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DEPARTMENT OF ENERGY
Environmental Management Los Alamos Field Office (EM-LA)
Los Alamos, New Mexico 87544

AUG 31 2015

CERTIFIED MAIL-RETURN RECEIPT REQUESTED

RECEIVED
AUG 31 2015
NMED
Hazardous Waste Bureau

John Kieling
Bureau Chief
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Drive East, Building 1
Santa Fe, NM 87505-6303

Dear Mr. Kieling:

Subject: Submittal of Reply of Approval with Modifications Work Plan for Los Alamos County Airport Landfill Cover Replacement Los Alamos National Laboratory EPA ID #NM0890010515, HWB-LANL-15-018

Per your request, please find enclosed two sets of hard copy replacement pages for tables two and three, figure 10, and other affected portions of the design report.

If you have any questions, please call Ramoncita N. Massey at (505) 665-7771 or e-mail her at Ramoncita.Massey@em.doe.gov.

Sincerely,

Christine Gelles
Acting Manager
Environmental Management
Los Alamos Field Office

Enclosures

37269

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The moisture retention data for the cover soil was also altered to reflect the addition of the rock (Equation 4). Each respective volumetric moisture content (saturated and residual) was altered per ASTM D4718 and Bouwer & Rice (1984). The revised moisture characteristic curve with respective van Genuchten parameters for input into the UNSAT H computer simulations (Table 2).

$$\boldsymbol{\theta_b = (1 - V_r) * \theta_s} \qquad \text{Equation 4}$$

$$where: \theta_{b,s\ or\ r} = volumetric\ moisture\ content, bulk$$

$$\theta_{s\ or\ r} = volumetric\ (saturated\ or\ residual) moisture\ content\ for\ soil, respectively$$

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 computer simulation are summarized in Table 2. The layers correspond to the profile shown in Figure 5.

Table 2. Soil Input Parameters

Soil	Depth BGS[1]	K_{sat}	Van Genuchten Parameters			
			θ_s	θ_r	α (1/cm)	n
Rock/Soil Admixture	0 to 0.5-ft (0 to 16 cm)	2.26E-03 in/sec (5.73E-03 cm/sec)	0.2635	0.046	0.0076	1.8637
Cover Soil	0.5-ft to 1.0-ft (17 cm to 31 cm)	3.39E-03 in/sec (8.60E-03 cm/sec)	0.3513	0.0613	0.0076	1.8637
Cover Soil	1.0-ft to 2.0-ft (32 cm to 61 cm)	1.69E-03 in/sec (4.3 E-03 cm/sec)	0.3513	0.0613	0.0076	1.8637
Cover Soil	2.0-ft to 3.0-ft (62 cm to 91 cm)	9.45E-07 in/sec (2.4E-06 cm/sec)	0.3317	0.0	0.0055	1.2128
Subgrade Soil	Beneath 3.0-ft (92 cm to 300 cm)	3.39E-04 in/sec (8.6E-04 cm/sec)	0.3513	0.0613	0.0076	1.8637

1. [1] below ground surface (BGS)

4.1.8 MODEL OUTPUT

The computer simulations output is summarized in Table 3 and Figure 10. The computer simulations involved running 10 typical years consecutively to mitigate any biases from assumed initial soil conditions, followed by the wettest year on record. The table below contains the tenth year of the average consecutive modeled years and the wettest year on record. The following 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) the remaining water storage capacity within the modeled soil profile.

Following the tables is a graphical summation (Figure 10) of the soil depth versus annual flux for the average climate year and wettest year on record, respectively. 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. At this depth the governing regulations (40CFR264.310 and 20.3.13.1313 NMAC) are satisfied for percolation.

Table 3. Computer Simulation Results

Year	Precip.	PET	Transp.	Evap.	Runoff	Percolation[1]	Store
Average Year	45.2 cm (17.8 in)	145.2 cm (57.2 in)	14.0 cm (5.5 in)	31.2 cm (12.3 in)	0	0	23.1 cm (9.1 in)
Wettest Year on Record	77.0 cm (30.3 in)	136.3 cm (53.6 in)	17.2 cm (6.8 in)	57.4 cm (22.6 in)	0	0	25.5 cm (10.0 in)

[1] Percolation is zero at a depth of 87 cm (34 in) for average climatic conditions; percolation is zero at a cover depth of 89 cm (35 in) for the wettest year on record.

40 CFR 264.310 and 20.3.13.1313 NMAC require that flux through the cover be minimized. Under typical climatic conditions for the site, the flux minimization criterion is satisfied for the cover profile at a depth of 87 cm (34 in). Refer to Figure 10. Actually flux is reduced to zero at this depth. For the wettest year on record with an annual precipitation in excess of 30-inches, the flux was minimized (zero) within the cover profile at a depth of just over 89 cm (35 in). Therefore, no flux is estimated for the 3 ft. thick cover profile modeled. Figure 10 represents the computer simulation results of a 3-foot thick cover profile whereby the bottom foot of soil is a higher fines content soil resulting for a mixture of 50% overburden (soil with a minimum of 25% fines) and a higher clay content soil (minimum fines content of 60%). Fines content is defined as the soil that passes a #200 sieve that generally represents silt and clay. The 18-inches directly above this bottom foot of blended soil is simply overburden (soil with a minimum fines content of 25%). The top 6-inches of soil are 75% overburden soil mixed with 25% rock by volume.

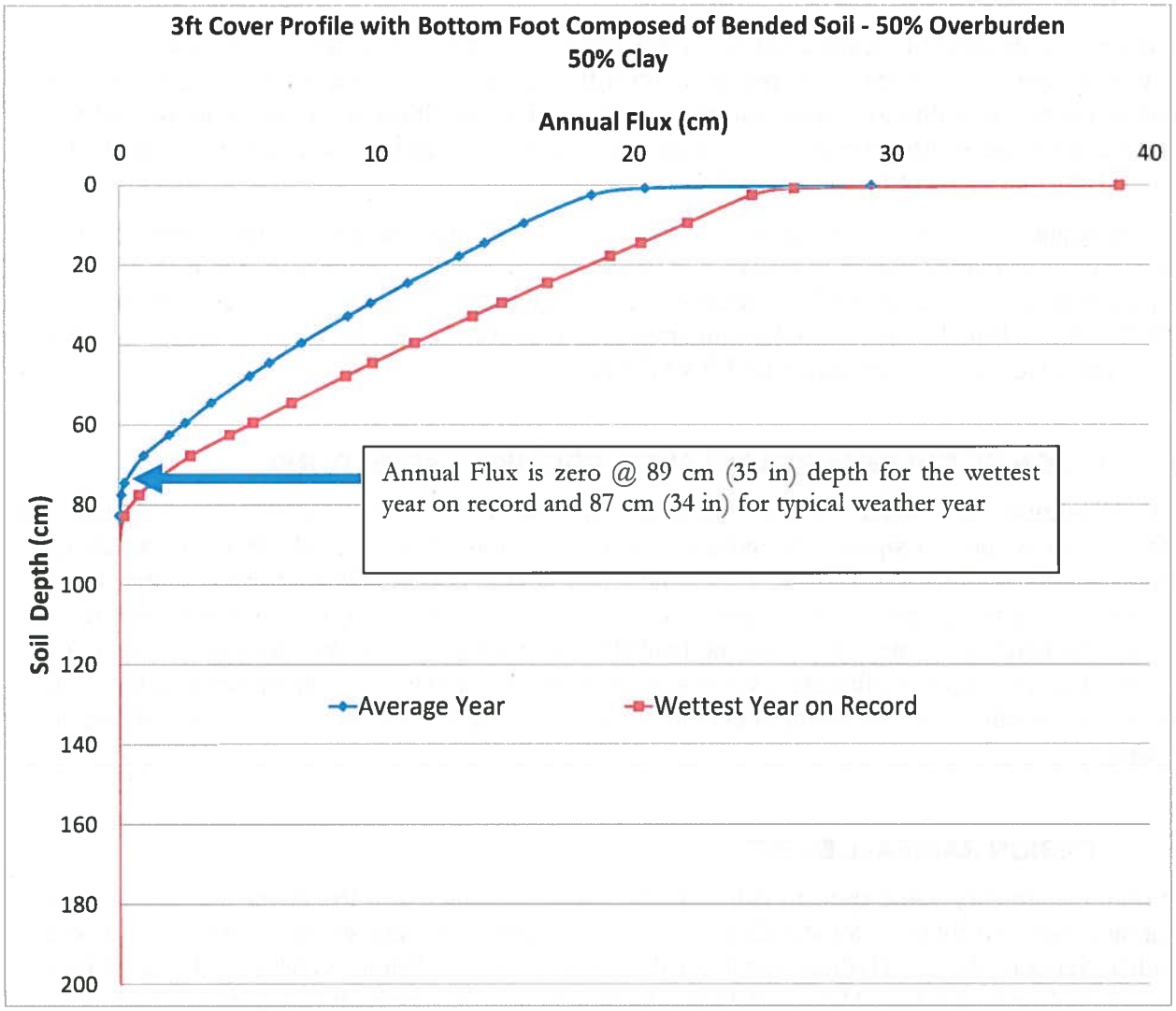

Figure 10. Computer Simulation Results

Conservatism was incorporated into the model in the form of limiting the precipitation rate to encourage 100% infiltration of precipitation into the cover profile. Furthermore, the modeling is one-dimensional and thus slope is not taken into account and thus there was no runoff due to slope. The upper 24 inches of the cover profile had its saturated hydraulic conductivity increased for the computer simulations to take into account potential changes to the soil hydraulic properties due to such things as freeze/thaw cycles, wet/dry cycles, biointrusion, and uncertainty in rock mixtures.

5.0 EROSION

The cover was designed to resist erosion. A top surface composed of a mixture of rock and cover soil was designed to mitigate the potential for rill or gully formation, as well as, reduce the potential for soil loss due to surface runoff. Research (Dwyer 2003) and monitoring of multiple projects within the southwestern United States has shown this surface admixture also promotes an effective establishment of native vegetation.

The following subsections summarize the design methodology and calculations performed to satisfy the performance objectives related to erosion. Section 5.1 summarizes the design of the rock/soil admixture. Section 5.2 summarizes the stability of the final slope as a rocky soil per NUREG 1623. Finally, section 5.3 summarizes the compliance of annual soil loss to less than two tons/acre/year as recommended by EPA (1991).

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

Rock/soil admixtures provide excellent 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 landfill cover surface, some winnowing of fines from the admixture is expected, creating a vegetated erosion-resistant surface sometimes referred to as a 'desert pavement'. The following rock/soil admixture design is for the cover surface or 'desert pavement'.

5.1.1 DESIGN RAINFALL EVENT

The rainfall intensity value used to calculate the runoff volume from the cover was determined using data supplied by the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) Hydrometerological Design Studies Center. The data from NOAA Atlas 14, Volume 1 for Los Alamos, NM was used whereby the one hour precipitation frequency estimate for a 100 return period is 2.17 inches (5.51 cm). The one hour time of concentration is conservative for any contributory area less than 50 acres (20 hectares) (Lindeburg 1989).

5.1.2 RUNOFF PREDICTION

The "rational method" was used to estimate runoff volumes. This method is commonly used in civil engineering applications and is a method approved by DOE (1989) for design of cover systems for sites regulated by the Uranium Mill Tailings Radiation Control Act of 1978 (i.e., UMTRA sites). 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 (Equation 5), the peak rate of runoff, (Q), in cubic feet per second (cfs) [runoff is actually in acre-inches/hour but is rounded to cfs] is given by the following expression:

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ENVIRONMENTAL MANAGEMENT
LOS ALAMOS FIELD OFFICE
CORRESPONDENCE COORDINATION SHEET

Package/Issue Title: Submittal of Reply of Approval with Modifications Work Plan for Los Alamos County Airport Landfill Cover Replacement	**Suspense/Need by Date:** 8/31/2015 **File Code:** 4782.6
POC Group/Phone # for Package: Ramoncita Massey-5-7771	**Admin Assist Initials:** kml KL for Annette Russell
Content Management ID Number(s): COR-EPO-8.27.2015-640424/ EPO-32RM-831-640424	

Background:
Submittal of Reply of Approval with Modification Work Plan for Los Alamos County Airport Landfill Cover Replacement, Los Alamos National Laboratory, EPA ID# NM0890010515 HWB-LANL-15-018.

Any Specific HQ's or Contractor Concerns/Sensitivities:
No concerns

Originator Analysis and Recommendation: (Why is this okay to sign?)
Information requested is being changed and submitted to NMED officially. We electronically submitted the unofficial changes already. They were simply just clarifications.

