THE DESIGN OF AN EVAPOTRANSPIRATION LANDFILL COVER FOR A SEMIARID SITE[1]

by

Patrick E. McGuire, Ph.D. and John A. England, P.E.[2]

Abstract. The Resource Conservation Recovery Act (RCRA) requires that regulated landfills have hydrologic barrier covers that comply with prescribed design criteria or an alternative that demonstrates equivalent performance. Alternative covers are attractive because of the lower cost as compared to conventional covers. In arid and semi-arid climates alternative covers rely on soil water storage, establishment of vegetation, and soil water loss through evapotranspiration to restrict deep drainage. Alternative covers may have an application in surface mining and reclamation for water and leachate management. The design and performance monitoring of an 8.1 ha evapotranspiration landfill cover (ETLC) within an U.S. Army facility located in central Colorado are described. The numerical, unsaturated flow model, UNSAT-H, was used to assess the hydrologic performance of the ETLC. Model simulations were conducted to predict the water balance based on climatic conditions, soil textures, soil cover thickness, and plant types. The predicted annual drainage through a 122-cm thick clay loam based on four continuous years of high annual precipitation and a 50 percent prairie grass cover was negligible (< 0.1 mm). A soil survey of the borrow area was conducted to inventory soil horizons that were suitable based on hydraulic and plant productivity characteristics. The plant species selected for the cover included a combination of warm and cool season native prairie grasses. Management practices to establish and maintain a permanent plant cover include cover crops, biosolids application, soil fertilization, mulching, supplemental irrigation, and mowing. Transect methods will be used to assess the seasonal composition, cover area, and vigor of plant species. Soil profiles will be monitored using neutron probe technology, thermocouple psychrometers, and lysimeters to assess soil water storage and water flux rates.

Additional Key Words: hydrologic waste barrier, tailings, reclamation.

Introduction

The RCRA was enacted in 1976 to manage solid and hazardous wastes. The RCRA Subtitle D and C programs address solid and hazardous waste management, respectively. RCRA landfills have prescribed or regulated design criteria. The prescribed top liner for a RCRA landfill is a resistive barrier constructed of materials that restrict drainage. The prescribed top liner construction materials include compacted fine–grained soils, a geomembrane, a geosynthetic clay liner or a combination of these materials.

[1]Paper presented at the 17th Annual National Meeting of the American Society for Surface Mining and Reclamation, Tampa, Florida, June 11-15, 2000.

[2]Patrick McGuire is a Senior Hydrologist with Earth Tech, 4738 N. 40th Street, Sheboygan, Wisconsin 53083. John England is a Senior Project Manager with Earth Tech, 5575 DTC Parkway, Suite 350, Englewood, Colorado 80111.

The purpose of the prescribed top liner is to isolate the underlying waste from precipitation and subsequent drainage. The isolation of waste from drainage water is necessary to reduce both the production of leachate and the potential for transport of constituents from the waste.

The RCRA regulations provide for an alternative to the prescribed landfill top liner if the performance of the alternative cover is equivalent to the prescribed cover. A description of alternative landfill cover types and the results of field demonstrations are provided by Benson (1997). Alternative landfill covers are attractive because the cost for design and construction is substantially less as compared to prescribed RCRA Subtitle C or D covers. The estimated costs to design and construct an alternative cover, Subtitle D cover, and Subtitle C cover, all with an area of 16 ha (40 acres), range from $1 to $8, $8 to $20, and $24 to $80 million dollars, respectively (Gee, 1999).

Proceedings America Society of Mining and Reclamation, 2000 pp 178-187
DOI: 10.21000/JASMR00010178

https://doi.org/10.21000/JASMR00010178

Mining wastes and overburden materials often contain constituents that are readily transported with drainage and therefore have the potential to degrade surface and/or groundwater quality. An alternative cover may provide a cost-effective method to isolate waste materials from drainage, reduce leachate production, and manage adverse impacts on water quality. Potential applications for an alternative cover in mining may include the areas of tailings management, reclamation, and remediation.

