward until the upward energy gradients overcame gravity and pulled the moisture back up.

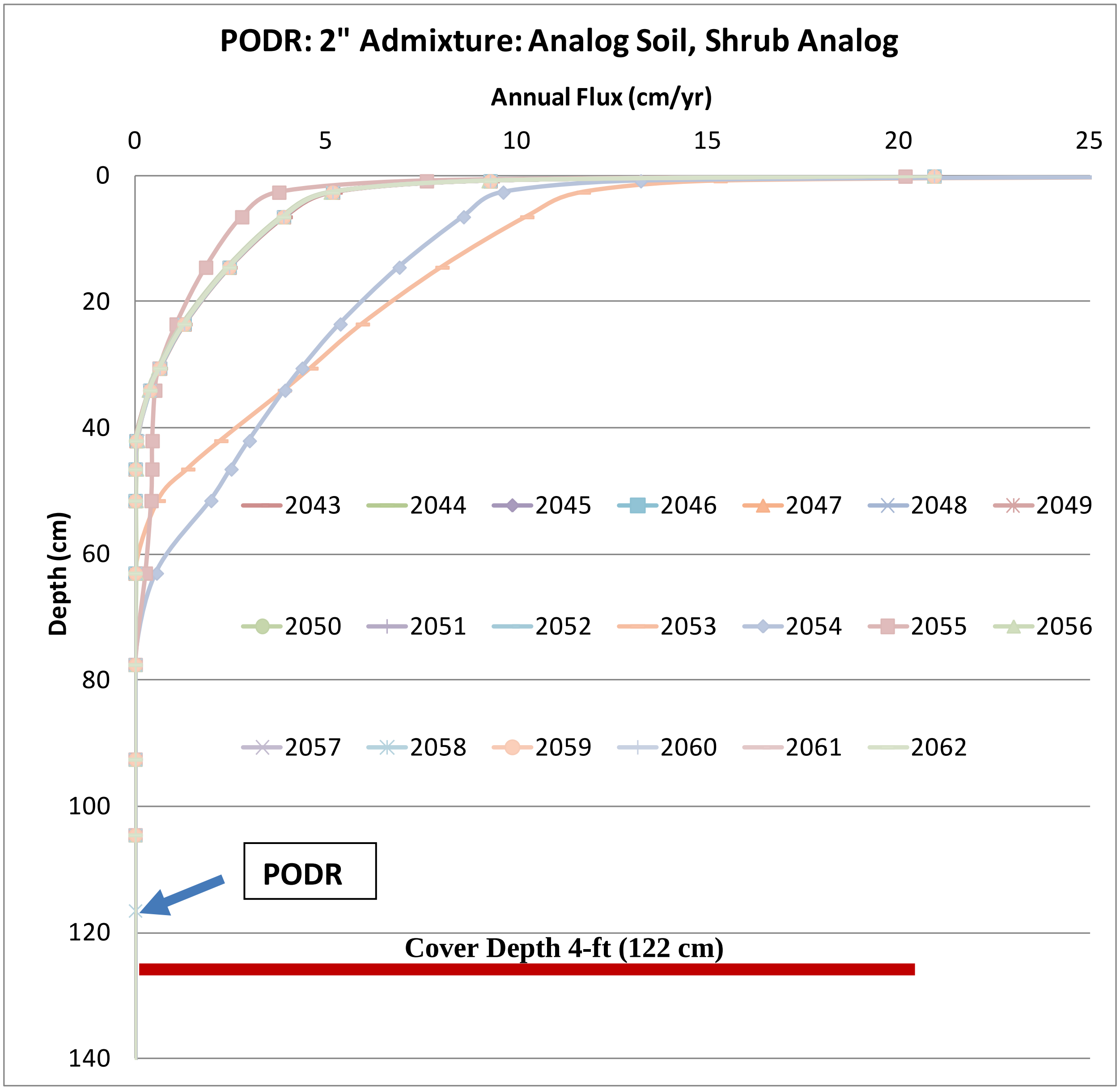


Figure 55. PODR for Long-Term Stage (Shrub Vegetation) of Long-Term Simulation with 2", 18" Deep Admixture