Organization	Concurrence Name	Initials	Concur Date	Comments
PT&C	K. Laskey	Preparer	8/27/15	
EM-LA	G. Falance	GF	8/27/15	
EM-LA	R. Massey	K.W. for R. Massey	8/28/15	
EM-LA	D. Rhodes	DSR	8-31-2015	
EM-LA	G. Henckel	CEH	31 Aug 2015	
EM-LA	C. Gelles	DSR for	8-31-2015	Acting

August 2015

ET COVER DESIGN REPORT

LOS ALAMOS COUNTY AIRPORT LANDFILL COVER REPLACEMENT

prepared for:
Department of Energy
Environmental Management Los Alamos Field Office (EM-LA)
Los Alamos Field Office
Los Alamos, NM 87544

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Revision 02

EXECUTIVE SUMMARY

This report provides a detailed summary of the design methodology, input parameters, unsaturated flow modeling, and applicable calculations justifying the cover profile for the Los Alamos County Airport Landfill. This cover system will replace a previously installed cover deemed to be inadequate (Dwyer 2012). The profile is comprised of a soil cover referred to as an Evapotranspiration (ET) cover with a gravel/soil surface admixture referred to as a 'desert pavement'. The cover system is designed to store infiltrated water until it can be removed via the combination of surface evaporation and transpiration through the vegetation collectively referred to as ET.

The new soil cover referred to as an Evapotranspiration (ET) Cover has been designed to meet applicable regulatory criteria and performance objectives. The cover is 3.0-ft thick that includes a surface layer composed of a 6-in thick rock/soil admixture (Figure 5). The overall profile provides adequate storage capacity to minimize flux from moving below the cover and attenuate radon gas from the covered mine spoils below established performance criteria. 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.

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1.0 INTRODUCTION

This Design Report summarizes the design of a new cover system to replace the previously installed cover system that featured an asphaltic surface deemed to be inadequate (Dwyer 2012). The asphalt cover system was installed in early 2007 on the solid waste landfill located adjacent to the Los Alamos County (LAC) Airport. This cover system is composed of an asphalt surface (MatCon) in conjunction with five reinforced concrete slabs (Figure 1). A passive gas collection system was also incorporated into the cover system. The north and east perimeter side slopes of the LAC Airport Landfill are a prescriptive cover with a compacted soil and vegetated surface. The eastern slope is reinforced by retaining structures. The existing airport hangar facilities are located adjacent to the western edge of the landfill. A surface water drainage trench is located to the south.

The LAC airport landfill was closed as a hazardous waste landfill following guidelines set forth in the Resource Conservation and Recovery Act (RCRA), Subtitle C closures (40 CFR 264, Subpart N as incorporated by 20.4.1.600 NMAC). The intent of the asphalt cover system was to perform equivalent to a prescriptive cover for at least the duration of the 30-year post-closure care period (DOE/EA-1515 Final Environmental Assessment for Proposed Closure of the Airport Landfills within TA73). The reinforced concrete slabs were installed to provide a foundation for future airplane hangars. The surrounding asphalt surface was to provide access for the airplanes in and out of the hangars. The asphaltic surface was a specialty product produced by MatCon, Inc. marketed to be relatively impermeable.

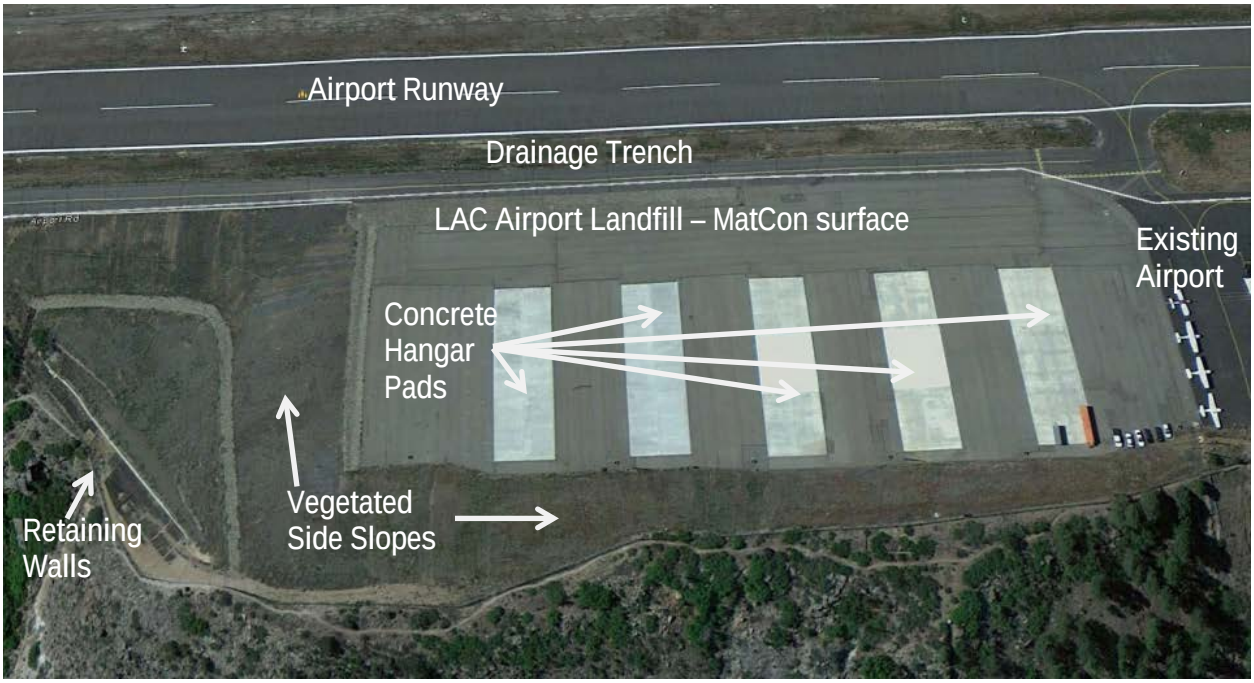

Figure 1. Aerial View of Previously Installed MatCon Cover & Concrete Hangar Pads (to be removed)

The US Department of Energy (DOE) began monitoring the LAC Airport Landfill in 2009. In December 2013, the DOE submitted to the New Mexico Environment Department (NMED) a *Formal Notification of Methane Levels at 100 Percent of the Lower Explosive Limit at Vent Risers along the North Edge of the Los Alamos Airport Landfill Cap and Request for a Waiver of the Implementation of an Active Gas Collection Using Blowers (Notification).* The NMED replied to this notification and waiver for active gas collection on July 25, 2014 (Pre-Design Work Plan, Dwyer Engineering 2014). The reply stated *"The Permittees must implement an active gas collection system or propose an alternative remedial measure to reduce infiltration of water into the landfill and to reduce methane levels below 100% LEL."* The reply further stated: *"The Permittees must submit a work plan for the implementation of an active gas collection system or an alternate remedial measure to NMED no later than September 30, 2014. Until the work plan is submitted to NMED, the Permittees must continue weekly monitoring at SWMU 73-001 (a) and continue to submit data to NMED on a monthly basis."*

In response to this NMED reply, the DOE submitted a Pre-Design Work Plan (Dwyer 2014) dated September 30, 2014, stating that the DOE will continue to monitor the landfill on the current schedule, but that the long-term solution will be to replace the cover system with a properly designed ET Cover. This Design Report summarizes the design of the cover profile to replace the existing asphalt cover.

2.0 LOS ALAMOS COUNTY AIRPORT LANDFILL BACKGROUND

The LAC airport is situated on one of the narrow mesas of the Pajarito Plateau that flank the eastern edge of the Jemez Mountains. The airport covers approximately 89 acres. Ground elevations range from approximately 7170 ft. above mean sea level (MSL) on the western end of the airport to approximately 7050 ft. on the eastern end. The runway grade is approximately 1.5 degrees toward the east. The airport is bounded on the north and east by steep slopes of the Pueblo Canyon. New Mexico State Road 502 trends along the south side of the property. Single unit housing is located west of the airport.

Two inactive solid waste disposal sites [the airport landfill, SWMU 73-001(a) and the debris disposal area (DDA), SWMU 73-001(d)] are located at the LAC Airport (Figure 2). This Design Report focuses only on the airport landfill, not the DDA. The DDA is mentioned for background information only. In late 2006 and early 2007, the Final Remedy landfill cover system was installed at the LAC airport landfill. The Final Remedy design and completion activities for the LAC airport landfill and the DDA were provided in the *Remedy Completion Report, DOE LASO TA-73 Airport Landfill SWMUs 73-001(a) and 73-001(d) April 2007 (North Wind and Weston 2007).* As a condition of the remedy approval, NMED required post-closure care and monitoring of these two inactive solid waste disposal sites and submission of an annual report summarizing results from this activity.

The LAC airport landfill operated from 1943 to 1973 for the disposal of solid waste consisting of household trash from the Los Alamos town site and office trash from Los Alamos Scientific Laboratory. Prior to 1965, some of the waste was incinerated and subsequently buried in the airport landfill. Approximately 489,500 cubic yards of waste was disposed of in the landfill. The LAC airport landfill continued to receive waste until June 1973. From 1984 to 1986, wastes were excavated from the western portion of the LAC airport landfill and placed in the DDA (Figure 2). The excavations were backfilled in preparation for construction of airport hangars and tie-down areas (LANL, 1998).

From 1984 to 1986, approximately 126,000 cubic yards of burned debris were excavated from the western end of the airport landfill and reburied in a pair of parallel trenches at the DDA. In late 2006 and early 2007, the asphalt landfill cover system was installed on the airport landfill (Figure 1). The final remedy design and completion activities for the landfill and the DDA were provided in the "Remedy Completion Report, DOE LASO TA-73 Airport Landfill, SWMUs 73-001(a) and 73-001(d)" (North Wind and Weston 2007). Approximately 50,000 cubic yards of waste were relocated within the SWMU boundary during the 2006 remedy construction activities. With the exception of a single container of Freon-113, uncovered and subsequently managed off-site, no other hazardous or radioactive materials were discovered. After waste relocation, regrading and compaction were conducted; the following features were installed for the LAC airport landfill cover (Figure 1):

- Approximately six acres of MatCon (Modified Asphalt Technology for Waste Containment) asphalt pavement;
- Five concrete hangar pads within the MatCon pavement area;
- Landfill-gas collection system;
- Two rock retaining walls;
- Concrete retaining wall;
- Turf reinforcement matting (TRM);

- Revegetation of approximately four acres with native grasses; and
- A storm water collection system consisting of five trench drains, seven drain inlets, approximately 1950-ft of associated buried concrete storm-sewer lines, an 18 inch-diameter high-density polyethylene outfall pipe approximately 110 ft. in length, and three riprap drainage channels.
- Side slopes composed of a vegetated 2.5 ft. thick earthen cover with a composite drainage layer within its profile.

The first formal inspection of the airport landfill was conducted in July 2009. Inspection activities were conducted as part of post-closure and care and monitoring requirements required under 40 Code of Regulations 265.310 for Resource Conservation and Recovery Act (RCRA) Subtitle C landfill facilities. The inspection focused on the individual elements of the landfill cover including: the MatCon pavement area and hangar pads, vegetated areas, rip rap drainage channels, concrete and rock retaining walls, the storm water collection system and all temporary erosion control features. Inspection activities and findings were documented in annual inspection reports, generally submitted to NMED February 2010.

Several erosion control modifications and storm water enhancements were made in late 2009 and the spring of 2010; however, noticeable settlement directly impacting hangar pads was not addressed. Significant differential settlement (as much as 2-ft in areas) has been measured in the cover surface to date (Dwyer 2014).

Although the land and hangar pads have been under LAC ownership and management since the 2007 land transfer, the County has not built hangars on the pads to date. This is due to the noted degradation of the asphalt cover and concrete hangar pads.

In 2009 and 2010, erosion features (rills and small gullies) associated with storm water runoff from the paved areas above the vegetated slopes was repaired. In addition, the curb along the taxiway was repaired and extended to redirect storm water away from the main vegetated slope. These repairs and enhancements were detailed in the “Final Construction Report for Los Alamos Airport Landfill TA-73, SWMU 73-001(a) Cover Improvements, Los Alamos, New Mexico” (North Wind 2010).

The NMED’s approval with modifications for the remedy completion report required monitoring of the storm water runoff from the site.

