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File name:	Target-ERID #.pdf
Version:	1.0
Document Type:	RPF Record
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Document Details:

Title:	ERID-098276 1) CONCEPTUAL COVER DESIGN REPORT FOR THE CME CLOSURE OF MDA G
ERID Number.StartPage:	ERID-098276
Office of Record:	ENV-ERSS
Date Received:	09/17/2007
Official Use Only:	N
Page Count:	48
Record Type:	Report
Document Date:	05/01/2007
To:(Addressees - Organization) *(separate multiple values with semicolons)*	N/A
From:(Senders - Organization) *(separate multiple values with semicolons)*	STEPHEN DWYER
Other Document Number(s): *(separate multiple values with semicolons)*	N/A
TA: *separate multiple values with semicolons)*	54
PRS Number(s): *(separate multiple values with semicolons)*	N/A
Record Box Number:	

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Conceptual Cover Design Report

for the

Corrective Measures Evaluation

for

Closure of MDA G

Prepared under contract to EnergySolutions

for

Los Alamos National Laboratory
Environmental Programs-Environmental
Restoration Support Services

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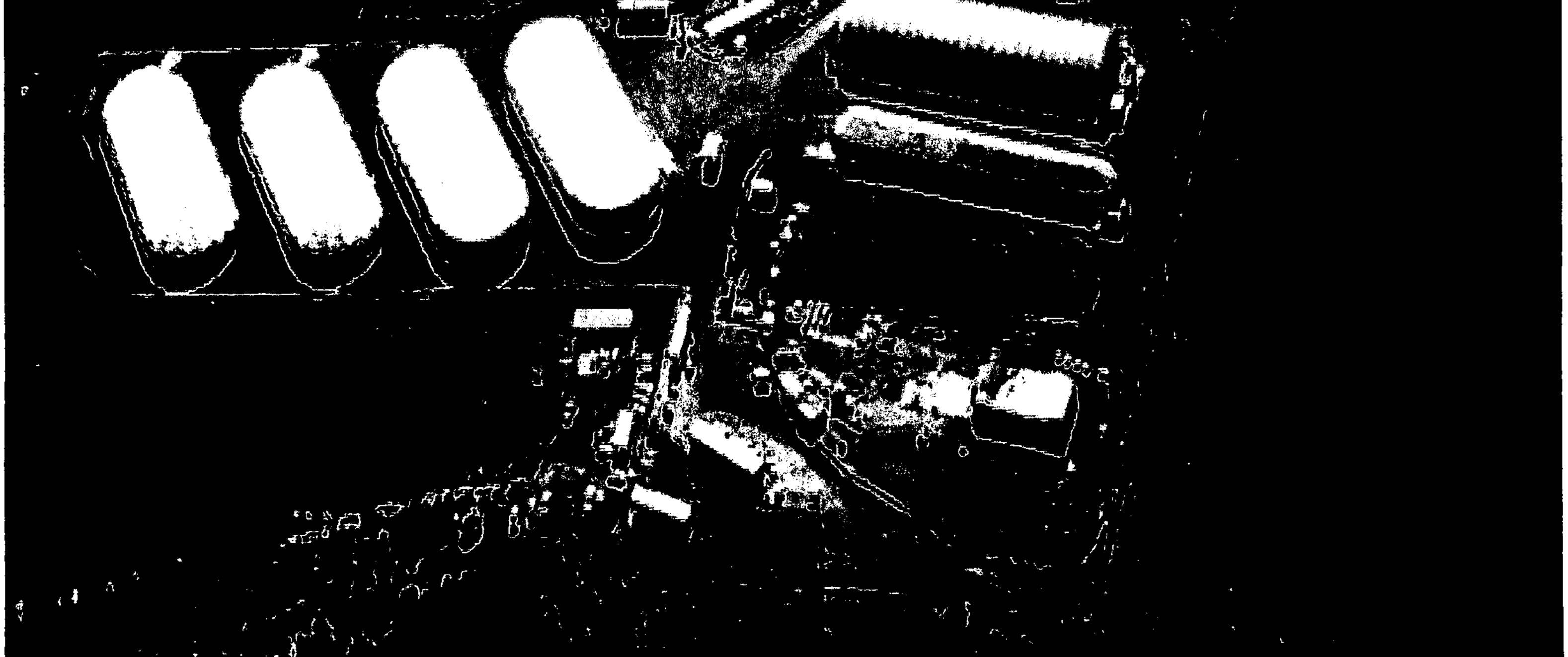

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1.0 EXECUTIVE SUMMARY

Dwyer Engineering, LLC was tasked to provide engineering input into the development of a conceptual cover profile for final closure of the Material Disposal Area (MDA) G site located at Los Alamos National Laboratory (LANL) in Los Alamos, New Mexico. Specifically, Dwyer Engineering was to provide a recommended cover profile based on storage capacity, erosion, and biointrusion considerations. Other considerations such as radon attenuation were completed by others. This conceptual profile was determined based on the best available information including assumptions required to overcome data gaps.

A conceptual cover profile was derived for the Corrective Measures Evaluation to remediate and close MDA G. The conceptual cover profile (Figure 3.1), consists of a soil profile referred to as an Evapotranspiration (ET) Cover. This cover is designed to store infiltrated water until it is removed by the combination of plant transpiration and surface evaporation (collectively referred to as ET). The cover system will use locally available soils and native vegetation to create a long-lasting cover that has a performance and design life commensurate with the projected hazardous life of the contained wastes. The Performance Assessment (PA) for MDA G indicated that the primary contaminant release vectors from the site are erosion and biointrusion. To minimize erosion, the cover surface was enhanced with a gravel admixture. A bio-barrier was placed beneath the soil cover to minimize the intrusion of flora and fauna into the underlying waste.

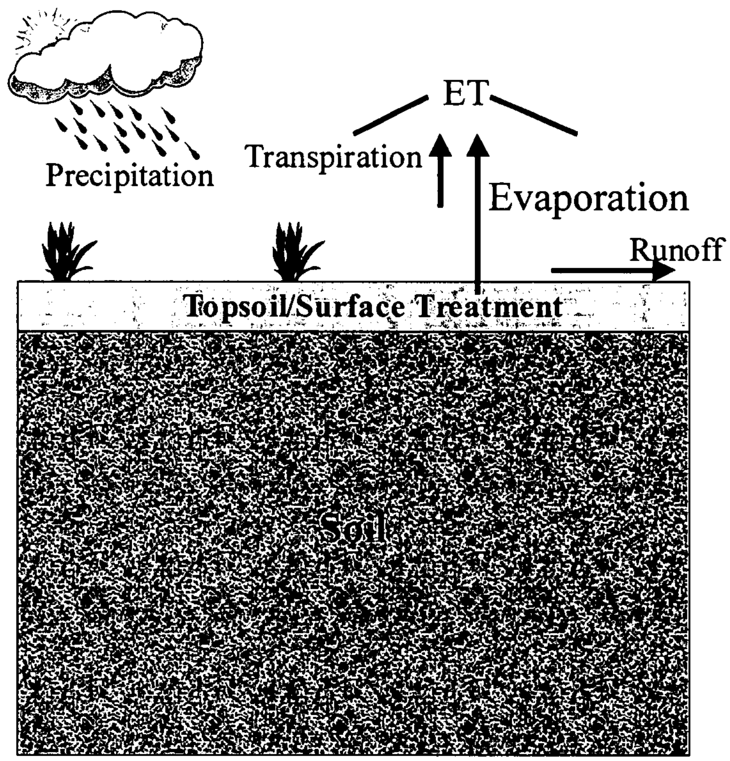
Unsaturated flow modeling of the proposed conceptual cover design determined that flux through the profile would essentially be zero thus satisfying the DOE Order 435.1 and RCRA-equivalence. The MDA G PA suggested a flux less than 1 mm/yr would limit the migration of contaminants due to surface infiltration. However, because MDA G contains Resource Conservation and Recovery Act (RCRA) wastes, regulations governing RCRA require the flux through a cover to be minimized. Soil from the TA61 proposed borrow site were modeled to determine their effectiveness in an ET Cover. The modeling revealed that a soil depth greater than 6.6 ft (2m) would be required to minimize flux. The TA61 soils were classified as a sandy loam (Shaw 2006), but have marginal storage capacity. Consequently, hydraulic properties of a typical sandy loam were modeled to verify if the soil depth requirement could be reduced. The modeling output showed that the typical sandy loam would minimize flux with a depth of about 5 ft (1.5 m). It is therefore recommended a soil amendment be included with the TA61 borrow soils to increase the storage capacity and soil nutrient availability. This site is also governed by Department of Energy (DOE) Order 435.1 which states that the cover should be designed to perform for 1000 year time period; the upper boundary condition should ideally be expanded to include climate scenarios that are expanded beyond the available weather data. However, this data is not available at this time. Engineering judgment was used to determine that 5 ft (1.5 m) of cover soil would offer adequate storage capacity even under an enhanced set of climate scenarios representative of a 1000 year return period to reduce infiltration to less than 1 mm/year. Especially considering that the inclusion of a bio-barrier in the cover profile introduced a capillary barrier that further enhances the storage capacity of the cover soil.