B.3 3-INCH, 27-IN DEEP ADMIXTURE

40CFR264.310, 20.3.13.1313 NMAC, and 10CFR61.51 require that flux through the cover be minimized. The 'point of diminishing returns' (PODR) is defined as the depth at which flux is effectively minimized; that is, the depth at which an additional increment of soil will no longer significantly reduce the flux. This depth of cover soil where flux is minimized is referred to as the Dwyer Point of Diminishing Returns Method (Dwyer et al 2007). Figure 11 contains all computer simulations years included for the cover geometry that included the top surface admixture to a depth of 27-inches. Figure 11 shows that the PODR is reached at a depth of about 115 cm (45-in)

for the long-term set of simulations that included a profile with the admixture top surface of 3-inch rock mixed with soil at a ratio of 33% to 67% by volume with the cover soil from the south drainage borrow area to a depth of 27-inches. The remainder of the profile included the same cover soil to a depth of 4-ft (122 cm) with mine spoils beneath this.

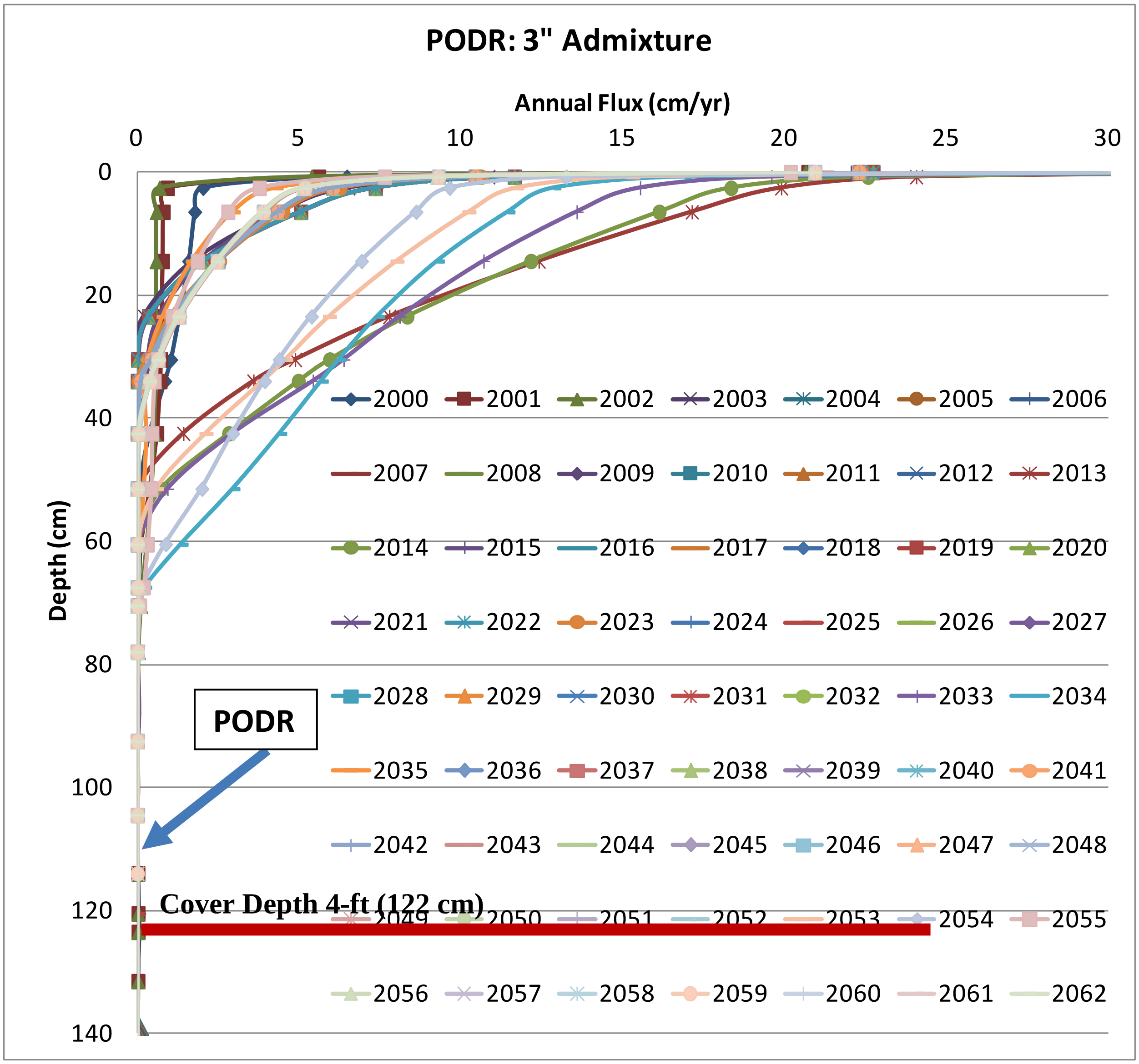


Figure 56. PODR for Long-Term Simulation with 3"Rock, 27" Deep Admixture in Profile

B.3.1 INITIAL TIME PERIOD OF LONG-TERM SIMULATION: NO VEGETATION

Figure 12 includes the three years from the 'initial' stage of the long-term simulation for the 4-ft cover profile with a 27-inch deep surface admixture layer. Figure 12 shows that the PODR is reached at a depth of about 85 cm (about 33-in) for the initial stage (no vegetation) of the long-

term set of simulations. The annual flux at this PODR is about 1E-03 cm/year. This flux is likely a result of the lower boundary condition (unit gradient) placed on the model profile.