This report describes an ETLC recently approved for an 8.1 ha (20 acres) landfill located in central Colorado. The landfill is within the U.S. Army facility at Fort Carson near Colorado Springs. The Fort Carson ETLC is the first alternative landfill cover approved by the Colorado Department of Public Health and Environment for a Subtitle C regulated landfill. The cover consists of a 122-cm (48-in) thick clay loam soil. The estimated cost of the ETLC is about $247,000 dollars ha^{-1} less as compared to a prescribed RCRA Subtitle C cover.

The performance of an ETLC is dependent on many variables including climatic conditions, soil and vegetation characteristics, and cover thickness. An ETLC stores water in the soil during the plant dormant period and removes the stored water during the growing season through evaporation and plant transpiration. An ETLC requires sufficient water storage capacity to maintain water within the cover, particularly during the plant dormant period, and thereby control drainage through the cover.

The following sections describe the process that was used to design the Fort Carson ETLC, management plans, and monitoring practices.

Evapotranspiration Cover Development

The development of the Fort Carson ETLC required water balance model simulations, soil characterization to assess materials, a vegetation management plan, and a monitoring plan.

Model Simulations

The hydrologic model, UNSAT-H, was used to assess the potential performance of cover configurations. UNSAT-H is a numerical, one-dimensional, finite difference model that was developed to predict the dynamic processes of infiltration, evaporation, transpiration, redistribution, and drainage within a vertical unsaturated soil column. The model predictions are based on climatic, soil, and plant conditions (Fayer & Jones, 1990).

Model simulations were conducted using 1984 Colorado Springs daily climatic data. This climatic data was used because the annual precipitation is the historical near maximum precipitation at 53 cm (21 in). All model simulations were conducted for a four-year period to predict the ETLC water balance following an extended period of historically high precipitation. All model simulations were conducted to represent a prairie grass cover of 50 percent with a leaf area index (ratio of leaf area to ground area) that ranged from 0.5 to 1.5 during the growing season. The model input parameters included a root density distribution to a depth of 89 cm (35 in) that is representative of prairie grasses (Weaver, 1958). Soil physical and hydraulic input parameter values for the model simulations were based on laboratory analysis of borrow area soil samples. Model input parameters to define soil hydraulic characteristics included van Genuchten fitting parameters (van Genuchten et al., 1991). These parameters were developed from soil water retention curves that define the relationship between soil water content and the tension that water is held in soil pores. The soil water retention data were also used to estimate the field water storage capacity of soils. Preliminary model simulations were conducted to assess the hydrologic performance of the ETLC for a range of soil conditions. Later simulations were based on an ETLC thickness of 122 cm and soil characteristics that were representative of the borrow area clay loam soil.

The results of model simulations that are representative of borrow area in-situ soils and borrow area soils at 75 and 85 percent of the maximum modified Proctor density are provided in Table 1. The predicted annual drainage through the base of the ETLC with in-situ and compacted soil is negligible at less than 0.02 cm. The predicted annual water loss through evapotranspiration typically exceeds the annual infiltration into the soil surface and indicates the potential for water loss in a semi-arid climate. The predicted annual soil water storage, greater than 15 cm (6 in), indicates the relatively high water holding capacity of the fine-grained soils.

Soil Characterization and Management

A soil survey was conducted in the borrow area to characterize soils. Ten soil profiles throughout the borrow area were described to a depth of at least 152 cm (59 in). Soil samples were collected from each soil horizon and submitted to a laboratory for analysis of physical, hydraulic, and fertility parameters. This information was used to inventory the location of suitable soils for ETLC construction, to identify those soils that were most productive and suited for the topsoil cover, to determine soil amendment requirements, and to assess the compaction limit that would not exceed a bulk density that inhibits plant root penetration and productivity.