2.0 INTRODUCTION

MDA G is located within Technical Area (TA) 54 at the Los Alamos National Laboratory in Los Alamos, New Mexico. TA-54 is located on Mesita del Buey and spans the boundary of the Cañada del Buey and Pajarito Canyon watersheds. TA-54 ranges in elevation between 6700 and 6800 ft with a depth to groundwater ranging between 900 and 980 ft. The major industrial activity at TA-54 has been waste storage and disposal. MDA G is a 100-acre site that has served as the Laboratory's principal radioactive solid waste storage and disposal site since routine operations began in 1959. The majority of stormwater runoff from MDA G enters the Pajarito Canyon watershed with a much smaller portion draining into Cañada del Buey, which is located within the Mortandad Canyon watershed.

This report provides a summary of the basis for the conceptual cover design for MDA G as part of the Corrective Measures Evaluation (CME) for remediation of the site. An ET Cover with an erosion resistant surface treatment and a bio-barrier will be constructed to provide adequate protection and risk reduction. The ET Cover consists of a single, vegetated soil layer constructed to represent an optimum mix of soil texture, soil thickness, and vegetation cover (Figure 2.1).

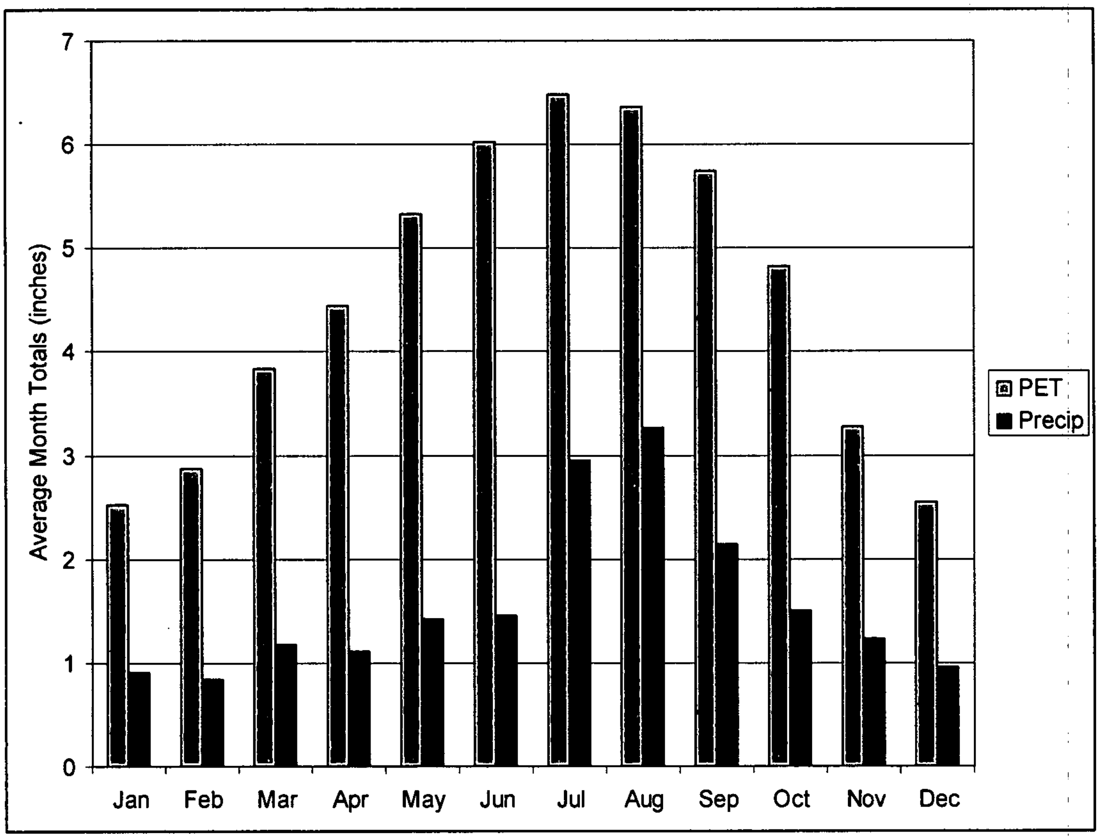
Figure 2.1
TYPICAL ET COVER PROFILE



The ET Cover concept relies on the soil to act like a sponge (Dwyer 2003). Infiltrated water is held in this "sponge" until it can be removed via ET. ET is defined as the combination of water removal due to both evaporation from the surface and transpiration through vegetation. Previous research has shown that a simple soil cover can be very effective at minimizing percolation and erosion, particularly in dry environments (http://www.clu-in.org/download/remed /epa542f03015.pdf#search ='evapotranspiration%20epa%20fact%20sheet).

The MDA G site is an ideal site for an ET Cover. First, it contains long-lived waste and source material such as radionuclides. Prescriptive covers that depend on geosynthetics cannot effectively be used for these sites because the geosynthetics will not last as long as the waste poses a significant risk nor will they meet the 1000 year performance period dictated under DOE Order 435.1. Additionally, the climate's demand for water or potential evapotranspiration (PET) far exceeds the actual supply of water (precipitation) as shown in Figure 2.2. The ET Cover offers another important advantage in that it provides for a deeper rooting medium that will provide an opportunity for native vegetation to survive lengthy drought periods because the water storage of the ET Cover is greater than that of a prescriptive cover.

Figure 2.2
Climate's demand for water (PET) vs. supply of water (precipitation) for Los Alamos, NM



3.0 CONCEPTUAL DESIGN

The cover system proposed for final closure as part of the CME for MDA G located at Los Alamos National laboratory in Los Alamos, NM is shown in figure 3.1. A brief description of each layer in the cover profile is contained in Table 3.1 with expanded descriptions contained in sections 3.1 to 3.5.