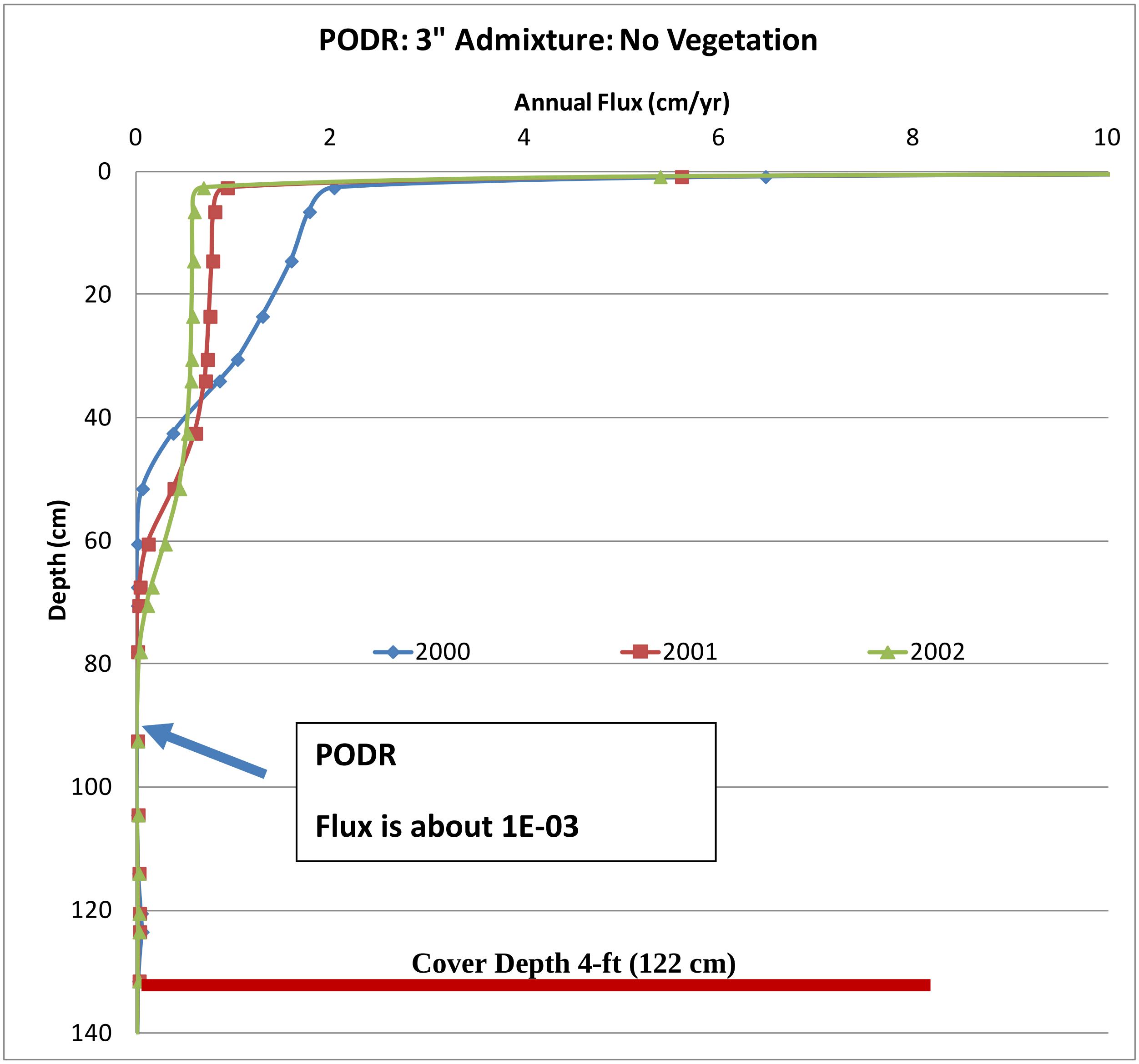


Figure 57. PODR for Initial Stage (No Vegetation) of Long-Term Simulation with 3", 27" Deep Admixture

B.3.2 SHORT-TERM TIME PERIOD OF LONG-TERM SIMULATION: RECLAIMED / DISTURBED VEGETATION

Figure 13 includes the twenty years from the 'short-term' stage of the long-term simulation for the 4-ft cover profile with a 27-inch deep surface admixture layer. Figure 13 shows that the PODR is reached at a depth of about 73-cm (29-in) for the short-term stage of the long-term set of simulations. The annual flux at this PODR is zero.

