APPENDIX B

EROSIONAL STABILITY

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B.1 INTRODUCTION

One of the technical criteria for the stability of the disposal cell is acceptable erosional stability from extreme storm events (Appendix A of 10 CFR 40). The NRC has interpreted this criterion to be able to safely pass the peak runoff from storms up to the Probable Maximum Precipitation (PMP) event (NRC, 1990; Johnson, 1999).

This appendix presents the hydrologic analysis and evaluation of erosion protection for the cover of the disposal cell. This analysis encompasses the following tasks:

1. Determine the PMP event for the disposal cell area.
2. Determine the peak unit discharge from the PMP on the drainage basins of the disposal cells.
3. Evaluate erosional stability of the disposal cell cover surface using the peak unit discharge.
4. Where required, calculate the median rock size for erosion protection materials on the disposal cell cover using the peak unit discharge.

These analysis tasks are described in the following sections.

B.2 PROBABLE MAXIMUM PRECIPITATION EVENT

This section discusses the precipitation event used to predict the peak discharges for design of the disposal cell cover. For long-term erosion protection of cover surfaces at 11e.(2) material disposal sites, the NRC-STP (NRC, 1990) requires that the PMP be used to determine the peak design discharge.

The depth of the PMP is derived from *Hydrometerological Report 51* (HMR 51, USCOE, 1978). HMR 51 provides depths for the all-season PMP for basins with an area of 10 square miles or larger. Figure 18 from HMR 51 indicates a PMP depth of 29 inches over a duration of 6 hours for a drainage basin of 10 square miles. For this analysis, it was necessary to derive the PMP event for a smaller duration and smaller drainage area. This was accomplished by using the *Hydrometerological Report 52* (HMR 52, USCOE, 1982). HMR 52 takes the PMP estimates from HMR 51 and applies them to specific drainage areas both temporally and spatially. From Figures 23 and 24 in HMR 52, the 1-hour PMP for a drainage area of one square mile is 0.65 times smaller than the 6-hour PMP for 10 square mile drainage areas. This results in a 1-hour PMP of 19 inches, which was used for this analysis. Factors for durations less than one hour where taken from Urban Drainage and Flood Control District Storm Drainage Criteria Manual (UDFCD, 2001) for durations of 5, 10, 15 and 30 minutes (see attachment of Table RA-4). The rainfall intensity was determined by multiplying the PMP depth by its corresponding duration based on the time of concentration for that specific drainage basin.

B.3 RUNOFF FROM THE PMP (PEAK DISCHARGE)

The Rational Method was used to determine the peak discharge from the PMP for evaluation of cover erosion protection. Five drainage areas were delineated on the cover of the disposal cell; four on the side slopes (north, south, east and west), and one on the top surface. The area of these drainage basins was calculated using computer-aided design (CAD) tools.

Time of Concentration. The time of concentration is computed using the Kirpich (1940) equation (give below) as recommended in the NRC STP.

$$T_c = 0.0078L^{0.77}(L/H)^{0.385}$$

Where:

T_c = time of concentration (minutes)
L = slope length (feet)
H = slope height (feet)

Table B.1 (below) shows the areas of each drainage basin, the slope, and slope length, which are used for the time of concentration calculation. As seen in Table B.1, all calculated times of concentration are less than 5 minutes except for the cover, which is 5.4 minutes. As recommended in the UDFCD Manual, any time of concentration less than 5 minutes does not lead to realistic runoff estimates, and therefore a T_c of 5 minutes was used for each basin.

Table B.1 Results of Time of Concentration Calculations

Description	Drainage Area (acres)	Slope (feet/feet)	Slope Length (feet)	Time of Concentration (minutes)
Top	7.8	0.01	500	5.4
North	2.5	0.20	190	0.9
South	1.4	0.20	110	0.6
East	1.8	0.20	100	0.5
West	3.6	0.20	225	1.0

The rainfall intensity for each basin is 66.1 inches per hour based on a T_c of 5 minutes. From Table RA-4 in the UDFCD Manual, a ratio of 0.29 is multiplied to the 1-hour PMP depth for a duration of 5 minutes. Rainfall intensities for each basin are determined as follows:

$$I = P_{pmp} \times F + T_c \times 60 \text{ min/hr}$$

Where:

I = intensity
P_{pmp} = 19 inches (depth of 1 hour PMP)
F = ratio of 5 minute duration to 1-hour duration
T_c = time of concentration (minutes)

Peak flow. The peak flow was calculated with the Rational Formula, as follows:

$$Q = CIA$$

Where:

Q = peak flow (cfs)
C = runoff coefficient = 0.8
I = rainfall intensity (inches/hour)
A = area (acres)

The NRC STP recommends using a conservative runoff coefficient of 0.8 when evaluating erosion protection for cover systems. Peak flow was then divided by the downstream width of the appropriate drainage area as follows:

$$q = Q/w$$

Where:

q = unit discharge (cfs/foot)
w = unit width (feet)

Table B.2 shows the results of the peak flow and unit discharge calculations for each drainage basin.

Table B.2 Results of Peak Flow and Unit Discharge for Each Drainage Basin

Description	Drainage Area (acres)	Rainfall Intensity (in/hr)	Peak Flow (cfs)	Downstream Width (feet)	Unit Discharge (cfs/acre)	Unit Discharge (cfs/foot)
Top	7.8	66.1	425.7	1200	54	0.35
North	2.5	66.1	126.9	575	55	0.23
South	1.4	66.1	79.3	600	53	0.16
East	1.8	66.1	116.3	830	53	0.15
West	3.6	66.1	222.1	850	53	0.25

For the top surface of the disposal cell, the peak flow in Table B.2 (425.7 cfs) represents the flow over the top of the east and south side slopes. The unit discharge (0.35 cfs/foot) is this flow distributed over the slope width at the top of the east and south side slopes (1,200 feet).

For sizing riprap for erosion protection on the side slopes, the unit discharge values in Table B.2 were used in evaluating the north and west side slopes. On the east and south side slopes, the unit discharge from the top surface (0.35 cfs/foot) was used, since this value was larger than the unit discharge for runoff from precipitation on the slope itself (0.15 and 0.16 cfs/foot). Due to the differences in time of concentration between the top surface and side slope runoff, the peak flows on the east and south side slopes were not added to the peak flow from the top surface.

B.4 TOP SURFACE EROSIONAL STABILITY

The top surface of the disposal cell was evaluated for erosional stability without a rock layer. As outlined in NRC (1990) and Johnson (1999), the peak discharge over the top surface (from Table B.2) was first converted to a peak velocity and depth of flow using Manning's Equation. The peak unit discharge flow (0.35 cfs/foot) was multiplied by a concentration factor of 3. Depending on surface roughness (due to vegetation conditions), peak velocities range from approximately 1.3 to 2.3 feet per second and corresponding depths of flow of 0.82 to 0.47 feet (for Manning's roughness coefficient values ranging from 0.10 to 0.04). Permissible velocities presented in Johnson (1999) for these depths of flow range from approximately 2.0 to 2.4 feet per second. This indicates that some of the peak velocities from the PMP are less than permissible velocities, but not under all of the surface roughness conditions that were analyzed. As the next step of evaluation, procedures for vegetated surfaces outlined in Temple and others (1987) were used (as recommended in the NRC STP).

Method of Analysis. Temple and others (1987) outlines procedures for channel design, including calculation of channel velocities and depths of flow. These procedures include methods for estimating stresses on channel vegetation as well as the channel surface soils. The evaluation for the disposal cell used the peak discharge values from the PMP (summarized in Table B.2) to conservatively represent the effective stresses from runoff on the cover surface. The stresses on both the vegetation and soils were evaluated.

The erosional stability of the cover surface was evaluated by calculating a factor of safety against erosion due to the peak runoff from the PMP. Factor-of-safety values were calculated as the ratio of the allowable stresses (the resisting strength of the cover vegetation or soils) to the effective stresses (the stresses impacted by the runoff flowing over the cover). The stress calculations are summarized below.

Allowable stresses. Allowable stresses for the cover soils were calculated using the equations in Temple and others (1987). Materials planned for cover soils range from silty clays to gravelly sandy silts (depending on how much of the underlying sandstone and siltstone is present in the cover material). For cohesive soils, the resistance is based on the plastic limit and void ratio of the material. From testing of on-site silty clay in 1996 (classified as a low-plasticity clay or CL), the plastic limit was 16 and the void ratio (at 90 percent of Standard Proctor density) was 0.723. The equation for allowable shear strength for cohesive soils is:

$$\tau_a = \tau_{ab} C_e^2$$

Where τ_a = allowable shear strength (in psf)

τ_{ab} = basis allowable shear strength (for a CL) = $(1.07\,[PL]^2 + 14.3[PL] + 47.7) \times 10^{-4}$

C_e = soil parameter = 1.48 – 0.57e
PL = plastic limit = 16
e = void ratio = 0.723

For the plastic limit and void ratio values given above, τ_{ab} = 0.055, C_e = 1.14 and τ_a = 0.063 psf.

For non-cohesive soils, the resistance is based on particle size, specifically the size where 75 percent of the material is finer, or d_{75}. For a d_{75} larger than 0.05 inches (1.27 mm, No. 14 sieve size, or a medium-grained sand), the allowable shear strength is:

$$\tau_a = 0.4\, d_{75}, \text{ where } d_{75} \text{ is in inches}$$

For a soil cover d_{75} of 0.157 inches (4 mm, No. 4 sieve size, or a coarse-grained sand), the allowable shear strength is 0.063 psf.

For a vegetated surface primarily of mixed grasses, the allowable vegetation shear strength is:

$$\tau_{va} = 0.75\, C_I$$

Where: τ_{va} = allowable vegetation shear strength (in psf)
C_I = cover index = $2.5\, [h(M)^{1/2}]^{1/3}$
h = stem length (in ft)
M = stem density factor

For average vegetation conditions, h=1.0, M=200 and C_I=6.05. For poor conditions, h=0.5, M=150, and C_I=4.57. The resulting vegetation shear stress values are 4.53 to 3.43 psf for average to poor vegetation conditions, respectively.

Effective stresses. The effective shear stress on soil due to peak runoff from the PMP was calculated as:

$$\tau_e = \gamma d S (1-C_F)(n_s/n)^2$$

Where: τ_e = effective shear stress (in psf)
γ = unit weight of water = 62.4 pcf
d = depth of flow (in ft)
S = slope of cover surface (0.01)
C_F = cover factor (0.7 for average vegetation, 0.5 for poor vegetation)

n_s = soil grain roughness factor (0.0156 for cohesive soil, 0.018 for soil with a d_{75} of 4 mm)
n = Manning's roughness coefficient (0.10 to 0.04)

The effective shear stress on vegetation is calculated as:

$$\tau_v = \gamma dS - \tau_e, \text{ where } \tau_v = \text{effective vegetal stress (in psf)}$$

Conservatively using poor vegetation conditions and a soil grain roughness factor for finer-grained soils, the effective shear stresses for Manning's n values are summarized below.

Manning's n value	0.04	0.10
Depth of flow, d (ft)	0.47	0.82
Effective shear stress, τ_e (psf)	0.0223	0.0062
Effective vegetal stress, τ_v (psf)	0.375	0.690

Factors of safety. The calculated factors of safety from the shear stresses above are outlined below.

Condition	Allowable Strength (psf)	Effective Stress (psf)	Factor of Safety (allowable/effective)
Vegetation on cover surface			
(average)	4.53	0.690	6.57
(poor)	3.43	0.375	9.15
Soils on cover surface			
(cohesive)	0.627	0.0223	2.83
(granular)	0.063	0.0062	10.16

The calculated factors of safety above show that for average to poor vegetation conditions, the allowable shear strengths are higher than the effective shear stresses on vegetation due to peak discharge from the PMP (with factors of safety above 6). For the conservative condition of no vegetation with the topsoil eroded away, the underlying cover soil shear strengths are higher than the effective shear strengths due to peak discharge for the PMP (with factors of safety above 2).

These analyses indicate that the cover on the top surface of the disposal cell can be vegetated without a riprap or rock mulch layer and meet the erosional stability criteria outlined in NRC (1990) and Johnson (1999). In the following section, riprap sizing calculations are included on the cover surface for comparative purposes.

B.5 RIPRAP SIZING FOR THE COVER SURFACES

The design unit discharge from each drainage basin was used to size riprap for the protective cover. The design unit discharge is based on the assumption of uniform sheet flow across the entire drainage basin. The NRC STP recommends using the Safety Factors Method for top surfaces (less than 10 percent) and Stephenson's method for side slopes (greater than 10 percent). Johnson (1999) recommends the use of the Abt method for side slopes, so this method was used for riprap sizing on the side slopes, with comparison with Stephenson's method.

The equation for the Safety Factors Method (Richardson and others, 1975) and Stephenson Method (Stephenson, 1979) are outlined in NUREG CR-4620 (Nelson and others, 1986). The key parameters used in the riprap sizing calculations are outlined below.

Flow Characteristics. The peak unit discharge values from Table B.2 were used to represent flow conditions on the cover surface. Where applicable, a concentration factor of 3 was used.

Rock Characteristics. Properties for durable rock from nearby gravel pits was used in the calculations. The rock specific gravity was 2.65, with a friction angle or angle of repose of 37 degrees (representing rounded rock, consistent with Table 4.8 of NUREG CR-4620), and a porosity of 0.33.

The riprap sizing results are summarized in Table B.3 below.

Table B.3 Results of Riprap Sizing Calculations

Drainage Basin	Design Unit Discharge (cfs/ft)	Slope (ft/ft)	Slope Length (ft)	Median Rock Size (inches) Stephenson	Median Rock Size (inches) Abt
Top	0.35	0.01	500	1.2[a]	0.9
North	0.23	0.20	190	2.4	2.5
South	0.35[b]	0.20	110	3.1	3.2
East	0.35[b]	0.20	100	3.1	3.2
West	0.25	0.20	225	2.5	2.6

[a] - Safety Factors Method
[b] – From discharge off of top surface

Using the Safety Factors method for the top surface, the median rock size is 1.2 inches. Using Abt's method for the side slopes (at 20 percent) the median rock size ranges from 2.5 inches on the north slope to 3.2 inches on the east and south slopes of the disposal cell (based on runoff from the top surface flowing over the east and south slopes).

For the disposal cell cover design, two modifications are made from standard surface riprap design, as outlined below.

Rock mulch. A rock mulch will be used for the riprap, utilizing alluvial (rounded) gravel from nearby sources with smaller materials to fill the void spaces. Using the median size for the east and south sides of the cell of 3.2 inches, the median rock mulch size for all of the side slopes was conservatively chosen to be 3.2 inches. The maximum size (based on available screen size) will be 6 inches. The rock mulch layer thickness (recommended to be 1.5 to 2 times the median size or at the maximum size in the NRC STP) will be 6 inches.

Below-surface layer. In order to promote establishment and maintenance of vegetation on the side slopes, the rock mulch layer will not be on the cover surface. A layer of topsoil (12 inches thick) will be the top layer on the side slopes, followed by the rock mulch layer (6 inches thick).

The topsoil will provide the seed bed and "A" horizon for plant establishment and growth, and the rock mulch layer will allow root penetration. The rock mulch layer will provide an erosion protection layer in the event that the topsoil is eroded.

B.6 REFERENCES

Abt, S.R. and T.L. Johnson, 1991. "Riprap Designs for Overtopping Flow." American Society of Civil Engineers, *Journal of Hydraulic Engineering*, Vol. 117, No. 8. August.

Abt, S.R., M.S. Khattak, J.D. Nelson, J.F. Ruff, A. Shaikh, R.J. Wittler, D.W. Lee, and N.E. Hinkle, 1988. "Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase II." *NUREG/CR-4651*, Vol. 2.

Johnson, T.L., 1999. "Design of Protective Covers." U.S. Nuclear Regulatory Commission (NRC), *NUREG 2615* Draft for Comment. February.

Nelson, J., S. Abt, R. Volpe, D. van Zyl, N. Hinkle, and W. Staub, 1986. "Methodologies for Evaluation of Long-term Stabilization Designs of Uranium Mill Tailings Impoundments." *NUREG/CR-4620,* U.S. Nuclear Regulatory Commission. June.

Richardson, E., D. Simons, S. Karak, K. Mahmood, and M. Stevens, 1975. "Highways in the River Environment-Hydraulics and Environmental Design Considerations." U.S. Department of Transportation, Washington, D.C.

Stephenson, D., 1979. "Rockfill in Hydraulic Engineering." *Developments in Geotechnical Engineering*, Vol. 27, Elsevier Scientific Publishing Company.

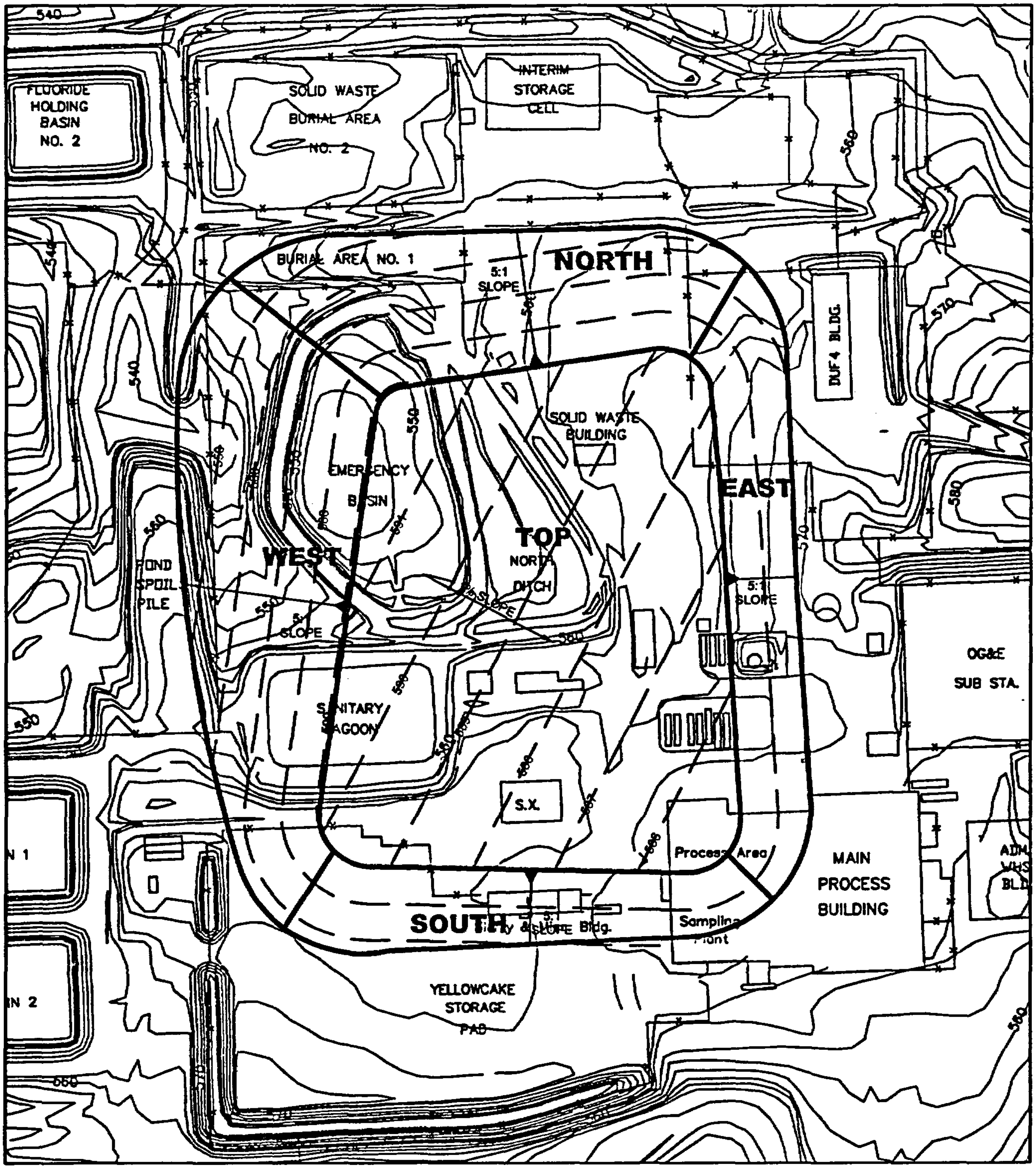
Temple, D.M., K.M. Robinson, R.A. Ahring, and A.G. Davis, 1987. "Stability Design of Grass-Lined Open Channels." *USDA Handbook 667.*

U.S. Corps of Engineers (COE), 1978. *Hydrometerological Report No. 51 (HMR51)* – "Probable Maximum Precipitation Estimates, United States East of the 105th Meridia." June.

U.S. Corps of Engineers (COE), 1982. *Hydrometerological Report No. 52 (HMR52)* – "Application of Probable Maximum Precipitation Estimates, United States East of the 105th Meridian." August.

U.S. Nuclear Regulatory Commission (NRC), 1990. "Final Staff Technical Position, Design of Erosion Protective Covers for Stabilization of Uranium Mill Tailings Sites." August.

Urban Drainage and Flood Control District (UDFCD), 2001. *Urban Storm Drainage Criteria Manual.* June.