Figure 3.1
MDA G CME Conceptual Cover Profile

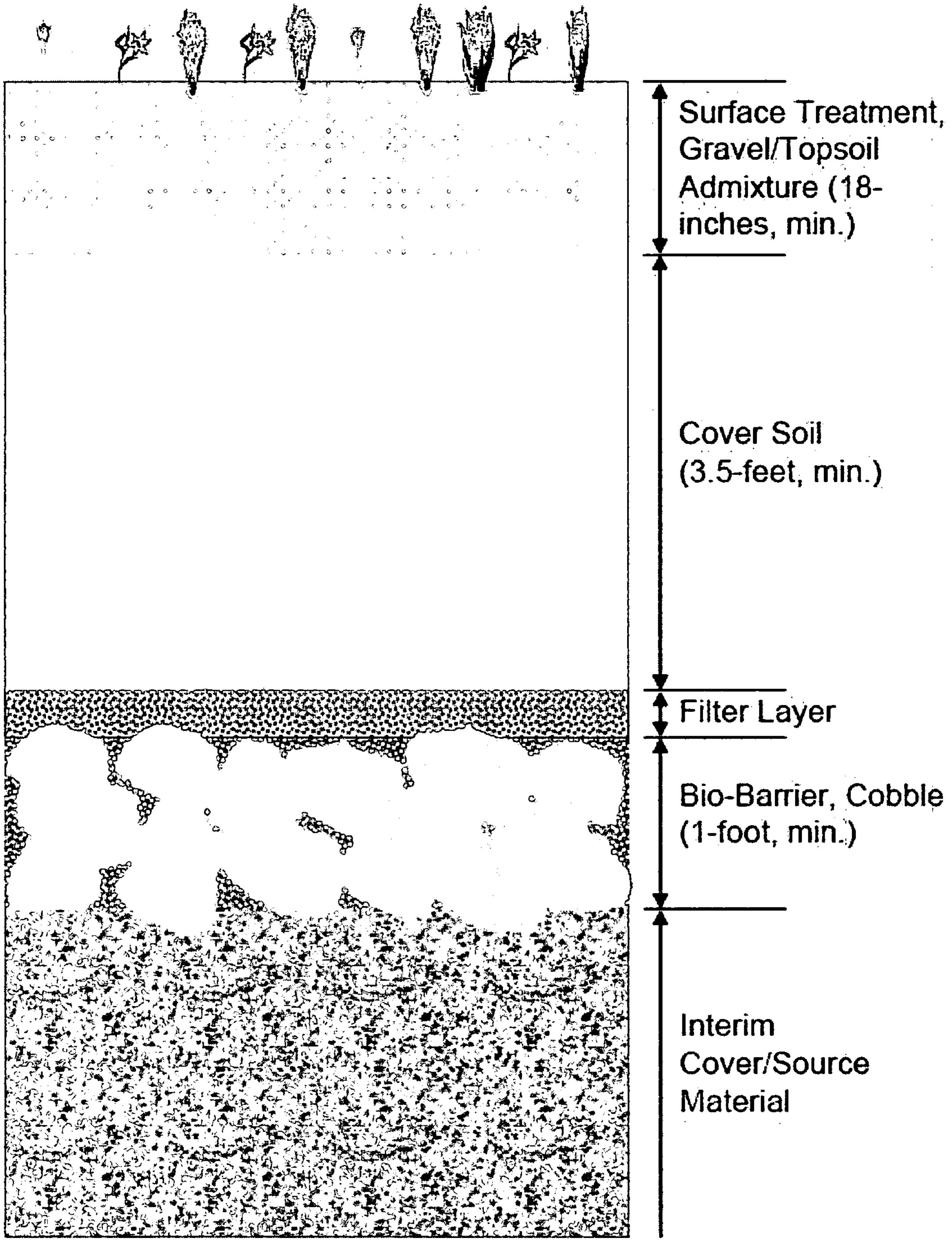


Table 3.1
MDA G CME Conceptual Cover Profile Layer Specifics and Justification

Cover System Layer	Design Specifics	Design Justification
Vegetation	The site is to be seeded with native vegetation composed of both cool and warm weather species (grasses). Refer to Table 3.1 for a recommended seed mix.	The vegetation will help stabilize the cover surface, minimize erosion, and remove infiltrated water via transpiration.
Surface Treatment	Mixture of cover soil and gravel. The gravel is to be mixed into the cover soil at a rate of 33% by weight. The gravel will be 1.75-inch (4.4 cm) to 3-inches (7.6 cm) in diameter. The cover soil will be capable of maintaining native vegetation with adequate storage capacity and nutrient availability. This layer will be a minimum of 18-inches thick (0.5 m).	The gravel/soil admixture is designed to minimize erosion due to both wind and surface runoff.
Cover Soil	The cover soil depth will be a minimum of 3.5-feet (1 m). The layer will consist of soil from TA61 with a determined mix of soil amendments. The cover soil will be capable of maintaining native vegetation with adequate storage capacity and nutrient availability.	Hydraulic characteristics of a typical sandy loam were used to determine the required soil depth because it is recommended that the TA 61 borrow soils be amended to possess the storage capacity of this soil type. The soil depth was determined using modeling where a depth of soil was determined to minimize flux. The modeling utilized the wettest decade on record as the upper boundary condition. However, because the site requires a 1000-year performance period, it was estimated that the added storage capacity offered by the inclusion of a bio-barrier that creates a capillary barrier was more than adequate to store any infiltration events that would occur over a

		1000-year return period.
Filter Layer	This layer is composed of sand and gravel that meet determined filter criteria to prevent the overlying finer cover soils from migrating into the underlying bio-barrier.	A thin layer placed directly on the bio-barrier to serve as a filter medium to prevent the overlying finer soils from migrating into the underlying bio-barrier.
Bio-barrier	A layer of minimum 6-inch (15 cm) diameter cobble composed of rock or concrete. The layer is to be a minimum of 1-foot thick (0.3 m).	The layer prevents biointrusion (burrowing animals and plant roots) from entering the underlying source material.
Subgrade	The upper foot of existing interim cover soil shall be scarified and recompacted to a minimum of 95% of the maximum dry density and dry of the optimum moisture content as determined per ASTM D698.	Provide a firm foundation for the construction of the cover profile. Provide the final grades and slopes for installation of a uniform cover profile.

3.1 VEGETATION

Seed and/or live plants used to revegetate disturbed areas at LANL shall be native to the Los Alamos vicinity. The following is the seed mix to be employed for the cover system at MDA G (Table 3.2).

Table 3.2
Seed Mix

Common Name	Scientific Name	% of mix	PLS (lbs/acre)
Sideoats grama	Bouteloua curtipendula	15%	3.75
Blue grama	Bouteloua gracilis	15%	3.75
Indian ricegrass	Oryzopsis hymenoides	10%	2.5
Western wheatgrass	Agropyron smithii	15%	3.75
Sand dropseed	Sporobolus cryptandrus	10%	2.5
Sheep fescue	Festuca ovina	20%	5
Firewheel	Gaillardia pulchella	3%	.75
Western yarrow	Achillea millefoium	2%	.5
Prairie coneflower	Ratibida columnifera	4%	1
Blue flax	Linum perenne lewisii	6%	1.5
TOTAL			**25 (drilled)**

SEED APPLICATION

Seeding of native vegetation on the cover systems shall be performed in the spring, after the last frost of the season and prior to the arrival of the summer rains that typically occur in July and August. Seeding shall not be done August 1 to September 30 to avoid germination too close to the first frost, as this can kill the new seedlings.

Revegetation shall be done by first preparing the soil by tilling and applying fertilizer. Care must be taken to ensure the rock/soil surface treatment maintains the desired ratio during this activity. Care must also be taken to ensure the rock/soil surface treatment layer is not mixed deeper into the cover profile. Slow-release organic fertilizers shall be applied as necessary to eliminate any deficiencies of the topsoil. Refer to Table 3.3 for recommended levels of available plant nutrients. Bio-Sol or similar fertilizer shall be applied at up to 1500 lbs/acre. Analyses of cover soils used will dictate the actual fertilizer rate required. Granular humate can be applied at 400-500 lbs/acre if in a hydroseeding slurry and up to 1800 lbs/acre if it is incorporated into the top 4 inches of the soil. Application rates of composted manure vary depending on the source (chicken, horse, etc.) and the type of materials (wood chips, paper, soil, etc.) used to compost. If composted manure is to be applied, nutrient content shall be tested and interpreted before it is used.

Drill seeding shall be the method used to apply the seed mix. Drilling introduces seed directly into the prepared seedbed by machine. Seeding shall be performed by drilling at a minimum rate of 25 Pure Live Seed (PLS) pounds per acre. In areas that limit equipment access, broadcast seeding may be used at a rate of 40 PLS pounds per acre.

3.2 SURFACE TREATMENT

The Performance Assessment for MDA G states that biointrusion and erosion are the two primary mechanisms to control contaminant releases from the site. To address the potential erosion of the cover system, a surface treatment is to be used composed of a mixture of gravel and cover soil. This admixture was designed following the procedure described in Dwyer et al (1999), and Dwyer et al (2006).

The gravel to soil mixture and gravel size was determined based on the most critical drainage section (north-south). With the addition of the gravel/soil admixture to the surface, annual soil loss due to both wind and runoff was estimated to be minimal. The gravel admixture shall include a mixture of 33% gravel by weight. The cover soil shall exhibit the storage capacity and soil nutrients described in section 3.3. Salts in this soil shall also be limited in the cover soil as described in section 3.3. The critical gravel size was determined to be 1.5 inches (3.8 cm) [use gravel between 1.5 inches (3.8 cm) to 3 inches (7.6 cm) in diameter] and the total gravel/soil admixture thickness is to be no less than 18 (0.5 m) inches. The design methodology and procedure with input and output specifics are included in Appendix A. Many of the input parameters required to calculate the specifics of this gravel admixture, surface treatment such as bulk density and percentage of silt/clay in the soil were estimated based on soil amendment requirements. Furthermore, slopes and slope lengths were estimated based on preliminary contours provided by PRO2SERVE. These estimates will be replaced with measured values during the final design phase as uncertainties are overcome.

Because the gravel is used to control erosion and is subject to weathering, it shall meet the durability requirements described in NUREG (1999). Refer to table 3.2 below.

Table 3.2
Scoring Criteria for Determining Rock Quality (NUREG 1999)

	Weighting Factor			Score										
	Limestone	Sandstone	Igneous	10	9	8	7	6	5	4	3	2	1	0
Specific Gravity (SSD)	12	6	9	2.75	2.70	2.65	2.60	2.55	2.50	2.45	2.40	2.35	2.40	2.25
Absorption (%)	13	5	2	0.1	0.3	0.5	0.67	0.83	1.0	1.5	2.0	2.5	3.0	3.5
Sodium Sulfate (%)	4	3	11	1	3	5	6.7	8.3	10	12.5	15	20	25	30
Abrasion (%)[1]	1	8	1	1	3	5	6.7	8.3	10	12.5	15	20	25	30
Schmidt Hammer	11	13	1	70	65	60	54	47	40	32	24	16	8	0
Tensile Strength (psi)	5	4	10	1400	1200	1000	833	666	500	400	300	200	100	<100

[1] 100 revolutions. Use only ASTM C131 for scoring purposes for consistency with basis for scoring system (DePuy 1965).

Notes:

1. Scores derived from Tables 6.2 and 6.7 of NUREG/CR-2642.
2. Any rock to be used must be qualitatively rated at least "fair" in a petrographic examination conducted by a geologist experienced in petrographic analysis.
3. Weighting Factors are derived from Table 7 of DePuy (1965), based on inverse of ranking of test methods for each rock type.
4. Test methods shall be standardized (e.g., ASTM) and shall be those described in DePuy (1965).

SOIL PLACEMENT

The gravel/soil admixture used as a surface treatment shall be placed in one uncompacted lift if practical. Two lifts are also acceptable provided the bottom lift is not overcompacted due to placement of the top lift. This surface treatment layer shall be placed as dry as possible, but no wetter than the optimum moisture content as determined by ASTM D698. Any excessive compaction this layer receives during placement shall be scarified. The loose-state of placement is to provide the best means for vegetation establishment. Over-compaction is one of the primary problems with revegetation efforts.

3.3 COVER SOIL

The cover soil layer beneath the gravel/soil admixture shall be a minimum of 3.5 feet (1 m) of amended soil meeting the water storage capacity properties of a typical sandy loam soil (ROSETTA 2000). The cover soil including the soil in the surface treatment (gravel admixture) must possess adequate storage capacity to retain infiltrated water until that water can be removed via ET. Furthermore, this soil must be able to provide a quality rooting medium to maintain native vegetation. This involves ensuring the soil has acceptable levels of plant available nutrients and its salt content is below acceptable levels.