The results for some of the physical and hydraulic laboratory analyses that were completed on in-situ soil samples collected from the borrow area are provided in Table 2. The soils are fine-grained and the texture for most soil horizons is a clay loam based on the U.S. Department of Agriculture Soil Classification System. The dry bulk density for borrow area in-situ soils is typically less than 1.3 g cm^{-3} (81 lb ft^{-3}). The saturated hydraulic conductivity is typically between 10^{-3} and 10^{-5} cm s^{-1}. The target bulk density of the ETLC is important for construction design. Compaction is a construction method to minimize future cover settlement, however excess compaction may affect plant productivity that is required for the ETLC hydrologic performance. Bulk densities above 1.45 g cm^{-3} in a clay loam may affect plant growth because of soil resistance to root penetration (Brady and Weil, 1999; Daddow and Warrington, 1983). The results for the borrow area samples subjected to moisture-density compaction tests are provided in Table 3. The bulk density and hydraulic conductivity values for samples compacted to 75 percent of the maximum density are similar to those of in-situ uncompacted soils. The bulk density and hydraulic conductivity values of samples compacted to 85 percent of the maximum density are greater than those reported for in-situ soils. The bulk densities at 85 percent of maximum density approach or exceed 1.45 g cm^{-3} (90 lb ft^{-3}). The hydraulic conductivity values at 85 percent of maximum density often are about 10^{-6} cm s^{-1} and may affect availability of water to plants. Based on the results of the moisture-density tests a target compaction that is between 75 and 80 percent of the maximum density was defined for construction of the ETLC.

The results for some of the soil fertility and salinity laboratory analyses that were completed on borrow area soil samples are provided in Table 4. The borrow area soils are not saline or sodic (Brady and Weil, 1999) and, therefore, do not require management considerations to address problems associated with these soil types. The soils typically have a soil paste pH near 8.0, a soil paste electrical conductance less than 2 mmhos cm^{-1}, and a sodium adsorption ratio less than 5. The upper soil horizons (A & B) are the most suitable for topsoil because of a higher organic matter content and more favorable soil structure for plant growth as compared to lower soil horizons. The upper 30 cm of the ETLC will be constructed with borrow area soil from the A and B horizons. The lower portions of the ETLC will be constructed with borrow area soil from the C horizon.

Vegetation Management

Vegetation is an important component of the ETLC because the hydrologic performance is dependent on soil water loss through evaporation and transpiration (evapotranspiration). Transpiration is the water loss associated with the transport of soil water through plant roots and out the stomata of plants during photosynthesis. Plant transpiration provides a means to remove soil water from the cover that has drained beyond the influence of surface evaporation.

The permanent vegetation for the ETLC is a combination of native warm and cool season grasses to include streambank wheatgrass, western wheatgrass, alkalai sacaton, galleta, blue grama, and sideoats grama. Native warm and cool season prairie grasses were selected because they provide an extended growing period with resulting soil water loss through transpiration, the grasses develop shallow and deep root systems that support erosion control and removal of soil water, and the grasses tolerate adverse environmental conditions. A description of the native grasses is provided in Table 5.

The management practices to establish and maintain vegetation include incorporation of biosolids and fertilizers into the topsoil, establishment of temporary spring oats cover crop, seedbed preparation, fall seeding of native grass seed, application of straw mulch and erosion mats, supplemental irrigation, and mowing for weed control. The organic matter content in soil is typically less than one percent, therefore, biosolids will be incorporated into the ETLC topsoil at a one-time application rate of 22 dry kg ha^{-1} (20 tons $acre^{-1}$) to improve productivity. The soil nutrient concentrations required to satisfy vegetation nutrient requirements on disturbed land are about 7 ppm for phosphorus (AB-DTPA extract), 120 ppm for potassium (AB-DTPA extract), and about 20 ppm for NO3-N (Mortvedt et al., 1995). The ETLC topsoil will be amended with nitrogen and phosphorus fertilizers to satisfy plant nutrient requirements.