SURFACE/SLOPE	SLOPE LENGTH (FT.)	SLOPE AREA (AC.)
TOP	500	7.8
WEST	225	3.6
EAST	100	1.8
SOUTH	110	1.4
NORTH	190	2.5

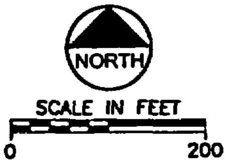


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FIGURE B.1
DRAINAGE AREAS USED IN EROSIONAL STABILITY ANALYSES

Date: DECEMBER 2002
Project: 100734
File: SITE-01.DWG

APPENDIX C

SEISMIC AND STATIC STABILITY

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C.1 INTRODUCTION

This appendix presents the methods, input and results for analysis of slope analysis for the disposal cell at the Sequoyah Fuels Corporation (SFC) Facility in Gore, Oklahoma. The analysis of slope stability was conducted according to applicable stability criteria under both static and seismic conditions, including geotechnical stability criteria in NRC (2002).

Slope stability analyses were performed using limit equilibrium methods with the aid of the computer program SLOPE/W (GEO-SLOPE, 1999). The SLOPE/W program calculates factors of safety by any of the following methods: (1) Ordinary Fellenius, (2) Bishop's Simplified, (3) Janbu's Simplified, (4) Spencer, (5) Morgenstern-Price, (6) U.S. Army Corps of Engineers, (7) Lowe-Karafiath, and (8) Generalized Limit Equilibrium. Spencer's method was used for these analyses, because it considers both force equilibrium and moment equilibrium in the factor of safety calculation.

C.2 CRITICAL CONDITIONS AND GEOMETRY

Slope stability analyses are typically conducted under scenarios that represent the critical conditions for construction and operation. For the disposal cell, these conditions include: (1) the period during cell construction, and (2) the long-term period after cell construction.

Key factors during construction are development of excess porewater pressures in foundation, berm or cover materials due to equipment or fill placement, or displacement of low-strength fill materials (such as sludges) in response to covering fill placement. These factors are not of concern for slope stability during cell construction. The foundation materials (unsaturated soils and underlying sedimentary rock) are not susceptible to development of excess porewater pressures. Disposed materials will be placed and covered in a manner to minimize void spaces and future settlement.

The long-term period after cell construction was analyzed along critical areas of the disposal cell slopes. Long-term, steady-state material properties and porewater pressure conditions were used to represent these areas.

Two cross-sections were selected for long-term slope stability analysis. Cross-section locations are shown on Figure C.1, and the geometry of each cross-section is shown on Figures C.2 and C.3. Critical cross-sections were selected based on overall disposal cell height as well as base topography. Cross-Section 1 (CS-1) was located to evaluate stability of the longest slopes of the disposal cell, while CS-2 was located to account for a typical slope length located over a downward-sloping foundation topography.

The cell profile for each critical cross-section was based on a reclamation cover thickness of 10 feet, underlain by contaminated site soils and foundation soils. The foundation soil layer was assumed to be 10 feet thick, based on site boring logs (discussed in Appendix A). The thickness of the contaminated site soils was determined based on the topography shown on Figure C.1.

Synthetic material (both Hypalon and HDPE) lining existing ponds on site will be removed and placed in the disposal cell as an initial infiltration barrier beneath the cover. The liner material will be placed within layers of disposed material and above the Layer A materials (the materials planned for disposal at the bottom of the cell). The liner material panels will be placed to form a continuous barrier, with the panels overlapped, and covered with disposed material. Due to the relatively low frictional resistance between these synthetic materials and surrounding soils, the liner material within the cell could form a weaker zone or potential failure surface. Therefore the liner elevation and orientation in the cell have an effect on calculated stability. For these analyses the liner was conservatively located at the top of the disposed material profile.

Slope stability analyses were performed by calculating factors of safety along circular failure surfaces as well as block and fully specified wedge failure surfaces. Circular failure surface analysis was conducted by targeting deeper, full slope failures. Small, shallow surface failures were not considered. Wedge failure surfaces were specified to occur along the synthetic liner. In both cases, a number of failure surfaces were analyzed to find the lowest factor of safety.

C.3 MATERIAL PROPERTIES

Materials properties used in SLOPE/W for cover soil, contaminated site soils and foundation materials were based on typical values for the materials present at the site (discussed in Appendix A). Material properties are discussed below and summarized in Table C.1.

Cover material. The soil cover will be constructed with materials derived from on-site soils and shallow sedimentary rock. These materials are present at the following locations considered as potential borrow areas: (1) the tornado berm, (2) the settling pond berms, and (3) the fertilizer pond berms. From drilling logs discussed in Appendix A, these materials range from a gravelly clay to a silty clay of low plasticity. From geotechnical testing of a sample of this material (documented in ESCI, 1998), the silty clay portion is a low-plasticity clay with a plasticity index of 17 and a maximum dry unit weight of approximately 107 pcf (Appendix A). Based on the general relationship between plasticity index and shear strength in Holtz and Kovacs (1981), the effective angle of internal friction (for a material with a plasticity index of 17) is 32 degrees. For this material placed between 90 and 95 percent of the maximum dry unit weight, the resulting dry unit weight would be approximately 100 pcf. In the stability analyses, the cover materials were conservatively represented by a dry unit weight of 100 pcf, an effective angle of internal friction of 30 degrees, and no cohesion.

Foundation materials. Foundation materials in the site area are primarily terrace deposits consisting of silts, sandy silts, silty clays, sandy gravelly clays, silty sandy clays and clays which overlie shale and sandstone units. A dry unit weight of 110 pcf was used for these materials, due to the higher density and gravel content of these materials relative to the potential cover materials. An angle of internal friction of 30 degrees with no cohesion was used to represent the shear strength of these materials.

Contaminated soils. Contaminated site soils are expected to consist of a mixture of soils, construction debris (such as concrete and structural materials and sediments). This material will be placed with a specified compactive effort to minimize voids, thus a dry unit weight of 120 pcf was used to account for the fill materials and compaction. Shear strength was represented by an effective angle internal friction of 32 degrees with no cohesion.

Synthetic liner. An effective angle of internal friction of 20 degrees was used to represent the soil/synthetic liner interface. This value was based on test data presented in the literature (Strachan and van Zyl, 1988). The synthetic liner was represented in the analyses as a one-foot thick layer with a dry unit weight of 60 pcf, typical of synthetic liner material.

Table C.1 Material Parameters Used in Stability Analyses

Material Type	Dry Unit Weight, γ (pcf)	Angle of Internal Friction, ϕ (degrees)	Cohesion, c (psf)
Cover Soil	110	30	0
Synthetic Liner	60	20	0
Contaminated Site Soils	120	32	0
Foundation Materials	110	30	0

C.4 SEISMIC ANALYSIS AND SEISMICITY

Stability analyses under seismic conditions were conducted as pseudo-static analyses, where a horizontal acceleration or seismic coefficient is applied to each cross-section. This coefficient (0.05 g) was based on a review of regional seismicity data as discussed below.

Analysis approach. If the materials in a structure are saturated and of low density or susceptible to significant loss of shear strength, an evaluation of the potential for liquefaction of these materials is conducted. The structure is then analyzed for slope stability based on a liquefied or reduced shear strength condition. If the materials in the structure are not susceptible to liquefaction or loss of shear strength, an analysis of the structure from seismic-induced accelerations is conducted. This consists of a stability analysis under an equivalent constant acceleration (described in Seed, 1979) or an evaluation of seismic-induced deformations (described in Makdisi and Seed, 1978). The equivalent, constant acceleration used in these analyses is the seismic coefficient, which is a fraction of the maximum seismically-induced acceleration anticipated at the site during the design period.

Seismicity. The site seismicity was reviewed in terms of: (1) general regional data, and (2) site area site-specific data, as discussed below.

Based on general seismicity information, the site is within a region of low seismicity. This region is classified as a Zone 1 area in U.S. Army Corps of Engineers (1982), with a recommended seismic coefficient of 0.025 g (where g is the acceleration of gravity). The region is classified as a Zone 1 area in IBCO (1991), with a recommended seismic coefficient of 0.075 g.

Site area seismicity was reviewed from local publications, an earthquake data search, and local geomorphic structure information. Annual seismology data in Oklahoma is compiled by the Oklahoma Geological Survey (Lawson and Luza, 1983, and Luza and Lawson, 1993). This data shows activity of low magnitude, with epicenters primarily in the central and south-central portion of the state.

A review of recorded or documented seismic activity within a 400-mile radius of the site was conducted from data compiled by the National Earthquake Information Center (NEIC) of the U.S. Geological Survey. The data was compiled from prior to 1811 through May 2000. The results were compared with data published by the Oklahoma Geological Survey from 1900 to 1998 compiled in Lawson and others (1979), Luza and Lawson (1993), and subsequent publications. The largest recorded events from the NEIC data are summarized in Table C.2.

Table C.2 Summary of Largest Events*

Rank	Date	Richter Magnitude	Distance from Site (mi)	(km)	Comments
1	Dec 16, 1811	7.2	263	424	New Madrid MO, a.m.
2	Dec 16, 1811	7.0	263	424	New Madrid MO, p.m.
3	Jan 5, 1843	6.0	257	414	New Madrid MO
4	Oct 22, 1882	5.5	116	186	South-central OK
5	Apr 5, 1867	5.1	266	429	Southern IL
6	Oct 21, 1965	5.1	156	251	Central OK
7	Apr 9, 1952	5.0	263	424	Northeast TX

* Events of Richter Magnitude 5.0 or greater, within 400-mile radius of site.

Not shown in Table C.2 are the 61 events between magnitude 4.0 and 5.0. All but three of these events were greater than 140 miles (224 km) from the site. The closest events greater than magnitude 2.0 are shown in Table C.3 below, arranged by proximity to the site.

Table C.3 Summary of Closest Events*

Rank	Date	Richter Magnitude	Distance from Site	
			(mi)	(km)
1	Jun 20, 1926	4.2	12	19
2	Mar 31, 1975	2.9	14	22
3	Oct 8, 1915	3.4	22	36
4	Mar 1, 1971	2.5	29	47
5	Mar 16. 1976	2.7	30	48
6	May 18, 1962	2.6	33	53
7	Nov 18, 1973	3.1	40	65
8	Dec 25, 1973	2.8	42	68
9	Apr 27, 1961	4.1	43	69
10	Mar 13, 1971	2.7	45	73
11	Jan 11, 1961	3.8	48	77
12	Dec 16, 1987	2.1	49	79
13	May 25, 1986	2.2	51	82
14	Mar 11, 1993	2.7	52	84
15	Jun 5, 1988	2.1	52	84
16	Nov 22, 1980	2.5	52	84
17	Jan 6, 1984	2.6	53	85
18	Sep 23, 1985	2.9	53	86
19	Jan 6, 1984	2.5	53	86
20	Dec 19, 1976	2.9	54	87
21	Sep 16, 1990	2.5	55	88
22	Mar 5, 1978	2.9	55	89
23	Sep 1, 1972	2.8	56	90
24	Sep 23, 1985	2.9	60	97

* Events within 100-km (62-mile) radius of site with Richter Magnitude greater than 2.0

The data summarized in the tables above show more events from recent years. This reflects the fact that seismographs that directly measure ground movement (to calculate the release of energy by the Richter Magnitude scale) came into use in the latter part of the twentieth century. Earlier seismic events (such as those in the nineteenth century) were based on observed damage and correlated with the Modified Mercalli earthquake intensity scale, then converted to Richter Magnitude. It should be noted that seismic events of Richter Magnitude 3.0 or less, which correlate roughly with Modified Mercalli intensity III or less, are generally not noticeable.

Tectonic features. The locations of seismic activity (from Table C.2) are concentrated in southeast Missouri and south-central Oklahoma. This data shows that the major observed seismic event in the site area within the past nearly 200 years was the New Madrid earthquake of 1811 (in southeast Missouri). Observed events of magnitude 6.0 or greater have been from epicenter locations over 250 miles from the site. Measured events within 62 miles (100 km) of the site are of low magnitude. The only event larger than magnitude 4.0 was observed in 1926 (estimated to be magnitude 4.2). Only five events were observed or measured above magnitude 3.0.

From the geologic review in the SCR (SFC, 1998), the region is "considered to be one of minor seismic risk." The facility lies on the southwest flank of the Ozark Uplift, a major but stable structural feature in northeast Oklahoma.

The SCR also describes structural features in the site area. The Carlile School Fault (CSF), a normal fault approximately 5,000 feet from the site, is described as an erosional ridge, not a tectonic ridge, since no fault scarps are present at the surface. The CSF is less than one mile long and has no surface evidence that it connects with any other faults. The Marble City Fault (MCF) is in the area of the Mulberry Fault, one of the primary structural features identified by the Oklahoma Geological Survey. Both structures were developed in early Pennsylvanian time (over 300 million years ago). The SCR states that the region "has been structurally stable since that time." NRC (1998) has determined that the CSF, MCF, and nearby South Fault of the Warner Uplift are not capable faults.

The SCR mentions that the most recent documented subsurface movement has occurred within the past 2,000 years along the Meers Fault System in southwest Oklahoma (Ramelli and others, 1987). This fault system is consistent with measured seismic events, and is approximately 200 miles from the site. Measured seismic activity in Oklahoma is concentrated in south-central Oklahoma corresponding with the Meers Fault System and the central Oklahoma Fault Zone, over 150 miles from the site.

Seismic acceleration. Generalized maps in Algermissen and others (1982) show that the maximum expected seismic ground acceleration at the site is less than 0.05 g, for a recurrence interval of 250 years. These ground accelerations are confirmed by determining capable (or potentially active) faults in the site area, estimating the maximum credible seismic event along these faults, then predicting ground acceleration at the site using attenuation relationships. From the review in NRC (1998), the known faults in the immediate site area are not capable faults. The nearest capable faults are along the Meers Fault System or the New Madrid area of southeast Missouri.

From attenuation relationships presented in Trifunac and Brady (1976) and Schnabel and Seed (1973), the largest observed seismic event in the area (the 1811 New Madrid event) would produce an attenuated peak acceleration at the site of less than 0.05 g. Based on a maximum credible earthquake on of the Meers Fault System, the attenuated peak acceleration at the site would be less than 0.05 g.

Seismic coefficient. For materials that do not liquefy or lose shear strength with seismic shaking, seismic slope stability is analyzed by a pseudo-static approach. This consists of application of an equivalent horizontal acceleration or seismic coefficient to the structure being analyzed (described in Seed, 1979). The seismic coefficient represents an inertial force due to strong ground motions during the design earthquake, and is represented as a fraction of the maximum expected seismic acceleration at the site (typically at the base of the structure). The coefficient for calculating seismic coefficient is typically 0.5 to 0.7 of the maximum expected acceleration. The 0.5 value typically represents operational conditions (a relatively short period of time), and the 0.7 value represents post-reclamation conditions (a relatively long period of time). This strategy has been adopted in review of uranium tailings facility design and documented in DOE (1989).

From the data summarized above, the maximum anticipated acceleration at the site is less than 0.05 g. Based on a maximum anticipated seismic acceleration of 0.05 g, the corresponding seismic coefficient would be 0.03 to 0.04. A seismic coefficient of 0.05 was used in the pseudo-static analyses to conservatively represent seismic conditions for stability analyses. A seismic coefficient of 0.05 is consistent with the generalized values for the area presented in U.S. Army Corps of Engineers (1982) and ICBO (1991). This seismic coefficient value is sufficiently low that a seismic deformation analysis (Makdisi and Seed, 1978) would not be necessary. For comparison, seismic coefficients of 0.10 to 0.15 are recommended in Seed (1979) for seismically active areas of California, with associated deformation analyses.

C.5 DISCUSSION OF ANALYSIS RESULTS

The results of stability analyses for each cross-section are presented in Table C.4. These values represent the lowest calculated factor of safety from a number of individual failure surfaces. The lowest factor of safety was found in the block specified wedge failure surfaces. All calculated factors of safety were significantly above the NRC recommended values of 1.5 for static and 1.1 for pseudo-static analysis. SLOPE/W input and output for each scenario are presented in Attachment C.1.

Table C.4 Stability Analysis Results

Cross-Section	Condition	Circular Failure Surface	Block Specified Wedge Failure Surface	Fully Specified Wedge Failure Surface
CS-1	Static	2.6	2.2	2.3
	Pseudo-static	2.0	1.8	1.8
CS-2	Static	2.5	2.3	2.3
	Pseudo-static	2.0	1.8	1.8

C.8 REFERENCES

Algermissen, S.T., D.M. Perkins, P.C. Thenhaus, S.L. Hanson, and B.L. Bender, 1982. "Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States," *USGS Open-File Report 82-1033.*

Earth Science Consultants, Inc. (ESCI), 1998. "Calculation Brief, RADON Analysis, Case I and Case II Scenarios, Sequoyah Fuels Corporation, Gore, Oklahoma, Project No. 4881-04." Prepared for SFC, December 9.

GEO-SLOPE International Ltd, 2001. *Slope/W, Version 5, User's Guide*, Calgary, Alberta.

Holtz, Robert D. and William D. Kovacs, 1981. *Introduction to Geotechnical Engineering*, Prentice-Hall, Inc., Englewood Cliffs, NJ.

International Commission on Large Dams (ICOLD), Committee on Seismic Aspects of Dam Design, 1989. "Selecting Seismic Parameters for Large Dams." *Bulletin 72*, ICOLD, Paris.

International Conference of Building Officials (ICBO), 1991. *Uniform Building Code*, 1991 Edition.

Lambe, T. William and Robert V. Whitman, 1969. *Soil Mechanics*, Massachusetts Institute of Technology, John Wiley & Sons, NY.

Lawson, J.E., and K.V. Luza, 1983. "Oklahoma Earthquakes 1983." *Oklahoma Geology Notes*, Oklahoma Geological Survey, University of Oklahoma, pp. 32-42.

Lawson, J.E., K.V. Luza, R.L. DuBois, and P.H. Foster, 1979. "Inventory, Detection, and Catalog of Oklahoma Earthquakes." *Oklahoma Geological Survey.* University of Oklahoma.

Luza, K.V. and J.E. Lawson, 1993. "Oklahoma Seismic Network." *NUREG/CR-6034*, U.S. Nuclear Regulatory Commission, July.

Makdisi, F.I. and H.B. Seed, 1978. "Simplified Procedures for Estimating Dam and Embankment Earthquake-Induced Deformations." *Journal of the Geotechnical Engineering Division*, ASCE, Vol. GT7, pp. 849-867, April.

Ramelli, A.R., D.B. Slemmons, and S.J. Brocoum, 1987. "The Meers Fault: Tectonic Activity in Southwestern Oklahoma." *NUREG/CR-4582*, U.S. Nuclear Regulatory Commission, March.

Schnabel, P.B. and H.B. Seed, 1973. "Acceleration in Rock for Earthquakes in the Western United States." *Bulletin of the Seismological Society of America*, vol. 63, no. 2, pp. 501-516. April.

Seed, H.B., 1979. "Considerations in the Earthquake-Resistant Design of Earth and Rockfill Dams," *Geotechnique*, Vol. 29, No. 3, pp 215-263.

Sequoyah Fuels Corporation (SFC), 1998. "Site Characterization Report." Prepared December 15.

Trifunac, M.D., and A.G. Brady, 1976. "Correlations of Peak Acceleration, Velocity, and Displacement with Earthquake Magnitude, Distance, and Site Conditions." *Earthquake Engineering and Structural Dynamics*, vol. 4, pp. 455-471.

U.S. Army Corps of Engineers (COE), 1982. "Engineering and Design Stability for Earth and Rockfill Dams," *EM 1110-2-1902.*

U.S. Department of Energy (DOE), 1989. "Technical Approach Document: Revision II, Uranium Mill Tailings Remedial Action Project," U.S. Department of Energy, Washington D.C.

U.S. Nuclear Regulatory Commission (NRC), 2000. "Standard Review Plan for the Review of a Reclamation Plan for the Mill Tailings Sites Under Title II of the Uranium Mill Tailings Radiation Control Act." *NUREG-1620.* Division of Waste Management, May.

U.S. Nuclear Regulatory Commission (NRC), 1998. "Sequoyah Fuels Corporation (SFC) Site Evaluation of Faults and Faulting: Input to Safety Evaluation Report." Note to James Shepherd, Sequoyah Fuels Corporation, from Philip Justus, NRC, December 3.

Strachan, C., and D. van Zyl, 1988. "Leach Pads and Liners," *In Introduction to Evaluation, Design and Operation of Precious Metal Heap Leaching Projects*, Society of Mining Engineers, Littleton, CO.