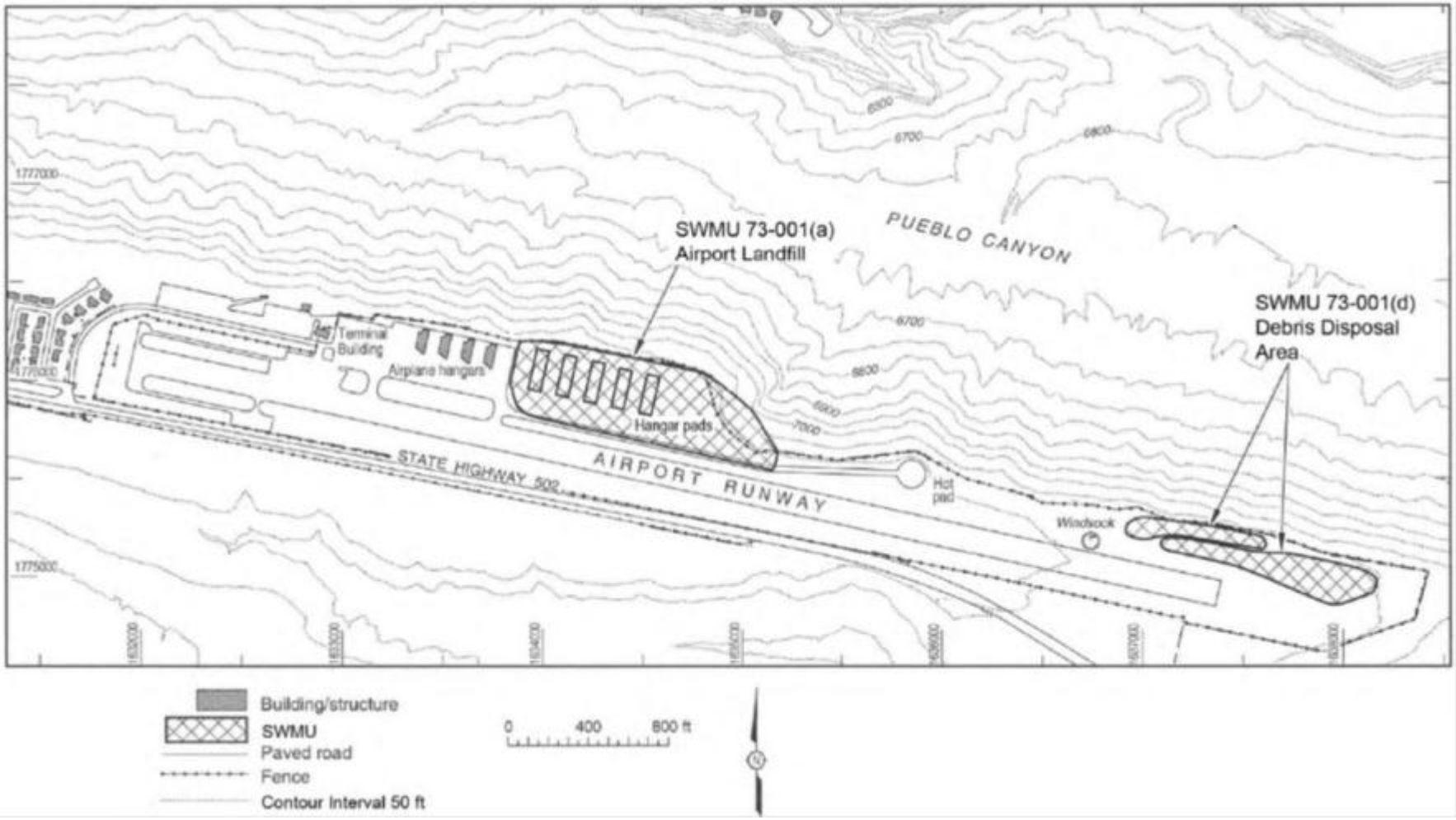

Figure 2. Landfill Locations (LANL 1998)

2.1 LAC AIRPORT LAND USE

The LAC Airport is situated on the eastern edge of the town site of Los Alamos, NM on a narrow mesa between State Road 502 and Pueblo Canyon (Figure 1). The LAC Airport was built in 1947 by the Atomic Energy Commission (predecessor to DOE) to serve the transportation needs of the Los Alamos Scientific Laboratory. The airport is currently owned and operated by the County of Los Alamos. The airport property was conveyed from DOE to the Los Alamos County in October 2008 and was formerly part of LANL Technical Area (TA) 73.

The airport is predominately used for general aviation purposes such as recreation and air taxi. An average of 30 operations (takeoffs and landings) occur daily (Ploeger 2009). The vast majority of operations involve single-engine propeller aircraft. Business jets and air-ambulance helicopters occasionally use the airport.

The single runway is 5,500 ft. long. The airport facilities consist of a terminal building, a two-story storage building (formerly the landfill incinerator building), four rows of T-hangars, various taxiways, two parking aprons, a self-service fueling station, the Hot Pad, and a strip of older hangars on the west end of the airport. Prior to 2000, the Hot Pad was used for loading and unloading LANL sensitive cargo. The Hot Pad is now used for aircraft parking and has six tie-down spots.

Pueblo Canyon extends along the north side of the airport and is undeveloped land. An unpaved road trends along the floor of the canyon. Road traffic typically consists of a few vehicles a day. The newer LAC waste-water treatment plant is located approximately 1.1 miles down the canyon from the Airport landfill.

The airport property and Pueblo Canyon are not located within the boundaries of the Santa Fe National Forest.

2.2 LOS ALAMOS, NM CLIMATE

Los Alamos, NM has a temperate mountain climate with four distinct seasons (LANL 1999). For the LANL meteorological station nearest the airport, the mean precipitation including snowmelt is approximately 18.7-in per year (LANL 2006). The peak months for precipitation are July and August (Figure 3) when afternoon thunderstorms can produce high intensity rainfall.

2.3 SITE GEOLOGY

The Bandelier Tuff (consolidated volcanic ash) forms the bedrock underlying the airport. The Hackroy series is developed from the tuff and is characterized as a well-drained sandy loam (NRCS 2008). The uppermost north-facing slope near the airport is steep and rocky with scattered scrub oak, chamisa, bunch grass, and juniper. Near the canyon floor, the slope lessens and the vegetation is dominated by ponderosa pine. The channel along the canyon floor is ephemeral and has stream flow only in response to heavy precipitation. The vertical relief from the airport paved area to the canyon floor is approximately 500-ft. The depth to groundwater beneath the airport is about 1200-ft (North Wind 2006). No water supply wells are located on the airport property or nearby in Pueblo Canyon.

3.0 PERFORMANCE OBJECTIVES & REGULATORY CRITERIA FOR COVER SYSTEM

Table 1 summarizes the performance objectives and regulatory criteria for the cover system. The specific design elements related to the cover and where it is described within this report are also contained in Table 1.

An important performance objective for the new cover system is the ability to accommodate subsidence or differential settlement. The existing cover is primarily being replaced due to problems encountered by differential settlement that has occurred since its installation. A fatal flaw in the previous asphalt cover system was the assumption that because of the age of the landfill there would be no significant settlement after installation of the cover and that the cover system would remain relatively impermeable. In fact, the cracking in the asphalt and concrete exaggerated ongoing settlement by allowing significant percolation into the underlying waste and accelerating the biodegradation of the waste that also leads to an increase in methane gas production. Exasperating the problem was the fact that all of the rain water that rain through the surface cracks into the underlying waste was trapped there because the existing cover system had a reverse capillary barrier with the base coarse/gravel layer below the asphalt and the underlying soil combined with the fact that there was no conductive layer that enabled water within the landfill to move upward in response to energy gradients created by the variance in the climate's demand for water or potential evapotranspiration as described in Section4.

The ET Cover does not relay on an impermeable layer to resist infiltration rather it relies on inflation moving into the cover and stored within the soil profile until evapotranspiration can remove it thus minimizing percolation into the underlying waste. Furthermore, the ET Cover is designed with a minimum 3.3% slope that encourages runoff from the site while providing an allowance for some differential settlement and still providing for a positive slope instead of ponding as was the case with the existing cover that was design relatively flat. An advantage of the ET Cover is that if significant differential settlement does occur, a simple fix is to add soil to depressed surface areas thus brings the surface back to its designed grade. Finally, the ET Cover is expected to minimize percolation into the underlying waste thus slowing the ongoing biodegradation of the waste. This will be monitoring via water balance of the cover system and methane gas monitoring as described in the Post-Closure Care and Monitoring Plan.

Table 1. Performance Objectives and Regulatory Criteria for Cover System

No.	Performance Objectives	Regulatory Criteria	Design element	Location summarized in Design Report
1	Minimize flux or deep percolation through cover system	40CFR264.310	Cover profile	Section 4
2	Minimal maintenance	40CFR264.310	ET Cover/Gravel /soil admix/veg	Section 4, Section 5
3	Minimize erosion	40CFR264.310	Gravel/soil admix	Section 5
4	Soil loss less than 2 tons/acre/year	EPA 1991	Gravel/soil admix	Section 5.3
5	Promote drainage off of cover	40CFR264.310 EPA 1991	Cover grades	3% minimum slope
6	Accommodate settlement/subsidence	40CFR264.310	ET Cover; Placement densities/moisture	Section 3
7	Cover permeability less than or equal to natural subsoils present	40CFR264.310	Cover material	Section 4

4.0 COVER PROFILE DEVELOPMENT

This report describes an Evapotranspiration (ET) Cover System that satisfies the stated performance objectives described in Section 3.0. The design methodology utilized is consistent with that recommended in ITRC (2003), EPA-909-R-11-007 (EPA 2012), and Dwyer et al (2006). Modeling was performed to evaluate an ET Cover profile (Section 4.1) utilizing an identified soil borrow source, native vegetation and site-specific climate data. The cover soil will be purchased and trucked to the site from an approved vendor. The soil laboratory testing data from these borrow sites is available in Borrow Study Report (Dwyer 2013). The computer simulations demonstrated that the recommended soil cover profile will minimize flux (Table 3 and Figure 10).

The final cover profile includes a rock/soil admixture surface layer designed to provide erosion resistance. The design of this layer is described in Section 5.1. The recommended cover soil profile will be installed over the prepared subgrade after removal of the asphalt cover and concrete hangar pads. The slope will have a minimum slope of 3%.

4.1 UNSATURATED MODELING OF COVER SYSTEM

This section summarizes the modeling performed in support of the design of the profile for the final cover system for the Los Alamos County Airport Landfill. The planned cover system is to be an earthen cover referred to as an Evapotranspiration (ET) Cover.

Los Alamos, NM has a temperate mountain climate with four distinct seasons (LANL 1999). For the LANL meteorological station nearest the airport, the mean precipitation including snowmelt is approximately 18.7-in per year (LANL 2006). The peak months for precipitation are July and August (Figure 3) when afternoon thunderstorms can produce high intensity rainfall. Figure 3 depicts the average monthly distribution of precipitation as well as the monthly climatic demand for water, referred to as potential evapotranspiration (PET). That is, figure 3 shows that for an average year the supply of water (precipitation) is far less than the climatic demand for water (potential evapotranspiration) for every month of the year. Thus a well-designed ET Cover that emphasizes storage of infiltrated meteoric water until it is removed via ET will work in this type of climate.

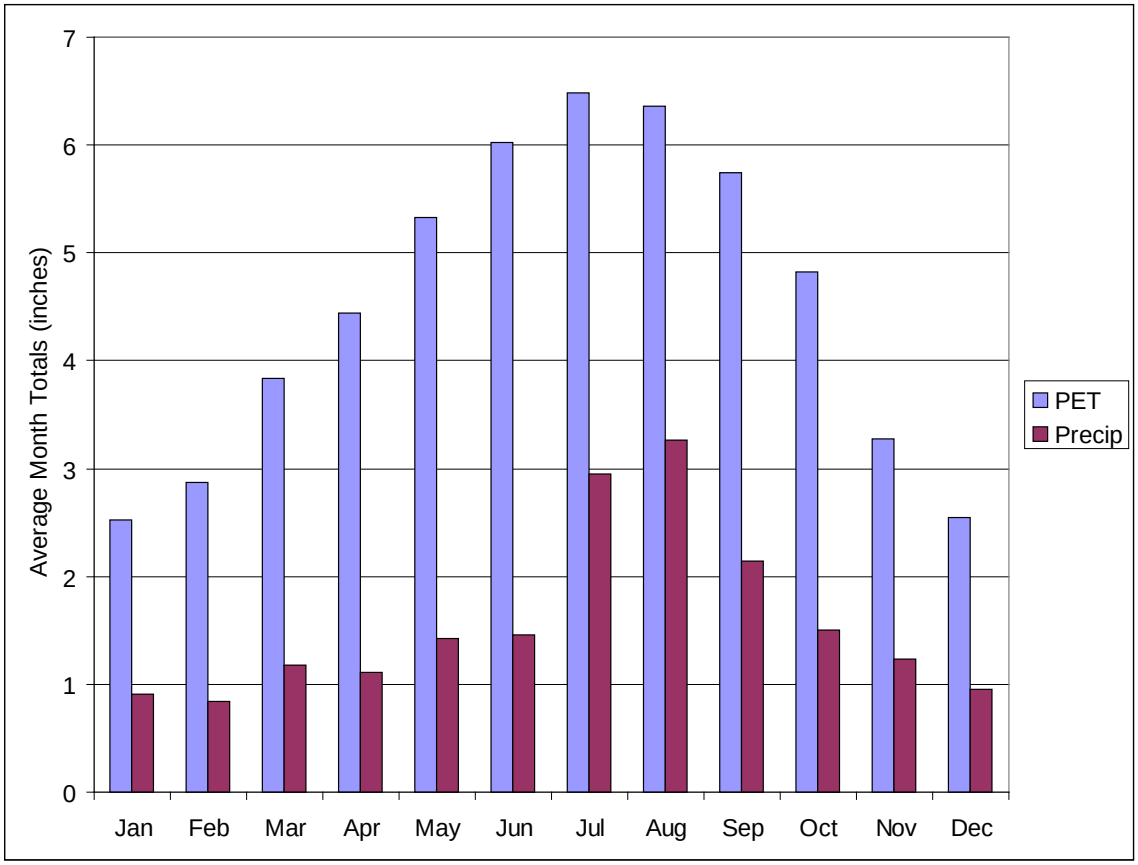

Figure 3. Los Alamos, NM Typical Climate's Demand for Water (PET) vs. Supply of Water (Precipitation)

Historically, HELP (Schroeder et al, 1994) has been the software 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) that is based on the Richard's equation used today 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 design guidance documents including ITRC (2003), EPA-909-R-11-007 (EPA 2012), and Dwyer et al (2006). Consequently, UNSAT-H was used on this project.

