APPENDIX E

INFILTRATION MODELING

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LIST OF ATTACHMENTS

E.1 INTRODUCTION

This appendix outlines the evaluation of the disposal cell cover system for infiltration of meteoric water and percolation or drainage of meteoric water out the bottom of the cover system. This appendix is an update of infiltration modeling described in Appendix E of the 2002 Preliminary Design Report (Reclamation Plan Appendix C), and reflects the revisions to the cover system over the disposal cell outlined in the Cell Construction Plan (Reclamation Plan, Attachment E).

The previous infiltration modeling evaluated a cover of uniform stratigraphy, with long-term vegetation consisting of grass, brush, and trees. The modeling described in this appendix evaluated the multilayered cover with long-term vegetation consisting of grass species only. Infiltration modeling was conducted with the TerreSIM model (described below), with confirmatory analyses conducted with the HELP model (Schroeder and others, 1997).

E.2 INFILTRATION MODEL AND INPUT PARAMETERS

The TerreSIM model is an MFG, Inc. model used to evaluate vegetation system and land use management and its impact on runoff and infiltration. The water balance module within the TerraSIM model was used to calculate infiltration through the disposal cell cover system under various cover material and vegetation scenarios. The TerreSIM model is a plant growth-based model that is structured to estimate evapotranspiration from specific plant species. The model incorporates root depth, root density, and above-ground canopy data. Cover soil properties are represented by water-holding capacities of soil types in the cover. The model description and results are presented in Attachment E.

A 200-year simulation period was used, with perennial grass species established initially (big bluestem, little bluestem, and indiangrass). Available data from Sallisaw Oklahoma was used in the modeling. Actual daily precipitation data from 1949-1993 was used for the data set. The annual precipitation over this period averaged approximately 45 inches. Only the top surface of the cell (at a one percent slope) was evaluated in the model, since the side slopes (at a 20 percent slope) would have less infiltration.

E.3 DISCUSSION OF TERRESIM MODEL RESULTS

The infiltration modeling with the TerreSIM model evaluated drainage out of the bottom of the root zone in the cover system. The clay layer at the base of the cover could not be incorporated into the model, due to the low potential for roots to penetrate the clay layer. Therefore the results described below are for infiltration through the root zone of the cover, and not through the entire cover system.

The infiltration modeling results in Attachment E can be discussed in two time periods: (1) the first 50 years of simulation (as permanent vegetation becomes established), and (2) the remaining 150 years of simulation (after permanent vegetation becomes established). For the years 1 through 50, the average annual rate of drainage through the root zone of the cover is 6.5 inches per year, or approximately 14 percent of average annual precipitation. For the years 51 through 200, the average annual rate of drainage through the root zone of the cover is 4.6 inches per year, or approximately 10 percent of average annual precipitation. These values are averages, and the data in Attachment E show a direct relationship between drainage and precipitation, with years of zero drainage through the root zone and years of higher drainage through the root zone. If deeper-rooted species are allowed to become established on the cover, the rates of drainage through the root zone will be less than the values listed above. For the entire 200-year simulation period, the average rate of infiltration is 5.1 inches per year or 11 percent of average annual precipitation.

E.4 EFFECT OF CLAY LAYER IN COVER SYSTEM

During the initial years after disposal cell construction, the synthetic liner at the base of the cover (immediately above the clay layer) will provide a barrier to downward-moving meteoric water and direct this meteoric water laterally through the liner cover material to the perimeter of the cell. The clay layer will provide a similar longer-term barrier. If the saturated hydraulic conductivity of the clay layer is 10^{-7} cm/sec (0.1 feet/year), the rate of flux through the clay layer (under unit gradient conditions) is 0.1 feet/year or 1.2 inches/year.

The results discussed above indicate that (on average) approximately 11 percent of average annual precipitation percolates downward through the cover past the root zone depth. Due to the lower saturated hydraulic conductivity of the clay layer, this percolating water would become perched within the drainage sand above the clay layer and migrate laterally along the top of the clay layer. For a saturated hydraulic conductivity of the clay layer of 10^{-7} cm/sec (1.2 in/yr), the downward migration through a unit area of clay layer would be 0.3 in/yr, based on a saturated zone above the top of the clay layer 0.5 ft thick. This simplified calculation indicates that the hydraulic conductivity of the clay layer controls infiltration through the bottom of the cover.

E.5 COMPARISON WITH HELP MODEL RESULTS

The HELP model (Schroeder and others, 1997) was used to track moisture migration through the cover system and provide a rough comparison of estimated infiltration with the TerreSIM model. The daily precipitation record in the HELP model database was Tulsa, Oklahoma (approximately 70 miles northwest of the site), with an average annual precipitation total of approximately 39 inches. The HELP model simulation period was 100 years. A grass cover (fair quality) with a root depth of seven feet was used in the model. A provision for lateral drainage was included in the model to represent the sand zone at the top of the clay layer. The other input values for the HELP model are summarized in the table below.

Cover Layer	Layer Thickness (in)	Saturated Hydraulic Conductivity (cm/sec)	Flow Direction
Topsoil	18	$3.7x10^{-4}$	Vertical only
Subsoil	60	$3.3x10^{-5}$	Vertical only
Drainage layer (sand)	18	$5.8x10^{-3}$	Vertical and lateral
Clay layer	24	$1.0x10^{-7}$	Vertical only

The modeling results are summarized in the table below.

Flow Component	Average Value (in/yr)	Standard Deviation (in/yr)	Fraction of Annual Precipitation (%)
Precipitation	38.70	7.401	100.00
Runoff	1.075	0.823	2.77
Evapotranspiration	34.95	4.85	90.31
Lateral drainage	1.19	0.745	3.07
Percolation (through base of clay layer)	1.49	0.487	3.85

The rate of downward meteoric water flow below the root zone is the sum of the lateral drainage and percolation in the table above, or 2.68 in/yr (6.9 percent of average annual precipitation). This estimated value is lower than that calculated with the TerreSIM model of 5.1 in/yr (11 percent of average annual precipitation). The percolation through the base of the clay layer (at the bottom of the cover) is approximately 1.49 in/yr, or slightly higher than the estimate for flow through the clay layer under a unit gradient (1.2 in/yr).

The modeling results indicate that a saturated zone would form at the top of the clay layer. The HELP model calculated a zone of saturation above the clay liner averaging 5.6 inches in thickness, with a standard deviation of 4.0 inches over the 100-year simulation period.