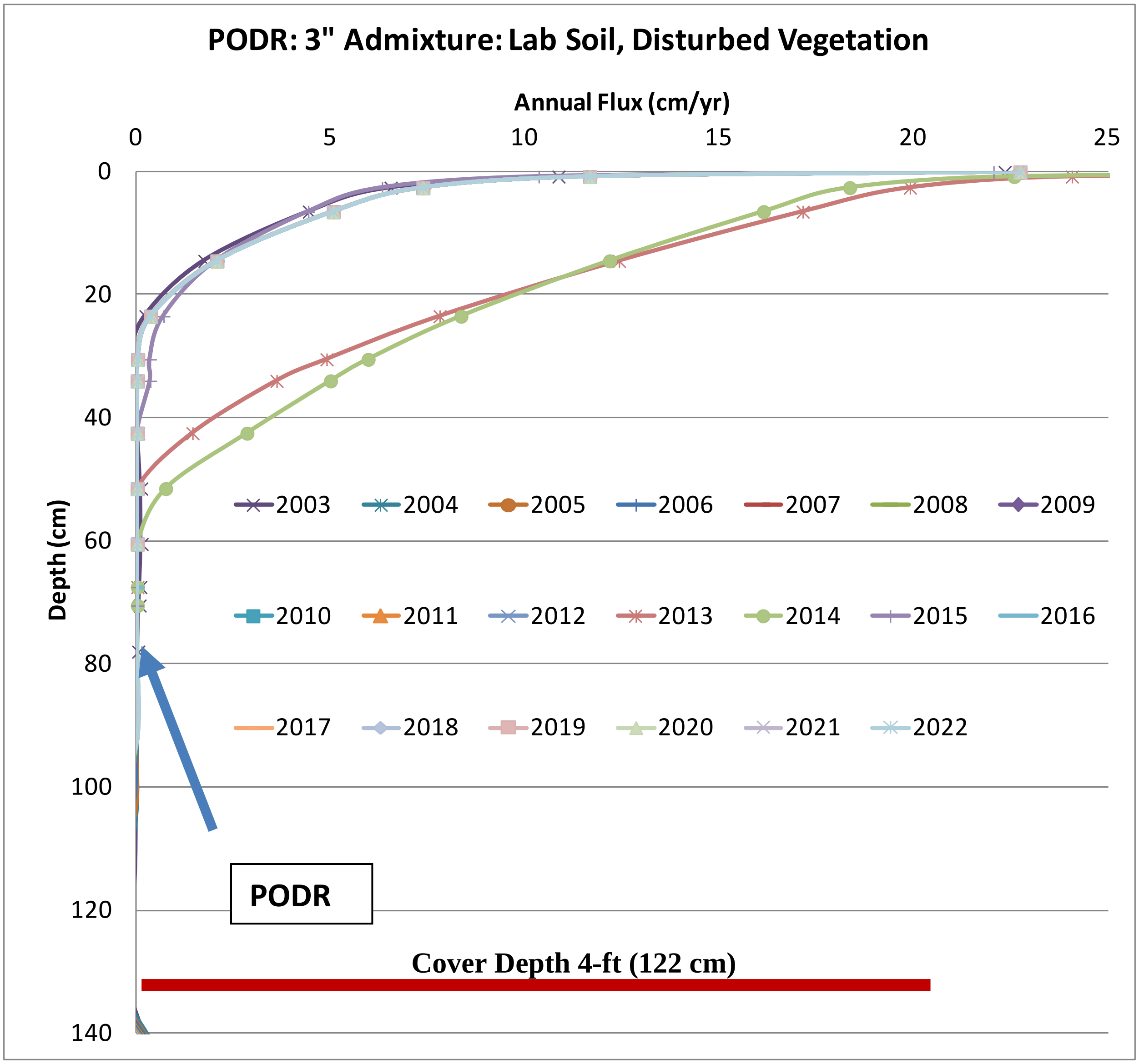


Figure 58. PODR for Short-Term Stage (Disturbed Vegetation) of Long-Term Simulation with 3", 27" Deep Admixture

B.3.3 INTERMEDIATE-TERM TIME PERIOD OF LONG-TERM SIMULATION: GRASSLAND VEGETATION

Figure 14 includes the twenty years from the 'intermediate' stage of the long-term simulation for the 4-ft cover profile with a 27-inch deep surface admixture layer. Figure 14 shows that the PODR is reached at a depth of about 107-cm (42-in) for the intermediate-term stage of the long-term set of simulations. The annual flux at this PODR is zero. The wet climate did not produce the deepest PODR, rather it was produced during an average climate year. The deepest PODR occurs in the average years following the two consecutive wet years. Those two wet years allowed more infiltration into the profile and although it did not make it to the base of the cover, it slowly moved downward until the upward energy gradients overcame gravity and pulled the moisture back up.