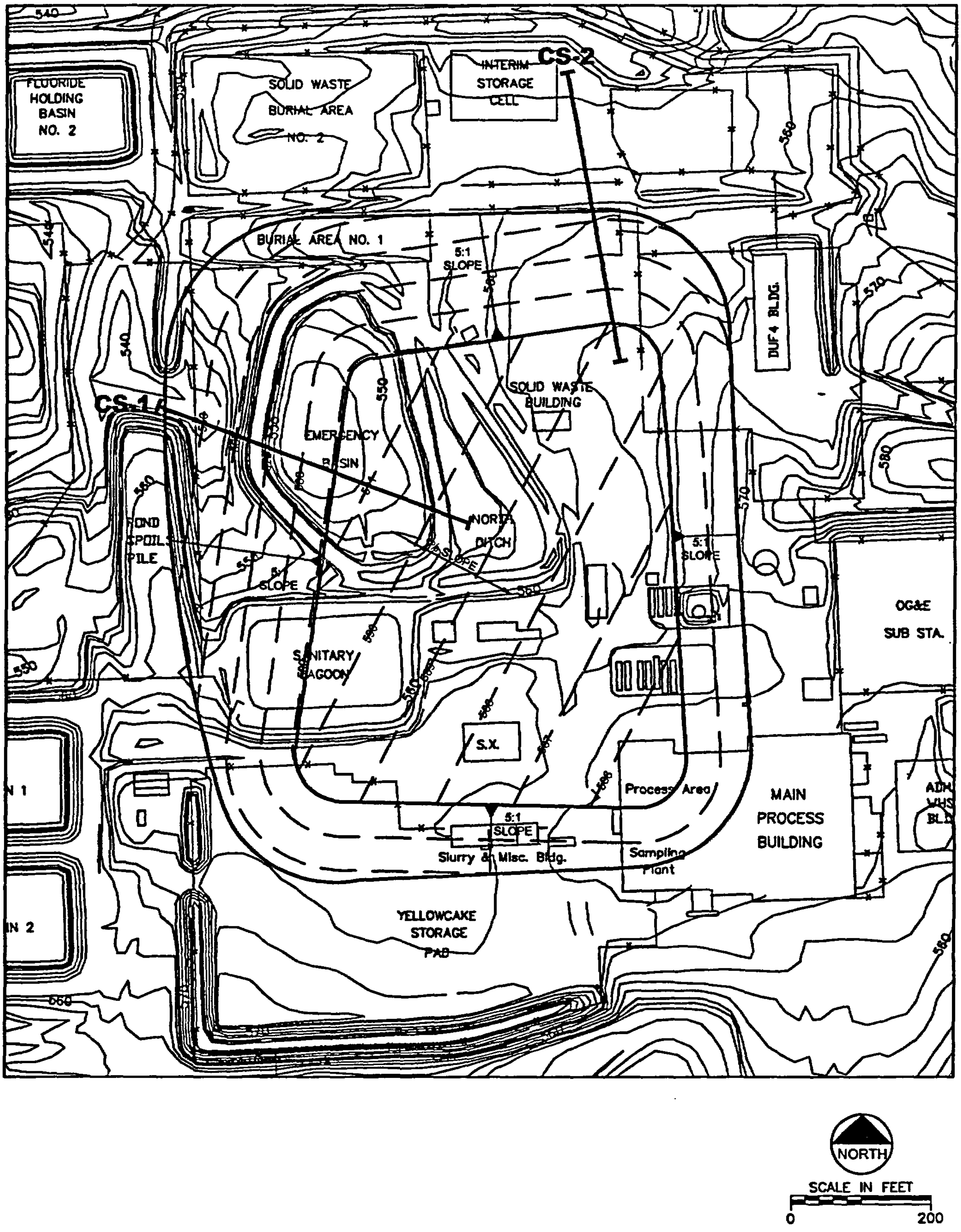

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FIGURE C.1
CRITICAL CROSS-SECTION LOCATIONS

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Project:	100734
File:	XSEC-LOC-1.DWG

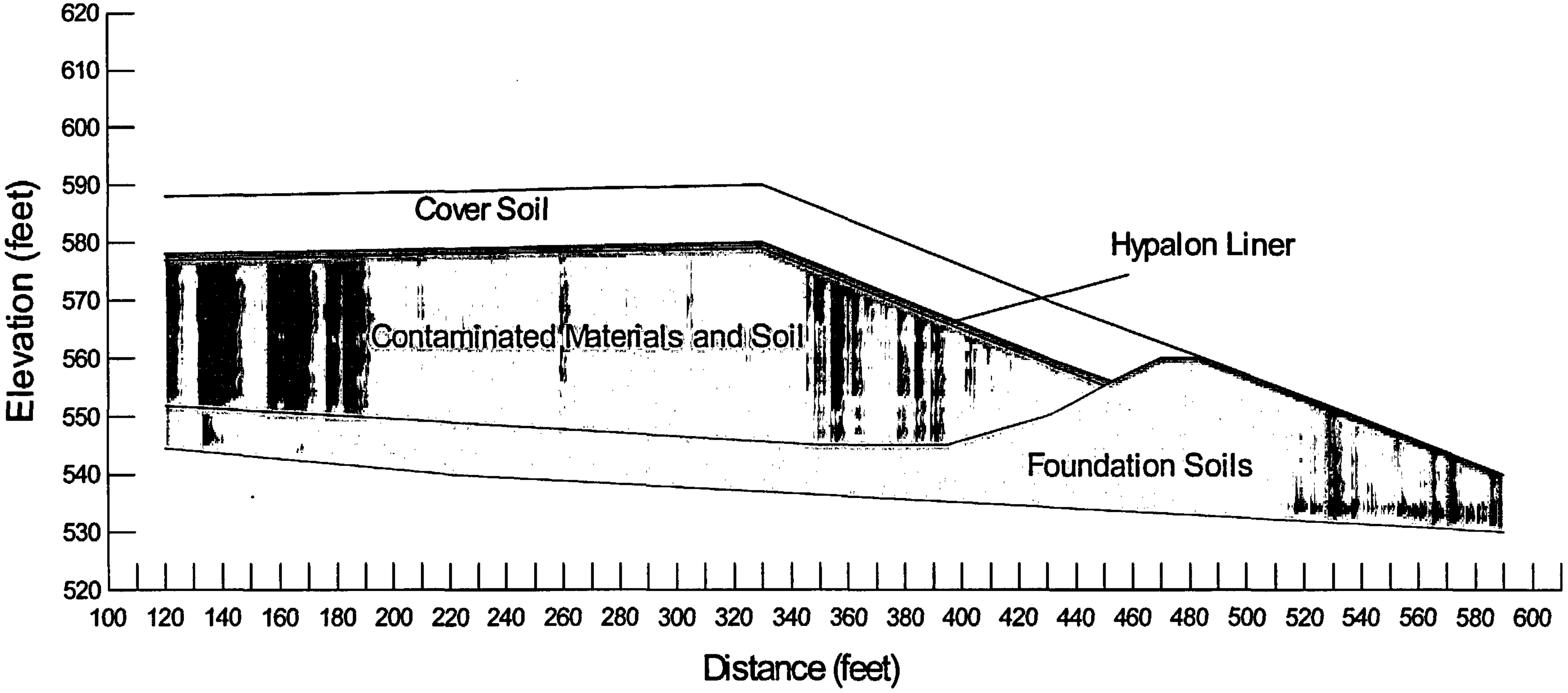

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FIGURE C.2
Critical Cross-Section 1 (CS-1) Geometry

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Project:	P:/100734/
File:	stability/cs-1.doc

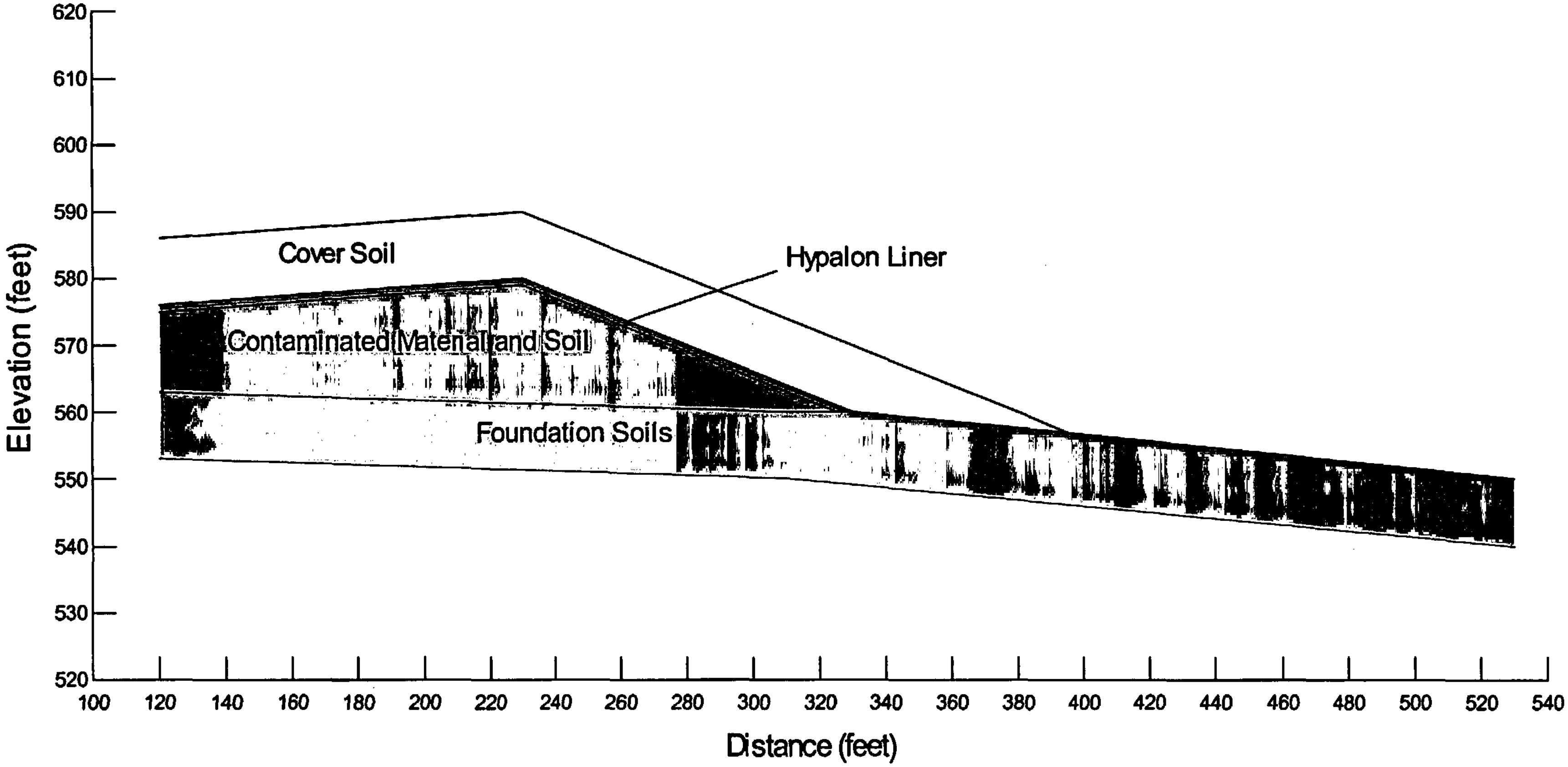

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FIGURE C.3
Critical Cross-Section 2 (CS-2) Geometry

Date:	December 2002
Project:	P:/100734/
File:	stability/figc3.doc

ATTACHMENT C1

SLOPE/W INPUT AND OUTPUT

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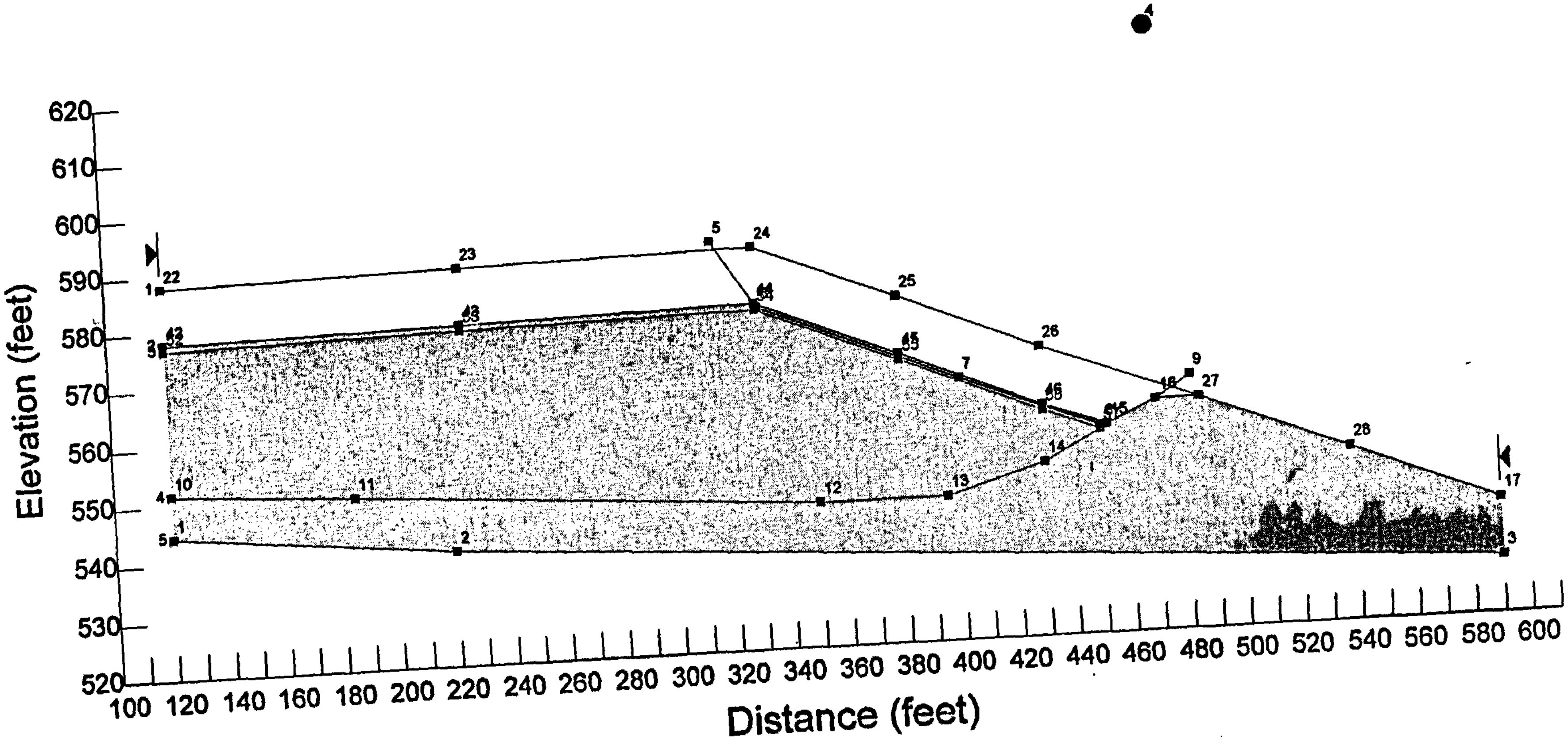
Last Saved Date: 9/24/02
Analysis Method: Spencer
Slip Surface Option: Fully Specified



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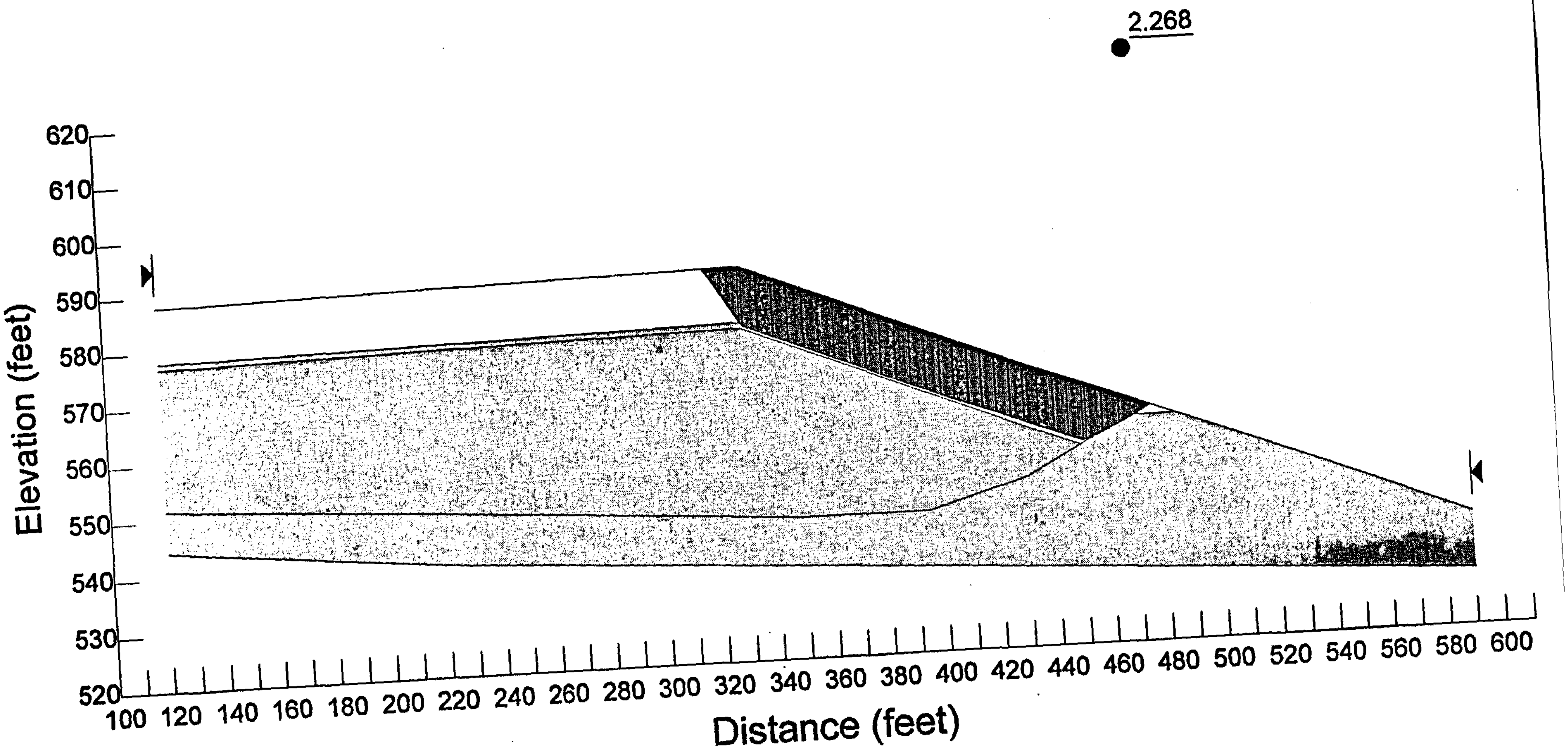

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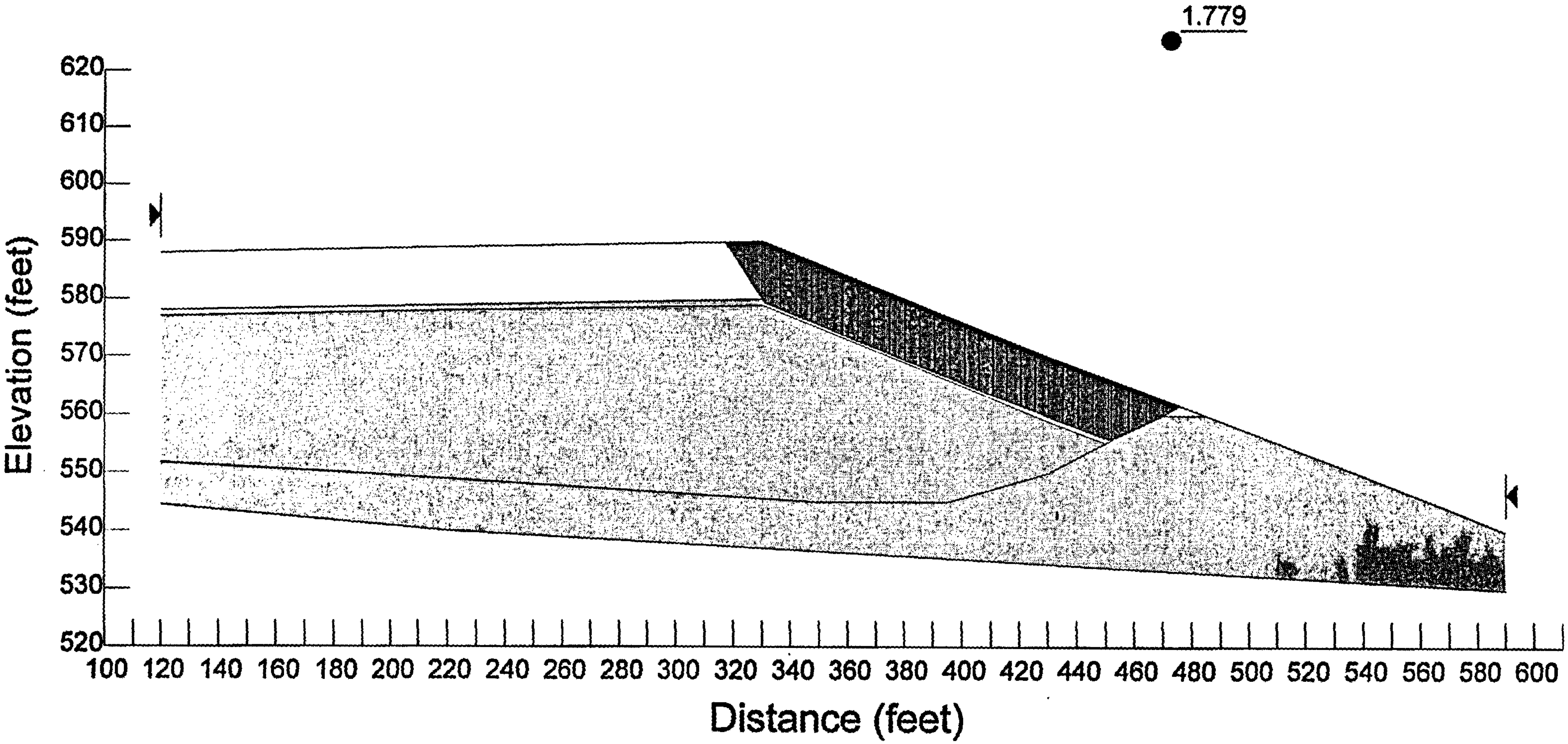