4.1.1 OVERVIEW OF UNSAT-H

UNSAT-H has been used to design many recent alternative earthen cover designs (ITRC 2003, Dwyer 2003, EPA-909-R-11-007, Dwyer et al 2006). 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 4. 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 the 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 for conservative infiltration and percolation estimates since landfill cover systems are generally sloped to encourage runoff.

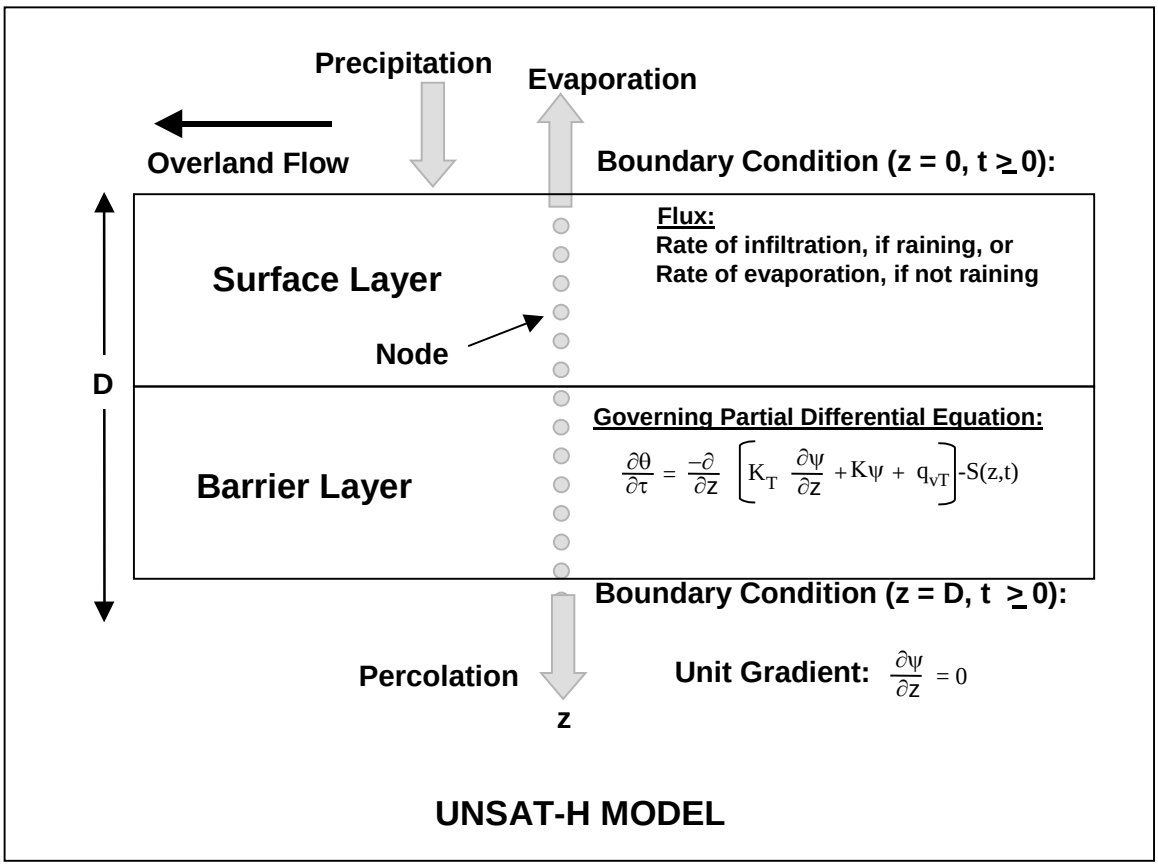

Figure 4. Schematic Representation of Water Balance Computation by UNSAT-H

Water that has infiltrated 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. 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.

4.1.2 UNSAT-H INPUT PARAMETERS

Input parameters were developed for simulations using UNSAT-H for the ET cover. These parameters were developed based on field and laboratory measurements, values from the literature, and expert opinion. These parameters are described in the following sections.

4.1.3 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. A general summary of the profile model is included in Figure 5. The rock/soil admixture is 25% rock to 75% soil (by volume) based on the design presented in Section 4.1.

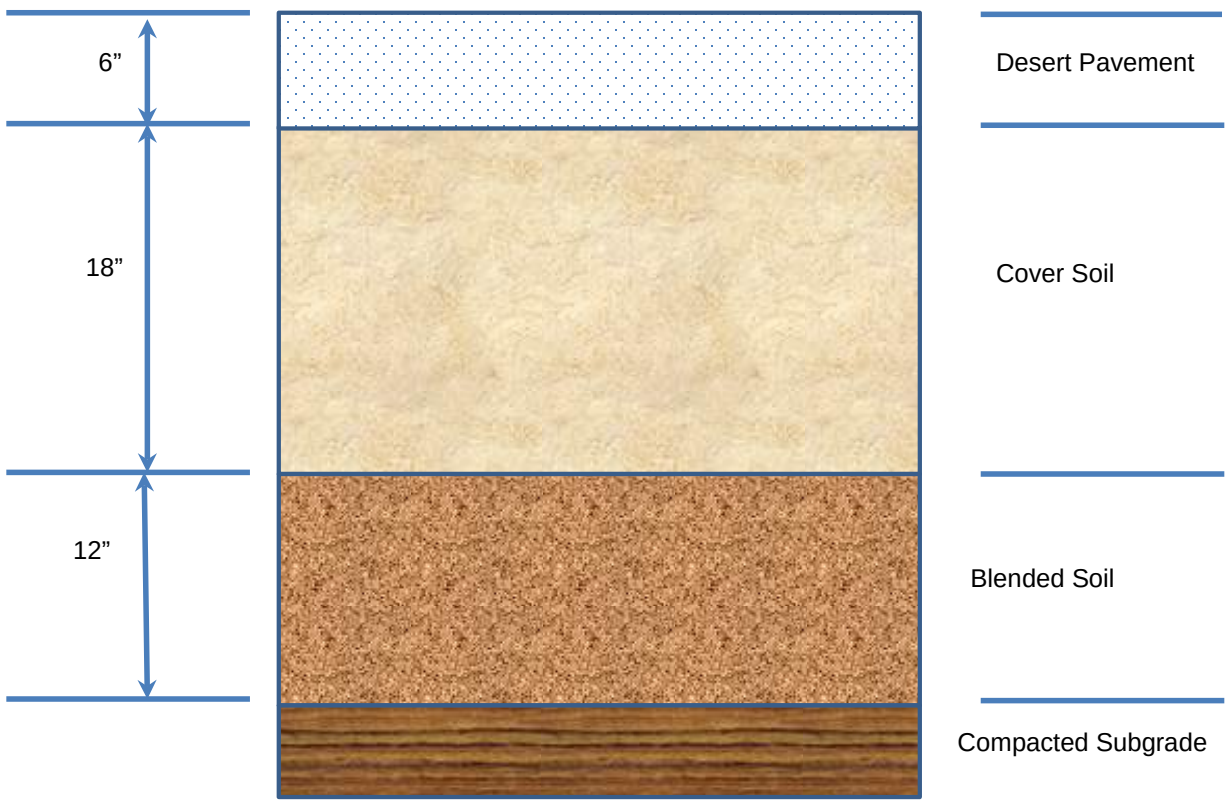

Figure 5. Cover Profile

4.1.4 BOUNDARY CONDITIONS

Weather from Los Alamos, NM was utilized as the upper boundary condition. All available historical weather data for Los Alamos was evaluated from 1910 to present. Typical climatic conditions as well as extreme conditions were evaluated to determine a minimum cover thickness. The specific year used to evaluate the profiles under typical conditions was 1942

(figure 6) with an annual precipitation of 18.45 in (46.86 cm). Extreme climatic conditions were also evaluated by evaluating the profile subject to the wettest year on record (figure 7). The year of 1941 was the wettest on record with an annual precipitation of 30.33 in (77.04 cm).

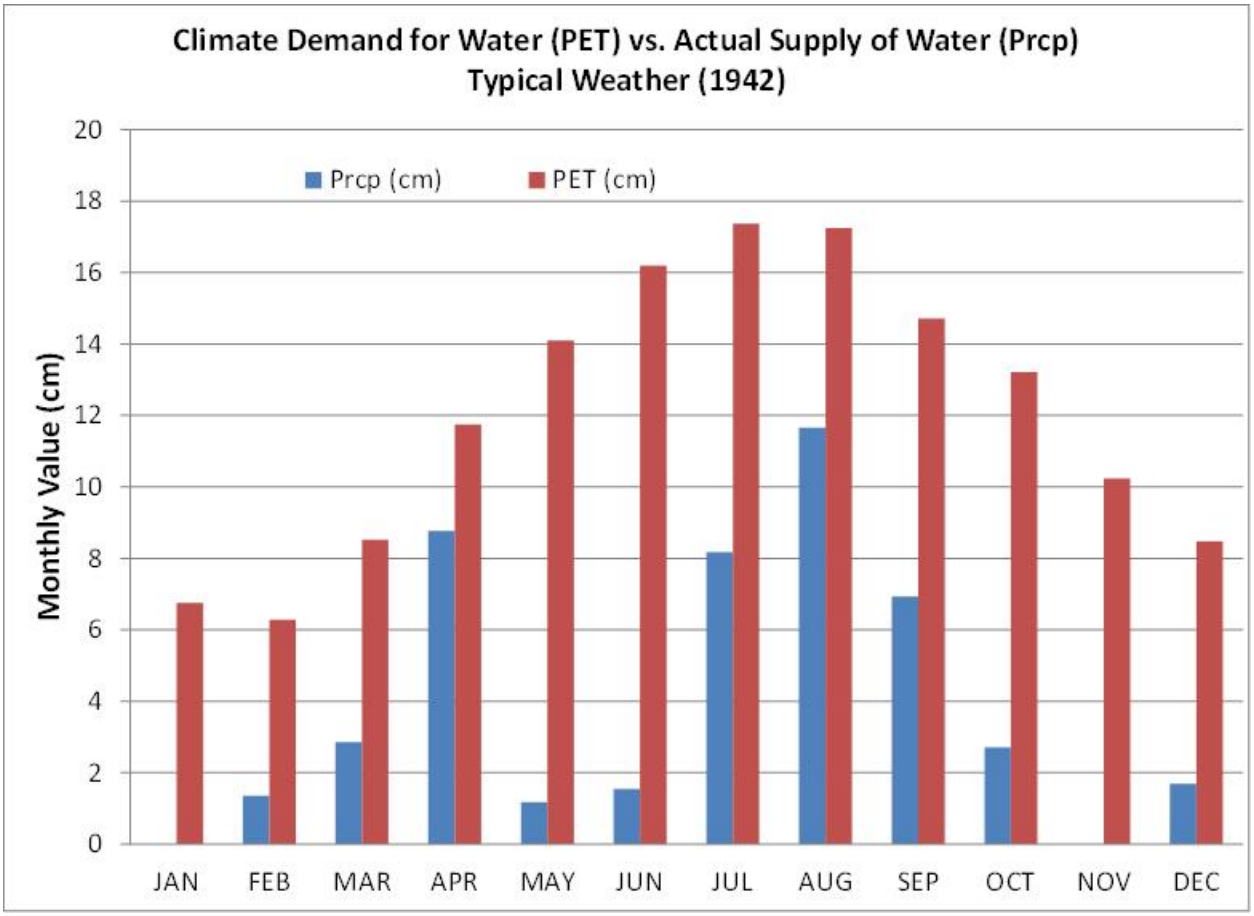

Figure 6. Climate Demand for Water vs. Supply of Water: Typical Weather (1942)