The depth of the cover soil was determined based on water storage requirements to meet RCRA-equivalency. That is, the depth of soil required to minimize flux per 40CFR264.310. The MDA G PA stated that as long as the flux through the cover was less than 1 mm/year, significant risk due to radionuclides would be mitigated and thus DOE Order 435.1 would be satisfied. Modeling using UNSAT H (Fayer 2000) was performed to determine the minimum thickness required to provide adequate storage capacity for an upper boundary condition consisting of the wettest decade in recorded history in Los Alamos (1985 to 1994).

Average hydraulic properties (Shaw 2006) from the TA61 soil borrow site were used as input parameters. The modeling output determined that a depth greater than 6.6 ft (2 m) would be required to minimize flux largely due to the lack of water storage capacity in the TA61 soils (Figure 3.2). The TA61 soils consist of crushed tuff and were classified as a sandy loam, but are on the coarser side of sandy loam soils. Another modeling exercise was performed utilizing typical sandy loam hydraulic properties (ROSETTA 2000) to ascertain if this soil type would decrease the soil depth requirement. This output (Figure 3.3) determined that approximately 1.5 m (5ft) of typical sandy loam soil would minimize flux to a point of diminishing returns (Dwyer et al 2006).

The depth of the surface treatment was determined to be a minimum of 1.5 ft (0.5 m). Therefore the additional cover soil depth required to minimize flux is 3.5 ft (1 m). This provides for a minimum cover soil depth of 5 ft (1.5 m). A third modeling exercise was performed to capture the entire conceptual design that includes all layers above the existing subgrade. This modeling output determined that flux through the cover will be negligible with the conditions modeled. It is important to note that the inclusion of a filter medium above the bio-barrier and the inclusion of a bio-barrier create a capillary barrier. Details of the modeling performed including specific input and output parameters are included in Appendix C.

Figure 3.2
TA 61 Soil: Point of Diminishing Returns (greater than 200 cm)

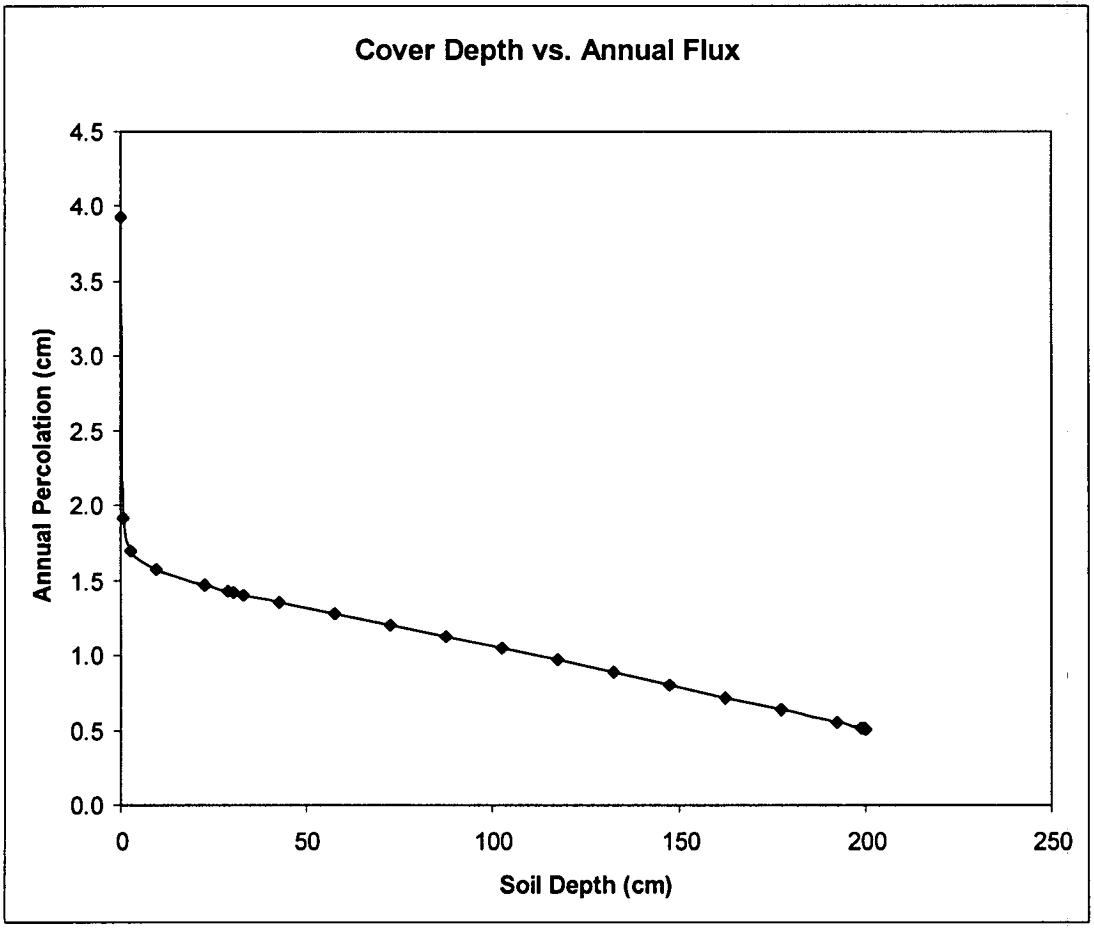
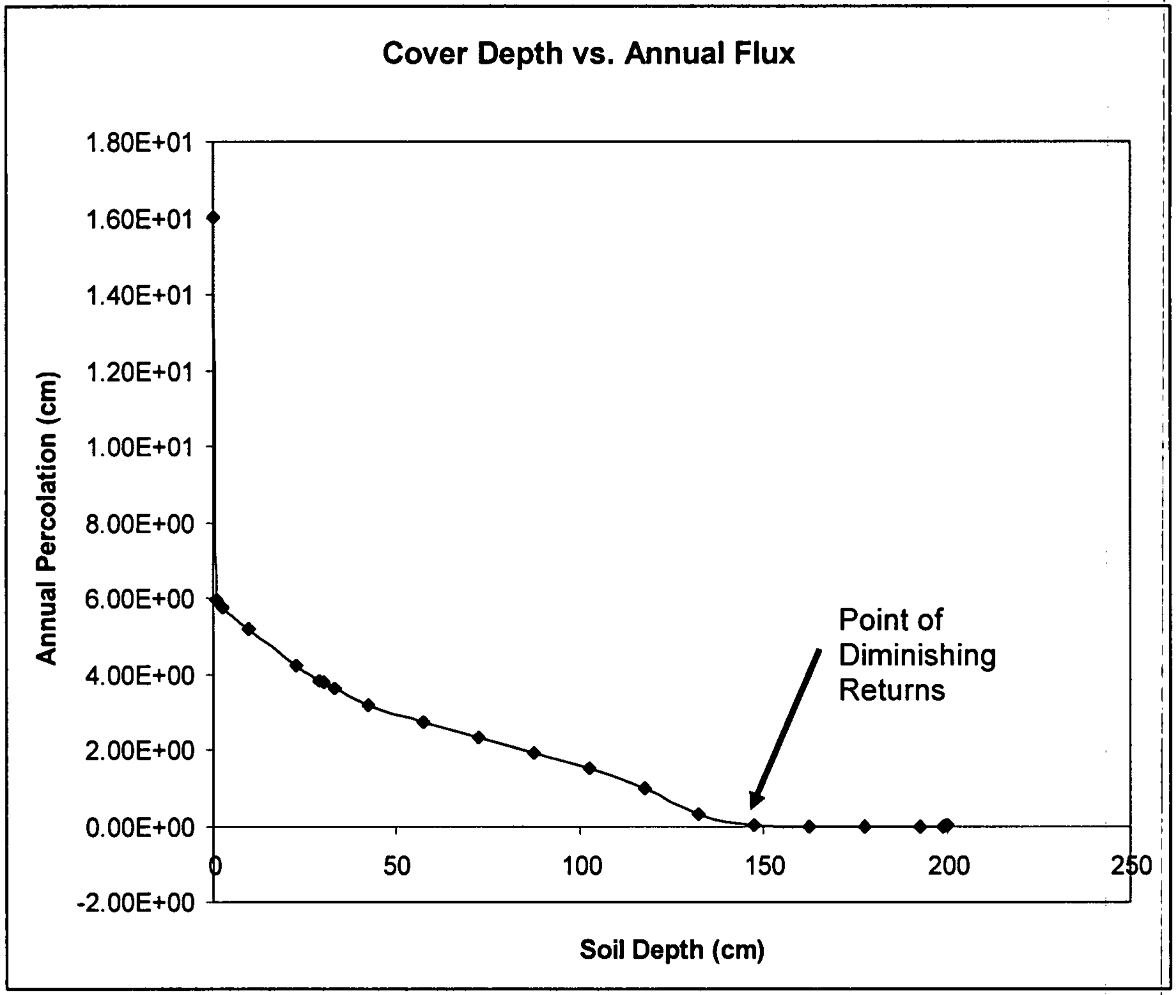


Figure 3.3
Typical Sandy Loam Soil: Point of Diminishing Returns (1.5 m)



The amendments shall ensure the cover soil is capable of maintaining a desired stand of native vegetation. The plant nutrients should allow for the final amended soil to meet the requirements listed in the following table.