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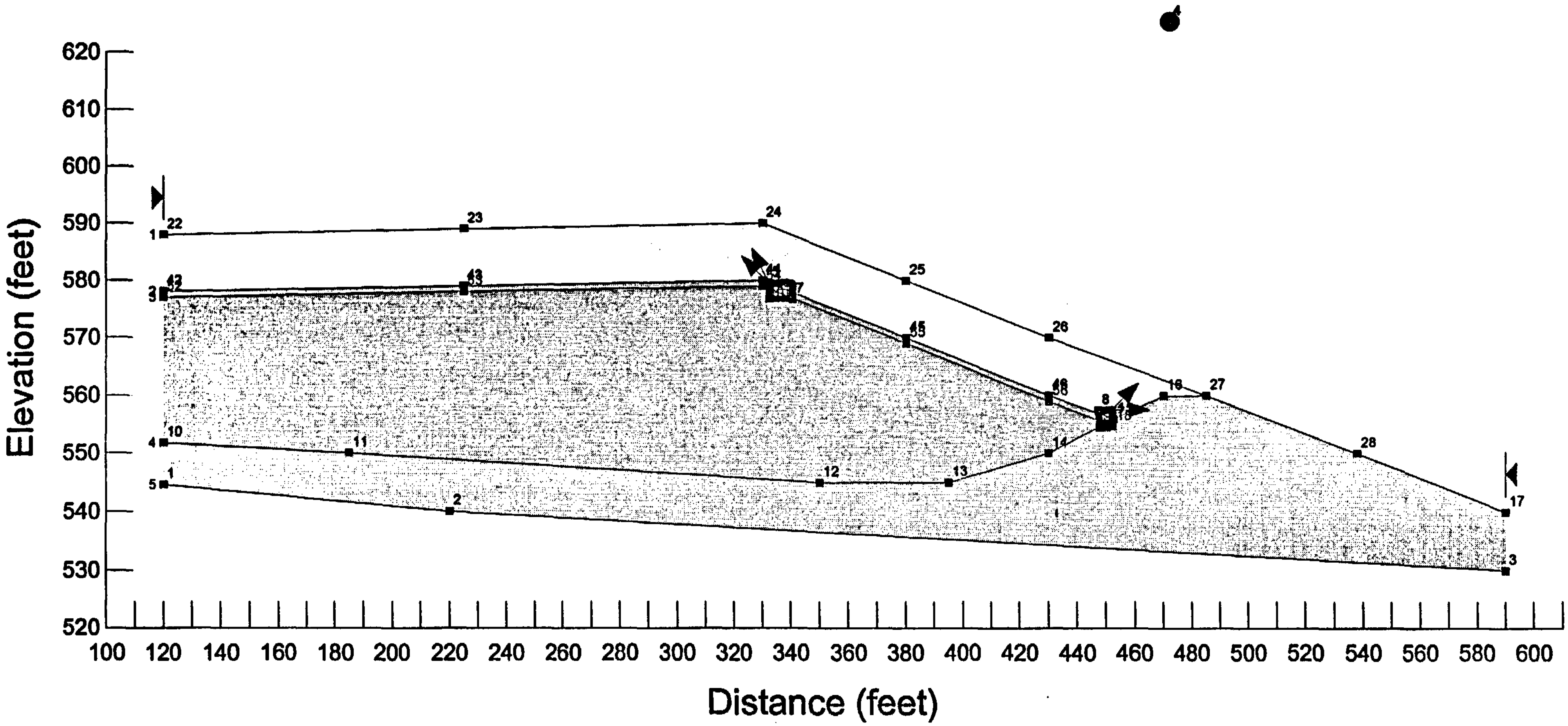

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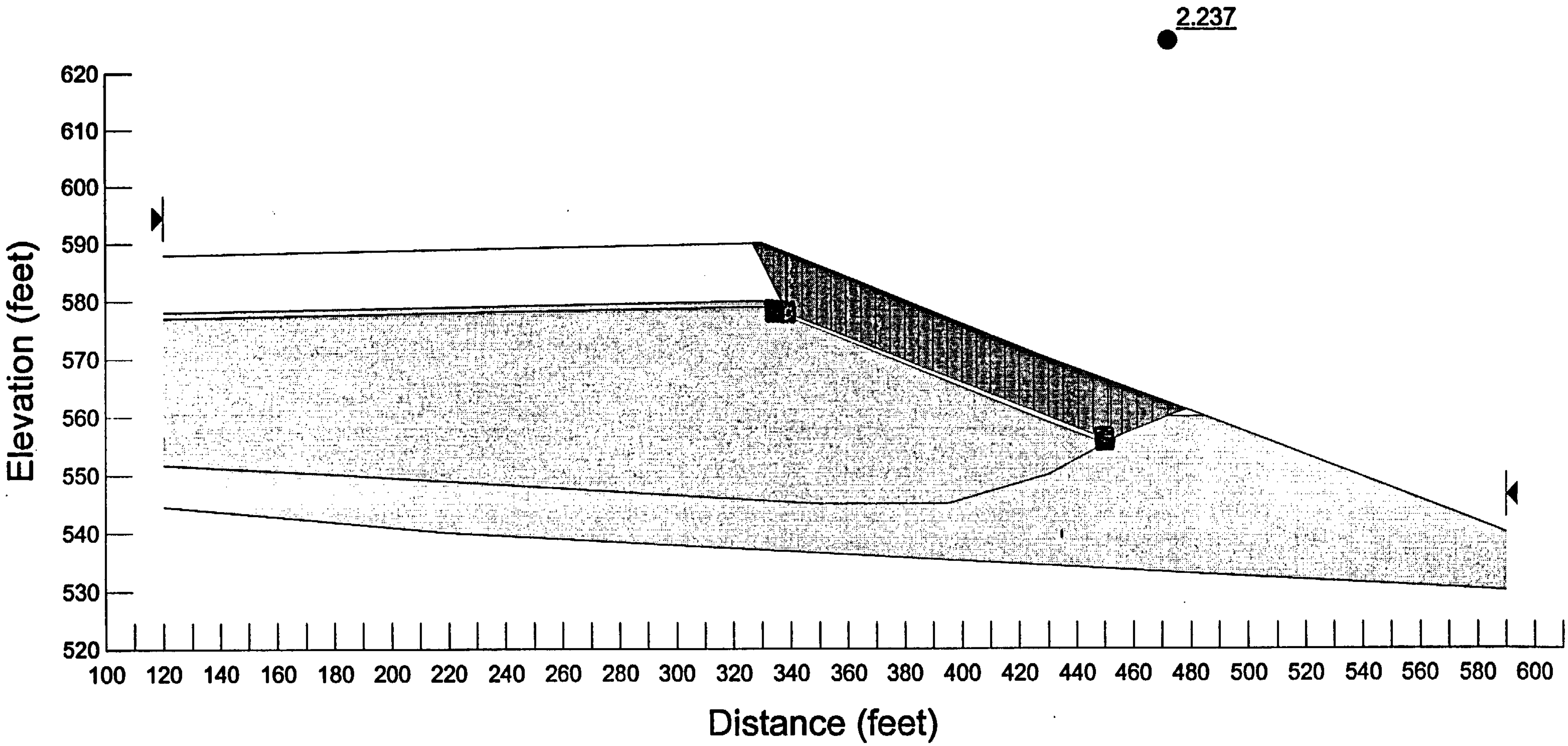

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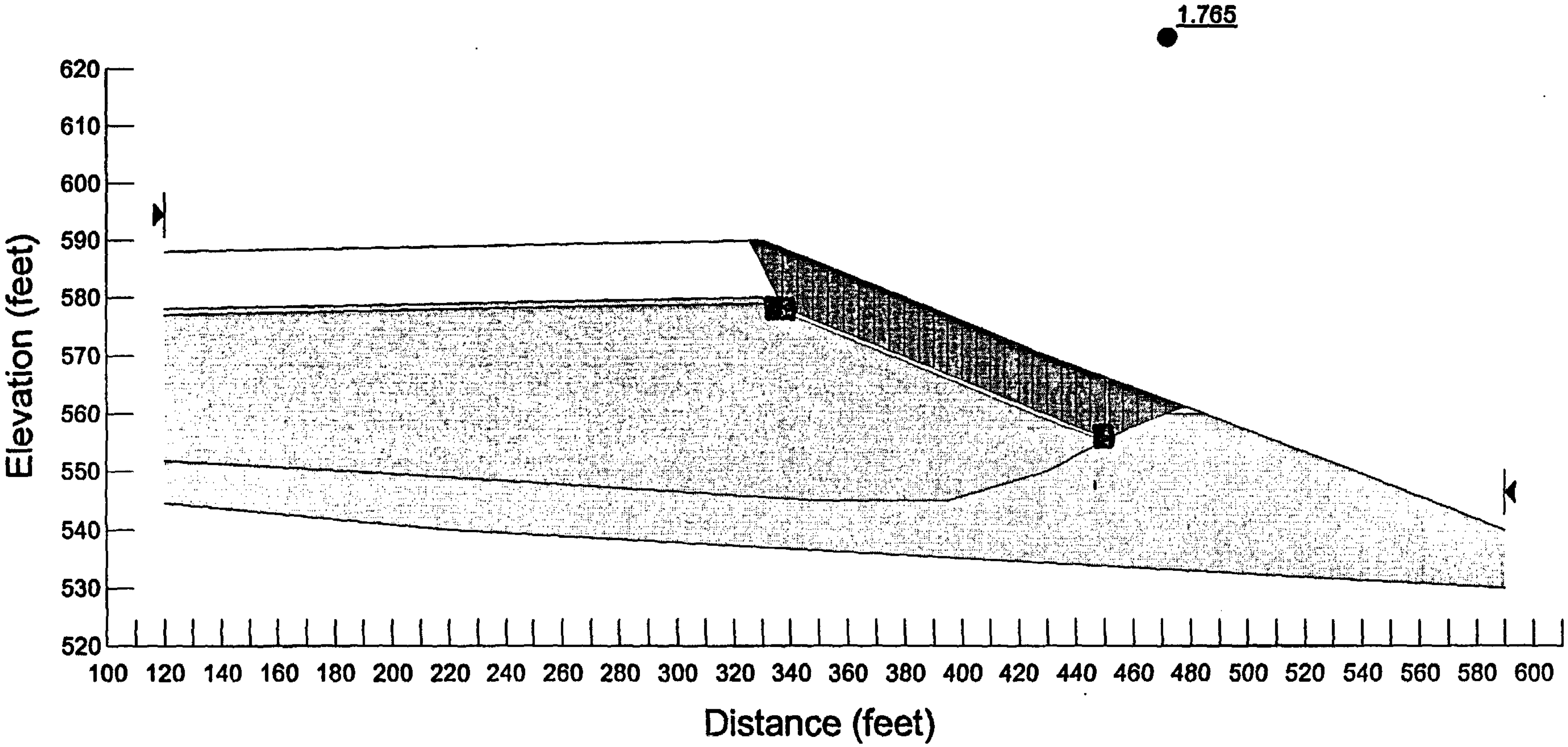

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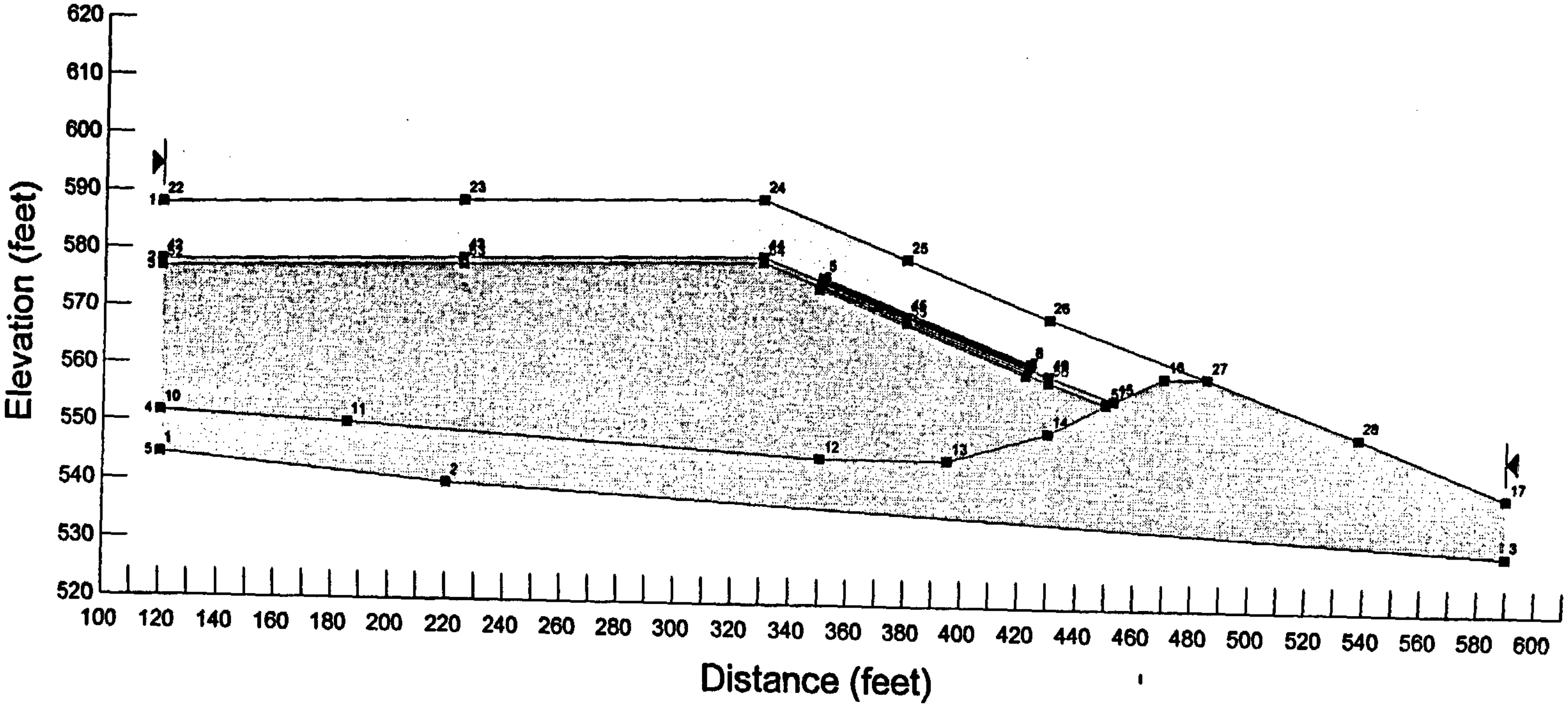

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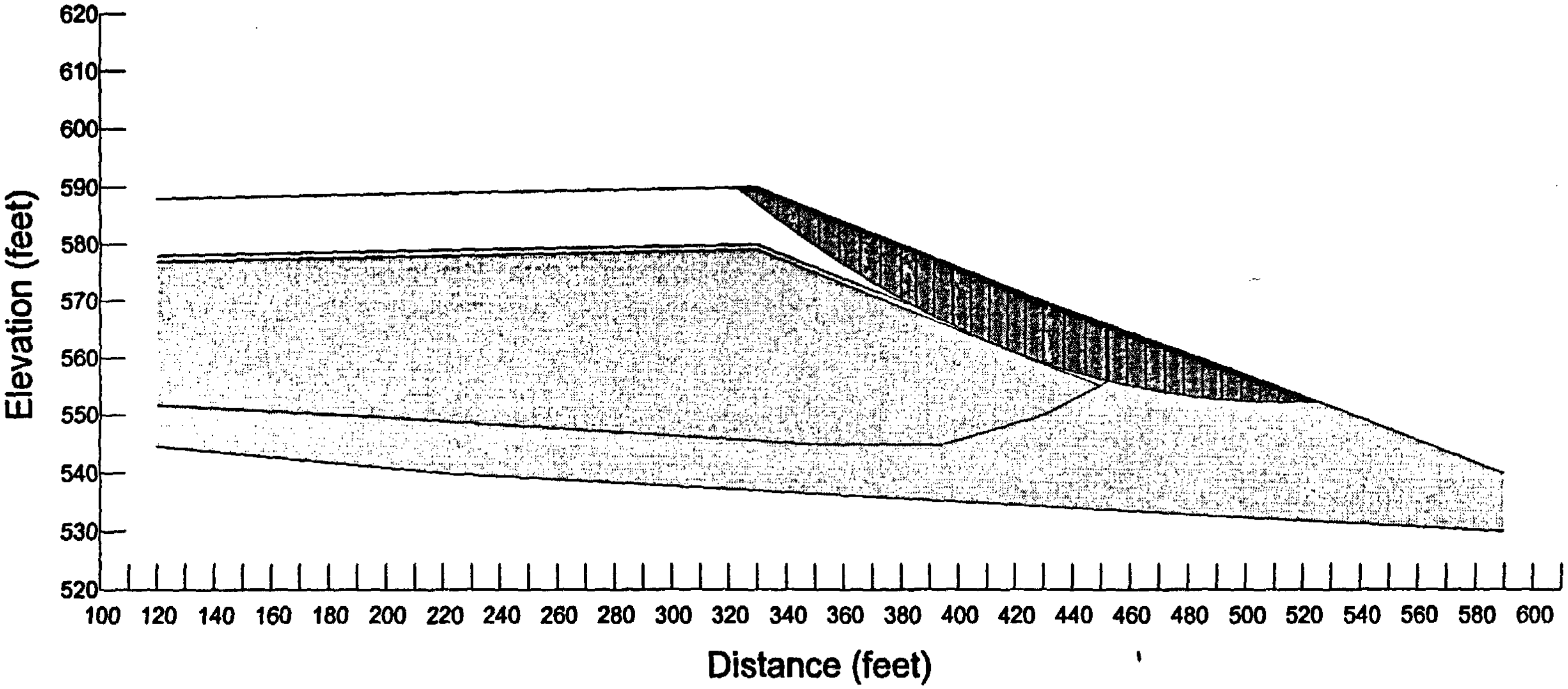

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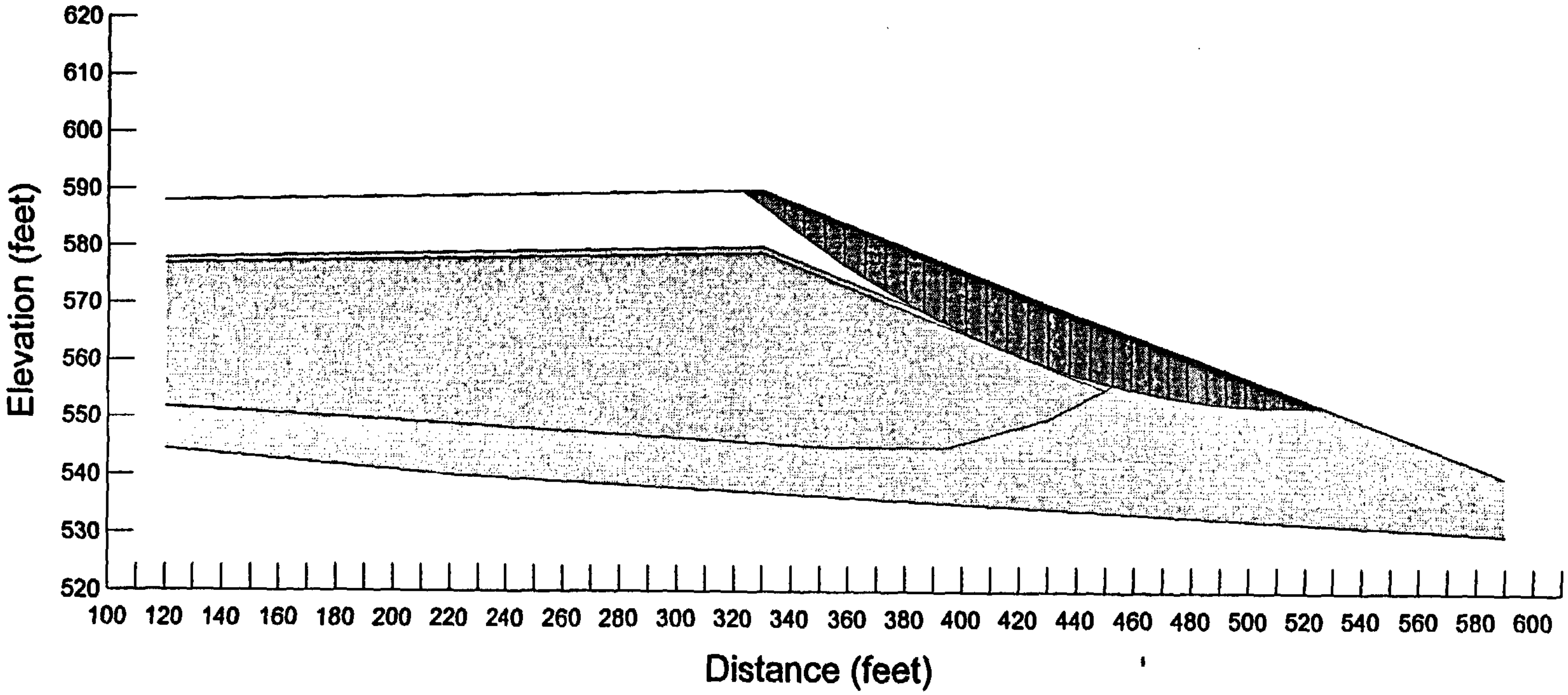