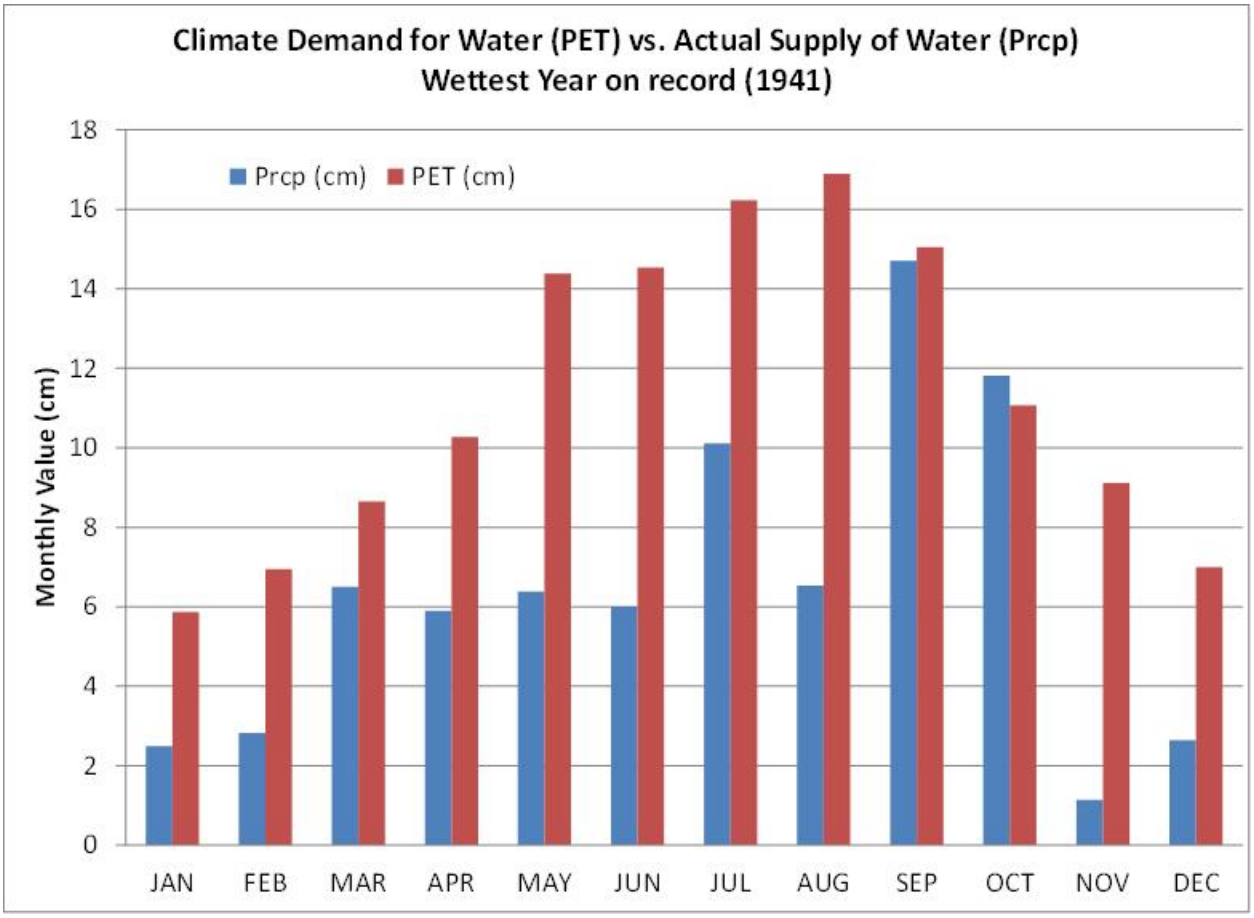

Figure 7. Climate Demand for Water vs. Supply of Water: Wettest Year on Record (1941)

The flow of water 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 generally set to a maximum hourly flux for these computer simulations of 0.4 inches (1 cm) per hour that produced no runoff while maximizing infiltration. This is conservative because it is expected at the site given the designed slopes that a significant percentage of precipitation will runoff the site 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 1) that is based on the value of the assigned leaf area index (LAI) and an equation developed by Ritchie and Burnett (1971) as follows:

$$T_p = PET\,[a + b(LAI)^c] \quad \text{where } d \le LAI \le e \qquad \textbf{Equation 1}$$

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 value and site latitude were input parameters used to calculate PET (Samani and Pessarkli, 1986). The Samani method used to calculate PET correlates very 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 developed by Equation 1 above. The PET or climatic demand for water versus the amount of rain is graphically presented for a typical year above in Figure 6 and wettest year on record in Figure 7.

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 model run consisted of ten consecutive average years followed by the wettest year on record. This allowed for nine consecutive average years in front of the selected model years to establish appropriate antecedent conditions.

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

4.1.5 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 8).

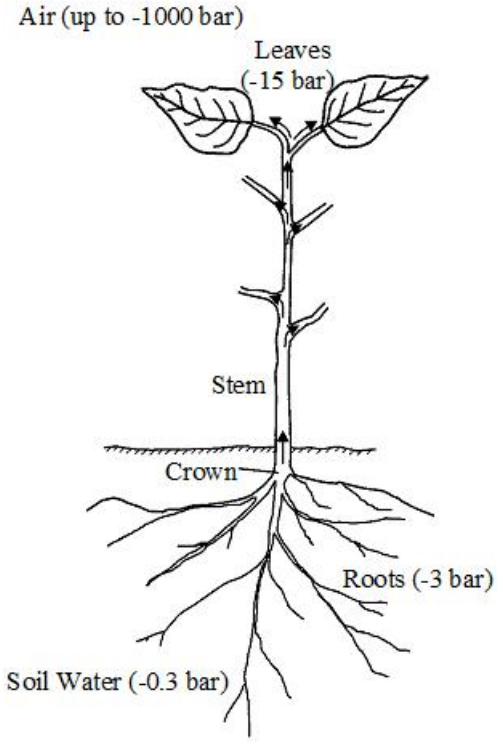

Figure 8. Typical Soil-Plant-Atmosphere Water Potential Variation (Hillel 1998)

The input parameters representing vegetation include the LAI, rooting depth and density, root growth rate, the suction head values that corresponds to the soil's field capacity, wilting point, and water content above which plants do not transpire because of anaerobic conditions. 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 2:

$$\mathbf{RLD = a\ exp(-bz) + c} \qquad \textbf{Equation 2}$$

where:

a,b, and c are fitting parameters

z = depth below surface

The cover profile (Figure 5) was modeled with vegetation on the surface. The parameters used for the RLD functions in Equation 2 were: a = 0.315, b=0.0073, and c = 0.076 (Fayer 2000). The time required for maximum rooting depth establishment was set at full depth beginning on day 1. The maximum rooting depth was conservatively set at 3 ft. (91 cm). This rooting depth is conservative because native grasses can reach depths up to 9 ft. (2.74 m) (Foxx et al 1984). A LAI of 1.1 was used that is consistent with a poor stand of grass (Simonton et al 1985). The growing degree day for the typical year of 1942 utilized is graphically presented in figure 9. The onset and termination of the growing season for the site were Julian days 83 and 335, respectively. The LAI was transitioned from 0 to 1.1 starting with Julian day 83 to 167. Day 167 through 211, the full LAI equal to 1.1 was utilized. The LAI was then transitioned down from 1.1 to 0 from Julian day 211 to 336. This was conservative since it is realistic that plants can transpire longer than indicated at this site. An average percent bare area of 37% was used (Simonton et al 1985). That is, vegetation coverage was only 63%. The assumed percent bare area of 37% essentially reduces the maximum LAI to 0.69 (63% of 1.1).

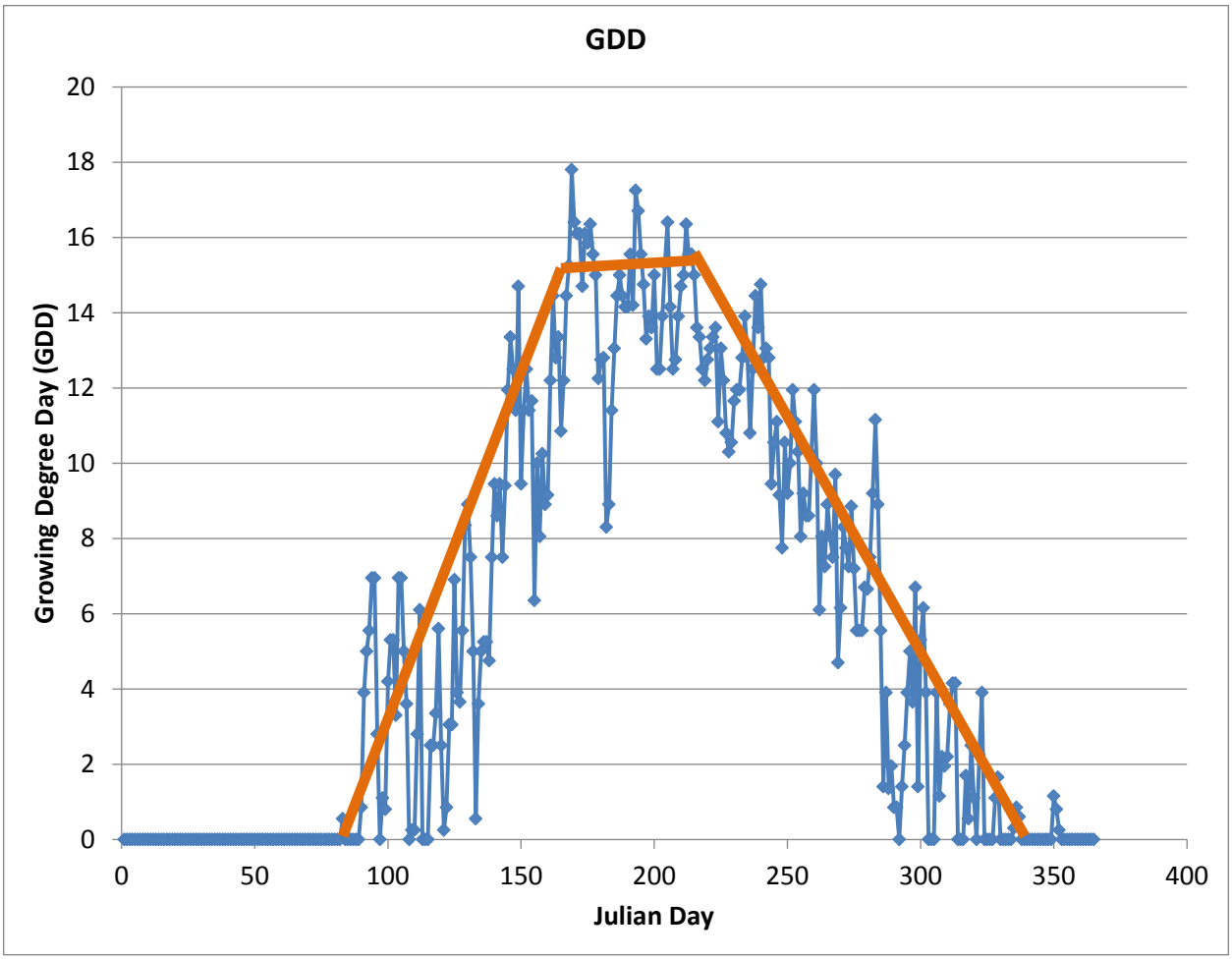

Figure 9. Growing Degree Day for Typical Year, Los Alamos, NM

4.1.6 SOIL PROPERTIES RELATED TO VEGETATION

Suction head values corresponding to the wilting point, field capacity, and a head value corresponding to the water content above which plants do not transpire because of anaerobic conditions were defined as input parameters in the model. Matric potential or suction heads are generally written as positive numbers, but in reality are negative values. Consequently, the higher the listed value - the greater the soil suction. The maximum water content a soil can hold after all downward drainage resulting from gravitational forces is referred to as its field capacity. Field capacity is often arbitrarily reported as the water content at about 330-cm of matric potential head (Jury et al. 1991). Below field capacity, the hydraulic conductivity is assumed to be so low that gravity drainage becomes negligible and the soil moisture is held in place by suction or matric potential.

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, which is typically defined as the water content at 656.2-ft (20,000 cm) of matric potential head for native grasses. This 656.2-ft (20,000 cm) value was conservatively used although some shrubs present near the

site could remove water from the soil to a suction of 3280.8-ft (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-ft (1000 cm) (Fayer 2000). The head value corresponding to the water content above which plants do not transpire because of anaerobic conditions was defined at 4-in (10 cm) based on the assumed moisture characteristic curves for the utilized soil hydraulic properties.

4.1.7 SOIL PROPERTIES

Soil mechanical and hydraulic properties were obtained from laboratory testing of multiple soil samples collected at various potential borrow sources. There are multiple potential and approved borrow sources for cover soil as summarized in the Cover Soil Borrow Investigation and specified in the Technical Specifications Section 02200 (Earthwork).. The upper 6-in rock/soil admixture will be composed of the mixture of rock and borrow soil from an approved vendor. The cover soil specifications define the allowable soil characteristics and placement density and moisture content. Soil textures from approved equal borrow sites will be accepted only if they meet the specified criteria and are pre-approved by the Engineer.

The hydraulic properties of the borrow soils modeled were obtained from laboratory testing of the various soil textures at a prescribed density of 90% of the maximum dry density (ASTM D698). 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% of its maximum dry density (MDD) with a small tolerance allowance (plus or minus 5 pcf of MDD).

The upper 6-in of the top deck cover profile will have rock mixed into it at a volumetric ratio of 25% rock to 75% soil. The rock size will have a D_{50} of 0.5-in. The mixture of rock into the soil effectively alters its hydraulic properties. Consequently, the hydraulic properties were altered for this upper 6-in layer (ASTM D4718). The following equation (Equation 3) was used to alter the saturated hydraulic conductivity based on the addition of rock (Peck and Watson 1979).

$$\boldsymbol{K_b = [K_s * 2(1 - V_r)]/(2 + V_r)} \qquad \text{Equation 3}$$

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

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

$$V_r = volume\ of\ rock$$

The calculated bulk saturated hydraulic conductivity for the admixture layer was then increased an order to account for dynamic processes such as freeze/thaw cycles, wet/dry cycles, and biointrusion. This resulted in added conservatism in the modeling results. Additionally, the depth of soil cover from 6 to 12-in below ground surface (BGS) also had its saturated hydraulic concavity increased by an order of magnitude to account for the dynamic processes mentioned above. The cover soil from 1 to 2-ft BGS had its saturated hydraulic conductivity increased by half an order of magnitude for the similar dynamic processes. The upper foot generally has the highest percentage of roots while the next foot has a reduced volume of roots. This is represented by the RLD described above in section 4.1.5.