E.6 REFERENCES

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Holtz, R., and W. D. Kovacs, 1981. *An Introduction to Geotechnical Engineering*, Prentice-Hall.

Schroeder, P.R., C.M. Lloyd, and P.A. Zappi, 1997. "Hydrologic Evaluation of Landfill Performance," *HELP Model Version 3.07*, developed by USACE Waterways Experiment Station for USEPA Risk Reduction Engineering Laboratory, November 1.

ATTACHMENT E.1

TERRESIM MODELING DESCRIPTION

TERRESTRIAL ECOSYSTEM SIMULATION MODEL (TERESIM©) RESULTS FOR THE SEQUOYAH FUELS GORE, OKLAHOMA, ON-SITE DISPOSAL CELL

INTRODUCTION

Sequoyah Fuels Corporation (SFC) is in the process of decommissioning the uranium mill facility in Gore, Oklahoma. One goal in this closure operation is to establish a vegetative community on the disposal cell that 1) will provide for surface stabilization of the site, 2) will minimize water drainage through the profile, and 3) will not compromise the integrity of the disposal cell.

A simplified application of the Terrestrial Ecosystem Simulation Model (TerreSIM©) was used to evaluate the preliminary cover designs for the Sequoyah Fuels Corporation on-site disposal cell. TerreSIM simulated vegetation and water dynamics associated with a soil profile of 1.5 feet of topsoil over 5 feet of subsoil, 1.5 feet of sand, and 2 feet of clay. The application assumed no synthetic liner was present. The TerreSIM application simulated vegetation and water dynamics associated with the proposed cover design through two vegetation scenarios: 1) the proposed design including local grass, shrub, and tree species, and 2) the proposed design with grass species only, assuming annual mowing. The simplified application used a 10,000m^2 area with a 1% slope to simulate a portion of the top area of the disposal cell design. The simulations were conducted for a 200 year period.

TerreSIM is a spatially-explicit, mechanistic, computer model that is used to simulate plant community development (above- and below-ground) over time, the responses of ecological systems to environmental stressors, and the hydrological dynamics related to ecosystem dynamics. It has been applied to revegetation, land-use planning, and ecological responses to environmental stressors by the US Army Corps of Engineers, Natural Resource Conservation Service, National Park Service, U.S. Forest Service, USAF Academy, US Marine Corps, CSIRO-Australia, City of Los Angeles and several mining companies.

OVERVIEW OF THE TERRESIM MODEL

TerreSIM is designed to simultaneously simulate ecosystem dynamics at three different spatial scales: Plots, Communities, and Landscapes (Figure 1). This approach allows adequate representation of ecological processes that operate at different spatial and temporal scales. Because TerreSIM uses mechanistic representations of each process at the most appropriate scale, linkages among different components of the community, ecosystem, and landscape can be projected with reasonable confidence.

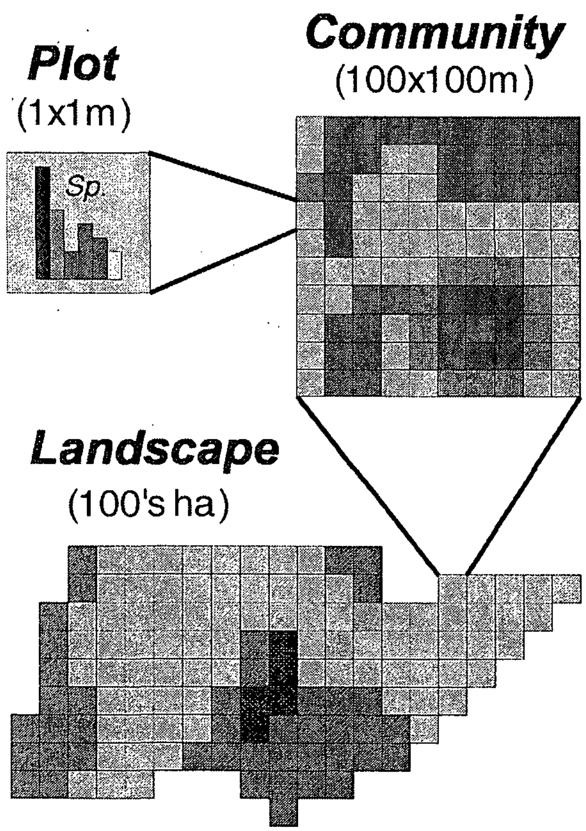

Figure 1. Scaling of the Plot, Community, and Landscape Modules in TerreSIM

The Plot Module in TerreSIM simulates ecological mechanisms and dynamics at the small scale (1-m2 to 400 m2). Most of the processes in TerreSIM related to plants (e.g., growth, water and nutrient uptake, and competition) and soils (e.g., water and nutrient transport through the profile, decomposition) are implemented in this module (Figure 2). This Module is comprised of a number of sub-modules, including Climate, Soil, Hydrologic, Plant, and Animals. Climatic inputs, primarily precipitation and potential evaporation, are based on historical data, stochastically generated, or some combination of both.