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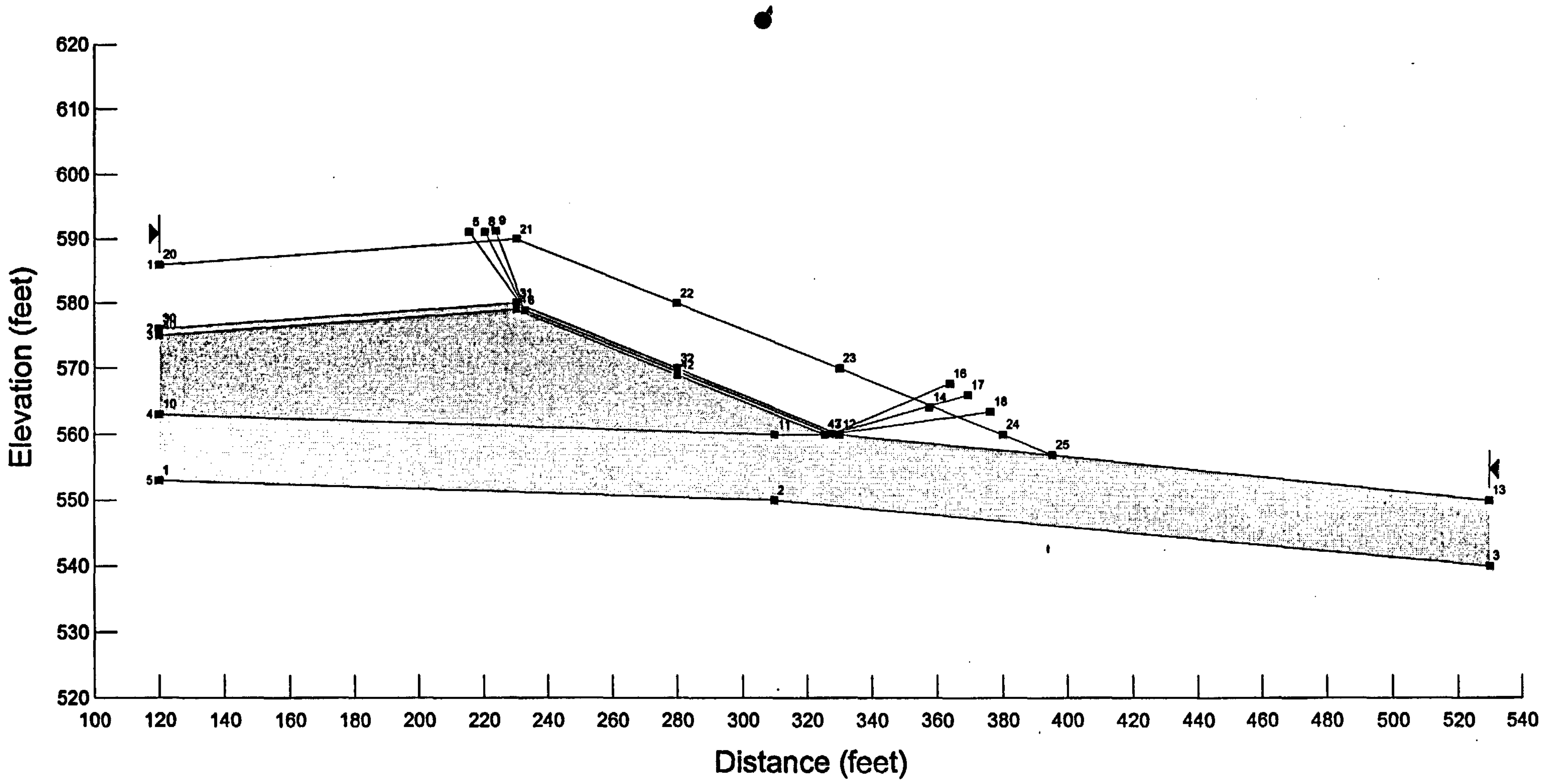

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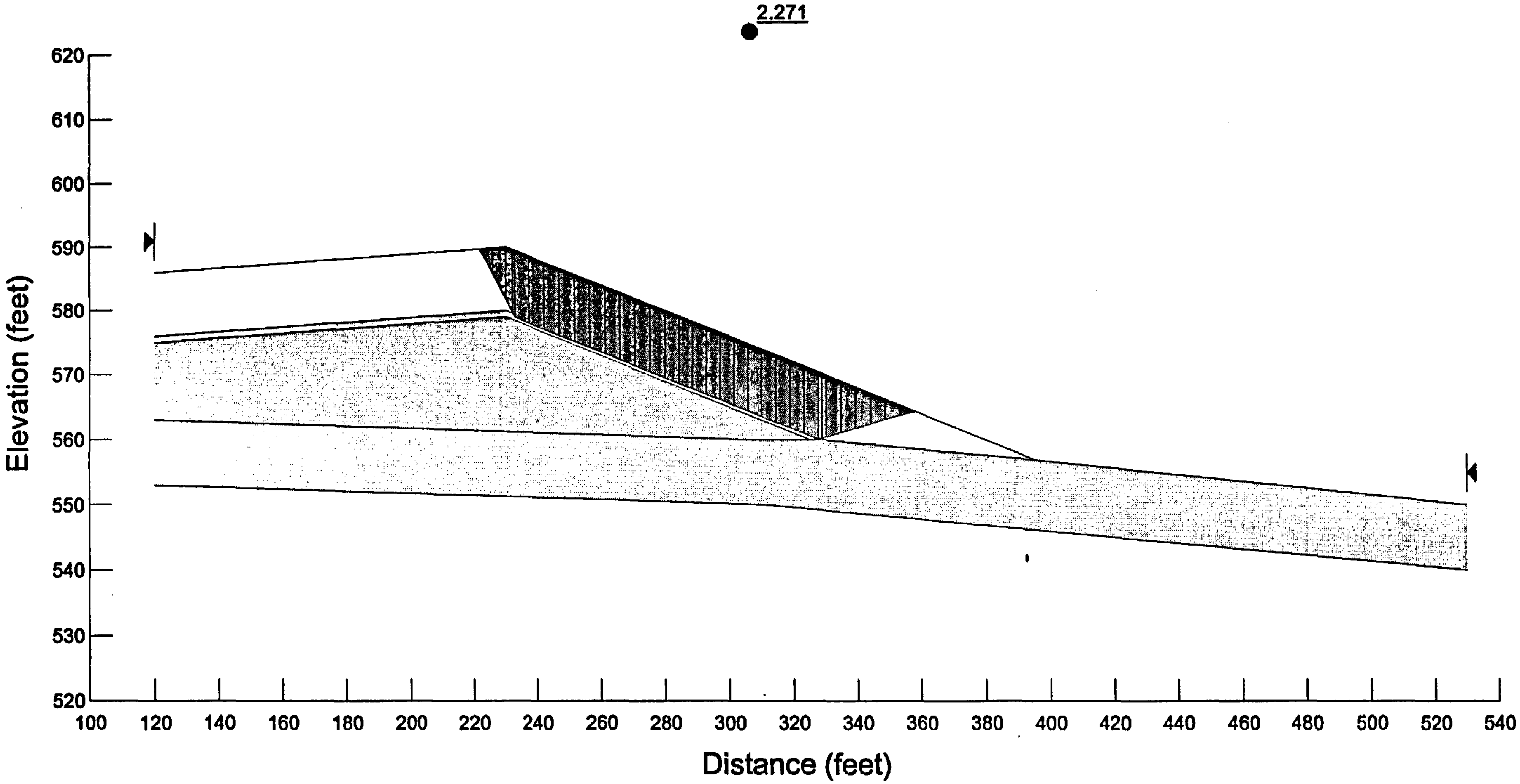

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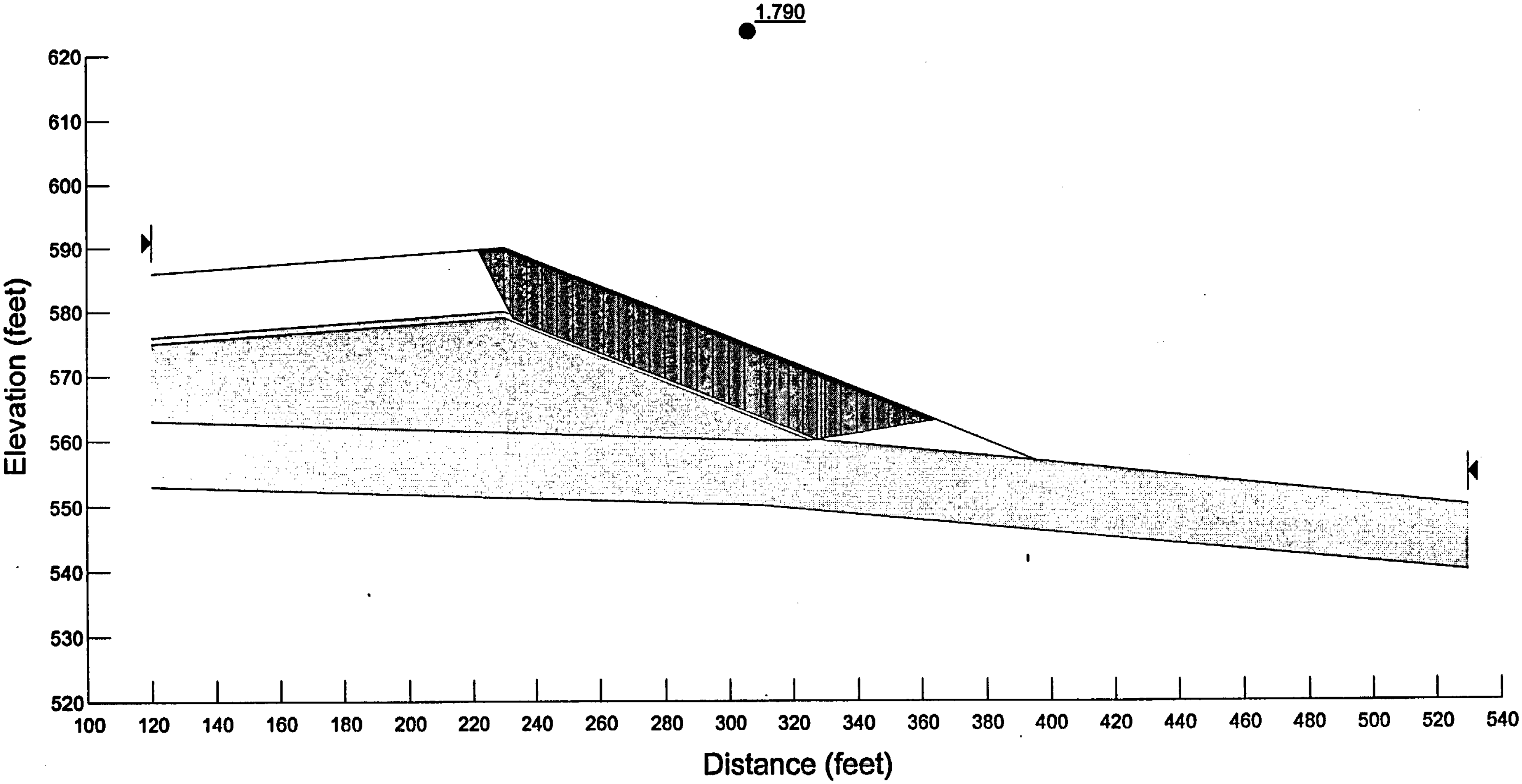

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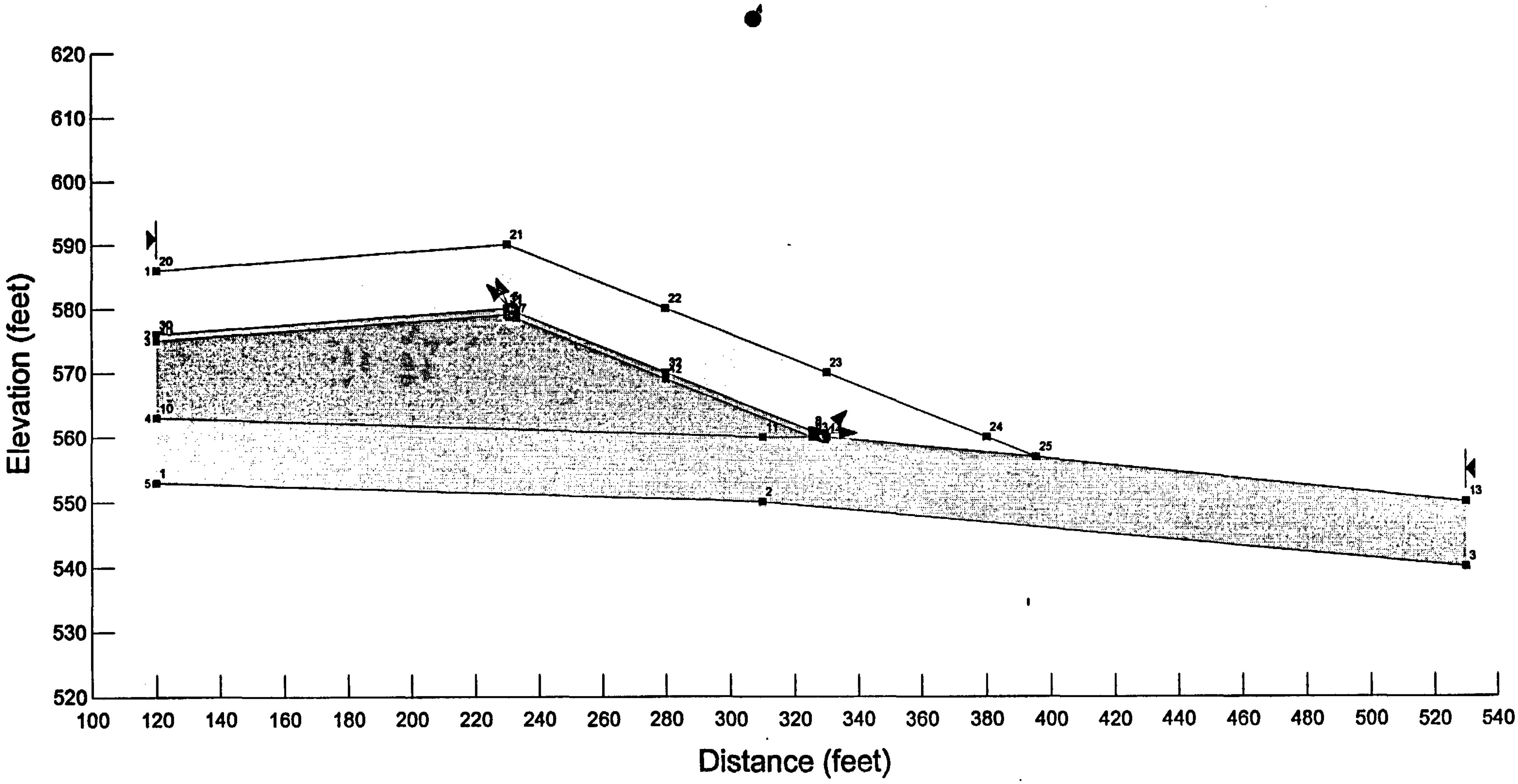

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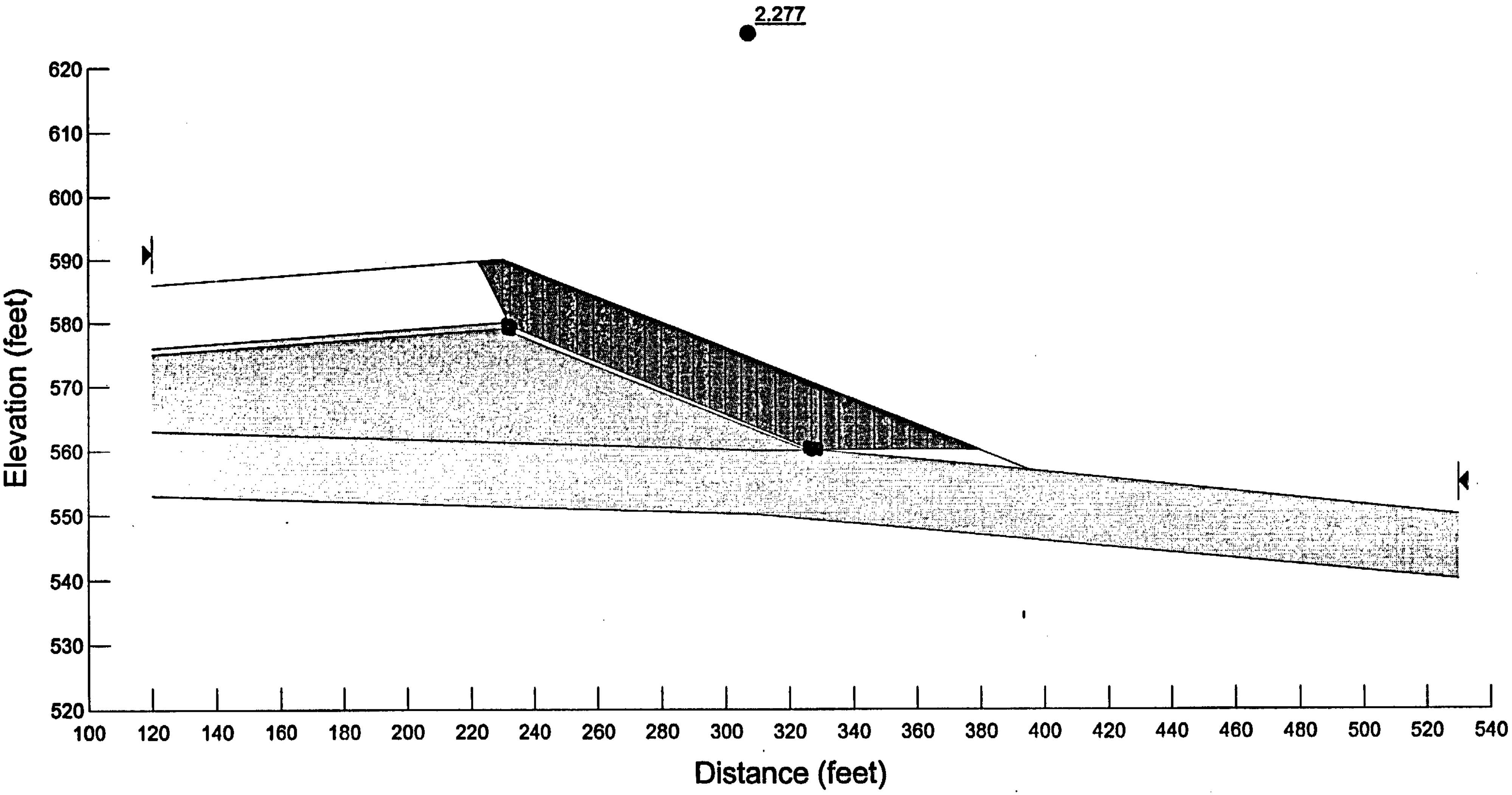

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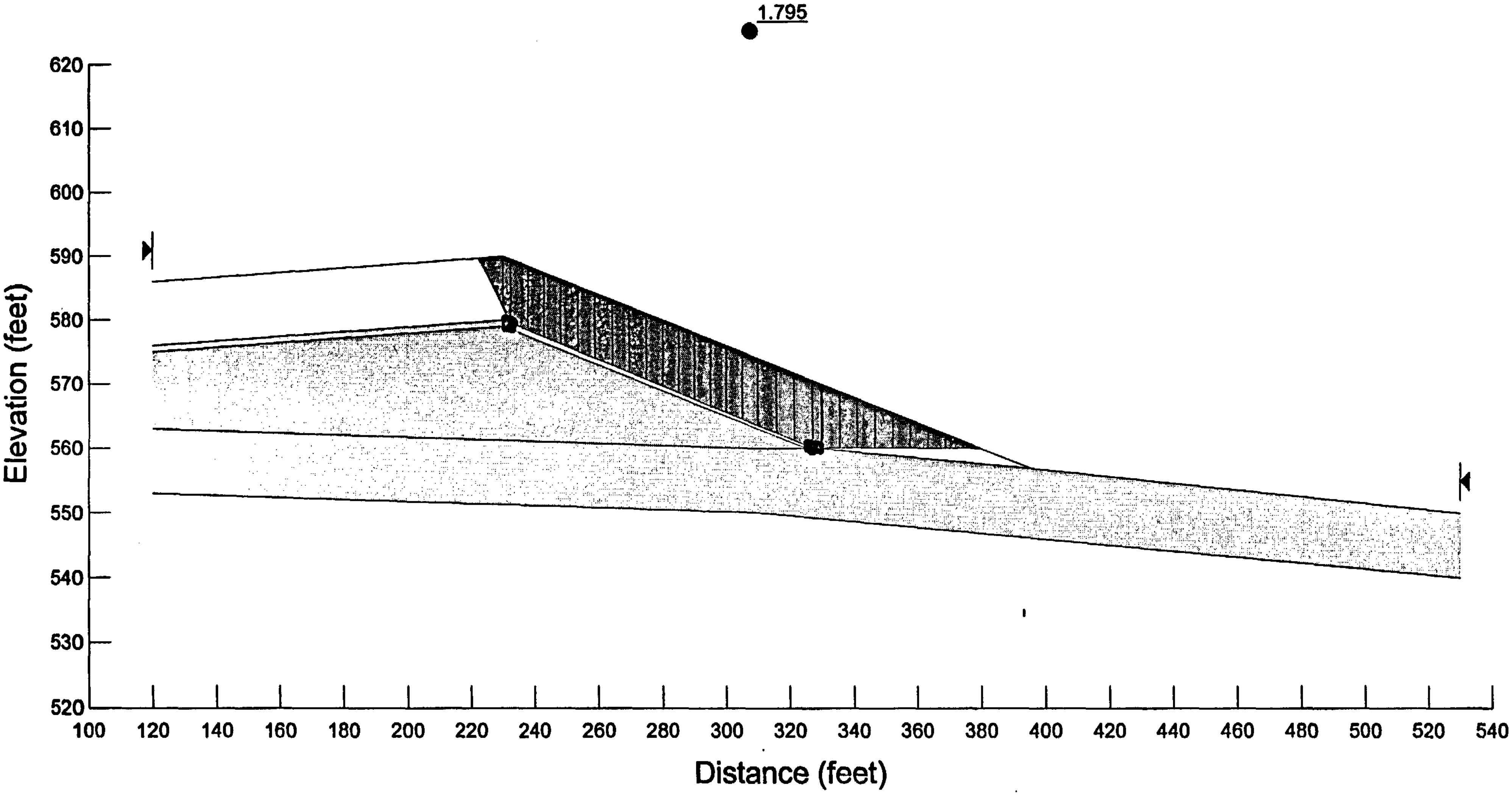