The moisture retention data for the cover soil was also altered to reflect the addition of the rock (Equation 4). Each respective volumetric moisture content (saturated and residual) was altered per ASTM D4718 and Bouwer & Rice (1984). The revised moisture characteristic curve with respective van Genuchten parameters for input into the UNSAT H computer simulations (Table 2).

$$\boldsymbol{\theta_b} = (\mathbf{1} - \boldsymbol{V_r}) * \boldsymbol{\theta_s} \qquad \text{Equation 4}$$

$$where: \theta_{b,s\ or\ r} = volumetric\ moisture\ content, bulk$$

$$\theta_{s\ or\ r} = volumetric\ (saturated\ or\ residual) moisture\ content\ for\ soil, respectively$$

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 computer simulation are summarized in Table 2. The layers correspond to the profile shown in Figure 5.

Table 2. Soil Input Parameters

Soil	Depth BGS[1]	K_{sat}	Van Genuchten Parameters			
			θ_s	θ_r	α (1/cm)	n
Rock/Soil Admixture	0 to 0.5-ft (0 to 16 cm)	2.26E-03 in/sec (5.73E-03 cm/sec)	0.2635	0.046	0.0076	1.8637
Cover Soil	0.5-ft to 1.0-ft (17 cm to 31 cm)	3.39E-03 in/sec (8.60E-03 cm/sec)	0.3513	0.0613	0.0076	1.8637
Cover Soil	1.0-ft to 2.0-ft (32 cm to 61 cm)	1.69E-03 in/sec (4.3 E-03 cm/sec)	0.3513	0.0613	0.0076	1.8637
Cover Soil	2.0-ft to 3.0-ft (62 cm to 91 cm)	9.45E-07 in/sec (2.4E-06 cm/sec)	0.3317	0.0	0.0055	1.2128
Subgrade Soil	Beneath 3.0-ft (92 cm to 300 cm)	3.39E-04 in/sec (8.6E-04 cm/sec)	0.3513	0.0613	0.0076	1.8637

1. [1] below ground surface (BGS)

The moisture retention data for the cover soil was also altered to reflect the addition of the rock (Equation 4). Each respective volumetric moisture content (saturated and residual) was altered per ASTM D4718 and Bouwer & Rice (1984). The revised moisture characteristic curve with respective van Genuchten parameters for input into the UNSAT H computer simulations (Table 2).

$$\boldsymbol{\theta_b} = (\mathbf{1} - \boldsymbol{V_r}) * \boldsymbol{\theta_s} \qquad \text{Equation 4}$$

$$where: \theta_{b,s\ or\ r} = volumetric\ moisture\ content, bulk$$

$$\theta_{s\ or\ r} = volumetric\ (saturated\ or\ residual) moisture\ content\ for\ soil, respectively$$

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.

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Cover Soil	0.5-ft to 1.0-ft (17 cm to 31 cm)	3.39E-03 in/sec (8.60E-03 cm/sec)	0.3513	0.0613	0.0076	1.8637
Cover Soil	1.0-ft to 2.0-ft (32 cm to 61 cm)	1.69E-03 in/sec (4.3 E-03 cm/sec)	0.3513	0.0613	0.0076	1.8637
Cover Soil	2.0-ft to 3.0-ft (62 cm to 91 cm)	9.45E-07 in/sec (2.4E-06 cm/sec)	0.3317	0.0	0.0055	1.2128
Subgrade Soil	Beneath 3.0-ft (92 cm to 300 cm)	3.39E-04 in/sec (8.6E-04 cm/sec)	0.3513	0.0613	0.0076	1.8637

1. [1] below ground surface (BGS)

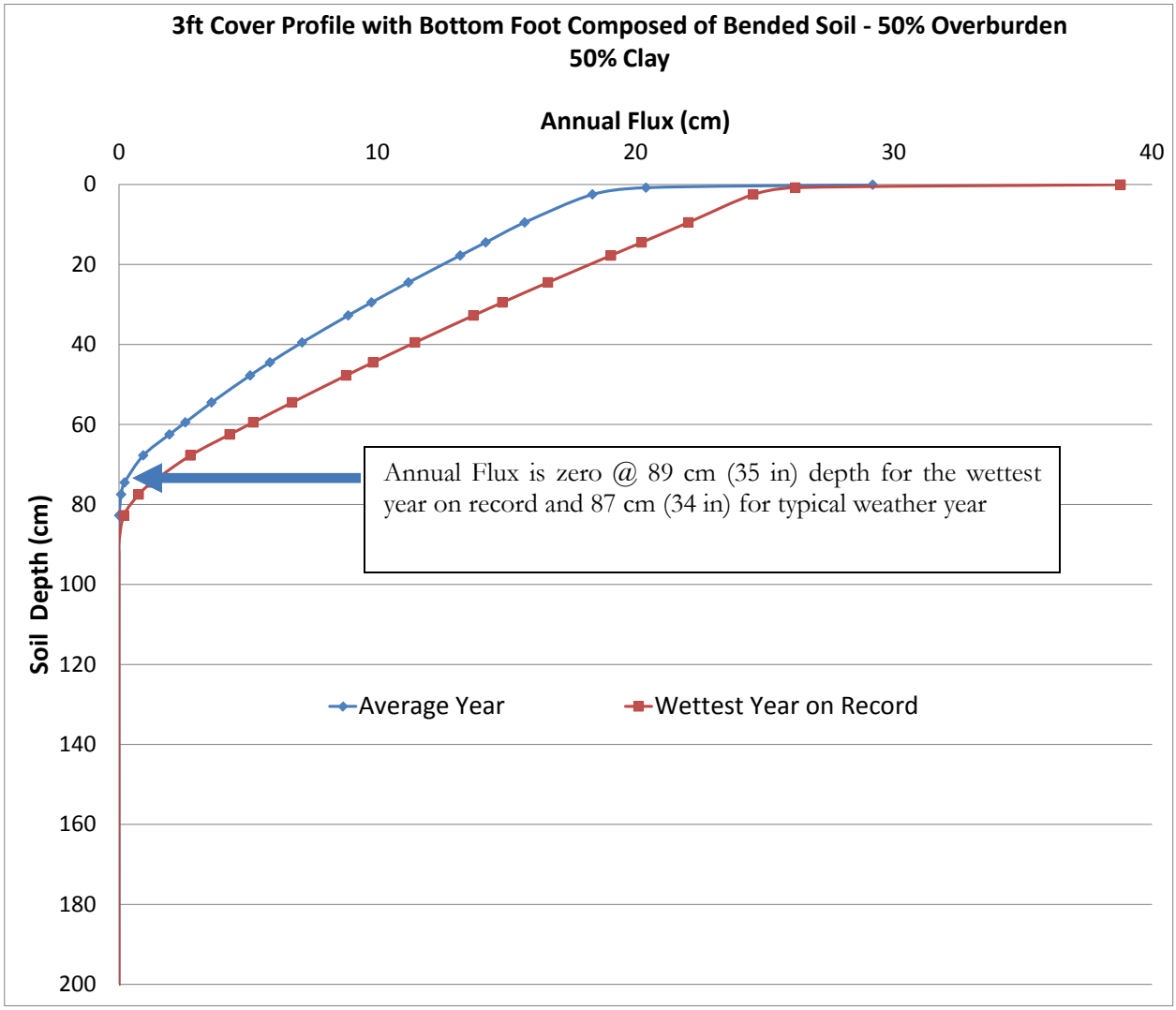

Figure 10. Computer Simulation Results

Conservatism was incorporated into the model in the form of limiting the precipitation rate to encourage 100% infiltration of precipitation into the cover profile. Furthermore, the modeling is one-dimensional and thus slope is not taken into account and thus there was no runoff due to slope. The upper 24 inches of the cover profile had its saturated hydraulic conductivity increased for the computer simulations to take into account potential changes to the soil hydraulic properties due to such things as freeze/thaw cycles, wet/dry cycles, biointrusion, and uncertainty in rock mixtures.

5.0 EROSION

The cover was designed to resist erosion. A top surface composed of a mixture of rock and cover soil was designed to mitigate the potential for rill or gully formation, as well as, reduce the potential for soil loss due to surface runoff. Research (Dwyer 2003) and monitoring of multiple projects within the southwestern United States has shown this surface admixture also promotes an effective establishment of native vegetation.

The following subsections summarize the design methodology and calculations performed to satisfy the performance objectives related to erosion. Section 5.1 summarizes the design of the rock/soil admixture. Section 5.2 summarizes the stability of the final slope as a rocky soil per NUREG 1623. Finally, section 5.3 summarizes the compliance of annual soil loss to less than two tons/acre/year as recommended by EPA (1991).

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

Rock/soil admixtures provide excellent 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 landfill cover surface, some winnowing of fines from the admixture is expected, creating a vegetated erosion-resistant surface sometimes referred to as a ‘desert pavement’. The following rock/soil admixture design is for the cover surface or ‘desert pavement’.

5.1.1 DESIGN RAINFALL EVENT

The rainfall intensity value used to calculate the runoff volume from the cover was determined using data supplied by the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) Hydrometerological Design Studies Center. The data from NOAA Atlas 14, Volume 1 for Los Alamos, NM was used whereby the one hour precipitation frequency estimate for a 100 return period is 2.17 inches (5.51 cm). The one hour time of concentration is conservative for any contributory area less than 50 acres (20 hectares) (Lindeburg 1989).

5.1.2 RUNOFF PREDICTION

The “rational method” was used to estimate runoff volumes. This method is commonly used in civil engineering applications and is a method approved by DOE (1989) for design of cover systems for sites regulated by the Uranium Mill Tailings Radiation Control Act of 1978 (i.e., UMTRA sites). 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 (Equation 5), the peak rate of runoff, (Q), in cubic feet per second (cfs) [runoff is actually in acre-inches/hour but is rounded to cfs] is given by the following expression:

Q = C I A **Equation 5**

where:

C = Runoff coefficient (dimensionless) = 0.3 (Lindebrg 1989)

I = Rainfall intensity (in/hr)

A = Surface area that contributes to runoff (acres) = $L^2/4$

The time of concentration was calculated as recommended by the National Resources Conservation Service (NRCS) (Lindeburg 2012) [Equation 6].

$$\boldsymbol{t_c = \frac{0.007*(nL)^{0.8}}{\sqrt{P}S^{0.4}}}$$ **Equation 6**

where:

$t_c = time\ of\ concentration$

$n = Manning\ roughness\ coefficient$

$L = slope\ length$

$P = rainfall\ intensity\ per\ NOAA\ Atlas\ 14\ for\ designated\ storm$

$S = slope\ (\frac{ft}{ft})$

Using n= 0.03 (NUREG 1623 and Chow 1959), L -= 153.5 ft., S = 0.0332, and P= 100-yr, 1-hr storm intensity value of 2.17 in/hr (NOAA Atlas 14, Vol. 1, version 5); the resulting time of concentration (t_c) is 3.83 minutes. However, Los Alamos County Design and Construction Standards (2008) state the minimum time of concentration is 10 minutes. The NRCS recommends the use of a 2-yr, 24-hr storm event. For Los Alamos, 2-yr, 24-hr storm event is 1.72 inches ((NOAA Atlas 14, Vol. 1, version 5)). However, the design is intended to resist a more severe storm with a higher intensity and shorter duration. Therefore, the 100-yr, 1-hr storm event was conservatively used which is 2.17 inches ((NOAA Atlas 14, Vol. 1, version 5)). The shorter duration, higher intensity storm is also better suited for the Los Alamos area where this type of storm is common.

The Rainfall Intensity value to be utilized in the Rational Formula is then calculated using the Steel formula [Equation 7] as recommended by the NRCS (Lindeburg 2012):

$$\boldsymbol{I = \frac{K}{t_c + b}}$$ Equation 7

where:

$I = rainfall\ intesnity\ (\frac{in}{hr})$

$K = steel\ formula\ coefficient for\ Region\ 6\ for\ a\ 100yr, 1hr\ storm$
$= 210\ (Lindeburg\ 2012, Figure\ 20.5)$

$b = steel\ formula\ coefficient for\ Region\ 6\ for\ a\ 100yr, 1hr\ storm$
$= 26\ (Lindeburg\ 2012, Table\ 20.2)$

Therefore, the resulting rainfall intensity (I) is 5.83 in/hr.

The contributory surface area was calculated based on the assumed configuration shown in figure 11 where L is the critical slope length. Slopes (3.3%) and slope length (153.5-ft) are from proposed contoured plans of the conceptual cover. The slopes and slope lengths were estimated to match the area configuration described here.