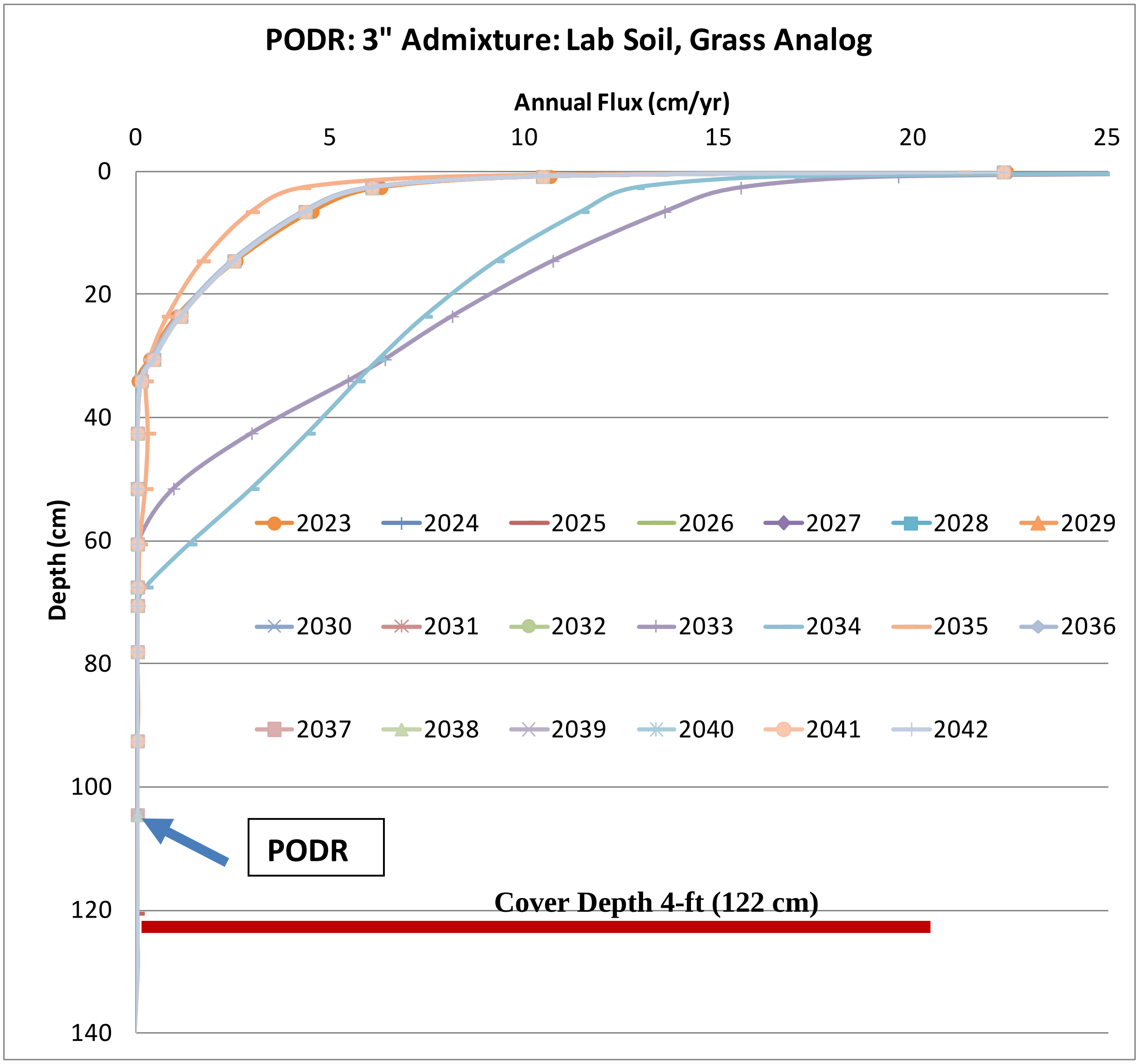


Figure 59. PODR for Intermediate-Term Stage (Grass Vegetation) of Long-Term Simulation with 3", 27" Deep Admixture

B.3.4 LONG-TERM TIME PERIOD OF LONG-TERM SIMULATION: SHRUBLAND VEGETATION

Figure 15 includes the twenty years from the 'long-term' stage of the long-term simulation for the 4-ft cover profile with a 27-inch deep surface admixture layer. Figure 15 shows that the PODR is reached at a depth of about 115-cm (45-in) for the long-term stage of the long-term set of simulations. The annual flux at this PODR is zero. The wet climate did not produce the deepest PODR, rather it was produced during an average climate year. The deepest PODR occurs in the average years following the two consecutive wet years. Those two wet years allowed more infiltration into the profile and although it did not make it to the base of the cover, it slowly moved downward until the upward energy gradients overcame gravity and pulled the moisture back up.