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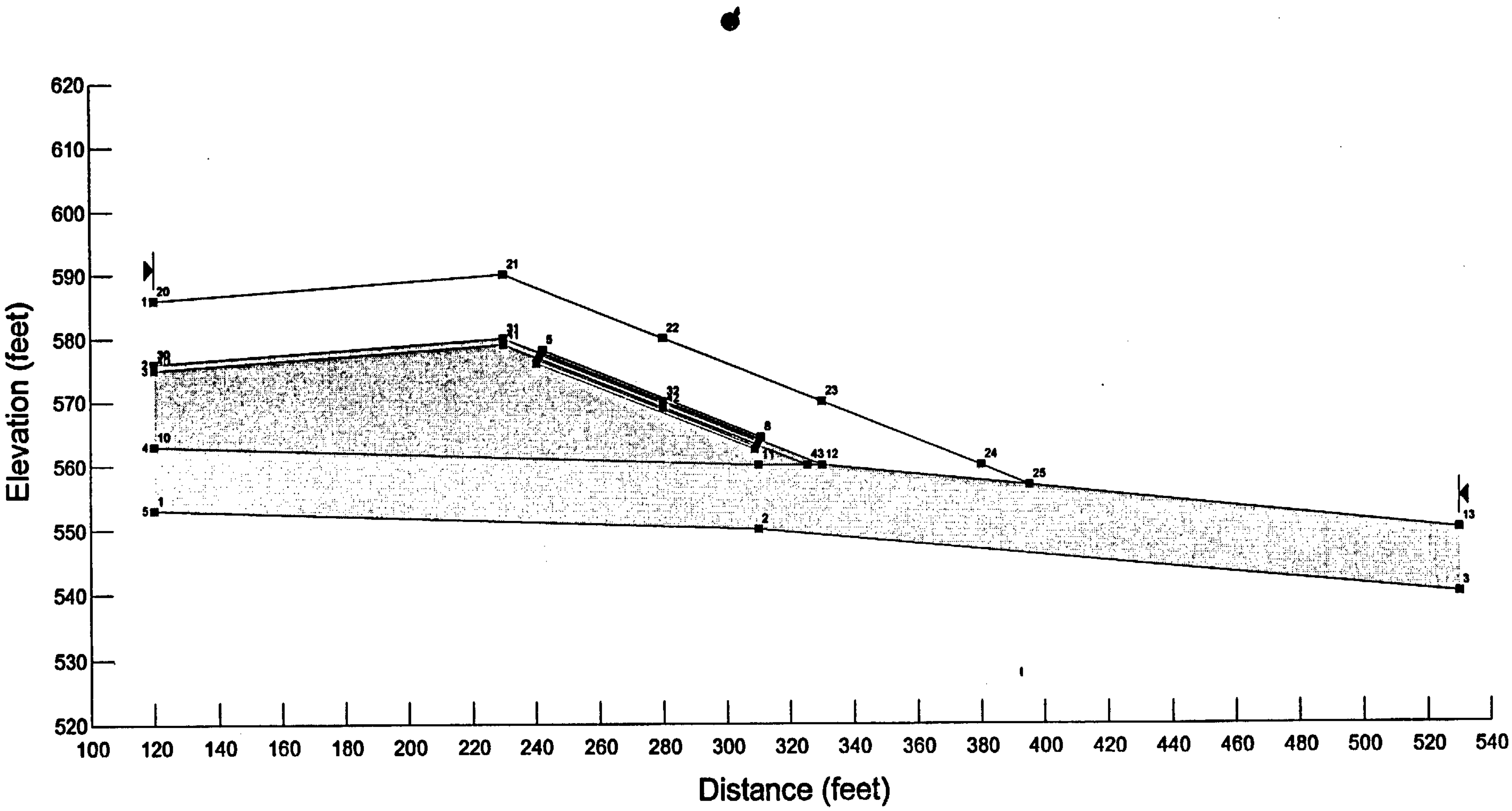

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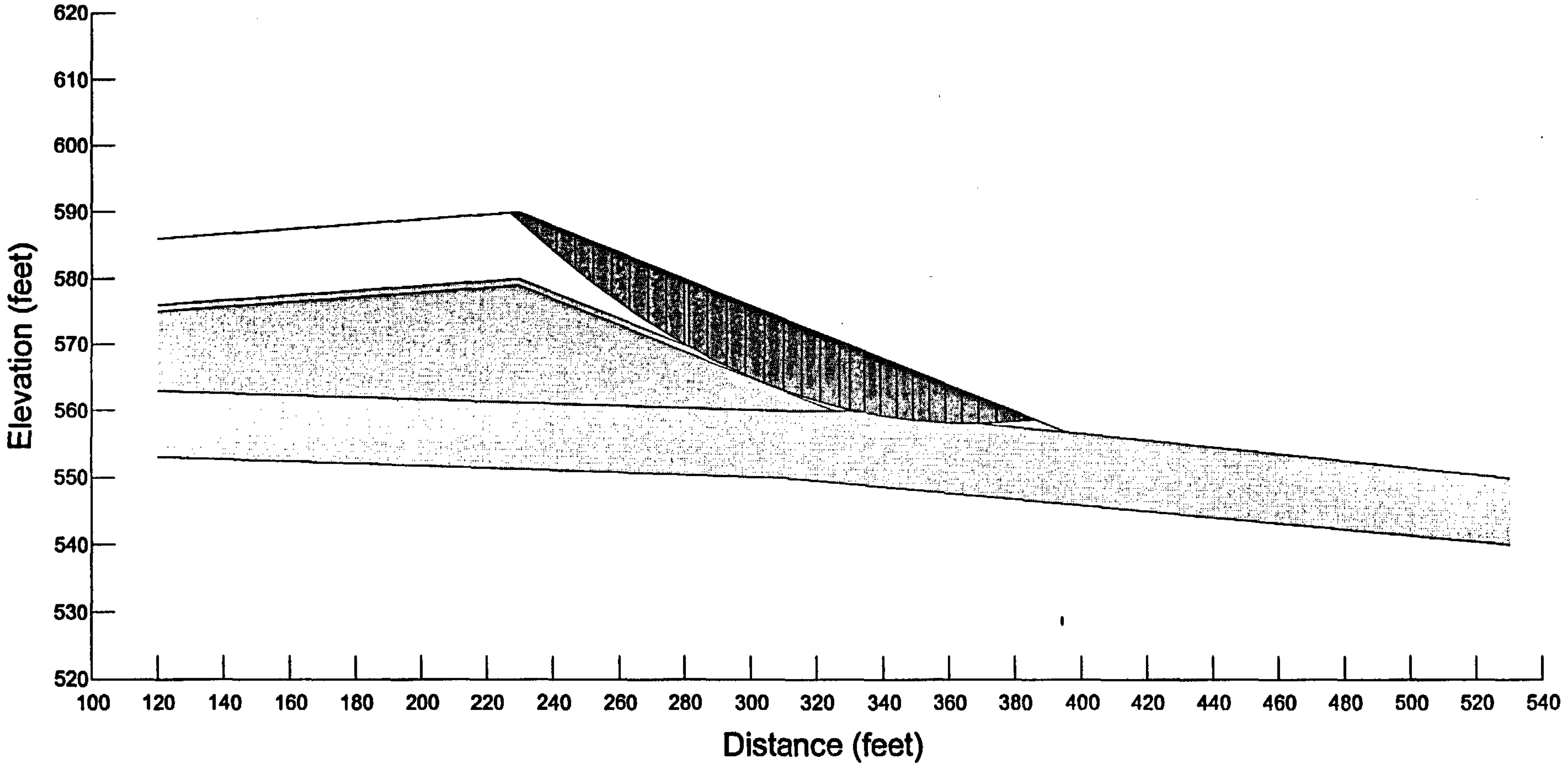

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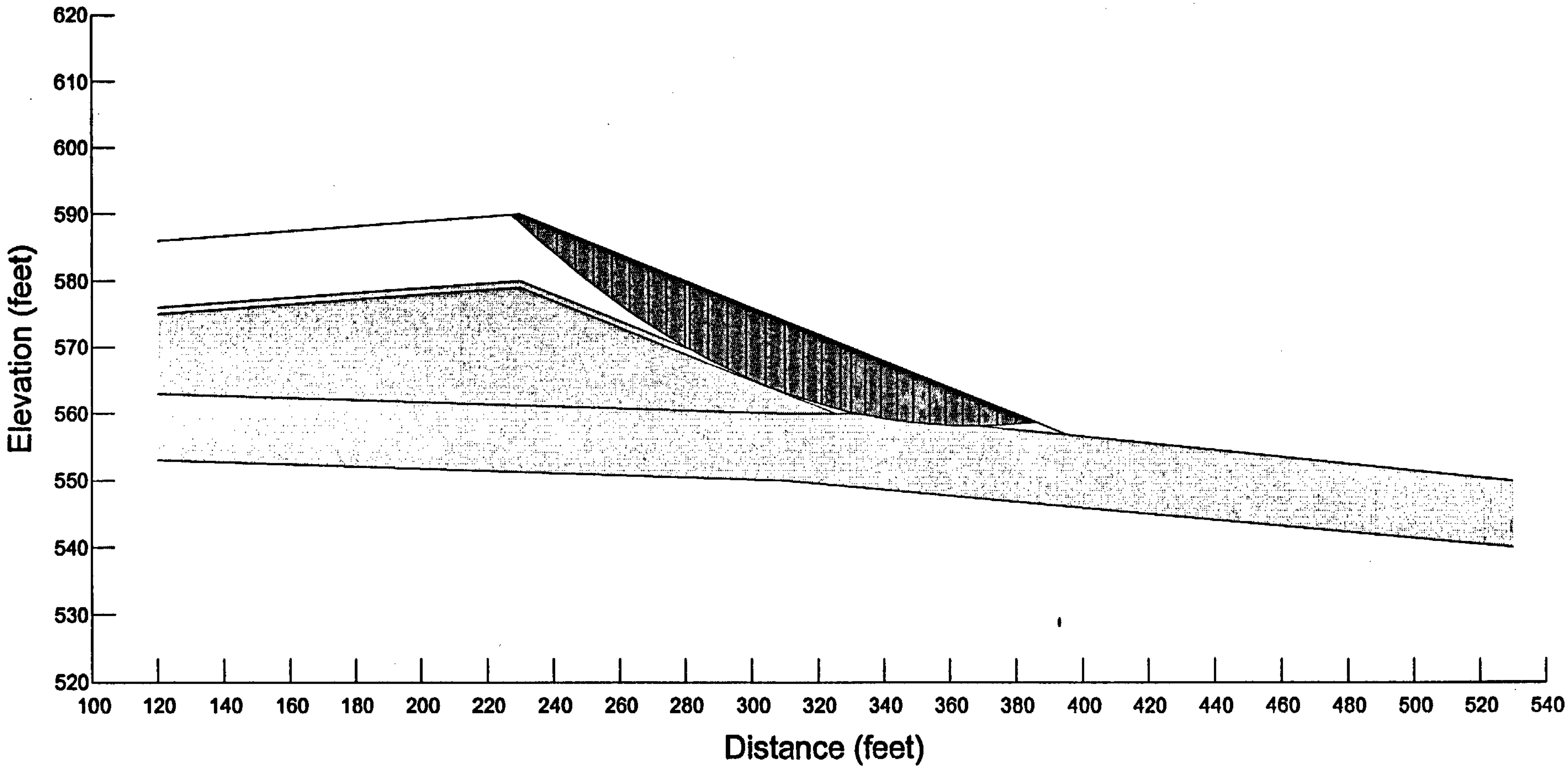

APPENDIX D

RADON EMANATION

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ATTACHMENTS

D.1 INTRODUCTION

This appendix presents the calculations of radon-222 emanation and gamma radiation exposure from the cover over the proposed Sequoyah Fuels Corporation disposal cell. Material characterization information for cover and disposed materials is presented in Appendix A. The proposed cover thickness is 10 feet, based on infiltration modeling and depths for plant moisture uptake described in Appendix E. The radon emanation calculations were conducted to ensure that the average rate of radon-222 emanation from the soil cover surface is less than the NRC performance standard of 20 pCi/m^2-sec (10 CFR 40, Appendix A).

Radon emanation was analyzed using the RADON model (NRC, 1989). The input parameters and modeling were conducted in accordance with guidance presented in NUREG/CR-3533 and Regulatory Guide 3.64 (NRC, 1984, 1989). The modeling was also conducted utilizing applicable information from evaluation of a multi-layered cover system for the disposal cell documented in ESCI (1996 and 1998). Gamma radiation exposure calculations are summarized in Section D.6 of this appendix.

D.2 ANALYZED PROFILE AND PHYSICAL PROPERTIES

The disposal cell profile analyzed with the RADON model is presented in Table D.1. This profile includes four specific layers of contaminated material below the reclamation cover, with the disposal scenario based on placing the materials with the highest radium-226 and thorium-230 activity concentrations lowest in the profile. The layer thicknesses shown in Table D.1 are based on estimated material volumes and average areas within the disposal cell. The individual volumes of the materials to be disposed are listed Attachment D.1 of this appendix (from SFC, 1998).

The physical properties of the disposed materials and cover materials are based on drill logs and testing described in Appendix A. For the RADON modeling, the critical physical properties of these materials are porosity and long-term moisture content.

As illustrated in Table D.1, the materials to be placed in the disposal cell are primarily on-site soils (generally sandy, silty clays). Exceptions are the Layer A materials, which consist of sludges and sediments, and Layer C materials, which consist of structural materials, miscellaneous buried materials and calcium fluoride solids. All of these materials were conservatively represented as soils with a porosity of 0.4 and a long-term moisture content (by weight) of 6 percent, with a resulting degree of saturation of 24 percent.

D.3 MATERIAL RADIOLOGICAL PROPERTIES

The radiological properties used in the RADON model for the contaminated soils are based on information presented in Appendix A. The radon emanation fraction from materials with a radium-226 activity concentration was 0.35 (the conservative default value used in the RADON model). The radon diffusion coefficient for cover and upper layers of disposed materials was calculated by the RADON model (from void ratio and moisture content). The calculated value was 0.0313 cm^2/sec.

Radium-226 activity concentrations of the materials in the disposal cell were estimated for each layer as a weighted average value from the individual material values. The volumes, weights and radionuclide activity concentration values from SFC (1998) are listed in Attachment D.1. Due to the relatively high activity concentration values of the Layer A materials (the raffinate sludge, Pond 2 residual materials, and basin sediments), these materials are the key source term parameters for the RADON modeling. As a result, the radium-226 and thorium-230 activity concentration values of these materials were evaluated in more detail for the RADON modeling. From review of sample analysis data by SFC, statistical summaries of natural uranium, radium-226 and thorium-230 activity concentrations were developed. The summary values for these materials are summarized in Attachment D.1. The mean values and 95 percent upper confidence interval values were selected to conservatively represent the range of source-term conditions for the RADON modeling.

Due to the amount of thorium-230 in these materials, the amount of radium-226 ingrowth due to thorium-230 decay was considered for the Layer A material source-term conditions. Natural uranium was not considered due to its significantly longer half-life. Ingrowth due to thorium-

230 decay was evaluated with time for the Layer A materials, with the maximum radium-226 values calculated of approximately 10,000 years from the present. For the RADON modeling, four source-term scenarios were evaluated: (1) mean values under current conditions; (2) mean values in 10,000 years accounting for thorium-230 decay; (3) 95 percent upper confidence-interval (UCI) values under current conditions, and (4) estimated 95 percent UCI values in 10,000 years accounting for thorium-230 decay. The mean values represent source term values consistent with the NRC closure performance standards for radon emanation of 20 pCi/square meter-second, averaged over the entire cover. The 95 percent upper confidence-interval values represent conservative source term values, especially if sludge treatment with filtration or addition of fly ash is not defined at this time. In addition, radionuclide activity concentrations based on dry weights were conservatively used.

D.4 MODEL INPUT VALUES

The key radiological input values used in RADON modeling are outlined by layer in the following subsections.

D.4.1 Layer A Materials

The Layer A materials (with the highest radium-226 and thorium-230 activity concentrations) are planned for placement as the lowest layer in the disposal cell, then covered with their underlying liner soil or subsoil.

The mean values of Layer A materials and associated characteristics are summarized in Table D.2. The weighted average radium-226 activity concentrations of 80 pCi/g for current conditions and 3,331 pCi/g for long-term conditions from Table D.2 were used for the Layer A input shown in Table D.1.

The 95 percent upper confidence-interval values of the Layer A materials and their associated characteristics are summarized in Table D.3 below. The weighted average radium-226 activity concentrations of 110 pCi/g for current conditions and 5,079 pCi/g for long-term conditions from Table D.3 were used for the Layer A input shown in Table D.1.

D.4.2 Layer B Materials

The other materials with relatively high thorium-230 activity concentrations are the clarifier liner materials, sanitary lagoon liner materials, and the Pond 1 spoils pile. These materials are planned to be excavated during or immediately after removal of Layer A materials, and placed in Layer B along with other liner materials and subsoils as listed in Table D.1. The mean activity concentrations for these materials under current conditions are summarized in Table D.4. The weighted average radium-226 concentration values from Table D.4 are 0.9 pCi/g under current conditions and 34 pCi/g under long-term conditions. These values are based on no detectable radium-226 and thorium-230 activity concentrations for four of the materials (calcium fluoride basin liner, Pond 3E clay liner, emergency basin soils, and north ditch soils). If the radium-226 and thorium-230 activity concentrations of the remaining three materials only are used (Pond 1 spoils pile, clarifier liners, and sanitary lagoon liner), the weighted average radium-226 activity concentrations are approximately 2 pCi/g under current conditions and 52 pCi/g under long-term conditions. These higher radium-226 values were conservatively used in the RADON modeling (Table D.1)

D.4.3 Layer C Materials

The materials comprising Layer C consist of structural materials, currently buried materials, calcium fluoride solids and contaminated trash and drums. The components with measurable radium-226 and thorium-230 activity concentrations are the calcium fluoride solids (Attachment D.1). These materials have a radium-226 activity concentration of approximately 1 pCi/g and a thorium-230 activity concentration of approximately 4.8 pCi/g. The calculated long-term radium-226 activity concentration for these materials is approximately 4 pCi/g. These values (1 and 4 pCi/g radium-226) were used to conservatively represent the source term conditions for all of the Layer C materials in the RADON modeling (Table D.1).

D.4.4 Layer D Materials

Layer D materials consist of contaminated subsoils and bedrock, with a maximum radium-226 activity concentration of approximately 1 pCi/g (Attachment D.1). This value was used for both current and long-term radon modeling (Table D.1).

D.5 RADON MODEL RESULTS

The RADON model output for the four scenarios outlined above is provided in Attachment D.2. The calculated radon-222 flux through the top of the cover (in terms of pCi/m^2-sec) is presented in the table below. As mentioned above, the NRC performance criterion is an average flux from the cover of less than 20 pCi/m^2-sec.

Scenario[a]	Calculated radon-222 exit flux (pCi/m^2-sec)
Current Conditions	
Mean values[b]	0.37
95% upper confidence interval values[b]	0.46
Long Term Conditions	
Mean values[b]	10.65
95% upper confidence interval values[b]	16.04

a From Table D.1
b From Attachment D.1

The RADON model was also run to back-calculate the radium-226 activity concentration of Layer A materials required to increase the radon-222 flux from the top of the cover to 20 pCi/m^2-sec. The required radium-226 value was 6,350 pCi/g.

The proposed cover system was evaluated for acceptable performance in reduction of radon-222 emanation from the disposal materials using modeling recommended by NRC, with the results compared with NRC criteria. Conservative assumptions in cover and disposal material porosity and moisture content were made, and conservatively high radium-226 activity concentrations were used. The conservative assumptions and values were used for the following reasons:

1. The radiological parameters used in the model were based on a limited number of samples, with analysis results showing significant variability. The existing data was evaluated statistically, with mean and 95 percent upper confidence interval values used in the modeling to represent a conservative range of source term parameters.

2. SFC is currently evaluating alternatives for dewatering or mixing components of the Layer A materials for placement in the disposal cell. Conservatively low disposed material moisture contents were used in the modeling to represent a lower-bound value that would accommodate the material preparation alternatives that SFC is evaluating.

With these conservative assumptions and values, the modeling results show that the proposed cover (and planned order of material disposal) maintains radon-222 emanation rates from the top of the cover within NRC performance standards for both current conditions, as well as a future time representing maximum thorium-230 ingrowth (10,000 years).

D.6 GAMMA RADIATION EXPOSURE

The gamma radiation exposure from covered areas of the site was estimated from exposure relationships presented in Schiager (1974) and Shleien (1992). The effect of a soil cover in reducing exposure from a gamma radiation source is calculated as the ratio of the shielded exposure rate (due to the soil) to the unshielded exposure rate. Using coefficients for soil, the shielded exposure rate is approximately 1/10 of the unshielded rate at a soil cover thickness of one foot. This ratio is 1/100 at a soil cover thickness of over two feet, and is 1/1000 at a soil cover thickness of over three feet. For a soil cover thickness of 10 feet, the ratio is approximately $1/10^9$. These calculations show that gamma radiation exposure is significantly reduced by a small thickness of soil cover.