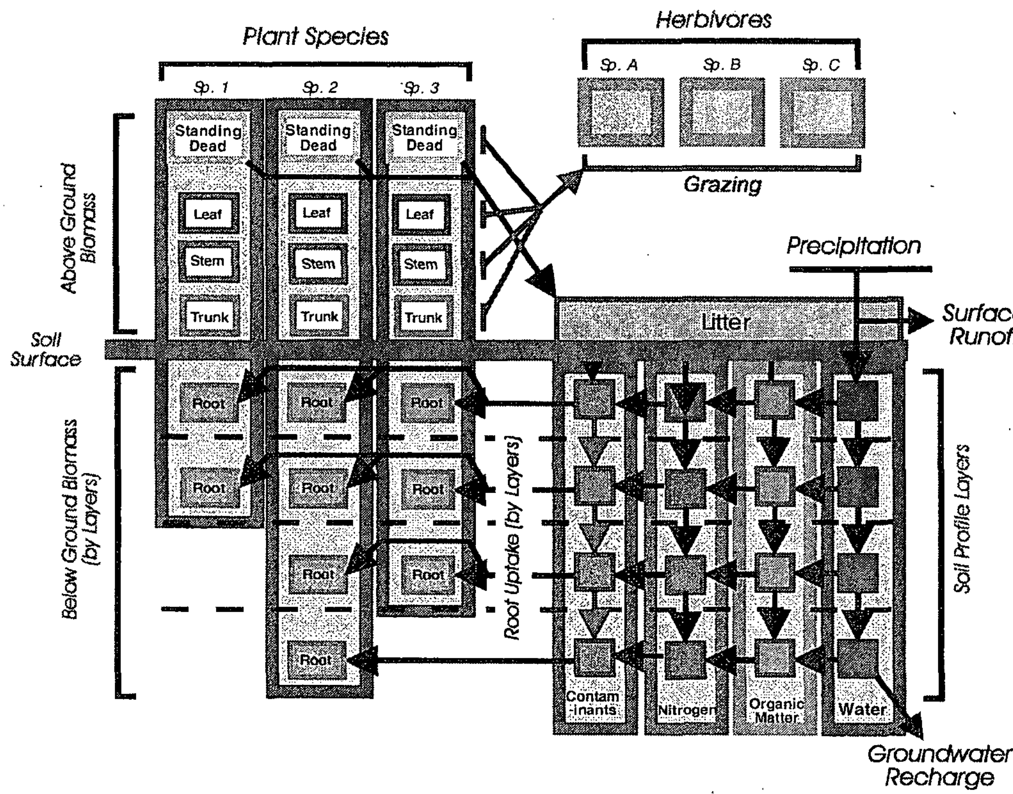

Figure 2. TerreSIM plot-level structure

The Soil Module represents the soil profile by partitioning it into up to thirteen different layers (horizons, sub horizons, or artificial layers). This representation incorporates the vertical depth, water content and holding capacity, nitrogen content, organic matter content, microbial activity, decomposition, and contaminant content and activity for each layer. The Hydrologic Module simulates small-scale precipitation dynamics, including interception by above-ground plant biomass, surface runoff, erosion and sediment mobilization, infiltration of water through the profile, mobilization and transport of nitrogen, organic matter, and contaminants, and subsurface export of water out of the profile.

The Plant Module represents the dynamics of above- and belowground components for each major plant species. Plant growth is simulated for each component (roots, trunk, stems, leaves, seeds, and standing dead), relative to season, resource requirements (water, nutrients, sunlight), and stressors (e.g., herbivory, competition, fire, trampling, chemical contaminants). The Animal Module consists of basic population parameters and diet attributes (preferences, utilization potential, competitive success) for each specified species (e.g., insects, rodent, native ungulates, livestock).

Different plots are represented as cells in the Community Grid (Figure 2). The Community Module focuses on spatial patterns and dynamic from the patch (400-m2) to the community (1-10 hectares) scales. These include spatial heterogeneity in soils, plants, and stressors among plots within the community, stressors such as fire propagation, grazing, and lateral flow of surface and subsurface water and materials, and important spatial patterns such as vegetation cover, habitats, and topography.

In an analogous manner, communities are the basic units in the Landscape Grid (Figure 2). This largest scale Module focuses on ecological processes operating at large spatial scales (1-km2 and larger). These include fire initiation regimes, climatic regimes, watershed-level water movement and transport of materials, and management practices such as prescribed fire, grazing operations, and weed control.

TerreSIM Simulation Outputs

Each simulation run of TerreSIM produces a large volume of data for all state variables (e.g., plant biomasses, soil water and nutrient contents, total surface runoff) and processes (e.g., water and nutrient transport and balances, plant production). These data are stored in a series of large text tables, typically on a monthly basis. Many of these data are also presented in graphical displays at the end of the simulation run.

These extensive output files serve a number of useful functions. These data are required for accurately testing and calibrating the TerreSIM application for particular communities and sites. In addition, these data can be sent in "real time" to other models running simultaneously.

Hydrological Dynamics in TerreSIM

An important component of TerreSIM at all scales is hydrological dynamics. The Plot Module focuses primarily on one-dimensional movement of water up and down in the soil profile. Precipitation events deliver water to each plot, which then percolates down into different layers in the profile. Evaporation removes water from the top horizons, and uptake by plant roots in each horizon is transpired as plants grow. The Community and Landscape Grids allow explicit representation of transport of water among different cells (Figure 3). This allows calculation of surface runoff, subsurface export, and transport of sediment, nutrients, and contaminants across the landscape.

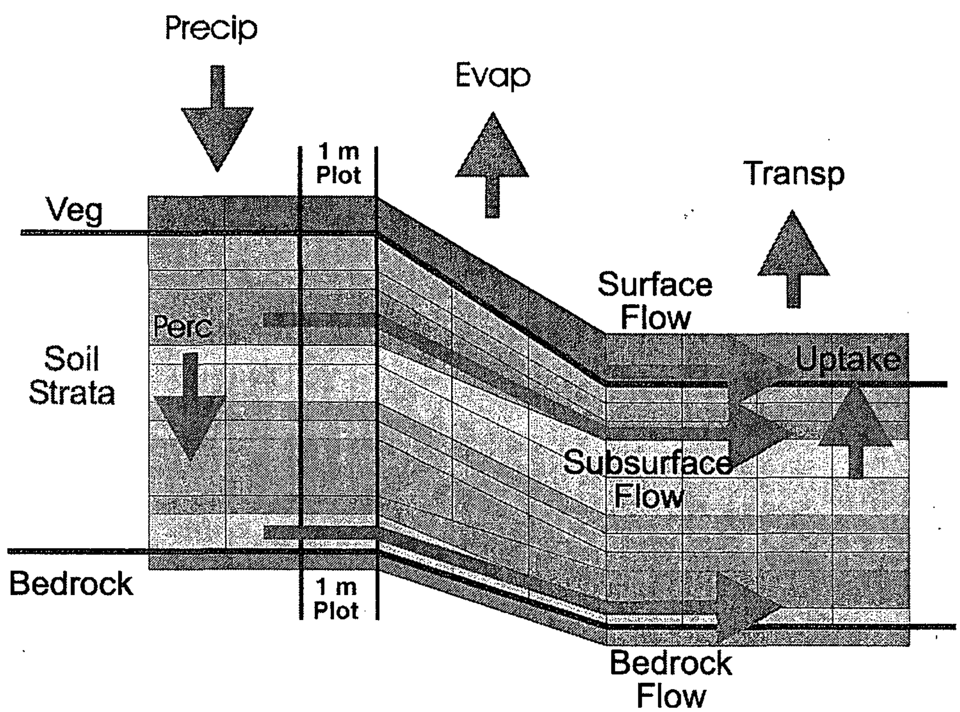

Figure 3. Hydrological dynamics in the TerreSIM Landscape Module

Among the various outputs produced in each TerreSIM simulation run are tables describing water pools and dynamics as well as summary graphical displays of total landscape runoff and export. These outputs allow projection of the effects of different climatic regimes, ecological stressors, vegetation dynamics, and management practices on surface and subsurface water quantity and quality.