Table 3.3
Recommended Available Plant Nutrients for Cover Soil

Test	Limits
CEC	Greater than 15
Percent organic matter	Greater than 2% (g/g)
N	Greater than 6 parts per million (ppm)
P	4 to 7ppm
K	61 to 120 ppm

Because it is unknown at this time where the amendments to the TA 61 will come from, it is also important to verify that the cover soils have tolerable quantities of salts. That is, the salt content in the soils shall be below levels that would hinder the establishment and growth of native vegetation. The final amended soils shall comply with the requirements outlined in the following table.

Table 3.4
Recommended Limitations of Salt in Cover Soil

Test	Limits
EC	Less than 8 µS/cm
SAR	Less than 6
ESP	Less than 15% (g/g)
$CaCO_3$	Less than 15% (g/g) – to 3-ft (91 cm) depth of cover; No limit below 3 ft (91 cm)

SOIL PLACEMENT

An important aspect involved with the construction of a soil cover system is that the soils are placed in a uniform manner. This will help limit preferential flow through the cover. Dwyer (2003) describes the impact of preferential flow in landfill covers. Preferential flow cannot be avoided, but necessary precautions shall be employed to ensure it is minimized. An important feature of the design specifications will involve determining an acceptable density range for installation of the cover soils. Furthermore, to increase the initial storage capacity of the cover system and mitigate the potential for desiccation cracking, the soils will be placed as dry as possible, but no greater than the optimum moisture content as determined by ASTM D698. The acceptable density and moisture content placement range is described as the acceptable compaction zone (ACZ).

The ACZ (Figure 3.4) is unknown as of the date of this report because the desired soil will require amendment to meet the performance objectives of the cover system. Therefore, the process involved in determining this ACZ is briefly described here. For further details refer to Dwyer et al (2006).

Determination of the ACZ for placement of cover soil:

1. Cover soil shall be placed at the goal density. The goal density is best determined from the borrow soil's in situ density. That is, over an extended period of time, a given soil will move toward its "natural" density state. Therefore, it is the goal of the soil installation to place the soil at a density that is as close to that "goal" density as possible from the onset. In this case because the soil will be amended, the goal density shall be assumed to be between 85 to 90% of the maximum dry density (MDD) as determined by ASTM D698.

2. Determine a standard proctor curve for the amended soil used per ASTM D 698, Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort, to obtain the respective maximum dry density (MDD) and optimum moisture content.

3. The allowable dry unit weight or soil density during construction shall then be the goal density plus or minus 5 pounds per cubic foot (pcf) (metric units).

4. The cover soils shall be placed as dry as possible not to exceed the optimum moisture content per ASTM D 698 derived for each borrow soil used. Installing soil dry will provide for a maximum initial water storage capacity in the cover and minimize the potential for desiccation cracking. This is particularly important when using clays (Suter et al. 1993, Dwyer 2003). This moisture

content is applicable for all soils in the cover system, including the upper foot (31 cm) of the interim cover or subgrade.

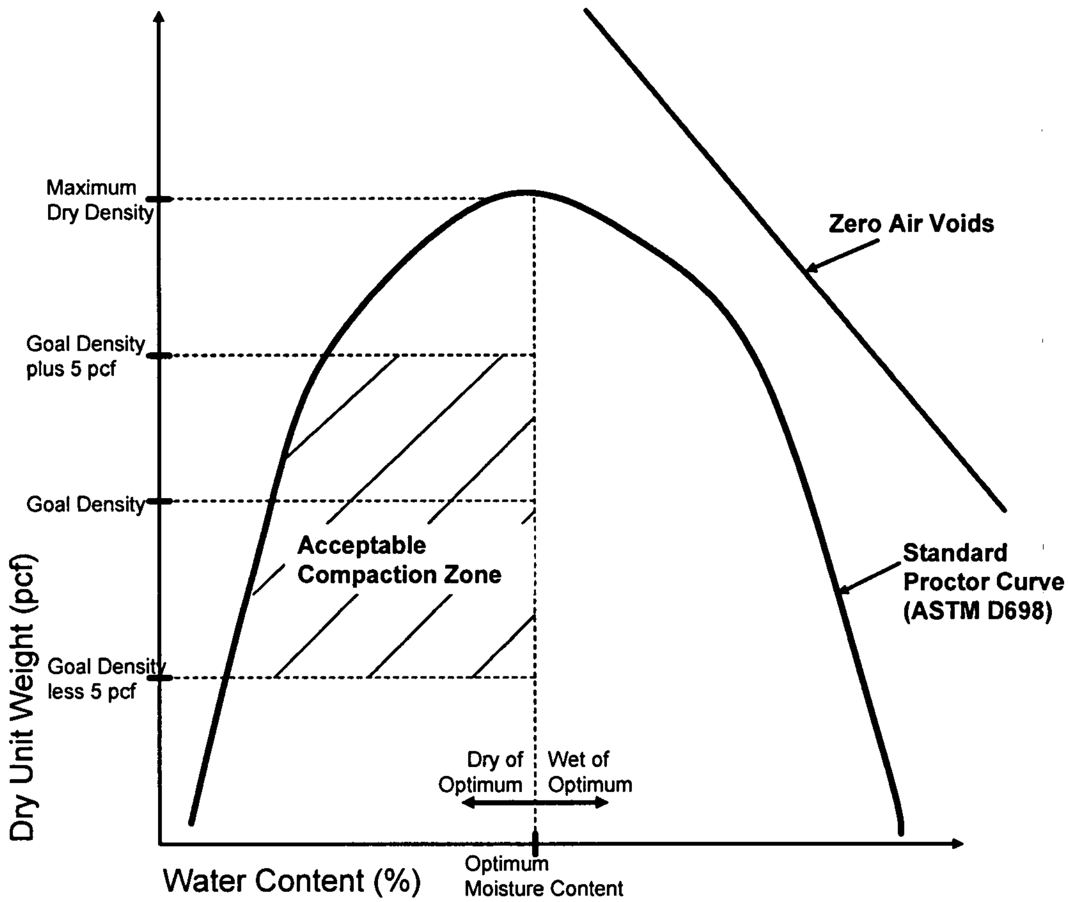


Figure 3.4. ACZ for Soil Placement shown in Hatch Marks

3.4 FILTER MEDIUM

A filter medium composed of sand and /or gravel shall be placed above the bio-barrier, between the bio-barrier and the overlying cover soil layer. This layer is designed to prevent the mixing of soil layers and meet specified filter criteria. The depth of this layer is to be determined in the field and will be the minimum depth required to completely cover the bio-barrier layer and provide a smooth and continuous surface layer for placement of the cover soil. For estimating purposes, this layer shall be assumed to be 6-inches (15 cm) thick.

The Performance Assessment performed for MDA G stated that the two primary mechanisms of concern for transport of contaminants from the site were biointrusion and erosion. There was significant uncertainty with regard to the analysis of biointrusion and erosion in the PA as well. Burrowing animals and roots are both of concern because they can bring contaminants to the surface. A bio-barrier is included in the conceptual design to minimize the potential for burrowing animals and roots from accessing the buried source materials. The bio-barrier is composed of large cobble. To prevent the mixing of finer cover soil into the cobble layer, a filter layer is included. A geotextile or other geosynthetics were not used as a filter fabric because they have limited performance lives that are significantly less than the 1000 year performance criteria (DOE Order 435.1) applied to the site.

The filter medium will be composed of coarse material (sand and/or gravel) that meet specific filter criteria to prevent the mixing of materials. These criteria are as follows:

$$\frac{D_{15}}{d_{85}} \leq 5$$ **Equation 3.1**

where:

D_{15} = particle size of the coarse soil for which 15% of the particles are finer,

d_{85} = particle size of the fine soil for which 85% of the particles are finer.

The filter design criteria summarized in Table 4.2-3 (DOE 1989) as well as the following requirements shall also be used:

- The filter material shall pass the three-inch sieve for minimizing particle segregation and bridging during placement. Smaller maximum particle sizes may be specified if practical. Also, filters must not have more than 5% passing the No. 200 mesh sieve to prevent excessive movement of fines in the filter.

- Filter material shall be reasonably well graded throughout the in-place layer thickness.

A capillary barrier will be formed with the inclusion of the filter medium beneath the fine cover soils. A second capillary barrier may also be formed between the filter medium and the cobble bio-barrier. Consequently, all requirements for a capillary barrier must be followed as outlined in Dwyer et al (2006). Of particular concern are long slope lengths and consequently the diversion capacity of the capillary barrier. The interface between the materials forming the capillary barrier(s) shall maintain a smooth and continuous interface. Discontinuities in this interface may result in significant preferential flow and must be prevented.

3.5 BIO-BARRIER

As stated in section 3.4, a bio-barrier is included in the cover profile to minimize the intrusion of flora and fauna into the buried source materials. The Performance Assessment for MDA G stated that biointrusion is a significant concern as a transport vector for contaminant release from the site. It is of particular concern for radionuclides that pose a risk to the surrounding environment for longer periods of time. A minimum 1-foot (0.3 m) thick layer of cobble with a minimum diameter of 6-inches (15 cm) will be included in the cover profile. This layer will minimize the potential burrowing of the animal of most concern at the site - gophers; as well as the intrusion of woody roots from plants such as shrubs, pinon, and juniper.