D.7 REFERENCES

Earth Science Consultants, Inc. (ESCI), 1998. "Calculation Brief, RADON Analysis, Case I and Case II Scenarios, Sequoyah Fuels Corporation, Gore, Oklahoma, Project No. 4881-04." Prepared for SFC, December 9.

Earth Science Consultants, Inc. (ESCI), 1996. "Conceptual Design Report, Decommissioning, Excavation, and Stabilization/Solidification Program." Prepared for SFC, December.

Schiager, K.J., 1974. "Analysis of Radiation Exposures on or Near Uranium Mill Tailings Piles." *Radiation Data and Reports*, Vol. 15, No. 7, July, pp. 411-425. Reprinted by U.S. EPA Office of Radiation Programs.

Shleien, B., 1992. *The Health Physics and Radiological Health Handbook*, Revised Edition, Scinta, Inc.

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

U.S. Nuclear Regulatory Commission (NRC), 1984. "Radon Attenuation Handbook for Uranium Mill Tailings Cover Design," NUREG/CR-3533.

Table D.1 Analyzed Disposal Cell Profile

Layer Thickness	Disposed Material		Radium-226 Activity Concentration (pCi/g)			
			Current Conditions		Long-term Conditions[c]	
			Mean Value[a]	95% UCI[b]	Mean Value	95% UCI
10'	Cover Materials	Topsoil Cover soils	0	0	0	0
7'	Layer D Materials	Contaminated subsoils Contaminated bedrock	1	1	1	1
4'	Layer C Materials	Calcium fluoride solids Buried materials Structural materials Contaminated trash and drums	1	1	4	4
3'	Layer B Materials	Liner soils Pond and basin subsoils	2	2	52	52
4'	Layer A Materials	Raffinate sludge Pond 2 residual materials Emergency basin, north ditch, and sanitary lagoon sediments	80	110	3331	5079
	Clay layer and subsoils		--	--	--	--

a Arithmetic mean value from SFC data.
b 95% upper confidence interval value from SFC data.
c Calculated from current conditions for radium-226 ingrowth from thorium-230 (Tables D.2, D.3 and D.4).

Table D.2 Layer A Mean Source Term Activity Concentrations

Mean Source Term Values (Current Conditions)

Material	Volume (cu ft)	Weight (10^9 g)	Nat. Uranium (pCi/g)	Radium-226 (pCi/g)	Thorium-230 (pCi/g)
Raffinate sludge	1,064,000	6.76	5720	157	9560
Pond 2 residual materials	635,000	17.8	357	49.9	1440
Emergency basin sediment	14,600	0.129	4210	332	16300
North ditch sediment	20,770	0.198	8430	7.18	211
Sanitary Lagoon sediments	10,365	0.099	12100	5.8	276
Totals	1,744,735	24.986	--	--	--
Weighted average	--	--	--	80	--

Mean Source Term Values (with Thorium-230 Ingrowth)

Material	Raffinate Sludge	Pond 2 Residual Materials	Emergency Basin Sediment	North Ditch Sediment	Sanitary Lagoon Sediment
Residual Radium-226 (pCi/g)					
0 years	157	49.9	332	7.2	5.8
500 years	127	40	268	6	5
5,000 years	18	6	38	1	1
10,000 years	2	1	5	0	0
20,000 years	0	0	0	0	0
Ingrowth from Radium-226 (pCi/g) from decay of Thorium-230					
0 years	0	0	0	0	0
500 years	1847	278	3150	41	53
5,000 years	8088	1218	13791	179	234
10,000 years	8606	1296	14674	190	248
20,000 years	7981	1202	13608	176	230
Total Radium-226 (pCi/g)					
0 years	157	50	332	7	6
500 years	1974	318	3417	47	58
5,000 years	8106	1224	13829	179	234
10,000 years	8608	1297	14678	190	249
20,000 years	7981	1202	13608	176	230

Mean Source Term Values (at 10,000 Years)

Material	Volume (cu ft)	Weight (10^9 g)	Radium-226 (pCi/g)
Raffinate sludge	1,064,000	6.76	8608
Pond 2 residual materials	635,000	17.8	1297
Emergency Basin sediment	14,600	0.139	14678
North ditch sediment	20,770	0.198	190
Sanitary Lagoon sediment	10,365	0.099	249
Totals	1,744,735	24.986	--
Weighted average	--	--	3331

Table D.3 Layer A 95 Percent Upper Confidence Interval Source Term Activity Concentrations

Upper Confidence-Interval Source Term Values

Material	Volume (cu ft)	Weight (10^9 g)	Nat. Uranium (pCi/g)	Radium-226 (pCi/g)	Thorium-230 (pCi/g)
Raffinate sludge	1,064,000	6.76	7500	218	15100
Pond 2 residual materials	635,000	17.8	472	67	1284
Emergency basin sediment	14,600	0.129	6030	508	29100
North ditch sediment	20,770	0.198	19500	13.9	499
Sanitary Lagoon sediments	10,365	0.099	18500	19.7	1120
Totals	1,744,735	24.986	--	--	--
Weighted average	--	--	--	110	--

Upper Confidence-Interval Source Term Values (with Thorium-230 Ingrowth)

Material	Raffinate Sludge	Pond 2 Residual Materials	Emergency Basin Sediment	North Ditch Sediment	Sanitary Lagoon Sediment
Residual Radium-226 (pCi/g)					
0 years	218	67	508	14	20
500 years	176	54	409	11	16
5,000 years	25	8	58	2	2
10,000 years	3	1	7	0	0
20,000 years	0	0	0	0	0
Ingrowth from Radium-226 (pCi/g) from decay of Thorium-230					
0 years	0	0	0	0	0
500 years	2918	379	5623	96	216
5,000 years	12776	1658	24620	422	948
10,000 years	13593	1764	26196	449	1008
20,000 years	12606	1636	24294	417	935
Total Radium-226 (pCi/g)					
0 years	218	67	508	14	20
500 years	3093	432	6032	108	232
5,000 years	12801	1666	24679	424	950
10,000 years	13596	1765	26203	449	1009
20,000 years	12606	1636	24294	417	935

Upper Confidence-Interval Source Term Values (at 10,000 Years)

Material	Volume (cu ft)	Weight (10^9 g)	Radium-226 (pCi/g)
Raffinate sludge	1,064,000	6.76	13596
Pond 2 residual materials	635,000	17.8	1765
Emergency Basin sediment	14,600	0.139	26203
North ditch sediment	20,770	0.198	449
Sanitary Lagoon sediment	10,365	0.099	1009
Totals	1,744,735	24.986	--
Weighted average	--	--	5079

Table D.4 Layer B Mean Source Term Activity Concentrations

Mean Source Term Values (Current Condition)

Material	Volume (cu ft)	Weight (10^9g)	Nat. Uranium (pCi/g)	Radium-226 (pCi/g)	Thorium-230 (pCi/g)
Pond 1 spoils pile	437,400	21.8	4.8	2.1	47
Clarifier liners	332,400	16.6	28	0.5	70
Calcium fluoride basin liner	95,285	4.76	13.3	--	--
Pond 3E clay liner	88,232	4.41	4.9	--	--
Emergency basin soils	162,500	8.12	95	--	--
North ditch soils	87,500	4.37	68	--	--
Sanitary lagoon liner	56,356	2.81	28	0.5	70
Chipped pallets	3,000	--	--	--	--
Totals	1,262,673	62.87	--	--	--
Weighted average	--	--	--	0.9	--

Mean Source Term Values (with Thorium-230 Ingrowth)

Material	Pond 1 Spoils Pile	Clarifier Lines	Sanitary lagoon liner
Residual Radium-226 (pCi/g)			
0 years	2	1	1
500 years	2	1	1
5,000 years	0	0	0
10,000 years	0	0	0
20,000 years	0	0	0
Ingrowth from Radium-226 (pCi/g) from decay of Thorium-230			
0 years	0	0	0
500 years	9	14	14
5,000 years	40	59	59
10,000 years	42	63	63
20,000 years	39	58	58
Total Radium-226 (pCi/g)			
0 years	2	1	1
500 years	11	14	14
5,000 years	40	59	59
10,000 years	42	63	63
20,000 years	39	58	58

Mean Source Term Values (at 10,000 Years)

Material	Volume (cu ft)	Weight (10^9g)	Radium-226 (pCi/g)
Pond 1 spoils pile	437,400	21.8	42
Clarifier liners	332,400	16.6	63
Calcium fluoride basin liner	95,285	4.76	--
Pond 3E clay liner	88,232	4.41	--
Emergency basin soils	162,500	8.12	--
North ditch soils	87,500	4.37	--
Sanitary lagoon liner	56,356	2.81	63
Chipped pallets	3,000	--	--
Totals	1,262,673	62.87	--
Weighted average	--	--	34

ATTACHMENT D.1

DISPOSAL MATERIAL CHARACTERIZATION SUMMARY

Disposal Material Characterization Summary*

Material	SCU No.[a]	Item No.[b]	Layer No.[c]	Volume (cu ft)[d]	Weight (10^9 g)	Nat. Uranium		Thorium-230		Radium -226	
						pCi/g	Ci	pCi/g	Ci	pCi/g	Ci
SLUDGES & SEDIMENTS											
Raffinate sludge	17	5	A	1,064,000	6.76	5914	37.14	9611.1	60.4	118.1	0.7
Pond 2 residual materials	18	8	A	635,000	17.8	288	10.77	1284	48.03	43.0	1.61
Emergency basin sediment	6	11	A	14,600	0.139	3864	0.54	33,900	4.71	885	0.123
North ditch sediment	9	11	A	20,770	0.198	3865	0.77	698	0.137	170	0.033
Sanitary lagoon sediment	7	10	A	10,365	0.099	12,884	1.28	276	0.50	5.8	0.008
Fluoride holding basin #1	13	7	C	171,400	2.62	311	0.82	4.8	0.013	0.8	0.002
Fluoride holding basin #2	12	7	C	186,000	2.85	356	1.02	4.8	0.014	0.8	0.002
Fluoride settling basins & clarifier	14	7	C	114,300	1.79	520	0.92	4.8	0.008	0.8	0.001
Buried calcium fluoride	15	7	C	96,380	--	--	1.52	--	--	--	--
Buried fluoride holding basin #1	15	7	C	57,200	0.875	313	0.27	4.8	0.004	0.8	0.001
LINER SOILS & SUBSOILS											
Clarifier liners	17	8	B	332,400	16.6	28	0.47	70	1.16	0.5	0.008
Calcium fluoride basin liner	12, 13, 14	8	B	95,285	4.76	13.3	0.064	--	--	--	--
Pond 3E clay liner	24	8	B	88,232	4.41	4.9	0.02	--	--	--	--
Emergency basin soils	6	11	B	162,500	8.12	95	0.78	--	--	--	--
North ditch soils	9	11	B	87,500	4.37	68	0.30	--	--	--	--
Sanitary lagoon liner	7	10	B	56,356	2.81	28	0.08	70	0.20	0.5	0.001
BURIED MATERIALS & DRUMS											
Pond 1 spoils pile	8	8	B	437,400	21.8	4.8	0.11	47	1.02	2.1	0.046
Interim storage cell	9	35	C	154,887	7.74	373	2.89	2.1	0.016	0.21	0.0016
Solid waste burials	5	12	C	51,100	--	--	0.681	--	--	--	--
DUF_4 drummed contaminated trash	--	2	C	2,200	--	--	0.37[e]	--	--	--	--
Other drummed contaminated trash	--	6	C	4,050	--	--	0.015	--	--	--	--
Empty contam. Drums	--	3	C	2,000	--	--	0.015	--	--	--	--

* From Appendix A of this report.

Disposal Material Characterization Summary (continued)*

Material	SCU No.[a]	Item No.[b]	Layer No.[c]	Volume (cu ft)[d]	Weight (10^9 g)	Nat. Uranium		Thorium-230		Radium -226	
						pCi/g	Ci	pCi/g	Ci	pCi/g	Ci
STRUCTURAL MATERIALS	(see below)	(see below)		568,550	51.6	168	8.67	--	--	--	--
Main plant building	1	13	C	[2,178,000]							
Solvent Extraction Building	2	13	C	[180,000]							
DUF$_4$ Building	29	13	C	[281,000]							
ADU/Misc. digestion building	21	13	C	[75,000]							
Laundry building	17	13	C	[12,500]							
Centrifuge building	17	13	C	[15,000]							
Bechtel building	30	13	C	[27,000]							
Solid waste building	10	13	C	[18,000]							
Cooling tower	2	13	C	[30,000]							
RCC evaporator	2	13	C	[18,750]							
Incinerator	10	13	C	[7,500]							
Concrete and asphalt	Various	13	C	511,795	46.5	168	7.81				
Scrap metal	--	4	C	100,000	--	--	0.15	--	--	--	--
Chipped pallets	--	--	B	3,000	--	--	--	--	--	--	--
SUBSOILS & BEDROCK											
Contaminated materials[f]	Various	14	D	3,574,000	178.5	250	44.8	--	--	--	--

* From Appendix A of this report.

a Site characterization unit number from Section 4 of SCR (SFC, 1998).

b Calculation item number in Attachment III of SCR.

c Layer number in disposal cell sequence.

d Values are from Attachment III of SCR; values in brackets are calculated building volumes from floor area and building height; disposal volume is 20 percent of building volume.

e Depleted uranium value

f Materials above 27 pCi/g natural uranium.

Statistical Summary of Layer A Materials

Emergency Basin

	U-nat	Th-230	Ra-226
Number of values	8	5	5
Minimum	1590	3790	186
25% Percentile	2670		
Median	3720	17100	276
75% Percentile	5440		
Maximum	8400	30000	534
Mean	4210	16300	332
Std. Deviation	2180	10300	142
Std. Error	770	4610	63.5
Lower 95% CI	2380	3540	156
Upper 95% CI	6030	29100	508

Raffinate Sludge

	U-nat	Th-230	Ra-226
Number of values	20	19	20
Minimum	1440	305	13.7
25% Percentile	3510	3360	61.1
Median	4820	5420	140
75% Percentile	6250	17400	183
Maximum	19200	48200	535
Mean	5720	9560	157
Std. Deviation	3800	11600	130
Std. Error	850	2650	29.2
Lower 95% CI	3950	3980	95.6
Upper 95% CI	7500	15100	218

North Ditch

	U-nat	Th-230	Ra-226
Number of values	5	5	5
Minimum	2200	12.8	1.4
25% Percentile			
Median	3020	90.5	6
75% Percentile			
Maximum	22300	475	16
Mean	8430	211	7.18
Std. Deviation	8880	232	5.41
Std. Error	3970	104	2.42
Lower 95% CI	-2590	-77.2	0.466
Upper 95% CI	19500	499	13.9

Sanitary Lagoon

	U-nat	Th-230	Ra-226
Number of values	9	3	3
Minimum	2300	8.2	0.9
25% Percentile	4530		
Median	12200	163	4.5
75% Percentile	19000		
Maximum	26100	656	11.9
Mean	12100	276	5.77
Std. Deviation	8270	338	5.61
Std. Error	2760	195	3.24
Lower 95% CI	5780	-565	-8.17
Upper 95% CI	18500	1120	19.7

Pond 2 Residual

	U-nat	Th-230	Ra-226
Number of values	67	63	63
Minimum	3.4	1.8	0.4
25% Percentile	15.3	32	2
Median	143	280	18
75% Percentile	510	2600	70.5
Maximum	2060	6820	230
Mean	357	1440	49.9
Std. Deviation	472	2070	66.4
Std. Error	57.7	261	8.37
Lower 95% CI	241	918	33.1
Upper 95% CI	472	1960	66.6

Values are in pCi/g; CI - confidence interval.