Performance Monitoring

Performance monitoring of the ETLC will be conducted for a minimum five-year period to assess hydrologic performance and vegetation condition. The monitoring system includes a weather station on site that records precipitation, temperature, and wind speed.

Hydrologic. Hydrologic performance monitoring of the ETLC will include measurements from lysimeters. A lysimeter is a subsurface device to measure the soil water condition. Three lysimeters will be installed within the ETLC to measure the drainage rate through the 122-cm thick soil. Each lysimeter consists of a polyethylene tank that is 147 cm (58 in) in vertical height and 152 cm (60 in) in diameter. The tanks are open on the top and have a dome shaped bottom to concentrate drainage. The top of each lysimeter will be installed in the cover 30 cm (12 in) below the vegetated surface. Soil will be placed in each lysimeter to represent surrounding soil cover conditions. Water that percolates through the cover soil within the lysimeter will be drained to a collection well for measurement. Lysimeter drainage volume will be measured monthly. Annual drainage of less than 1 cm will indicate adequate hydrologic performance.

A neutron probe is an instrument that measures the soil water content based on neutron thermalization. Neutron probe access tubes will be installed through the ETLC soil profiles at locations within the lysimeters, adjacent to lysimeters, and at five additional locations. A portable neutron probe will be used to measure the soil water content at 15-cm (6-in) intervals throughout the cover profile at the eleven monitoring locations. The soil water content data will be collected monthly. The data will be used to assess change in water storage, soil water content as related to soil depth, and to compare the measured soil water storage with the field capacity water storage. Measurement of soil water storage within the ETLC profile that is near or greater then the field capacity will indicate inadequate hydrologic performance.

Thermocouple psychrometers are instruments that measure the tension that water is held in soil pores or the hydraulic potential. Thermocouple psychrometers will be installed at eight locations adjacent to neutron probe access tubes. The psychrometers will be installed along a vertical plane at depths of 91 cm (36 in), 122 cm (48 in), and 152 cm (60 in) below the ETLC cover. The psychrometers measure hydraulic potentials and will be used to assess vertical hydraulic gradients that indicate the potential for water to move upward or downward. The psychrometer data will be used in combination with soil hydraulic conductivity data to estimate soil water flux rates. The estimated downward flux rate near the base of the ETLC will be compared to lysimeter measurements.

Vegetation. Transects to monitor vegetation will be established at three locations on the ETLC. Each transect will extend 61 m (200 feet) in length. Four 1 m^2 quadrants will be established along each transect. Vegetation data will be collected in the spring and fall from each quadrant. The data will include plant species, plant species height, estimated leaf area index, total composition of each species, and the percent bare area. Each year, in July, aerial color and color infrared photographs will be obtained to document the overall ETLC vegetation condition.

Summary

An alternative cover may provide a cost-effective method to isolate waste materials that result from mining operations. The design and performance monitoring of a 8.1 ha evapotranspiration landfill cover (ETLC) at Fort Carson, a U.S. Army facility located in Colorado Springs, are described. The assessment to determine the potential performance and the required thickness of the ETLC was based on numerical hydrologic simulations and characterization of soils that would be used for cover construction. The analysis resulted in a ETLC that consists of a 122-cm thick clay loam texture soil that is vegetated with a combination of warm and cool season native grasses. The estimated cost of the ETLC is about $247,000 dollars ha^{-1} less as compared to a prescribed RCRA Subtitle C cover. Performance monitoring will include drainage lysimeter measurement of water that percolates through the ETLC, soil water content measurements throughout the ETLC profile, measurement of vertical hydraulic gradients using thermocouple psychrometers and estimates of water flux rates, and establishment of sample areas to monitor the ETLC vegetation.

Literature Cited

Benson, Craig H. 1997. A review of alternative landfill cover demonstrations. Environmental Geotechnics Report No. 97-1. Department of Civil & Environmental Engineering, University of Wisconsin, Madison.