Another hydrological capability of TerreSIM is simulation of water use by layer in the soil profile. This combined with the TerreSIM capability of simulating root dynamics by species, allows for the evaluation of water use dynamics by different types of plants over time (Figure 4). This is especially important in the evaluation of revegetation designs and successional dynamics.

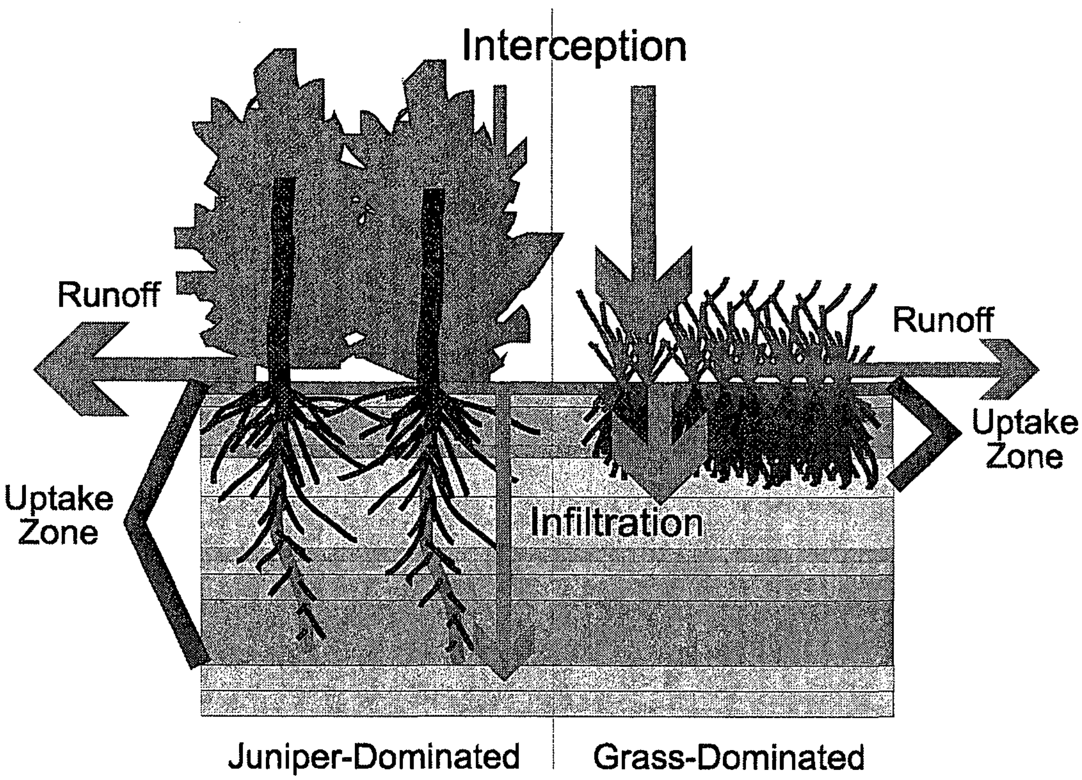

Figure 4. Hydrological dynamics in grassland and juniper woodlands

PARAMETERIZATION OF TERRESIM FOR THE DISPOSAL CELL

Application of the TerreSIM model to any management situation requires a formal parameterization process. Because TerreSIM simulates all aspects of ecosystem dynamics, suitable parameters must be implemented for reasonable simulation of each of the wide variety of ecosystem processes in the model. Most of the effort expended in a TerreSIM application involves gathering, converting, and incorporating these data into the model. The actual TerreSIM simulation runs can be conducted in a short period of time, even for a variety of alternative scenarios.

Some of the data required for TerreSIM parameterization are site-specific, i.e., they must be derived for the specific situation and locale. The most obvious local data are climatic, e.g., precipitation and temperature. In addition, descriptions of each soil profile and each plant community type at the site are required for initial conditions. Other data can be obtained from a variety of data sources, including ecological literature. Most of these relate to the ecology of different plant species within the communities at the location.

Climate and Soils Parameterization

A key input into TerreSIM is daily precipitation data. TerreSIM implements a hydrological module which uses daily precipitation as input for simulation of soil infiltration, surface runoff, and percolation through the soil profile. The nearest long-term weather station to the Gore Facility is the Sallisaw weather station, which lies approximately 20 miles to the east. This data set includes 44 years of complete daily precipitation data. TerreSIM simulation runs utilized this data set, recycling the data from year one after 44 years of the model run.

The temperature regime at the site is implemented in the TerreSIM model in a series of matrices which represent monthly timing and variations in a variety of physical and ecological processes. The following processes are representative of these processes: monthly pan evaporation; monthly changes in rate of snow melt; monthly proportion of snow versus rain for precipitation; and months for beginning and end of growing season, seed production, and germination for each plant species. These data were derived from existing climatic data for this locale and from ecological literature.

The cell cover profile was developed by MFG, Inc, as described elsewhere in this document. The simplified community scale TerreSIM application modeled a portion of the top section of the preliminary disposal cell mound design. This modeled area was 10,000 m2 (108,000ft2) with a 1% slope. Infiltration would be the greatest on the flatter slope area, so the simplified model application estimated infiltration for the entire mound conservatively. The local Lonoke Loam soil characteristics were used for the topsoil layers in the model simulations. The subsoil characteristics were derived from test pit data from the borrow areas near the site.

Plant Community Parameterization

The initial plant community in the simplified TerreSIM simulation of ecological and hydrological dynamics on the cover design was a seed bank consisting of three local perennial grasses: big bluestem, little bluestem, and indiangrass, as well as five local tree species: post oak, red oak, hickory, sycamore, and ash. Although it is a minor species in the area, sycamore was included because it is faster growing and has potentially shallower roots than the surrounding oaks and hickories which would be expected to move into the area whether planted or not. Sycamore is a good potential species that could be included in planting of the disposal cell post construction. The species selected are by no means the only species that will be planted or invade the disposal cell, but are dominates in the surrounding area, and therefore most likely to occur at the site naturally. These constitute a very basic plant community which was all that was required for this simplified application.