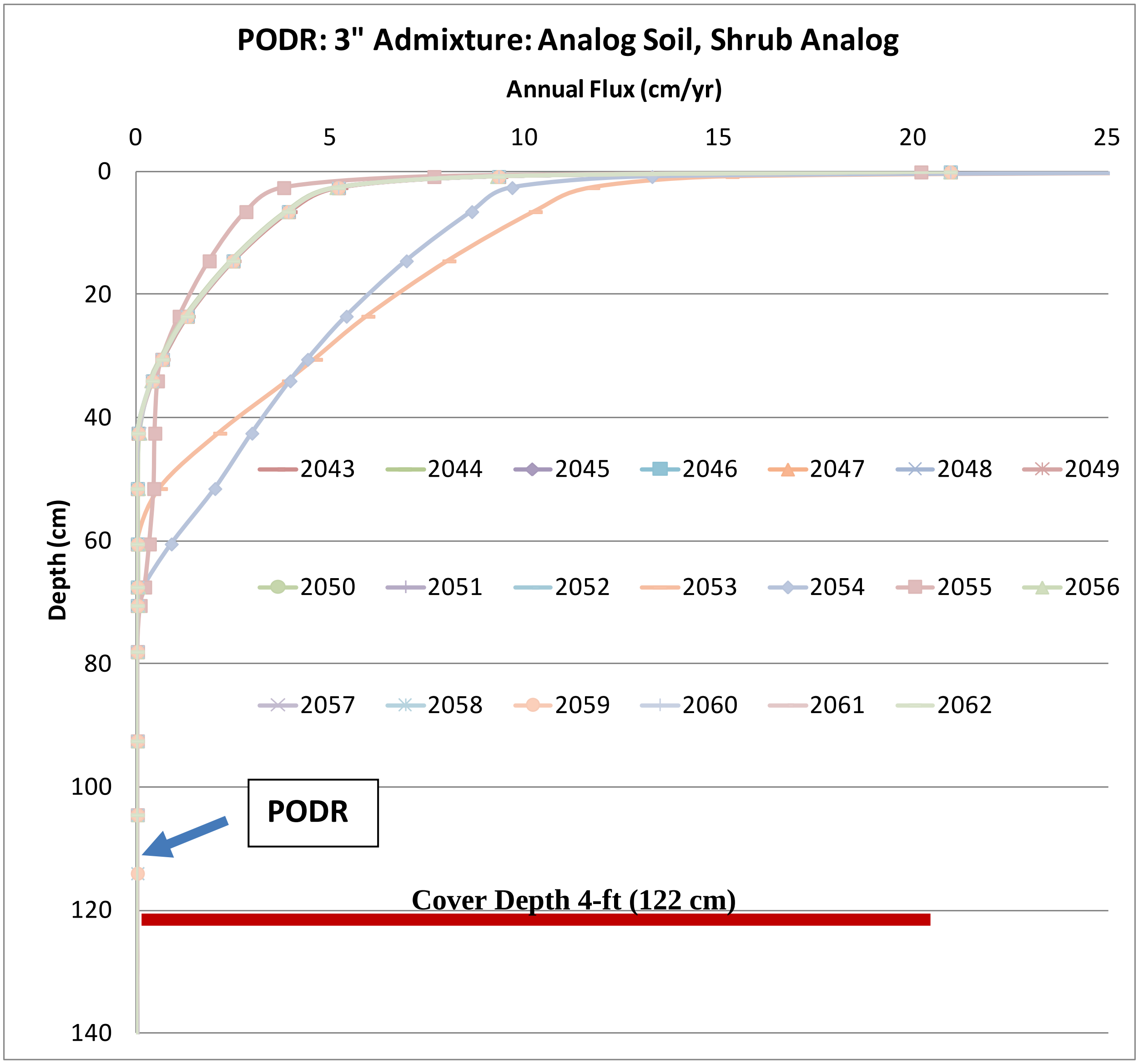


Figure 60. PODR for Long-Term Stage (Shrub Vegetation) of Long-Term Simulation with 3", 27" Deep Admixture

APPENDIX C

MODELING SENSITIVITY ANALYSES OF COVER SYSTEMS WITHOUT VEGETATION

The ET Cover was evaluated without vegetation since it may take one to several years for a quality stand of vegetation to be established. The cover without vegetation was modeled for a five-year period. It should be noted that average precipitation climate was utilized for the analysis of the cover without vegetation. This is considered conservative, given it is highly likely that the seeded vegetation will germinate during a typical year given the cover meets all applicable soil texture and nutrient requirements in the construction specifications are satisfied. Table 1 provides an overview of the net annual flux for these simulations. Although these simulations do not yield a net zero flux as the profiles with vegetation do (Appendixes A and B), the annual flux is very small. Furthermore, from the graphics provided in Appendixes A and B, the PODR and thus regulatory criteria regarding flux was satisfied well within the 4-ft cover profile. These annual flux rates are many orders of magnitude less than the existing cover profile is yielding (Dwyer 2017).