Biointrusion in a landfill cover system refers to the flora and fauna (including insects) interactions or intrusion into the cover system. Biointrusion is important in that it can represent a mechanism leading to vertical transport of contaminants to the ground surface via plant root uptake or soil excavation by burrowing animals and insects. Furthermore, biointrusion can lead to increased infiltration and preferential flow of surface water through the cover system as well as contribute to the change in the soil layer's hydraulic properties. However, the increased soil moisture resulting from burrowing effects on infiltration can actually stimulate increased plant growth, leading to an increase in plant transpiration (Hakonson 2000, Gonzales et al. 1995) and a resulting net decrease in flux.

Vertical transport by biota may be small over a short time scale; however, over many decades these processes may become dominant in mobilizing buried waste (Hakonson 1998). Burrowing by animals and insects have the potential to access buried waste several meters below ground surface, which may lead to chemical and radiation exposures to organisms and physical transport of waste upward in the soil profile to ground surface, to biota, and across the landfill surface to offsite areas. These processes are enhanced by erosion (wind/water), transport of animals moving on/off the landfill, deposition of soil particles on biological surfaces from rain splash and wind re-suspension, and wind transport of senescent vegetation to offsite areas.

There are many studies, many of which are summarized in Dwyer et al (2006) that discuss the effects of biointrusion on cover systems and waste sites. Several specifically applicable to MDA G are summarized in Appendix B.

3.6 SUBGRADE/INTERIM COVER PREPARATION

MDA G currently has an interim soil cover over it. This site will require being cleared and grubbed as well as some regrading including cut/fill operations to bring the site to grade prior to placement of the final cover system. The elevations and grades shall comply with those shown on the project drawings provided by others. At a minimum depth, the upper foot (31 cm) of the interim cover or subgrade shall be scarified and recompacted prior to placement of the bio-barrier. This recompacion shall produce a density not less than 95% of the maximum dry density as determined by ASTM D698.

Furthermore, the moisture content shall be placed dry of the optimum moisture content as determined by ASTM D698.

4.0 References:

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47.

APPENDIX A
GRAVEL ADMIXTURE DESIGN

DESIGN RAINFALL EVENT

The rainfall intensity value used to calculate the runoff volume was determined using data supplied by the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) Hydrometerological Design Studies Center and is available on the internet on NOAA's Precipitation Frequency Data Server (http://hdsc.nws.noaa.gov/hdsc/pfds/sa/nm_pfds.html). The data from NOAA Atlas 14 for Los Alamos, NM was used whereby the 30 minute precipitation frequency estimate for a 1000 return period is 2.46 inches (6.25 cm). The 30 minute time of concentration is conservative for any contributory area less than 50 acres (20 hectares) (Lindeburg 1989).

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). Refer to "LANL Engineering Standards Manual," Section G20 (http://engstandards.lanl.gov/engrman/3civ/pdfs/Ch3_G20-R1.pdf). The rational method is based on the assumption that rainfall occurs uniformly over the watershed at a constant intensity for a duration equal to the time of concentration.

Using the rational method, 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:

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

where:

C = Runoff coefficient (dimensionless)

I = Rainfall intensity (in/hr)

A = Surface area that contributes to runoff (acres)

The value for "I" in this case was 2.46 inches/hour (6.25 cm/hr). For storms with return periods longer than 100 years, DOE recommends the use of C = 1.0 (DOE 1989). The surface area was calculated based on the assumed configuration shown in figure A.1 where L is the critical slope length. Slopes and slope lengths were estimated from proposed contoured plans of the MDA G 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.

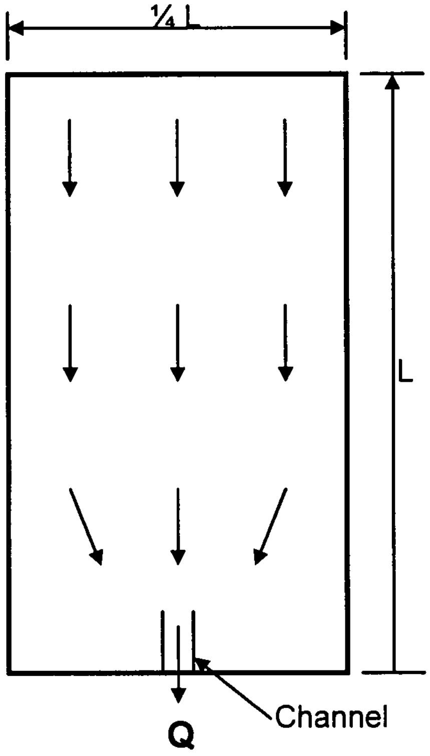


Figure A.1
Contributory area for gully formation

Channel Geometry

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

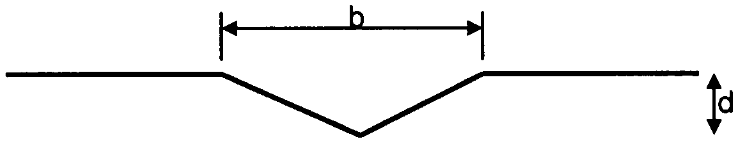


Figure A.2
Channel geometry

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:

$$b = 37\ (Q_m^{0.38} / M^{0.39}) \qquad \textbf{Equation A.2}$$

where:

b = width of flow (ft);

Q_m = mean annual flow (cfs);

M = percentage of silts and clays in soils.

The mean annual flow (Q_m) is assumed to be between 10% and 20% of the peak rate of runoff (Q) (Dwyer et al. 1999). In this case 20% was conservatively 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 A.3**

where:

F = width to depth ratio = b/dh;

F_r = Froude Number ≈ 1.0.

These equations were solved simultaneously to yield the channel width and depth for the given peak flow rate and percentage of silt and clay. Refer to Table A.1 for the summary of calculations performed.

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:

$$D_c = \tau / F_s(\gamma_s - \gamma)$$ **Equation A.4**

where:

τ = total average shear stress (pcf);

F_s = Shield's dimensionless shear stress = 0.047;

γ_s = specific weight of soil (pcf);

γ = water density = 62.4 pcf.

The total average shear stress is given by:

$$\tau = \gamma\, d_h\, S$$ **Equation A.5**

where:

S = slope (ft/ft).

d_h = hydraulic depth (ft)

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 (Ys) (Figure A.3) to establish an armor layer is given by (Pemberton and Lara 1984):

$Y_s = Y_a [(1/P_{c)}-1]$ **Equation A.6**

where:

Y_s = scour depth;

Y_a = armor layer thickness;

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

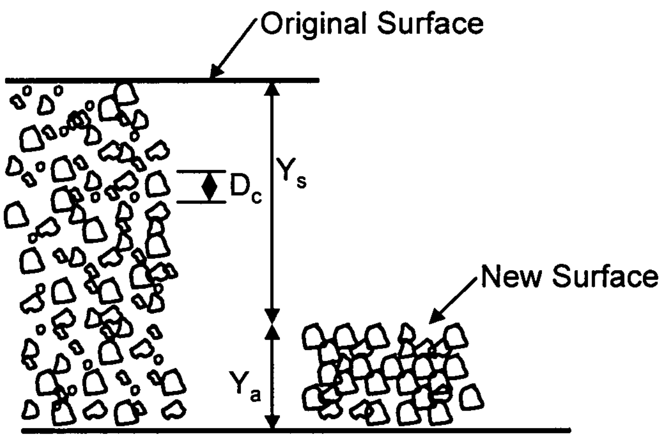


Figure A.3
"Desert Pavement" development

Table A.1 summarizes the gravel admixture calculations performed including critical input and output parameters. The slopes and slope lengths were estimated based on approximate drainage paths and contributory areas as they relate to that assumed in this set of calculations. The first column describes the section that is related to the project drawings produced by PRO2SERVE (not part of this report).

TABLE A.1
GRAVEL ADMIXTURE CALCULATIONS SUMMARY

Section	C Value	I (in/hr)	S (%)	Slope Length (ft)	Q (cfs)	Q_m (cfs)	% silt/clay[1]	Bulk Density[1] (pcf)	Critical Gravel Size [2] (in)	Ratio	Total depth req'd (inches)
DA1	1.0	2.46	2.7	350	1.73	0.17	20	115	0.75	33%	9
DA2	1.0	2.46	3	500	3.53	0.35	20	115	1.25	33%	15
DA3	1.0	2.46	4	375	1.99	0.20	20	115	1.25	33%	15
DA4	1.0	2.46	2.8	800	9.04	0.90	20	115	1.50	33%	18
DA5	1.0	2.46	3.5	500	3.53	0.35	20	115	1.25	33%	15
DA6	1.0	2.46	2	750	7.94	0.79	20	115	1.00	33%	12
DA7	1.0	2.46	2	750	7.94	0.79	20	115	1.00	33%	12

[1] assumed values based on amendments and gravel mixture
[2] value rounded up to nearest quarter inch

APPENDIX B
BIOINTRUSION STUDIES

Plutonium is the best example of a radionuclide whose transport to animals in arid ecosystems is dominated by physical processes. Data from many field sites and source conditions show that gut availability of plutonium and other contaminants bound to soil in a variety of animals including rodents, deer and cattle is very low (gut to blood transfer $<10^{-5}$) leading to very low concentrations of contaminant in internal tissues and organs (Smith, 1977; Moore et al., 1977; Hakonson and Nyhan, 1980; Arthur et al., 1987). Highest concentrations of most soil contaminants in dry, dusty environments are usually found in tissues exposed to the external environment. Those tissues include the pelt, gastro-intestinal tract, and lungs. At Los Alamos, about 96% of the plutonium body burden in rodents from the canyon liquid waste disposal areas was in the pelt and gastro-intestinal tract (Hakonson and Nyhan, 1980).