A variety of parameters are required to simulate dynamics of each plant species. These include morphological data (e.g., aboveground height, root zonation, ratio of root to aboveground biomass), physiological data (e.g., water- and nitrogen-use efficiencies, maximum growth rate, allocation of production to above- and belowground plant parts), and seasonal data (e.g., specific months for spring leaf-out, seed production, seed germination, and winter dormancy). These have been compiled for a wide variety of plant species in the western US and elsewhere, and incorporated into a database for use in TerreSIM applications. Data sets for each plant in the design seed bank were compiled from this database, and then incorporated into this TerreSIM application.

SIMULATION RESULTS

There are four sources for water loss from the revegetated disposal cell: evaporation, transpiration, runoff, and drainage. Evaporation is water loss directly from surfaces to the atmosphere, and TerreSIM separates evaporation by source, i.e., leaf surface of the plant community, soil surface (including the litter layer), and snow pack. Transpiration is evaporative water loss through plants. In most models, evaporation and transpiration are combined into evapotranspiration (ET). However, the dynamics of the two sources can be very different. Therefore, they are modeled separately in TerreSIM. Runoff is overland movement of water from the site. Export is percolation of water through the profile, past the rooting zone (infiltration). It is not direct drainage of the water from the site.

Table 1 summarizes the model output for the hydrological dynamics over the 200-year simulation period for the scenario including grass, shrub and tree species. For the simulated 10,000 m^2 subset of the top area of the disposal cell, total drainage equals 85692.06 m^3 (22,637,442 gal) of water over a 200 year period. The percent of precipitation lost to infiltration over the first 50 years is 15.09%. Drainage ceases by year 45, when the tree component of the vegetation is established successfully. Various sensitivity tests on the TerreSIM runs indicate a slight variation in time to little or no infiltration (up 48 years) and total percent precipitation lost to infiltration annually (up to 40% in some years).

Table 1. TerreSIM simulation results for water dynamics (m^3) on a 10,000 m^2 portion of the top area of the disposal cell design including tree and shrub components

		Evaporation				
Year	Precipitation	Canopy	Soil	Transpiration	Runoff	Export
1	11371.58	526.83	1473.67	3424.81	2.76	3834.12
2	11414.76	560.58	665.09	425.9	66.77	8256.71
3	12453.62	572.6	61.59	629.88	61.03	9344.41
4	8801.1	659.88	54.62	1309.29	6.85	5965.6
5	10248.9	1046.9	66.15	2838.14	31.84	5603.69
6	7762.24	1100.3	55.27	5082.09	7.48	1617.15
7	7683.5	2217.75	89.2	5562.37	0	70.06
8	8135.62	1972.56	92.9	4541.47	6.97	0
9	17363.44	4342.33	91.81	7643.35	52.38	3285.95

10	14711.68	5188.26	112.37	8380.43	51.2	0
11	13032.74	5374.91	106.3	6902.37	2.91	0
12	10398.76	4239.3	108.24	5118	0	0
13	13634.72	5264.27	106.64	6729.84	277.51	0
14	9349.74	4423.78	100.81	4116.02	0	0
15	6670.04	3594	98.48	2657.18	0	0
16	9733.28	4134.19	86.25	4324.5	15.13	0
17	9309.1	4126.46	100.31	4288.64	0	0
18	9636.76	4006.86	84.19	3317.33	0	0
19	9903.46	4949.32	104.6	3514.06	0	0
20	14066.52	5519.05	96.54	4586.02	0	1341.17
21	12448.54	4812.66	96.21	4343.86	188.64	89.61
22	12608.56	5563.67	80.26	4103.12	69.64	2691.02
23	12344.4	5426.93	78.44	3650.86	59.48	856.14
24	8968.74	3981.43	77.55	3230.67	2.28	603.08
25	18435.32	7472.11	94.95	2995.63	98.63	4301.24
26	12796.52	5027.74	89.8	2897.72	79.59	3618.94
27	11468.1	5347.92	75.66	2767.02	27.1	2259.45
28	10038.08	5360.53	86.45	2672.16	12	1425.53
29	9070.34	4221.78	69	2533.76	35.07	1437.44
30	9316.72	3770.85	53.4	2515.69	2.23	1772.52
31	9900.92	4986.76	81.13	2488.02	0	1370.22
32	7706.36	4101.91	71.89	2563.31	0	441.51
33	13703.3	6707.34	82.73	2548.02	163.72	3351.27
34	10063.48	4493.18	69.76	2656.55	0	1425.59
35	14046.2	6448.78	85.86	2645.86	41.82	2893.49
36	12951.46	5838.61	71.57	2765.81	27.12	2191.2
37	12633.96	6026.61	86.02	2761.83	48.46	2778.22
38	14135.1	5355.39	71.72	2921.8	0	2326.12
39	8524.24	4535.37	63.91	2875.72	17.48	1196.17
40	11386.82	5484.14	62.11	3104.1	0	520.82
41	19281.14	8285.83	90.77	3103.21	58.8	3304
42	14051.28	5551.01	82.78	3338.06	75.75	3260.08
43	11551.92	5643.71	79.27	3338.41	0	529.94
44	12600.94	5367.41	83.79	3621.46	0	746.69
45	11371.58	6217.87	67.23	3567.56	0	982.91
46	11414.76	6533.14	68.38	3943.19	1.61	0
47	12453.62	6701.95	73.69	3099.78	0	0
48	8801.1	5559.48	62.08	3000.8	0	0
49	10248.9	6560.39	76.91	3209.99	0	0
50	7762.24	3910.37	52.41	2330.46	0	0
60	9733.28	5930.39	45.39	2612.98	0	0
70	12796.52	7682.52	54.56	3955.4	0	0
80	12951.46	7872.92	44.2	2934.28	0	0
90	11414.76	7940.9	41.85	2280.84	0	0
100	10398.76	7101.07	45.19	2356.79	0	0
110	12608.56	10094.87	49.17	2836.97	0	0
120	7706.36	6089.62	31.87	880.74	0	0