Brady, N. and R. Weil. 1996. The nature and properties of soils. 12th edition. Prentice Hall, Inc., Upper Saddle River, New Jersey.

Daddow, R. and G. Warrington. 1983. Growth limiting soil bulk densities as influenced by soil texture. USDA-Forest Service Watershed Systems Development Group, WSDG Report TN-00005. Fort Collins, Colorado.

Fayer, M. J. and T. Jones. 1990. Unsaturated soil water and heat flow model . Version 2.0. Pacific Northwest Laboratory, Richland, Washington.

Gee, G.W. March 1999. Summary of the remediation technologies development forum. Phtytoremediation action team. Alternative cover assessment program meeting. EPA, San Francisco, California.

Mortvedt, J.J., D.H. Smith, and E.F. Redente. 1995. Fertilizer suggestions for revegetation of disturbed lands. Colorado State University Cooperative Extension, No. 0.536. Fort Collins, Colorado.

van Genuchten, M. Th., F.J. Leij, and S.R. Yates. December 1991. The RETC code for quantifying the hydraulic functions of unsaturated soils. EPA/600/2-91/065. USDA Salinity Laboratory. Riverside California.

Weaver, J.E. 1958. Summary and interpretation of underground development in natural grassland communities. Ecological monographs, Volume 28. Duke University Press, Durham, N.C.

TABLE 1
MODELING RESULTS FOR EVAPOTRANSPIRATION FINAL COVER

Soil Horizon[2]	Soil Texture[2]	Sample Type	Predicted Annual Water Balance (cm/yr)[1]						
			Precipitation	Runoff	Infiltration	Evaporation	Transpiration	Storage	Percolation
A	Clay	In-Situ	53.3	33.1	20.7	17.6	4.3	22.1	<0.01
B	Clay Loam	In-Situ	53.3	47.3	6.1	6.5	0.5	22.4	<0.01
B	Clay Loam	In-Situ	53.3	33.1	20.2	16.9	3.6	15.8	<0.01
C1	Clay Loam	In-Situ	53.3	14.5	38.8	23.4	15.8	23.4	0.01
A	Clay	75% Proctor	53.3	0.19	53.6	24.1	31.2	22.2	0.01
B	Clay Loam	75% Proctor	53.3	0.8	53.1	24.3	30.7	25.2	0.01
C1	Silt Loam	75% Proctor	53.3	1.1	52.8	24.7	29.2	22.5	0.02
C2	Clay Loam	75% Proctor	53.3	0.02	53.8	25.8	30.3	21.7	0.02
C3	Sandy Clay Loam	75% Proctor	53.3	0.7	53.1	25.2	29.2	21.2	0.02
A	Clay	85% Proctor	53.3	40.7	13.2	11.5	3.1	12.3	<0.01
B	Clay Loam	85% Proctor	53.3	43.7	6.4	5.8	2.0	15.9	<0.01
C1	Silt Loam	85% Proctor	53.3	41.5	12.4	10.9	3.0	15.1	<0.01
C2	Clay Loam	85% Proctor	53.3	28.3	25.5	19.0	7.9	16.9	<0.01
C3	Sandy Clay Loam	85% Proctor	53.3	40.0	13.8	12.0	3.2	13.8	<0.01

NOTES:

1 Model simulation results based on:

- Soil thickness of 122 cm.
- A 50 percent vegetative cover area with root depth to 89 cm.
- Period of 4 continuous years of Colorado Springs climatic conditions from wet year of 1984.
- Soil physical and hydraulic characteristics that represent borrow area in-situ soils, and borrow area soils compacted to 75 and 85 percent of the maximum modified Proctor test density.