Because soil passes through the gastro-intestinal tract of free-ranging animals on a daily basis, there is a potential to redistribute soil radionuclides across the landscape. Studies at Nevada Test Site with cattle (Moore et al., 1977), at Rocky Flats Plant with mule deer and small mammals (Little, 1980; Arthur, 1979), and at Idaho National Engineering Laboratory with small mammals and coyotes (Arthur and Markham, 1983; Arthur et al., 1980) demonstrate that horizontal (and vertical in the case of burrowing animals) redistribution of soil plutonium does occur as animals move within and outside contaminated areas. However, the magnitude of this transport was shown to be very small over the short-term (Arthur, 1979; Arthur and Markham, 1983; Arthur et al., 1980).

There are circumstances where animal transport of soil contaminants can assume more importance. For example, fission product sludge containing 90Sr and 137Cs in a salt form was released to unlined cribs at Hanford and the cribs were backfilled with clean soil. A large animal, probably a coyote or badger then burrowed down to the sludge and created direct access for other animals seeking the salts including jackrabbits (O'Farrell and Gilbert, 1975). Jackrabbits ingested the radioactive salts, became contaminated and then excreted 90Sr on the ground surface. Levels of 90Sr in excreta were found over a 15 km^2 surface area (O'Farrell and Gilbert, 1975). This incident with 90Sr and jackrabbits was a special case that involved liquid waste sludge disposal trenches that were not adequately covered.

Potentially more soluble strontium and cesium transport to animals in arid ecosystems involves a combination of physical and physiological processes. The more tightly bound these radionuclides are to soil (related to clay content of soil and local climate); the more their transport will be governed by soil particle transport. Data on Sr90 and Cs137 in small mammals from the Nevada Test Site (Romney et al., 1983) and at a burial ground at Idaho National Engineering Laboratory (Arthur et al., 1987) show relatively high concentrations of these radionuclides in lung, pelt and gastro-intestinal tract similar to plutonium. This suggests that physical transport of these more "soluble" radionuclides is also important as with plutonium. The bioavailability of radionuclides such as cesium and strontium will depend on chemical form, local environmental conditions, and the structure and function of the relevant food webs.

Tritium would be one of the few exceptions to the general observation that physical transport mechanisms dominate in the transport of soil surface contaminants to biota. Uptake by roots or sorption through the leaf surface would dominate in tritium transport to vegetation. Levels of tritium in animals would reflect levels in the source (i.e., concentration ratios are 1 or less) since tritium is not concentrated as it moves through abiotic and biotic pathways. Furthermore, tritium in vegetation is available to nectivorous organisms such as honeybees as well as herbivores. While tritium is readily transported through ecosystems, it is rapidly turned over in biological systems at rates corresponding to water turnover in these systems. In humans, body water turnover is about 3 days (RHH, 1970).

Although vegetation is very important in controlling erosion and percolation in landfill covers (Nyhan et al., 1984), deeply penetrating plant roots have the potential to access buried waste and bring plant available constituents including landfill contaminants to the surface of the site (Klepper et al., 1979; Foxx et al., 1984; Tierney and Foxx, 1987). Contaminants such as tritium can be incorporated within plant tissue and enter the food web of herbivorous or nectivorous organisms. For example, at Los Alamos National Laboratory tritium transport away from a controlled low-level waste site occurred via the soil moisture/plant nectar/honey bee/ honey pathway (Hakonson and Bostick, 1976). As another example, deep-rooted Russian Thistle (Salsola kali) growing over the waste burial cribs at Hanford penetrated into the waste, mobilized 90Sr, and then transferred it to the ground surface. The contaminated surface foliage was transferred away from the cribs when the matured Thistle (tumbleweeds) blew away from the site (Klepper et al., 1979). Two mechanisms for soil contaminant transport to terrestrial plants are absorption by roots and deposition of contaminated soil particles on foliage surfaces. Field studies suggest that deposition of soil particles on foliage surfaces is a major transport mechanism for soil associated contaminants under many arid site and contaminant source conditions (Romney and Wallace, 1976; Romney et al., 1987; White et al., 1981; Arthur and Alldredge, 1982).

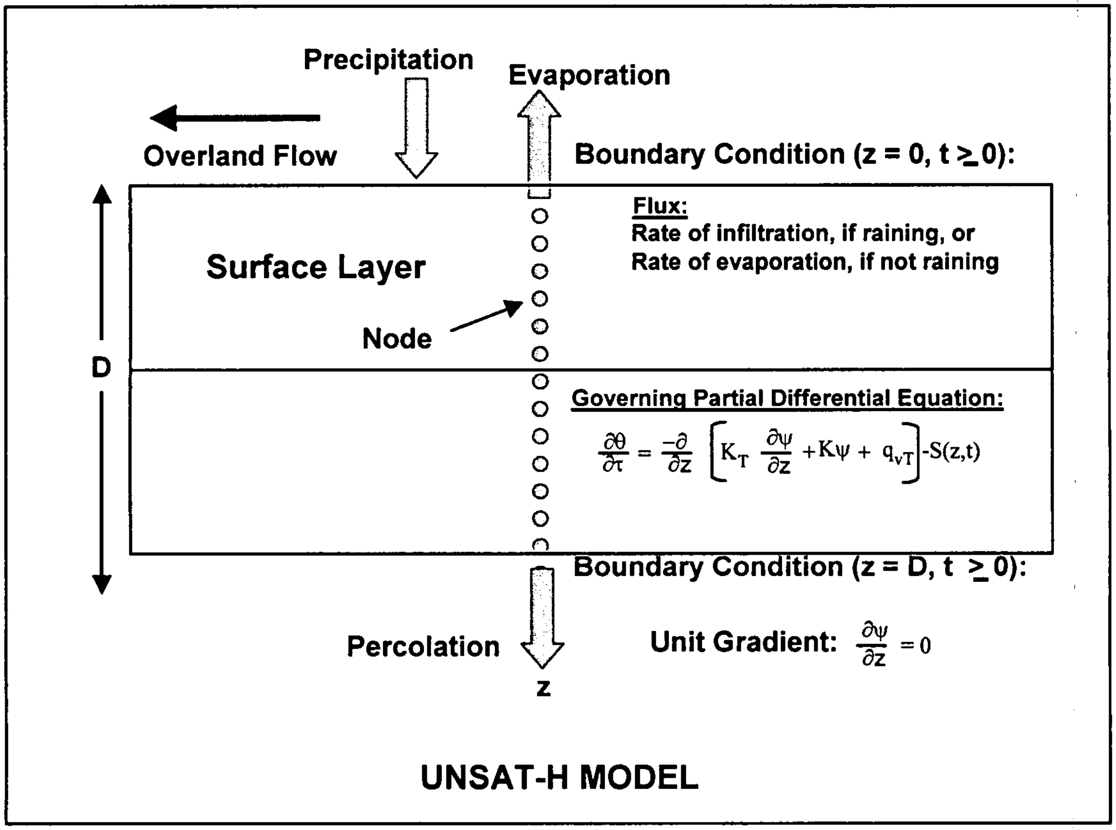
APPENDIX C
MODELING

Overview of UNSAT-H

UNSAT-H has been used to design many recent alternative earthen cover designs (Dwyer 2003). Unlike most unsaturated flow programs, UNSAT-H was specifically developed for the evaluation of earthen covers. 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 C.1. 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.

Figure C.1
SCHEMATIC REPRESENTATION OF WATER BALANCE COMPUTATION BY UNSAT-H (modified from Khire 1995)



Water that has infiltrated a soil profile during an UNSAT-H simulation moves upward or downward as a consequence of gravity and matric potential. 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.

UNSAT-H Input Parameters

A set of input parameters were developed for simulations using UNSAT-H for the given cover profiles. These parameters were developed based on field and laboratory measurements, values from the literature, and expert opinion.

Model Geometry

The model geometry was based on the depth of the cover profile modeled.

Boundary Conditions

The MDA G site in Los Alamos, NM is located in a dry environment where the climate's demand for water referred to as PET far exceeds the actual supply of water or precipitation (Figure 2.2). These are ideal conditions for deployment of an earthen soil cover such as an ET Cover.

The flow of water across the surface and lower boundary of the cover profile is determined by boundary condition specifications. 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 C.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:

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

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 UNSAT-H program partitioned PET into E_p and T_p. PET was derived from daily weather parameters obtained from this weather data. T_p was calculated using a function developed by Equation 1 above.

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.