130	14051.28	9886.42	47.88	1934.17	0	0
140	8135.62	5189.22	26.11	1560.48	0	0
150	9636.76	6258.56	31.41	1112.64	0	0
160	10038.08	8593.56	41.58	1405.35	0	0
170	14135.1	8232.45	35.2	1799.99	0	0
180	8801.1	6560.82	31.4	1467.58	0	0
190	9349.74	7175.5	31.33	1498.69	0	0
200	8968.74	6559.34	32.31	1367.77	0	0
Total - 200 years (not all years shown above)						
	2284907.8	1429445.1	12146.8	479352.97	2082.45	85692.06
% of Ppt	100%	62.56%	0.53%	20.98%	0.09%	3.75%
Total - 50 years						
	567766	229115	6040.76	176986.1	1592.25	85692.06
% of Ppt	100%	40.35%	1.06%	31.17%	0.28%	15.09%

Because deep rooted tree species could compromise the integrity of the disposal cell, a second scenario was modeled that excludes trees and shrubs for 200 years through annual mowing. Table 2 summarizes the model output for the hydrological dynamics for this scenario. For the simulated 10,000 m^2 subset of the top area of the disposal cell, total drainage from this scenario equals 257973.4 m^3 (68,149,349 gal) of water over a 200 year period. The percent of precipitation lost to infiltration over the first 50 years is 14.38% and 11.29% over the 200 year model run. Drainage is present in most years of the model run.

Table 2. TerreSIM simulation results for water dynamics (m^3) on a 10,000 m^2 portion of the top area of the disposal cell design assuming no tree and shrub components

		Evaporation				
Year	Precipitation	Canopy	Soil	Transpiration	Runoff	Export
1	11371.58	243.7	2270.83	2029.12	5.74	4706.03
2	11414.76	632.95	217.15	2637.67	68.78	6778.55
3	12453.62	1028.09	75.7	4170.22	38.97	5014.5
4	8801.1	1182.67	83.34	4962.91	3.06	2724.47
5	10248.9	1622.16	105.01	5396.07	23.38	2561.12
6	7762.24	1167.96	77.97	5115.53	6.8	0
7	7683.5	1849.56	100.38	5779.9	0	86.64
8	8135.62	1500.14	94.22	5253.42	10.68	0
9	17363.44	2806.83	88.77	5940.31	77.77	4982.77
10	14711.68	2966.73	110.81	5873.36	83.13	4543.81
11	13032.74	3006.77	96.71	5899.83	79.7	3419.67

12	10398.76	2324.11	92.34	5907.07	58.32	1973.57
13	13634.72	2813.48	93.11	5932.84	471.04	2287.69
14	9349.74	2382.68	91.27	5957.65	11.48	231.15
15	6670.04	1985.54	92.9	5908.08	25.26	0
16	9733.28	2201.07	83.49	6014.35	29.6	0
17	9309.1	2222.01	96.47	6034.23	45.15	0
18	9636.76	2142.15	84.47	5945.64	4.16	0
19	9903.46	2399.76	100.79	5877.55	27.81	0
20	14066.52	2838.46	98.63	6163.13	8.4	1961.17
21	12448.54	2226.94	105.83	6122	264.57	1212.27
22	12608.56	2941.1	82.94	5986.64	158.95	3262.12
23	12344.4	2947.84	99.11	6203.35	159.23	555.17
24	8968.74	2252.38	85.79	6185.79	15.51	0
25	18435.32	3631.18	95.1	6207.19	179.62	4241.35
26	12796.52	2425.09	92.33	6222.68	193.09	2780.06
27	11468.1	2676.96	91.13	6239.38	40.14	1613.54
28	10038.08	2712.5	96.16	6276.99	22.17	399.44
29	9070.34	2187.78	97.1	6269.42	61.2	802.73
30	9316.72	2012.77	77.43	6083.55	26.44	12.33
31	9900.92	2557.9	99.18	6317.1	1.82	0
32	7706.36	2010.18	91.83	5987.43	0	0
33	13703.3	3129	109.02	6356.98	316.82	906.66
34	10063.48	2244.92	97.14	6278.55	5.99	648.79
35	14046.2	2967.9	96.6	6308.35	122.11	1710.17
36	12951.46	2560.95	110.69	6308.41	46.61	1867.98
37	12633.96	2725.86	111.29	6313.25	98.3	2533.97
38	14135.1	2108.69	105.72	6317.39	1.74	2060
39	8524.24	2235.94	102.19	6171.35	27.46	967.77
40	11386.82	2303.35	90.33	6342.48	18.18	301.16
41	19281.14	3063.93	101.15	6326.44	108.93	4903.88
42	14051.28	1911.3	99.42	6333.17	126.59	3475.09
43	11551.92	2226.75	110.56	6335.7	0	1144.66
44	12600.94	2046.85	108.46	6338.74	1.26	898.47
45	11371.58	2699.17	99.87	6341.58	3.59	1563.03
46	11414.76	2732.01	102.77	6344.44	36.03	129.1
47	12453.62	2491.25	102.56	6347.13	23.61	892.82
48	8801.1	2108.94	89.79	6349.73	0	843.89
49	10248.9	2345.85	106.9	6352.2	15.24	644.24
50	7762.24	1510.64	77.1	5448.94	4.57	0
60	9733.28	2215.54	83.26	6185.51	30.76	0
70	12796.52	2442.65	93.06	6308.58	191.14	2677.88
80	12951.46	2561.82	110.66	6344	50.83	1827.34
90	11414.76	2732.84	102.77	6364.14	37.6	104.55
100	10398.76	2417.84	91.49	6315.37	59.68	1490.05
110	12608.56	2969.88	83.62	6236.55	158.79	2982.28
120	7706.36	2010.05	91.9	5944.02	0	0
130	14051.28	1913.45	99.46	6358.48	131.55	3427.82
140	8135.62	1656.5	87.56	5080.13	4.8	0

150	9636.76	2157.35	84.31	5554.22	0	0
160	10038.08	2718.53	96.58	6318.89	22.15	348.5
170	14135.1	2110.38	105.72	6351.4	20.2	2002.92
180	8801.1	2109.82	89.75	6369.84	0	834.05
190	9349.74	2443.73	90.99	6326.07	12.75	0
200	8968.74	2268.26	86.08	6302.63	25.47	0
Total - 200 years (not all years shown above)						
	2284907.8	486074	21478.09	1226478	13996.91	257973.4
% of Ppt	100%	21.27%	0.939%	53.67%	0.613%	11.29%
Total - 50 years						
	567766	113312.7	7089.85	293815.2	3159	81641.83
% of Ppt	100%	19.95%	1.25%	51.75%	0.57%	14.38%