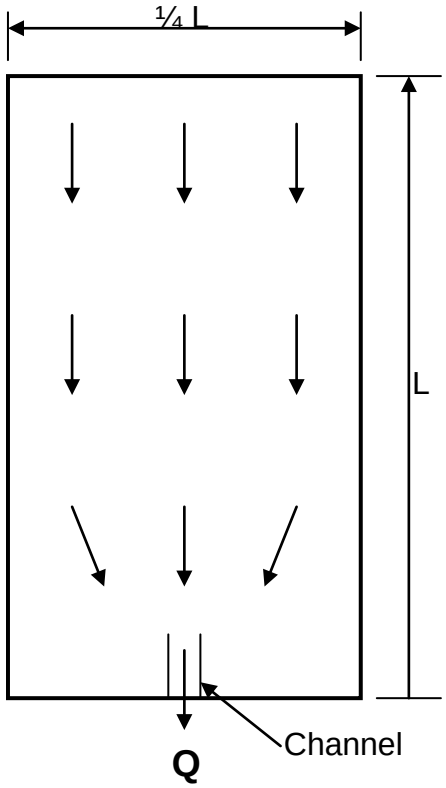

Figure 11. Contributory area for gully formation

5.1.3 CHANNEL GEOMETRY

The channel geometry shown in Figure 12 is that assumed for the gully formation.

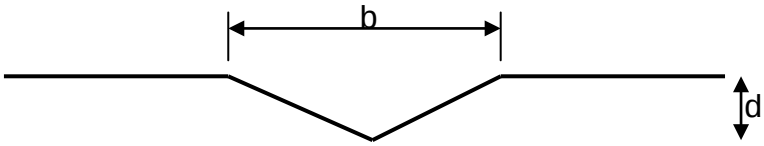

Figure 12. Channel geometry

The geometry of the channel that forms is based on regression equations [Equation 8 and 9] 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 8**

where:

b = width of flow (ft.);

Q_m = mean annual flow (cfs);

M = percentage of silts and clays in soils (30.1% for applicable borrow soil, (Borrow Cover Soil Report, Dwyer Engineering 2015).

The mean annual flow (Q_m) is assumed to be between 10% and 20% of the peak rate of runoff (Q) (Dwyer et al. 2007). In this case 20% 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 9**

where:

F = width to depth ratio = b/dh;

F_r = Froude Number ≈ 1.0.

5.1.4 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. This incipient particle size (D_c) was calculated using the Shield's Equation [Equation 10]:

$$D_c = \tau / F_s(\gamma_s - \gamma)$$ **Equation 10**

where:

τ = total average shear stress (psf);

F_s = Shield's dimensionless shear stress = 0.047;

γ_s = specific weight of soil (pcf) [measured, (Borrow Cover Soil Report, Dwyer Engineering 2015)];

γ = water density = 62.4 pcf.

The total average shear stress [Equation 11] is given by:

$$\tau = \gamma\ d_h\ S \qquad \textbf{Equation 11}$$

where:

S = slope (ft/ft).

d_h = hydraulic depth (ft)

5.1.5 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. The material larger than the incipient particle size will not be displaced or eroded, and can form an armoring that will protect the channel from further erosion from similar or lesser storm events.

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

$$Y_s = Y_a\ [(1/P_{c)}-1] \qquad \textbf{Equation 12}$$

where:

Y_s = scour depth;

Y_a = armor layer thickness;

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

5.1.6 ROCK/SOIL ADMIXTURE SUMMARY

An excel spreadsheet was used to simultaneously solve the multiple equations described above. Table 4 presents the calculated results for the surface rock/soil admixture.

Table 4. Rock/Soil Admixture Summary

Q (cfs)	Qm (cfs)	b (in)	dH (in)	τ (psf)	Dc (in)	use D50 (in)	% rock	Ya (in)	Ys (in)	total depth (in)
0.24	0.05	36.9	0.68	0.11	0.28	0.5	25	1.5	4.5	6

5.2 LONG-TERM STABILITY OF ROCKY SOIL COVER

The long-term stability of the cover surface with the addition of the rock/soil admixture can be determined by Equation 13 (NUREG 1623):

$$S_s^{7/6} = [65*t^{5/3}]/[P*L*F*n]$$ Equation 13

where:

S_s = maximum stable slope (%);

t = 0.4*D75 = 0.2 in;

P = rainfall intensity = 8.06 in/hr;

L = slope length = 153.5 ft;

F= 3 (NUREG 1623);

n = 0.03.

solving, S_s = 8.35% (this represents the steepest stable slope under the given rock/soil admixture design and slope length for the site)

Therefore, since S_s = 8.35% is greater than the actual slope of 3.32%, the slope is stable.

5.3 SOIL LOSS

The Revised Universal Soil Loss Equation (RUSLE) represents a revision of the Universal Soil Loss Equation (USLE) technology in how the factor values in the equation are determined. RUSLE [Equation 14] is explained in the U.S. Department of Agriculture (USDA) Handbook 703, "Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)." The RUSLE is expressed as:

$$A_s = R_e K (LS) C P_c$$ **Equation 14**

Where:

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

R_e = rainfall energy/erosivity factor (dimensionless) = 25 --- see figure 14;

K = soil erodibility factor (dimensionless) = 0.26 --- see figure 13;

LS = slope length and steepness factor (dimensionless) =0.4 --- see figure 15;

C = vegetative cover and management factor (dimensionless) = 0.21 (RUSLE2 software); and

P_c = conservation support practice factor (dimensionless) = 1 (no conservation support practice prescribed).

Solving:

A_s = 25*0.26*0.4*0.21*1 = 0.55 tons/acre/yr

The EPA (1991) recommends a maximum soil loss due to erosion of 2 tons/acre/year. Since the annual soil loss of 0.55 tons/acre/year is less than 2 tons/acre/year, the performance criteria for soil loss/erosion (EPA 1991) is satisfied.

The following figures are derived from Agriculture Handbook 703.

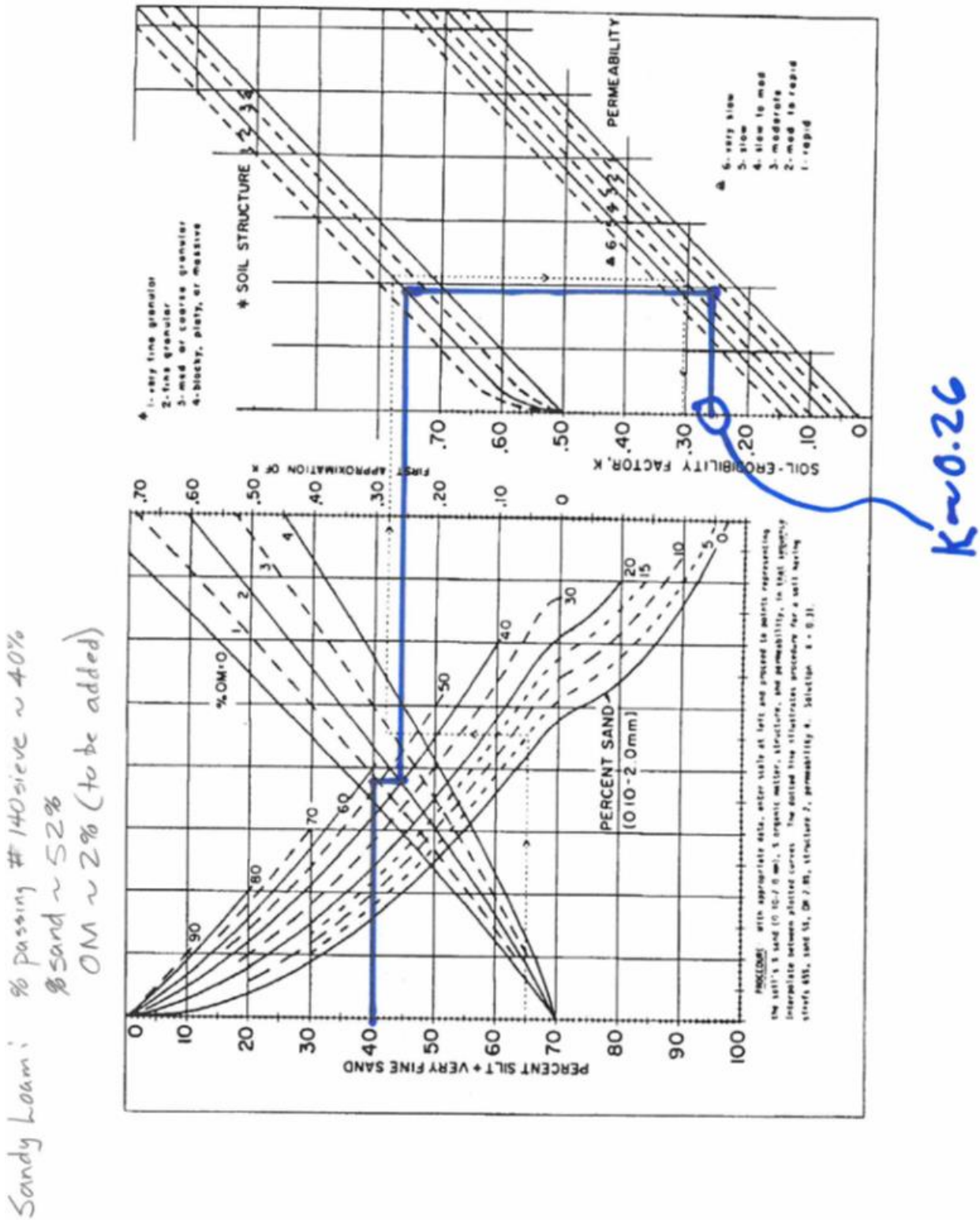

Figure 13. RUSLE K Factor, Ag Handbook 703

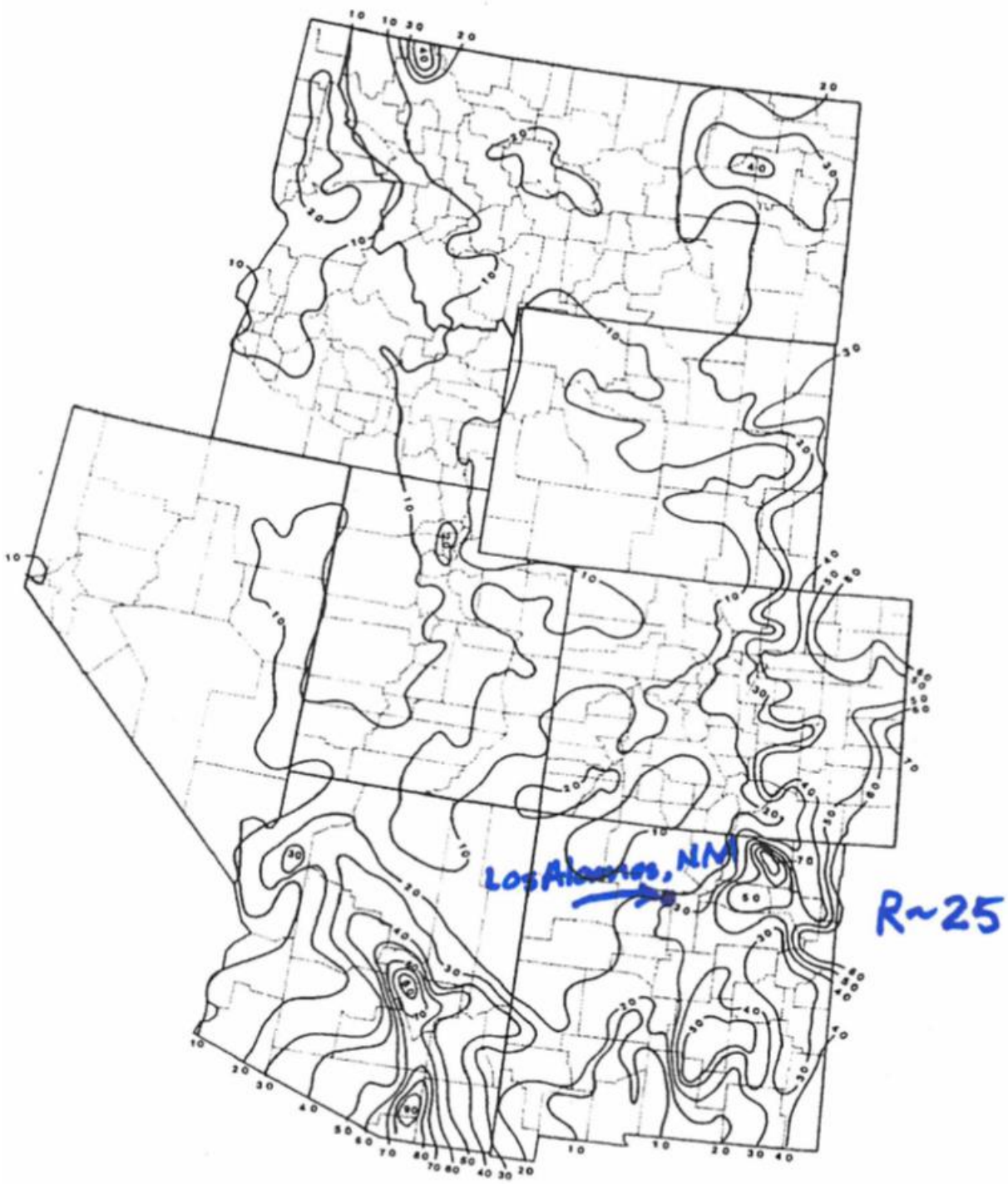

Figure 2-2. Isoerodent map of western United States. Units are hundreds ft·tonf·in(ac·h·yr)$^{-1}$.