2 Soil horizon and textured based on United States Department of Agriculture Soil Classification terminology.

TABLE 2
SOIL PHYSICAL AND HYDRAULIC PARAMETER ANALYSIS RESULTS: IN-SITU SOIL SAMPLES

Location	Sample		Parameters					
	Depth (inches)	Soil Horizon[1]	Particle Size sand/silt/clay (%)	Soil Texture (USDA)[1]	Bulk Density	Volumetric Moisture Content (%)	Hydraulic Conductivity (cm/s)	Saturation (%)
Soil Profile 1	5-7	A	32/27/41	Clay	1.27	21	2.5×10^{-6}	48
Soil Profile 1	23-25	B	30/31/39	Clay Loam	1.25	12	4.0×10^{-7}	47
Soil Profile 1	55-57	C1	28/39/33	Clay Loam	1.18	11	6.9×10^{-3}	46
Soil Profile 2	5-7	A	34/33/33	Clay Loam	1.16	10	4.6×10^{-4}	39
Soil Profile 2	17-19	B	29/30/41	Clay	1.25	10	5.6×10^{-6}	47
Soil Profile 2	61-62	C1	30/38/32	Clay Loam	1.17	12	1.4×10^{-5}	45
Soil Profile 3	5-7	A	37/21/42	Clay	1.25	22	2.1×10^{-3}	47
Soil Profile 3	19-21	B	40/27/33	Clay Loam	1.14	16	1.6×10^{-4}	41
Soil Profile 3	48-50	C1	46/23/31	Sandy Clay Loam	1.13	23	5.6×10^{-5}	39
Soil Profile 3	91-93	C2	37/33/30	Clay Loam	1.15	21	1.0×10^{-4}	45
Soil Profile 5	7-9	B	42/21/37	Clay Loam	1.10	24	2.0×10^{-6}	44
Soil Profile 5	34-36	C1	36/34/30	Clay Loam	1.18	25	1.4×10^{-4}	42
Soil Profile 8	0-3	A	39/37/24	Loam	1.10	22	1.3×10^{-2}	43
Soil Profile 8	12-14	B	29/36/35	Clay Loam	1.18	14	1.1×10^{-5}	40
Soil Profile 10	69-71	C2	49/21/30	Sandy Clay Loam	--	--	3.5×10^{-3}	--

NOTES:
[1] U.S. Department of Agriculture Soil Survey and Classification Terminology.

TABLE 3
SOIL PHYSICAL PARAMETER LABORATORY ANALYSIS RESULTS: MODIFIED PROCTOR TEST SAMPLES

	Proctor Test[1]									
	Sample		Dry Bulk Density (g/cm^3)			Moisture Content (% g/g)			K_{sat} (cm/s)	
Location	Depth (inches)	Soil Horizon	75	85	Max	75	85	Max	75	85
Soil Profile 1	5-7	A	1.20	1.36	1.61	20.3	20.4	19.7	2.4×10^{-3}	6.2×10^{-6}
Soil Profile 1	102-105	C2	1.25	1.51	1.66	15.8	15.6	16.2	8.8×10^{-4}	9.6×10^{-6}
Soil Profile 3	91-93	C2	1.23	1.38	1.64	18.6	19.1	18.7	2.7×10^{-4}	2.1×10^{-3}
Soil Profile 5	111-113	C3	1.31	1.49	1.76	16.0	16.3	16.2	3.3×10^{-4}	2.6×10^{-6}
Soil Profile 8	12-14	B	1.17	1.32	1.57	23.0	23.3	22.2	1.1×10^{-3}	1.1×10^{-6}
Soil Profile 8	39-41	C1	1.21	1.38	1.63	22.4	22.2	21.5	3.0×10^{-4}	2.1×10^{-6}

NOTES:

1 Borrow area samples compacted to 75 and 85 percent of maximum Proctor test density and also maximum density.

K_{sat} Saturated hydraulic conductivity.