CONCLUSIONS

The model output indicate significant drainage in most years if woody species are not present. The impact that trees have on the water balance of the site is through more use of water throughout the profile, as well as increased precipitation interception and canopy evaporation. The TerreSIM output demonstrates significant water loss form the canopy evaporation in the first scenario. The second (no tree) scenario is less favorable because water infiltration is present over the 200 year model run, and as a large portion of annual precipitation (11.29%). However, if annual mowing is not included as part of the long-term maintenance of the facility, oaks and other deep rooted tree species are expected to establish and eventually dominate the site as part of the natural ecological succession of the site. These species have to ability to physically compromise the integrity of disposal cell over time, through deep root proliferation. Therefore, sycamore is a recommended species to be included in planting of the disposal cell post construction, if long term maintenance is not provided for. Sycamore is faster growing and has potentially shallower roots than the oaks and hickories, and therefore would not compromise the integrity of the disposal cell. In addition, sycamore can prevent the invasion and dominance of the site by oaks and other deep rooted species for several hundred years through competition.

ATTACHMENT E.2

HELP MODELING RESULTS

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:     U:\sfc\DATA4.D4
TEMPERATURE DATA FILE:       U:\sfc\DATA7.D7
SOLAR RADIATION DATA FILE:   U:\sfc\DATA13.D13
EVAPOTRANSPIRATION DATA:     U:\sfc\DATA11.D11
SOIL AND DESIGN DATA FILE:   U:\sfc\LDX10-7.D10
OUTPUT DATA FILE:            U:\sfc\LDX10-7.OUT