Figure 14. RUSLE R Factor, Ag Handbook 703

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

LS=0.4

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	0.26	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	2.06	2.54	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	2.86	3.41	4.52	6.63	8.29	9.72	12.16	14.26	16.13	17.84	20.92	26.17	30.68	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 15. RUSLE LS Factor, Ag Handbook 703

6.0 MISCELLANEOUS CALCULATIONS

Miscellaneous calculations including volume approximations for waste removal and replacement, concrete removal, cover soil needed, hydrology, drainage channel sizing are included in the Attachment at the end of this report.

7.0 SUMMARY

An ET Cover was designed to replace the existing asphaltic cover over the Los Alamos County Airport Landfill. The cover was designed to satisfy all performance objectives and regulatory criteria cited in section 3 of the report for a RCRA Subtitle C facility.

Advantages of an ET Cover include: (1) it utilizes natural soils and materials; (2) its operation is less reliant on engineered systems than covers employing resistive barriers; (3) it does not appreciatively degrade over time; (4) it maintains integrity in the event of differential settlement; (5) it provides for better slope stability compared to covers employing a geomembrane; (6) it provides long-term oxidation of methane and NMOC emissions(all soil cover systems naturally regulate methane through both physical barrier and methane oxidation processes); (7) Improved vegetation (increased soil storage capacity & deeper rooting medium); (8) Improved erosion control and slope stability (increased vegetation density and increased rooting mass results in reduced runoff and less erosion); (9) Improved longevity due to it being a natural sustainable system resulting in better long-term performance; and (10) it requires minimal maintenance and is relatively easy to maintain and repair; and (11) its construction is easier and thus more reliable (Dwyer 2000).

In summary, an ET Cover is composed of natural soils and they are designed to mimic or assist natural processes, as opposed to trying to resist them (as is the case with engineered barrier systems). For this reason they are well suited to perform over the long term, which is a key goal of a final cover system.

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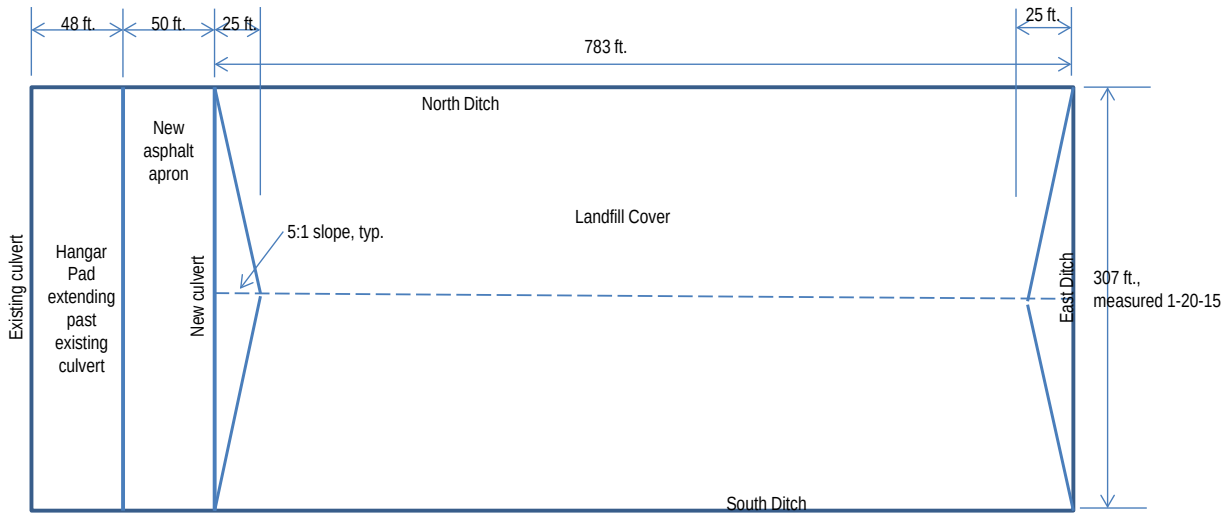
ATTACHMENT

Hydrology Calculations:



Los Alamos, NM (NOAA Atlas 14, Vol. 1):

Storm	Guidance
100 yr./1hr = 2.17 in	EPA Guidance (NOAA Atlas 14, Vol. 1, version 5))
10 yr./24 hr. = 2.48 in	NM DOT Design Event (NOAA Atlas 14, Vol. 1, version 5)
25 yr./ 24 hr. = 2.94 in	NM DOT Check Event (Extreme) (NOAA Atlas 14, Vol. 1, version 5)

Use Rational formula (per NM DOT for less than 150 acres):

$$Q = CIA$$

Where:

$$C = 0.3\ [ref.\ Lindeberg\ 1989]$$

$$I = Rainfall\ Intensity\ \left(\frac{in}{hr}\right)$$

$$A = contributory\ area - conservatively\ assume\ half\ of\ landfill$$

$$A = {}^{1}/_{2}\,(783\ ft)(307\ ft) = 120{,}190.5\ ft^2 = 2.76\ acres$$

- Look @ 100yr/1hr event per EPA & 25 yr./24 hr. event per NM DOT to determine worst case:

$$t_c = time\ of\ concentration = \frac{0.007 * (nL)^{0.8}}{\sqrt{P} * S^{0.4}}$$

Where:

$$n = Manning\ coef.(for\ cover - Ref.: Chow\ 1959) = 0.03$$

$$L = slope\ length = \frac{307}{2} = 153.5\ ft$$

$$P = storm\ intensity = 2.17\frac{in}{hr}\ [100\ \text{yr.} / 1\ \text{hr. storm}]$$

$$S = slope\ of\ cover = 0.0332\ ft/ft$$

$t_c = \frac{0.007*(0.0332*153.5)^{0.8}}{\sqrt{2.17}*0.0332S^{0.4}} = 0.0639\ hr = 3.83\ minutes$, use 10 minutes per minimum time of concentration allowed per Los Alamos County Design and Construction Standards (2008)

$$I = Intensity = \frac{K}{t_c + b}$$

Where:

$$K = 210\ [Ref.: Lindeburg\ 2012, Fig\ 20.5\ for\ 100\ yr\ frequency]$$

$$b = 26\ [Ref.: Lindeburg\ 2012, Table\ 20.2\ for\ 100\ yr\ frequency]$$

$$I = \frac{210}{10 + 26} = 5.83\ in/hr$$

- Look @ 25yr/24hr event per NM DOT:

$t_c = \frac{0.007*(0.0332*153.5)^{0.8}}{\sqrt{2.94}*0.0332S^{0.4}} = 0.055\ hr = 3.3\ minutes$, use 10 minutes per minimum time of concentration allowed per Los Alamos County Design and Construction Standards (2008)

$$I = \frac{155}{10 + 26} = 4.3\ in/hr$$

Where:

$$K = 155\ [Ref.: Lindeburg\ 2012, Fig\ 20.5\ for\ 25\ yr\ frequency]$$

$$b = 26\ [Ref.: Lindeburg\ 2012, Table\ 20.2\ for\ 25\ yr\ frequency]$$

Use 100 yr. / 1 hr. storm as worst case with I = 5.83 in/hr.

Therefore,

$$\underline{Q = 0.3 * 5.83 * 2.76 = \mathbf{4.8\ cfs}}$$

Size North Channel:

Slope of site West to East – keep slope with new channel = 1.3%

Q= 4.8cfs per Hydrology calculations

N= 0.023 for gravel lined channel

Calculations utilized open channel calculator software available on internet: http://www.eng.auburn.edu/~xzf0001/Handbook/Channels.html

V-shaped channel; with 2:1 side slopes:

Calculate minimum channel depth with above listed parameters:

Depth = 0.80 ft.

V = 3.7 ft. / sec

Possible slope variances in other channels: look @ 2% to 0.5%:

For slope = 2%.....Depth = 0.74ft with V = 4.3 fps

For slope 0.5%.....Depth = 0.97 ft with V = 2.6 fps

Therefore, minimum flow height of 1 ft. is good for all possible slopes within the channels around perimeter of landfill.

Size New Rip Rap:

Reference: Abt and Johnson (1988)

$$D_{50} = 5.23 * S^{0.43} * Q_d^{0.56} = rock\ size$$

Where:

$$S = slope = 1.3\% = 0.013 ft/ft$$

$$Q_d = design\ flow\ rate$$

$$Q_d = Q * C_R * C_m$$

$$Q = flow\ rate\ per\ rational\ Formula = 4.8\ cfs$$

$$C_R = rock\ coefficient = 1.0$$

C_m=coefficient of movement = 1.35

$$Q_d = 5.8 * 1.35 * 1 = 6.52\ cfs$$

$$D_{50} = 5.23 * 0.013^{0.43} * 6.52^{0.56} = 2.31\ (crushed\ rock)$$

For rounded rock use Factor of Safety of 40%, therefore:

$$D_{50} = 2.31 * 1.4 = 3.23\ in\ (rounded\ rock)$$

Use $D_{50} = 4\ in$

Depth = 2 x $D_{50} = 8\ in, minimum$

Waste Volume (approximate):

Average depth of waste per drilling = $8 + 3 + 17.5 + 11.5 + 3.5 + 7.5/_6 = 8.5\ ft$

Surface area = 100*150 = 15,000 ft^2

Volume of waste = 15,000 * 8.5 = 127,500 ft^3 **= 4722 cubic yards**

Waste to be spread of remaining landfill footprint – along crown/full length

Assume 3 ft. thick waste spread over length of 700 ft.,
Width of waste = 182/3= 61 ft. wide

Cover Soil Volume Required (approximate):

Horizontal slope length = 150 ft. @ slope 3.32% (rise of 5 ft.)

Effective slope length = $\sqrt{150^2 + 5^2} \approx 150ft$

Gravel Admixture: 25% gravel to 75% soil by volume for 6 in depth

Area = 770 ft. x 300 ft. = 231,000 ft2 = 5.3 acres

Depth = 3 ft. – 0.25(0.5) = 2.875 ft.

Compacted volume = 664,125 ft3 = **24,597.2 CY**

Convert to weight:

Assume density max = 130 PCF,

Placed @ 90% of MDD = 130*0.9 = 117 PCF

Weight = 664,125 * 117 * 1 ton/2000 lbs. = **38,851.3 tons**

Removal Volume of Concrete Hangar Pads:

2 East Pads: 195' x 63', 9" thick

Plus: 3' wide x 2' deep perimeter
Plus: 7' x 7' x 2' deep footings (4 each)
Plus: concrete drain trench : [5" x 16" x 2' + 8" x 10"] x 195 '

Volume:	195x63x9/12	= 9213.75 ft^3	slab
+	3(2-0.75)(195+195+63+63)	= 1935 ft^3	perimeter
+	7(7)(2-0.75)(4 each)	= 245 ft^3	footings
+	{[5"(16")(2) + 8(10)]/144 in^2/ft^2}{195}	= 325 ft^2	trench
	Subtotal	=11,718.75 ft^3	
	x 2 pads	=23437.5 ft^3 = 868 CY	

3 west Pads: 202.5' x 60', 6" thick

Plus: 2.75' wide x 1.5' deep perimeter perimeter
Plus: 2.5' x 1.5' x [202.5'*2 +60'*9 length] waffle
Plus: [5" x 16" x 2' + 8" x 10"] x 202.5 ' concrete drain trench

Volume:	202.5*60*6/12	= 6075 ft^3	slab
+	2.75*1.5*(202.5*2 + 60*2)	= 2165.6 ft^3	perimeter
+	2.5*1.5[202.5*2 + 60*9]	= 3543.8 ft^3	footings
+	{[5"(16")(2) + 8(10)]/144 in^2/ft^2}{202.5}	= 337.5 ft^2	trench
	Subtotal	=12,121.9 ft^3	
	x 3 pads	=36,365.6 ft^3 = 1347 CY	

Total = 2,215 CY

Available Borrow Soils Volume Estimates:

1. LANL Borrow Source #1 (2-10-15) 5133 CY
2. Alcalde, NM:
    a. Clay (2-10-15) = 1.5’ (2*43560.2) = 130,681 ft3 = 4840 CY
    b. Sandy Soil under clay = dependent on depth excavated
    c. Rocky Loam (2-10-15) = 5000 CY +
3. Espanola Transit (Jan 2015):
    a. Clay 6000 tons
    b. Silt 10,000 tons
    c. Overburden 25,000 CY +
4. LANL Borrow #2 - TA54 (Mar 2015) 10,000 CY
5. LANL Borrow Source #3 – Sigma Mesa (May 2015) 6,000+ CY