Table 104. Sensitivity Analyses Annual Flux (cm/yr) Without Vegetation for 4-ft (122 cm) Cover

Profile	Borrow	Yr1	Yr2	Yr3	Yr4	Yr5
Admixture with 1.5-inch rock	East Borrow Soil, Remolded (EB-B6-03), Grass	2.66E-03	2.69E-03	4.02E-03	9.68E-03	2.00E-02
	North Drainage Soil, Remolded (NB-B2-04), Grass	1.41E-02	5.09E-02	7.87E-02	9.08E-02	9.55E-02
	South Drainage Soil, Remolded (SB-B4-01), Grass	6.21E-04	6.20E-04	6.20E-04	6.25E-04	7.08E-04
	West Borrow Soil, Remolded (WB-B1-06), Grass	5.98E-04	5.96E-04	5.97E-04	6.71E-04	1.59E-03
Admixture with 2-inch rock	East Borrow Soil, Remolded (EB-B6-03), Grass	2.66E-03	2.67E-03	3.37E-03	6.54E-03	1.28E-02
	North Drainage Soil, Remolded (NB-B2-04), Grass	1.35E-02	3.94E-02	6.31E-02	7.58E-02	8.20E-02
	South Drainage Soil, Remolded (SB-B4-01), Grass	6.21E-04	6.20E-04	6.20E-04	6.22E-04	6.54E-04
	West Borrow Soil, Remolded (WB-B1-06), Grass	5.98E-04	5.96E-04	5.97E-04	6.22E-04	9.05E-04
Admixture with 3-inch rock	East Borrow Soil, Remolded (EB-B6-03), Grass	2.66E-03	2.66E-03	3.22E-03	6.04E-03	1.17E-02
	North Drainage Soil, Remolded (NB-B2-04), Grass	1.32E-02	3.63E-02	5.67E-02	6.75E-02	7.30E-02
	South Drainage Soil, Remolded (SB-B4-01), Grass	6.21E-04	6.20E-04	6.20E-04	6.21E-04	6.46E-04
	West Borrow Soil, Remolded (WB-B1-06), Grass	5.98E-04	5.96E-04	5.96E-04	6.18E-04	8.93E-04
Admixture with 1.5-inch rock	East Borrow Soil, Analog, Grass	2.66E-03	2.79E-03	5.93E-03	1.69E-02	3.40E-02
	North Drainage Soil, Analog, Grass	1.57E-02	1.29E-01	2.38E-01	2.81E-01	2.93E-01
	South Drainage Soil, Analog, Grass	2.43E-03	2.58E-03	8.18E-03	3.70E-02	9.18E-02
Admixture with 2-inch rock	East Borrow Soil, Analog, Grass	2.66E-03	2.70E-03	4.11E-03	9.55E-03	1.91E-02

Profile	Borrow	Yr1	Yr2	Yr3	Yr4	Yr5
	North Drainage Soil, Analog, Grass	1.41E-02	9.82E-02	1.91E-01	2.37E-01	2.56E-01
	South Drainage Soil, Analog, Grass	2.43E-03	2.52E-03	5.97E-03	2.38E-02	6.05E-02
Admixture with 3-inch rock	East Borrow Soil, Analog, Grass	2.66E-03	2.66E-03	3.58E-03	8.11E-03	1.70E-02
	North Drainage Soil, Analog, Grass	1.37E-02	9.02E-02	1.71E-01	2.10E-01	2.27E-01
	South Drainage Soil, Analog, Grass	2.43E-03	2.50E-03	5.70E-03	2.25E-02	5.54E-02