Upper Boundary Condition - Climate Data

The surface boundary condition during evaporation was modeled as a flux that required daily weather data. The wettest decade on record was used (1985 to 1994) from Los Alamos National Laboratory (weather.lanl.gov). The annual precipitation totals for this decade are summarized in Tables C.2 to C.4. Because the RCRA requirements to minimize flux was the regulatory driver for determining the storage capacity requirements of the cover profile, it was determined that the wettest decade on record would provide a conservative measure to evaluate the RCRA-equivalency of the cover profile.

VEGETATION DATA

Vegetation will generally increase ET from the cover because a plant's matric potential or suction is orders of magnitude higher than that of the soil (Figure C.2). 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 root length density (RLD) is assumed to follow an exponential function such as that defined in Equation C.2:

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

where:
a,b, and c are fitting parameters
z = depth below surface

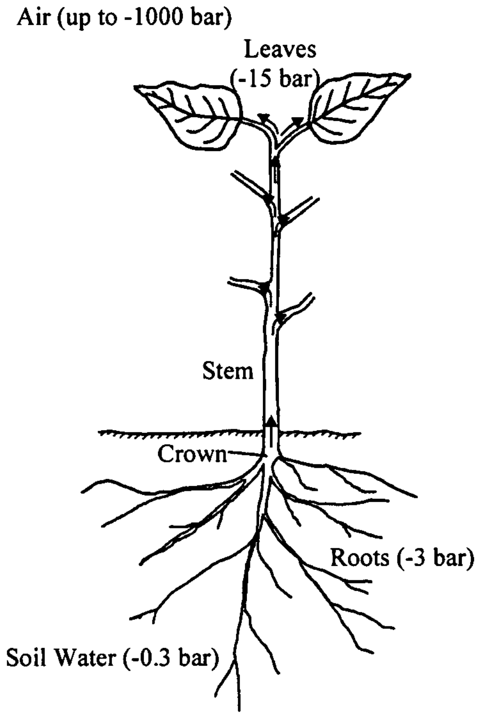
The parameters used for the RLD functions in Equation C.2 were: a = 0.315, b=0.0073, and c = 0.076 (Fayer 2000). The time required for maximum rooting depth establishment was set at full depth beginning on day 1. The rooting depth was set at 6.6-feet (200 cm) (Foxx et al 1984). An average LAI of 0.65 was used (McDowell et al 2005). This value represents an average of values reported for the site of 0.3 and 1.0. The onset and termination of the growing season for the site were Julian days 74 and 288, respectively (EIS, Appendix E). The LAI was transitioned from 0 to 0.65 starting with Julian day 74 to 90. Day 91 through 270, the full LAI equal to 0.65 was utilized. The LAI was then transitioned down from 0.65 to 0 from Julian day 271 to 288. This was conservative since it is realistic that plants can transpire longer than indicated at this site. An average percent bare area of 84.4% was used. This value represents an average of reported values for the area of 91.5% and 77.3 % (Tierney and Foxx 1982). The relative humidity for the site was set at 51% based on the average conditions for Los Alamos (Los Alamos Climatology internet site).

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. 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. 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. The wilting point was conservatively assumed to be 20,000 cm (typical for native grasses) used although the shrubs present at the site could remove water from the soil to a suction of 100,000 cm (Figure C.2). 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.

Figure C.2
TYPICAL SOIL-PLANT-ATMOSPHERE WATER POTENTIAL VARIATION
(Hillel 1998)



Soil Properties

Soil hydraulic properties were obtained from laboratory testing of soil samples collected from the TA61 borrow site (Shaw 2006). The saturated hydraulic conductivity of the soils were obtained using flexible wall permeameters in accordance with ASTM D 5084. Unsaturated soil properties were obtained from data using pressure plates and water columns (depending on the suction values) to develop values of water content as a function of pressure head (ASTM D 6836). These data were then used as input into the RETC code (van Genuchten et al 1991) to compute curve fitting parameters used to estimate the moisture characteristic curve (van Genuchten 1980). The Mualem conductivity function was used to describe the unsaturated hydraulic conductivity of the soils. 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 are 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. The soil properties used as input parameters are summarized in Table C.1.

Table C.1
COVER SOIL PROPERTIES

Cover Profile	Soil Layer Type	Soil Layer Depth	van Genuchten Parameters				Sat. Hydr. Cond. (cm/hr)
			θ_s	θ_r	α	n	
TA61 BORROW SOILS USED (BH1 @ 15 TO 25-FT DEPTH)							
Cover Soil Only	Cover Soil	6.6 ft (200 cm)	0.2454	0	0.0027	1.6175	17.64
TYPICAL SANDY LOAM (ROSETTA 2000)							
Cover Soil Only	Cover Soil	6.6 ft (200 cm)	0.387	0.039	0.0267	1.4488	1.5951
CONCEPTUAL COVER DESIGN WITH TYPICAL SANDY LOAM							
Conceptual Cover Profile	Gravel/ Soil Admixture	1.5 ft (46 cm)	0.383	0.039	0.0267	1.4488	1.5951
	Cover Soil	3.5 ft (108 cm)	0.383	0.039	0.0267	1.4488	1.5951
	Filter Layer	6 in (15 cm)	0.34	0.026	0.0597	2.81	65.52
	Bio-barrier	1 ft (31 cm)	0.374	0.017	2.5075	2.47	15912.0

Modeled Percolation

Percolation results from the redistribution of water through a soil profile in response to gradients formed by differences in the energy state of the water. Flux is defined as the volume flow rate per unit area (Jury et al 1991) through a given soil profile. Other mechanisms that might induce water redistribution, such as geothermal gradients and barometric pressure fluctuations, have been shown to be minor contributors to water flow in most instances (Jones 1978, Gee and Simmons 1979). Tables C.2 TO C.4 present predicted annual flux values for the modeled cover profiles under the typical or average annual precipitation volumes.

Table C.2 summarizes a monolithic soil profile modeled with hydraulic soil properties from the TA61 borrow site. The soil sample that possessed a saturated hydraulic conductivity closest to the overall average of all soil samples tested form the site was used. The overall average was calculated to be 6.6E-03 cm/sec. This soil sample was BH1 taken from a depth of 15 to 25-ft. The saturated hydraulic conductivity for sample BH1 was 4.9E-03 cm/sec. As seen in figure 3.2, the Point of Diminishing Returns (Dwyer et al 2006) was greater than 6.6 ft (200 cm). Consequently, it was determined that the soil would require amendment to improve its water storage capacity and thus decrease the soil depth required. The soil amendment will also provide for adequate plant available nutrients.

The TA61 soils were characterized as sandy loams. However, they were relatively coarse sandy loams. Table C.3 summarizes a monolithic soil profile that used a typical sandy loam with somewhat better storage capacity than the TA61 soils. This value was obtained from ROSETTA (2000). These soils are commonly found throughout New Mexico. These soils significantly improved the cover performance by producing a Point of Diminishing Returns at about 5 ft (1.5 m).

Table C.4 summarizes the output from the actual conceptual cover profile that includes all layers. The addition of the bio-barrier created a capillary barrier. The final predicted flux through the cover profile utilizing a sandy loam soil overlying a coarse material was zero.

Table C.2.
WETTEST DECADE CLIMATE DATA WITH TA61 SOILS

Cover Depth (cm)	Annual Flux (cm/year)										
	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Average
50	5.53	4.11	3.14	4.68	3.17	3.92	6.01	0.98	2.05	4.43	3.80
100	2.84	1.70	1.42	2.37	1.31	1.51	3.06	0.47	1.22	2.04	1.79
150	1.12	0.56	0.71	0.95	0.40	0.06	1.19	0.30	0.49	0.72	0.65
200	.05	0.03	0.03	0.03	0.29	0.26	0.03	0.04	0.02	0.02	0.08
Precipitation (cm)	49.76	47.48	40.34	42.55	35.74	43.31	47.78	32.11	32.54	43.05	41.47

Table C.3.
WETTEST DECADE CLIMATE DATA WITH TYPICAL SOILS FOR SANDY LOAM (ROSETTA 2000)

Cover Depth (cm)	Annual Flux (cm/year)										
	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Average
50	4.31	3.37	2.94	4.28	1.69	3.03	5.39	1.19	2.07	3.64	3.20
100	7.16E-2	1.13	1.59	1.94	8.43E-1	8.17E-1	2.31	1.37	6.15E-1	7.31E-1	1.14
150	0	0	5.41E-4	9.12E-2	5.33E-1	1.69E-1	1.96E-1	7.70E-1	2.29E-1	9.21E-2	2.08E-1
200	0	0	0	0	0	6.93E-6	6.72E-6	7.25E-6	9.14E-6	1.71E-5	4.71E-6
Precipitation (cm)	49.76	47.48	40.34	42.55	35.74	43.31	47.78	32.11	32.54	43.05	41.47

Table C.4.
WETTEST DECADE CLIMATE DATA WITH CONCEPTUAL COVER PROFILE THAT UTILIZED TYPICAL SOILS FOR SANDY LOAM (ROSETTA 2000)

Cover Depth (cm)	Annual Flux (cm/year)[1]										
	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Average
Base of Cover	0	0	0	0	0	0	0	0	0	0	0
Precipitation (cm)	49.76	47.48	40.34	42.55	35.74	43.31	47.78	32.11	32.54	43.05	41.47

[1] values less than 1E-10 cm/year were approximated to be zero