TABLE 4
SOIL FERTILITY AND SALINITY PARAMETER ANALYSIS RESULTS

Location[1]	Sample		Chemical Parameters[3]													
	Depth (inches)	Soil Horizon[2]	pH	EC (mmhos/cm)	Soluble Salts (meq/l)				SAR	OM (%)	NH_4-N (mg/kg)	NO_3-N	p	K	CEC (meq/100g)
Soil Profile 1	5-7	A	6.3	0.5	2.0	1.1	1.7	0.5	1.3	1.7	2.49	6.60	1.0	325	24.2
Soil Profile 1	23-23	B	7.9	0.5	2.0	1.2	3.0	0.4	2.4	1.0	0.31	3.10	0.5	353	22.3
Soil Profile 1	55-57	C1	8.2	2.1	10.8	5.4	14.2	0.5	5.0	0.5	0.03	2.85	6.3	215	21.4
Soil Profile 1	102-105	C2	8.1	1.7	6.9	2.8	10.4	0.3	4.7	0.6	0.66	2.64	5.8	206	21.2
Soil Profile 2	5-7	A	6.7	0.6	3.7	2.0	0.5	0.7	0.3	2.1	0.52	8.65	7.8	385	21.1
Soil Profile 2	17-19	B	7.3	0.4	1.5	0.8	1.5	0.4	1.5	1.2	1.30	4.44	0.7	309	26.8
Soil Profile 2	61-62	C1	8.1	3.1	27.1	10.1	18.6	0.5	4.3	0.6	0.42	1.53	5.6	166	22.9
Soil Profile 2	111-113	C2	8.2	1.7	5.6	2.2	11.1	0.2	5.6	0.6	1.43	4.54	6.8	139	22.6
Soil Profile 2	144-146	C3	8.1	2.1	14.0	4.1	13.8	0.2	4.6	0.5	1.08	5.16	9.5	132	15.4

NOTES:

[1] Analyses were conducted at four additional locations, but were not included.
[2] U.S. Department of Agriculture Soil Survey and Classification terminology.
[3] CEC = Cation Exchange Capacity (AB-DTPA extract).
Ca = Calcium (soluble salt from paste extract).
Mg = Magnesium (soluble salt from paste extract).
Na = Sodium (soluble salt from paste extract).
P = Phosphorus (AB-DTPA extract).
K = Potassium (soluble salt from paste extract and plant available from AB-DTPA extract).
pH = Reciprocal log of hydrogen ion concentration (paste).
EC = Electrical Conductance (paste).
SAR = Sodium Adsorption Ratio.

TABLE 5
NATIVE GRASS MIXTURE DATA

		Growth Form					
Common Name	Scientific Name	Type	Estimated Height (feet)	Estimated Root Depth (feet)	Growing Season	Soil Adaptation	Optimum Precipitation Range (inches)
streambank wheatgrass	*Agropyron riparium*	sod forming	1 - 2.5	2 - 5	cool	sand - clay	9 - 19
western wheatgrass	*Agropyron smithii*	sod forming	1 - 2.5	2 - 7	cool	sand - clay	10 - 20
alkali sacaton	*Sporobolus airoides*	bunch grass	1 - 3	2 - 4	cool	sand - clay	10 - 20
galleta	*Hilaria jamesii*	sod forming	0.5 - 1.7	2 - 5	warm	sand - clay	10 - 18
blue grama	*Bouteloua gracilis*	sod forming	0.5 - 2.5	1 - 5	warm	sand - clay	10 - 20
sideoats grama	*Bouteloua curtipendula*	bunch grass	1 - 1.5	2 - 6	warm	sand - clay	12 - 20

NOTES:

All species used in the above mix are native plant species.

Sources: Hersman, Carl W., et. al., 1995. Native Grasses. Bulletin 450A, Colorado State University Cooperative Extension.
Thornburg, Ashley A., 1982. Plant Materials for Use on Surface-Mined Lands in Arid and Semiarid Regions - USDA Soil Conservation Service.
Weaver, J.E., 1954. North American Prairie. Johnsen Publishing Company, Lincoln, Nebraska.