TIME:  10:35     DATE:   9/26/2006


******************************************************************************

     TITLE:  SFC LATDRN#1

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                  LAYER  1
                                  --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  8
          THICKNESS                  =     18.00   INCHES
          POROSITY                   =      0.4630 VOL/VOL
          FIELD CAPACITY             =      0.2320 VOL/VOL
          WILTING POINT              =      0.1160 VOL/VOL
          INITIAL SOIL WATER CONTENT =      0.2441 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.369999994000E-03 CM/SEC
        NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.63
                FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.
```

LAYER 2

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 13

THICKNESS	=	60.00	INCHES
POROSITY	=	0.4300	VOL/VOL
FIELD CAPACITY	=	0.3210	VOL/VOL
WILTING POINT	=	0.2210	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2941	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.330000003000E-04	CM/SEC

LAYER 3

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 2

THICKNESS	=	18.00	INCHES
POROSITY	=	0.4370	VOL/VOL
FIELD CAPACITY	=	0.0620	VOL/VOL
WILTING POINT	=	0.0240	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0804	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.579999993000E-02	CM/SEC
SLOPE	=	1.00	PERCENT
DRAINAGE LENGTH	=	520.0	FEET

LAYER 4

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	18.00	INCHES
POROSITY	=	0.4270	VOL/VOL
FIELD CAPACITY	=	0.4180	VOL/VOL
WILTING POINT	=	0.3670	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06	CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE # 8 WITH A

FAIR STAND OF GRASS, A SURFACE SLOPE OF 1.%
AND A SLOPE LENGTH OF 520. FEET.

SCS RUNOFF CURVE NUMBER	=	78.10	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	17.800	ACRES
EVAPORATIVE ZONE DEPTH	=	87.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	22.927	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	38.067	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	15.564	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	31.171	INCHES
TOTAL INITIAL WATER	=	31.171	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
TULSA OKLAHOMA

STATION LATITUDE	=	36.12 DEGREES
MAXIMUM LEAF AREA INDEX	=	3.50
START OF GROWING SEASON (JULIAN DATE)	=	85
END OF GROWING SEASON (JULIAN DATE)	=	311
EVAPORATIVE ZONE DEPTH	=	87.0 INCHES
AVERAGE ANNUAL WIND SPEED	=	10.50 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	64.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	67.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	66.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	68.00 %

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TULSA OKLAHOMA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
1.35	1.74	3.14	4.15	5.14	4.57
3.51	3.01	4.37	3.41	2.56	1.82

NOTE: TEMPERATURE DATA FOR TULSA OK
WAS ENTERED FROM AN ASCII DATA FILE.

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR TULSA OKLAHOMA
AND STATION LATITUDE = 36.12 DEGREES

WARNING: TEMPERATURE FOR YEAR 1902 USED WITH PRECIPITATION FOR YEAR 1

****

ANNUAL TOTALS FOR YEAR 1

	INCHES	CU. FEET	PERCENT
PRECIPITATION	32.52	2101247.250	100.00
RUNOFF	0.059	3790.714	0.18
EVAPOTRANSPIRATION	31.739	2050755.120	97.60
DRAINAGE COLLECTED FROM LAYER 3	0.0003	18.371	0.00
PERC./LEAKAGE THROUGH LAYER 4	0.036063	2330.173	0.11
AVG. HEAD ON TOP OF LAYER 4	0.0012		
CHANGE IN WATER STORAGE	0.686	44352.367	2.11
SOIL WATER AT START OF YEAR	31.171	2014077.620	
SOIL WATER AT END OF YEAR	31.857	2058430.000	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.383	0.00

****

WARNING: TEMPERATURE FOR YEAR 1903 USED WITH PRECIPITATION FOR YEAR 2

****

ANNUAL TOTALS FOR YEAR 2

	INCHES	CU. FEET	PERCENT
PRECIPITATION	47.69	3081441.250	100.00
RUNOFF	1.575	101770.961	3.30
EVAPOTRANSPIRATION	42.496	2745813.250	89.11

DRAINAGE COLLECTED FROM LAYER 3	2.1790	140791.719	6.66
PERC./LEAKAGE THROUGH LAYER 4	1.956869	126441.125	5.98
AVG. HEAD ON TOP OF LAYER 4	10.3640		
CHANGE IN WATER STORAGE	-4.110	-265547.781	-12.56
SOIL WATER AT START OF YEAR	35.419	2288589.000	
SOIL WATER AT END OF YEAR	31.310	2023041.120	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	0.162	0.00

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WARNING: TEMPERATURE FOR YEAR 2000 USED WITH PRECIPITATION FOR YEAR 99

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ANNUAL TOTALS FOR YEAR 99

	INCHES	CU. FEET	PERCENT
PRECIPITATION	32.41	2094140.120	100.00
RUNOFF	0.325	21005.488	1.00
EVAPOTRANSPIRATION	29.376	1898090.870	90.64
DRAINAGE COLLECTED FROM LAYER 3	1.5789	102021.117	4.87
PERC./LEAKAGE THROUGH LAYER 4	1.725507	111491.875	5.32
AVG. HEAD ON TOP OF LAYER 4	7.0038		
CHANGE IN WATER STORAGE	-0.595	-38470.301	-1.84
SOIL WATER AT START OF YEAR	31.310	2023041.120	
SOIL WATER AT END OF YEAR	30.714	1984570.870	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.000	0.000	0.00
ANNUAL WATER BUDGET BALANCE	0.0000	1.063	0.00

****

WARNING: TEMPERATURE FOR YEAR 2001 USED WITH PRECIPITATION FOR YEAR 100

****

ANNUAL TOTALS FOR YEAR 100

	INCHES	CU. FEET	PERCENT
PRECIPITATION	41.31	2669204.250	100.00
RUNOFF	1.131	73094.703	2.74
EVAPOTRANSPIRATION	38.142	2464531.750	92.33
DRAINAGE COLLECTED FROM LAYER 3	0.7320	47299.844	1.77
PERC./LEAKAGE THROUGH LAYER 4	1.463748	94578.609	3.54
AVG. HEAD ON TOP OF LAYER 4	3.1643		
CHANGE IN WATER STORAGE	-0.159	-10301.267	-0.39
SOIL WATER AT START OF YEAR	30.714	1984570.870	
SOIL WATER AT END OF YEAR	30.328	1959593.250	
SNOW WATER AT START OF YEAR	0.000	0.000	0.00
SNOW WATER AT END OF YEAR	0.227	14676.317	0.55
ANNUAL WATER BUDGET BALANCE	0.0000	0.555	0.00

****

****

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS   1 THROUGH 100

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	1.36	1.76	3.08	4.27	5.30	4.36
	3.53	2.98	4.06	3.61	2.55	1.83
STD. DEVIATIONS	0.91	1.01	1.66	2.50	2.84	2.51

	2.42	1.76	2.52	2.58	1.82	1.26

RUNOFF

TOTALS	0.056	0.022	0.061	0.099	0.231	0.112
	0.069	0.050	0.113	0.179	0.075	0.008
STD. DEVIATIONS	0.234	0.082	0.122	0.170	0.386	0.214
	0.185	0.183	0.237	0.456	0.198	0.026

EVAPOTRANSPIRATION

TOTALS	0.630	0.941	1.827	2.821	6.432	7.456
	5.908	3.622	2.755	1.365	0.674	0.516
STD. DEVIATIONS	0.212	0.313	0.509	0.649	0.636	0.928
	2.175	2.091	1.123	0.370	0.140	0.154

LATERAL DRAINAGE COLLECTED FROM LAYER 3

TOTALS	0.0722	0.0645	0.0748	0.0932	0.1384	0.1544
	0.1448	0.1160	0.0959	0.0877	0.0757	0.0740
STD. DEVIATIONS	0.0589	0.0582	0.0722	0.0891	0.1100	0.1122
	0.0980	0.0712	0.0572	0.0541	0.0490	0.0537

PERCOLATION/LEAKAGE THROUGH LAYER 4

TOTALS	0.1119	0.1006	0.1142	0.1224	0.1443	0.1493
	0.1456	0.1317	0.1216	0.1219	0.1126	0.1136
STD. DEVIATIONS	0.0511	0.0482	0.0521	0.0571	0.0636	0.0591
	0.0512	0.0464	0.0412	0.0413	0.0427	0.0469

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 4

AVERAGES	3.8297	3.7883	4.0738	5.6159	8.2868	9.5217
	8.1235	6.1064	5.0772	4.4828	4.0050	3.8303
STD. DEVIATIONS	3.6762	4.0821	4.7417	7.0733	8.0448	8.1688
	6.1224	3.9787	3.0581	2.7735	2.6129	3.0098

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 100

	INCHES	CU. FEET	PERCENT

PRECIPITATION	38.70	(7.401)	2500406.5	100.00
RUNOFF	1.075	(0.8231)	69443.65	2.777
EVAPOTRANSPIRATION	34.947	(4.8450)	2258096.25	90.309
LATERAL DRAINAGE COLLECTED FROM LAYER 3	1.19164	(0.74610)	76996.617	3.07936
PERCOLATION/LEAKAGE THROUGH LAYER 4	1.48990	(0.48652)	96268.164	3.85010
AVERAGE HEAD ON TOP OF LAYER 4	5.562	(3.973)		
CHANGE IN WATER STORAGE	-0.006	(4.2935)	-398.08	-0.016

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          PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
-------------------------------------------------------------------------
                                             (INCHES)      (CU. FT.)
                                            ----------    -------------
   PRECIPITATION                               6.67        430975.375

   RUNOFF                                      3.071       198422.4690

   DRAINAGE COLLECTED FROM LAYER  3            0.01514        978.39587

   PERCOLATION/LEAKAGE THROUGH LAYER  4        0.012616       815.18628

   AVERAGE HEAD ON TOP OF LAYER  4            48.762

   MAXIMUM HEAD ON TOP OF LAYER  4            57.013

   LOCATION OF MAXIMUM HEAD IN LAYER  3
         (DISTANCE FROM DRAIN)               289.3 FEET

   SNOW WATER                                  2.25        145213.0620


   MAXIMUM VEG. SOIL WATER (VOL/VOL)                     0.3669

   MINIMUM VEG. SOIL WATER (VOL/VOL)                     0.1789


    ***  Maximum heads are computed using McEnroe's equations.  ***

         Reference:  Maximum Saturated Depth over Landfill Liner
                     by Bruce M. McEnroe, University of Kansas
                     ASCE Journal of Environmental Engineering
                     Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 100

LAYER	(INCHES)	(VOL/VOL)
1	4.3567	0.2420
2	16.1454	0.2691
3	2.1396	0.1189
4	7.6860	0.4270
SNOW WATER	0.227	

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