P:\100734\disposal cell design\sourcestats.xls

ATTACHMENT D.2

RADON MODEL OUTPUT

```
                   -----*****! RADON !*****-----

Version 1.2 - MAY 22, 1989 - G.F. Birchard tel.# (301)492-7000
U.S. Nuclear Regulatory Commission Office of Research

         RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: seqnew-1

DESCRIPTION: Current Mean Values

              CONSTANTS

RADON DECAY CONSTANT                       .0000021     s^-1
RADON WATER/AIR PARTITION COEFFICIENT      .26
DEFAULT SPECIFIC GRAVITY OF COVER & TAILINGS             2.65

              GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS               5
DEFAULT RADON FLUX LIMIT                   20           pCi m^-2 s^-1
LAYER THICKNESS NOT OPTIMIZED
DEFAULT SURFACE RADON CONCENTRATION        0            pCi l^-1
RADON FLUX INTO LAYER 1                    0            pCi m^-2 s^-1
SURFACE FLUX PRECISION                     .001         pCi m^-2 s^-1


              LAYER INPUT PARAMETERS

LAYER 1       Layer A Materials


THICKNESS                                  121.92       cm
DEFAULT POROSITY                           .4
CALCULATED MASS DENSITY                    1.59         g cm^-3
MEASURED RADIUM ACTIVITY                   80           pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT        .35
CALCULATED SOURCE TERM CONCENTRATION       2.337D-04    pCi cm^-3 s^-1
WEIGHT % MOISTURE                          6            %
MOISTURE SATURATION FRACTION               .238
CALCULATED DIFFUSION COEFFICIENT           3.131D-02    cm^2 s^-1


LAYER 2       Layer B Materials


THICKNESS                                  91.44        cm
DEFAULT POROSITY                           .4
CALCULATED MASS DENSITY                    1.59         g cm^-3
MEASURED RADIUM ACTIVITY                   2            pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT        .35
CALCULATED SOURCE TERM CONCENTRATION       5.843D-06    pCi cm^-3 s^-1
WEIGHT % MOISTURE                          6            %
MOISTURE SATURATION FRACTION               .238
CALCULATED DIFFUSION COEFFICIENT           3.131D-02    cm^2 s^-1
```

```
LAYER 3       Layer C Materials


THICKNESS                                   121.92       cm
DEFAULT POROSITY                            .4
CALCULATED MASS DENSITY                     1.59         g cm^-3
MEASURED RADIUM ACTIVITY                    1            pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT         .35
CALCULATED SOURCE TERM CONCENTRATION        2.922D-06    pCi cm^-3 s^-1
WEIGHT % MOISTURE                           6            %
MOISTURE SATURATION FRACTION                .238
CALCULATED DIFFUSION COEFFICIENT            3.131D-02    cm^2 s^-1

LAYER 4       Layer D Materials


THICKNESS                                   213.36       cm
DEFAULT POROSITY                            .4
CALCULATED MASS DENSITY                     1.59         g cm^-3
MEASURED RADIUM ACTIVITY                    1            pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT         .35
CALCULATED SOURCE TERM CONCENTRATION        2.922D-06    pCi cm^-3 s^-1
WEIGHT % MOISTURE                           6            %
MOISTURE SATURATION FRACTION                .238
CALCULATED DIFFUSION COEFFICIENT            3.131D-02    cm^2 s^-1

LAYER 5       Cover


THICKNESS                                   304.8        cm
DEFAULT POROSITY                            .4
CALCULATED MASS DENSITY                     1.59         g cm^-3
MEASURED SOURCE TERM CONCENTRATION          0            pCi cm^-3 s^-1
WEIGHT % MOISTURE                           6            %
MOISTURE SATURATION FRACTION                .238
CALCULATED DIFFUSION COEFFICIENT            3.131D-02    cm^2 s^-1
```

```
                DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

  N       F01        CN1        ICOST       CRITJ       ACC
  5    0.000D+00  0.000D+00       0       2.000D+01  1.000D-03

LAYER     DX          D          P           Q          XMS       RHO
  1    1.219D+02  3.131D-02  4.000D-01  2.337D-04  2.385D-01   1.590
  2    9.144D+01  3.131D-02  4.000D-01  5.843D-06  2.385D-01   1.590
  3    1.219D+02  3.131D-02  4.000D-01  2.922D-06  2.385D-01   1.590
  4    2.134D+02  3.131D-02  4.000D-01  2.922D-06  2.385D-01   1.590
  5    3.048D+02  3.131D-02  4.000D-01  0.000D+00  2.385D-01   1.590


BARE SOURCE FLUX FROM LAYER 1:  8.687D+01 pCi m^-2 s^-1


                RESULTS OF THE RADON DIFFUSION CALCULATIONS


                LAYER    THICKNESS    EXIT FLUX      EXIT CONC.
                            (cm)    (pCi m^-2 s^-1)  (pCi l^-1)

                  1      1.219D+02     4.841D+01     4.928D+04
                  2      9.144D+01     2.348D+01     2.420D+04
                  3      1.219D+02     8.763D+00     9.687D+03
                  4      2.134D+02     2.233D+00     2.148D+03
                  5      3.048D+02     3.656D-01     0.000D+00
```

```
                    -----*****! RADON !*****-----

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U.S. Nuclear Regulatory Commission Office of Research

         RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: seqnew-2

DESCRIPTION: Mean Values at 10000 years


              CONSTANTS

RADON DECAY CONSTANT                       .0000021     s^-1
RADON WATER/AIR PARTITION COEFFICIENT      .26
DEFAULT SPECIFIC GRAVITY OF COVER & TAILINGS             2.65


              GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS               5
RADON FLUX LIMIT                           20           pCi m^-2 s^-1
LAYER THICKNESS NOT OPTIMIZED
DEFAULT SURFACE RADON CONCENTRATION        0            pCi l^-1
RADON FLUX INTO LAYER 1                    0            pCi m^-2 s^-1
SURFACE FLUX PRECISION                     .001         pCi m^-2 s^-1


              LAYER INPUT PARAMETERS

LAYER 1       Layer A Materiasl


THICKNESS                                  121.92       cm
DEFAULT POROSITY                           .4
CALCULATED MASS DENSITY                    1.59         g cm^-3
MEASURED RADIUM ACTIVITY                   3331         pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT        .35
CALCULATED SOURCE TERM CONCENTRATION       9.732D-03    pCi cm^-3 s^-1
WEIGHT % MOISTURE                          6            %
MOISTURE SATURATION FRACTION               .238
CALCULATED DIFFUSION COEFFICIENT           3.131D-02    cm^2 s^-1

LAYER 2       Layer B Materials


THICKNESS                                  91.44        cm
DEFAULT POROSITY                           .4
CALCULATED MASS DENSITY                    1.59         g cm^-3
MEASURED RADIUM ACTIVITY                   52           pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT        .35
CALCULATED SOURCE TERM CONCENTRATION       1.519D-04    pCi cm^-3 s^-1
WEIGHT % MOISTURE                          6            %
MOISTURE SATURATION FRACTION               .238
CALCULATED DIFFUSION COEFFICIENT           3.131D-02    cm^2 s^-1
```

```
LAYER 3       Layer C Materials


THICKNESS                                   121.92       cm
DEFAULT POROSITY                            .4
CALCULATED MASS DENSITY                     1.59         g cm^-3
MEASURED RADIUM ACTIVITY                    4            pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT         .35
CALCULATED SOURCE TERM CONCENTRATION        1.169D-05    pCi cm^-3 s^-1
WEIGHT % MOISTURE                           6            %
MOISTURE SATURATION FRACTION                .238
CALCULATED DIFFUSION COEFFICIENT            3.131D-02    cm^2 s^-1


LAYER 4       Layer D Materials


THICKNESS                                   213.36       cm
DEFAULT POROSITY                            .4
CALCULATED MASS DENSITY                     1.59         g cm^-3
MEASURED RADIUM ACTIVITY                    1            pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT         .35
CALCULATED SOURCE TERM CONCENTRATION        2.922D-06    pCi cm^-3 s^-1
WEIGHT % MOISTURE                           6            %
MOISTURE SATURATION FRACTION                .238
CALCULATED DIFFUSION COEFFICIENT            3.131D-02    cm^2 s^-1


LAYER 5       Cover


THICKNESS                                   304.8        cm
DEFAULT POROSITY                            .4
CALCULATED MASS DENSITY                     1.59         g cm^-3
MEASURED SOURCE TERM CONCENTRATION          0            pCi cm^-3 s^-1
WEIGHT % MOISTURE                           6            %
MOISTURE SATURATION FRACTION                .238
CALCULATED DIFFUSION COEFFICIENT            3.131D-02    cm^2 s^-1
```

```
                DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

  N        F01        CN1       ICOST       CRITJ       ACC
  5    0.000D+00  0.000D+00       0       2.000D+01  1.000D-03

LAYER      DX         D          P          Q          XMS       RHO
  1    1.219D+02  3.131D-02  4.000D-01  9.732D-03  2.385D-01  1.590
  2    9.144D+01  3.131D-02  4.000D-01  1.519D-04  2.385D-01  1.590
  3    1.219D+02  3.131D-02  4.000D-01  1.169D-05  2.385D-01  1.590
  4    2.134D+02  3.131D-02  4.000D-01  2.922D-06  2.385D-01  1.590
  5    3.048D+02  3.131D-02  4.000D-01  0.000D+00  2.385D-01  1.590

BARE SOURCE FLUX FROM LAYER 1:  3.617D+03 pCi m^-2 s^-1


                RESULTS OF THE RADON DIFFUSION CALCULATIONS


              LAYER    THICKNESS    EXIT FLUX    EXIT CONC.
                         (cm)     (pCi m^-2 s^-1) (pCi l^-1)

                1      1.219D+02    2.036D+03    2.025D+06
                2      9.144D+01    9.903D+02    9.693D+05
                3      1.219D+02    3.669D+02    3.587D+05
                4      2.134D+02    6.505D+01    6.256D+04
                5      3.048D+02    1.065D+01    0.000D+00
```

```
                   -----*****! RADON !*****-----

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U.S. Nuclear Regulatory Commission Office of Research

         RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: Seqnew-3

DESCRIPTION: Current 98% UCI Values


              CONSTANTS

RADON DECAY CONSTANT                       .0000021     s^-1
RADON WATER/AIR PARTITION COEFFICIENT      .26
DEFAULT SPECIFIC GRAVITY OF COVER & TAILINGS             2.65


              GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS               5
DEFAULT RADON FLUX LIMIT                   20           pCi m^-2 s^-1
LAYER THICKNESS NOT OPTIMIZED
DEFAULT SURFACE RADON CONCENTRATION        0            pCi l^-1
RADON FLUX INTO LAYER 1                    0            pCi m^-2 s^-1
SURFACE FLUX PRECISION                     .001         pCi m^-2 s^-1


              LAYER INPUT PARAMETERS

LAYER 1       Layer A Materials


THICKNESS                                  121.92       cm
DEFAULT POROSITY                           .4
CALCULATED MASS DENSITY                    1.59         g cm^-3
MEASURED RADIUM ACTIVITY                   110          pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT        .35
CALCULATED SOURCE TERM CONCENTRATION       3.214D-04    pCi cm^-3 s^-1
WEIGHT % MOISTURE                          6            %
MOISTURE SATURATION FRACTION               .238
CALCULATED DIFFUSION COEFFICIENT           3.131D-02    cm^2 s^-1


LAYER 2       Layer B Materials

THICKNESS                                  91.44        cm
DEFAULT POROSITY                           .4
CALCULATED MASS DENSITY                    1.59         g cm^-3
MEASURED RADIUM ACTIVITY                   2            pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT        .35
CALCULATED SOURCE TERM CONCENTRATION       5.843D-06    pCi cm^-3 s^-1
WEIGHT % MOISTURE                          6            %
MOISTURE SATURATION FRACTION               .238
CALCULATED DIFFUSION COEFFICIENT           3.131D-02    cm^2 s^-1
```

```
LAYER 3       Layer C Materials

THICKNESS                                  121.92       cm
DEFAULT POROSITY                           .4
CALCULATED MASS DENSITY                    1.59         g cm^-3
MEASURED RADIUM ACTIVITY                   1            pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT        .35
CALCULATED SOURCE TERM CONCENTRATION       2.922D-06    pCi cm^-3 s^-1
WEIGHT % MOISTURE                          6            %
MOISTURE SATURATION FRACTION               .238
CALCULATED DIFFUSION COEFFICIENT           3.131D-02    cm^2 s^-1

LAYER 4       Layer D Materials

THICKNESS                                  213.36       cm
DEFAULT POROSITY                           .4
CALCULATED MASS DENSITY                    1.59         g cm^-3
MEASURED RADIUM ACTIVITY                   1            pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT        .35
CALCULATED SOURCE TERM CONCENTRATION       2.922D-06    pCi cm^-3 s^-1
WEIGHT % MOISTURE                          6            %
MOISTURE SATURATION FRACTION               .238
CALCULATED DIFFUSION COEFFICIENT           3.131D-02    cm^2 s^-1

LAYER 5       Cover

THICKNESS                                  304.8        cm
DEFAULT POROSITY                           .4
CALCULATED MASS DENSITY                    1.59         g cm^-3
MEASURED SOURCE TERM CONCENTRATION         0            pCi cm^-3 s^-1
WEIGHT % MOISTURE                          6            %
MOISTURE SATURATION FRACTION               .238
CALCULATED DIFFUSION COEFFICIENT           3.131D-02    cm^2 s^-1
```

```
                DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

  N        F01        CN1       ICOST       CRITJ       ACC
  5    0.000D+00  0.000D+00      0       2.000D+01  1.000D-03

LAYER      DX          D          P          Q         XMS        RHO
  1    1.219D+02  3.131D-02  4.000D-01  3.214D-04  2.385D-01   1.590
  2    9.144D+01  3.131D-02  4.000D-01  5.843D-06  2.385D-01   1.590
  3    1.219D+02  3.131D-02  4.000D-01  2.922D-06  2.385D-01   1.590
  4    2.134D+02  3.131D-02  4.000D-01  2.922D-06  2.385D-01   1.590
  5    3.048D+02  3.131D-02  4.000D-01  0.000D+00  2.385D-01   1.590


BARE SOURCE FLUX FROM LAYER 1:  1.194D+02 pCi m^-2 s^-1


                RESULTS OF THE RADON DIFFUSION CALCULATIONS


                LAYER    THICKNESS    EXIT FLUX     EXIT CONC.
                           (cm)     (pCi m^-2 s^-1) (pCi l^-1)

                  1      1.219D+02    6.691D+01    6.731D+04
                  2      9.144D+01    3.223D+01    3.272D+04
                  3      1.219D+02    1.199D+01    1.283D+04
                  4      2.134D+02    2.799D+00    2.692D+03
                  5      3.048D+02    4.582D-01    0.000D+00
```

```
                    -----*****! RADON !*****-----

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U.S. Nuclear Regulatory Commission Office of Research

         RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: Seqnew-4

DESCRIPTION: 95% UCI Values at 10000 years

              CONSTANTS

RADON DECAY CONSTANT                       .0000021     s^-1
RADON WATER/AIR PARTITION COEFFICIENT      .26
DEFAULT SPECIFIC GRAVITY OF COVER & TAILINGS             2.65


              GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS               5
DEFAULT RADON FLUX LIMIT                   20           pCi m^-2 s^-1
LAYER THICKNESS NOT OPTIMIZED
DEFAULT SURFACE RADON CONCENTRATION        0            pCi l^-1
RADON FLUX INTO LAYER 1                    0            pCi m^-2 s^-1
SURFACE FLUX PRECISION                     .001         pCi m^-2 s^-1


              LAYER INPUT PARAMETERS

LAYER 1       Layer 1 Materials


THICKNESS                                  121.92       cm
DEFAULT POROSITY                           .4
CALCULATED MASS DENSITY                    1.59         g cm^-3
MEASURED RADIUM ACTIVITY                   5079         pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT        .35
CALCULATED SOURCE TERM CONCENTRATION       1.484D-02    pCi cm^-3 s^-1
WEIGHT % MOISTURE                          6            %
MOISTURE SATURATION FRACTION               .238
CALCULATED DIFFUSION COEFFICIENT           3.131D-02    cm^2 s^-1


LAYER 2       Layer B Materials


THICKNESS                                  91.44        cm
DEFAULT POROSITY                           .4
CALCULATED MASS DENSITY                    1.59         g cm^-3
MEASURED RADIUM ACTIVITY                   52           pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT        .35
CALCULATED SOURCE TERM CONCENTRATION       1.519D-04    pCi cm^-3 s^-1
WEIGHT % MOISTURE                          6            %
MOISTURE SATURATION FRACTION               .238
CALCULATED DIFFUSION COEFFICIENT           3.131D-02    cm^2 s^-1
```

```
LAYER 3       Layer C Material


THICKNESS                                 121.92        cm
DEFAULT POROSITY                          .4
CALCULATED MASS DENSITY                   1.59          g cm^-3
MEASURED RADIUM ACTIVITY                  4             pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT       .35
CALCULATED SOURCE TERM CONCENTRATION      1.169D-05     pCi cm^-3 s^-1
WEIGHT % MOISTURE                         6             %
MOISTURE SATURATION FRACTION              .238
CALCULATED DIFFUSION COEFFICIENT          3.131D-02     cm^2 s^-1


LAYER 4       Layer D Materials


THICKNESS                                 213.36        cm
DEFAULT POROSITY                          .4
CALCULATED MASS DENSITY                   1.59          g cm^-3
MEASURED RADIUM ACTIVITY                  1             pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT       .35
CALCULATED SOURCE TERM CONCENTRATION      2.922D-06     pCi cm^-3 s^-1
WEIGHT % MOISTURE                         6             %
MOISTURE SATURATION FRACTION              .238
CALCULATED DIFFUSION COEFFICIENT          3.131D-02     cm^2 s^-1


LAYER 5       Cover


THICKNESS                                 304.8         cm
DEFAULT POROSITY                          .4
CALCULATED MASS DENSITY                   1.59          g cm^-3
MEASURED SOURCE TERM CONCENTRATION        0             pCi cm^-3 s^-1
WEIGHT % MOISTURE                         6             %
MOISTURE SATURATION FRACTION              .238
CALCULATED DIFFUSION COEFFICIENT          3.131D-02     cm^2 s^-1
```

```
                DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

  N      F01         CN1        ICOST      CRITJ        ACC
  5   0.000D+00   0.000D+00      0      2.000D+01   1.000D-03

LAYER    DX          D           P           Q          XMS        RHO
  1   1.219D+02   3.131D-02   4.000D-01   1.484D-02   2.385D-01   1.590
  2   9.144D+01   3.131D-02   4.000D-01   1.519D-04   2.385D-01   1.590
  3   1.219D+02   3.131D-02   4.000D-01   1.169D-05   2.385D-01   1.590
  4   2.134D+02   3.131D-02   4.000D-01   2.922D-06   2.385D-01   1.590
  5   3.048D+02   3.131D-02   4.000D-01   0.000D+00   2.385D-01   1.590

BARE SOURCE FLUX FROM LAYER 1:  5.515D+03 pCi m^-2 s^-1


                RESULTS OF THE RADON DIFFUSION CALCULATIONS


                LAYER    THICKNESS    EXIT FLUX     EXIT CONC.
                           (cm)     (pCi m^-2 s^-1) (pCi l^-1)

                  1      1.219D+02    3.114D+03     3.076D+06
                  2      9.144D+01    1.500D+03     1.466D+06
                  3      1.219D+02    5.548D+02     5.418D+05
                  4      2.134D+02    9.800D+01     9.426D+04
                  5      3.048D+02    1.604D+01     0.000D+00
```

APPENDIX E

INFILTRATION MODELING

TABLE OF CONTENTS

LIST OF TABLES

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.

The conceptual design of the disposal cell documented in ESCI (1996) included a layered cover system with a four-foot thick compacted clay zone for control of downward-moving meteoric water. The HELP infiltration model (Schroeder and others, 1994) was used to evaluate infiltration of precipitation into and through the cover system. The HELP modeling results showed long-term rates of drainage from the bottom of the cover ranging from 0.01 to 0.78 inches per year, or approximately 0.02 to 2.0 percent of average annual precipitation (ESCI, 1996).

As mentioned in this report, the proposed cover system over the disposal cell varies from the 1996 conceptual design in two areas: (1) the cover system is limited to a topsoil and subsoil zone, and (2) the cover surface is designed to promote full-self-sustaining vegetation. The performance of this cover system (in terms of performance in reducing drainage of meteoric water through the cover) was evaluated using both the HELP model and the TerreSIM model, as described in the following sections.

E.2 EVALUATION OF THE COVER SYSTEM WITH THE HELP MODEL

The top surface of the cover system was first evaluated with the HELP model for comparison with the 1996 conceptual design, and to establish conservatively high values for drainage from the cover. The proposed cover system evaluated with the model consisted of a 1.5-foot thick topsoil layer over an 8.5-foot thick subsoil zone. The physical properties of these materials are discussed in Appendix A.

The vegetation type modeled for the cover system was a grass and brush system, with a 10-foot root depth (the maximum depth available for upward moisture migration by plant use). Climate data used in the model was Tulsa Oklahoma data (incorporated in the HELP model), which has an average annual precipitation of 38.70 inches. A simulation period of 100 years was used, with the full vegetative cover in place throughout the simulation period.

The key input values and results of the HELP modeling are summarized in Table E.1, with the full results presented in Attachment E.1. For the cover system described above, the calculated annual drainage from the cover is approximately 0.91 inches, or 2.3 percent of average precipitation. Other variations of the cover system were evaluated, which show slightly higher rates of cover drainage.

Since the HELP model was developed for landfill cover applications, calculated drainage values may be conservatively high due to limitations in assessing evaporation from plant litter and vegetation canopy (for treed areas), and actual uptake of moisture from specific brush and tree species. For these reasons, the TerreSIM model was used to estimate drainage from the cover system under long-term vegetation conditions, as described below.

E.3 EVALUATION OF THE COVER SYSTEM WITH THE TERRESIM MODEL

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 has been used to calculate drainage from cover systems under various cover material and vegetation scenarios. This module of the TerreSIM model was used to evaluate drainage from the proposed cover system over the disposal cell, with the model description and results presented in Attachment E.2.

The same cover material physical properties described above were used for the TerreSIM model. Although a slightly thicker topsoil zone and cover zone were used, this does not significantly affect the cover drainage values due to the density of roots in the upper 6 to 8 feet of the cover profile.

A 200-year simulation period was used, with planted grass and tree seedling species established initially, and the trees maturing at approximately 45 years into the simulation. Available data from Sallisaw Oklahoma was used in the modeling (with annual precipitation averaging approximately 45 inches).

The key input values and results are summarized in Table E.1. The calculated annual drainage from the cover in the first 45 years of simulation is approximately 7.75 inches/year or 17.2 percent of precipitation. After 45 years, the calculated annual drainage from the cover is zero, meaning that evaporation and transpiration from the vegetated cover is equivalent to precipitation.

In the initial period after disposal cell construction, drainage through the bottom of the cover calculated with the TerreSIM model is approximately 17 percent of precipitation. During this period, evapotranspiration accounts for approximately 70 percent of precipitation. This is due to precipitation infiltrating the cover and not being intercepted or retained in the vegetative canopy, plant litter at the ground surface, or in the root zone. With sufficient time for tree development, evapotranspiration accounts for approximately 88 percent of precipitation, along with a reduction in drainage through the bottom of the cover to essentially zero. The remaining fraction of precipitation is accounted for as plant biomass storage, litter storage, and soil storage.

During the same period of full vegetative cover, the HELP model results show evapotranspiration to be approximately 98 percent of precipitation, and drainage through the bottom of the cover to be approximately 2 percent of precipitation. The HELP model does not account for water in plant biomass or litter storage.

During the initial years after disposal cell construction, the synthetic liner material planned for incorporation within the layers of disposal material will perform as a barrier to downward-moving meteoric water. In the long term, the performance of the vegetation and cover system will minimize migration of meteoric water from beneath the root zone.

E.4 REFERENCES

Earth Science Consultants, Inc. (ESCI), 1996. "Conceptual Design Report, Decommissioning, Excavation, and Stabilization/Solidification Program." Prepared for SFC, December.

Schroeder, P. R., C. M. Lloyd, and P. A. Zappi. 1994. "Hydrologic Evaluation of Landfill Performance Model," Risk Reduction Engineering Laboratory, EPA, June.

Table E.1 Cover Infiltration Modeling Summary

Model	HELP	TerreSIM	
INPUT VALUES			
Layer 1 – Topsoil			
Material	Sandy silt	Sandy silt	
Permeability (cm/s)	1 x 10^{-5}	--	
Thickness (ft)	1.5	2.0	
Layer 2 – Subsoil			
Material	Gravelly clay	Gravelly clay	
Permeability (cm/s)	1.2 x 10^{-4}	--	
Thickness (ft)	8.5	9.0	
Root Depth (ft)	8	11	
Climate Data Source	Tulsa, OK	Sallisaw, OK	
Average annual precipitation (in)	38.7	45.0	
Length of simulation (years)	100	200	
RESULTS			
Calculated Values	Averaged over 100 years	Averaged over first 45 years	Averaged over next 155 years
Runoff (in/yr)	0.21	0.023	0.002
(% of precipitation)	0.5	0.005	0.004
Evapotranspiration (in/yr)	37.6	31.8	39.39
(% of precipitation)	97.2	70.4	87.8
Cover Drainage (in/yr)	0.91	7.75	0
(% of precipitation)	2.3	17.2	0

ATTACHMENT E.1

HELP MODEL OUTPUT

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              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:\help307\sfc\TULP100.D4
TEMPERATURE DATA FILE:        U:\help307\sfc\TULT100.D7
SOLAR RADIATION DATA FILE:    U:\help307\sfc\TULSR100.D13
EVAPOTRANSPIRATION DATA:      U:\help307\sfc\TULE100.D11
SOIL AND DESIGN DATA FILE:    U:\help307\sfc\3L#10.D10
OUTPUT DATA FILE:             U:\help307\sfc\3L#10.OUT


TIME:   9:37     DATE:  10/16/2002


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

     TITLE:  Sequoyah 3L, 120ft root

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


     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  71
           THICKNESS                  =     18.00    INCHES
           POROSITY                   =      0.4500 VOL/VOL
           FIELD CAPACITY             =      0.3300 VOL/VOL
           WILTING POINT              =      0.2400 VOL/VOL
           INITIAL SOIL WATER CONTENT =      0.3662 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =   0.999999975000E-05 CM/SEC
```

```
                              LAYER  2
                              --------

                 TYPE 1 - VERTICAL PERCOLATION LAYER
                     MATERIAL TEXTURE NUMBER  10
  THICKNESS                     =     102.00    INCHES
  POROSITY                      =       0.3980 VOL/VOL
  FIELD CAPACITY                =       0.2440 VOL/VOL
  WILTING POINT                 =       0.1360 VOL/VOL
  INITIAL SOIL WATER CONTENT    =       0.1924 VOL/VOL
  EFFECTIVE SAT. HYD. COND.     =  0.119999997000E-03 CM/SEC


                              LAYER  3
                              --------

                 TYPE 1 - VERTICAL PERCOLATION LAYER
                     MATERIAL TEXTURE NUMBER  72
  THICKNESS                     =      12.00    INCHES
  POROSITY                      =       0.3500 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.     =  0.100000005000E-02 CM/SEC


               GENERAL DESIGN AND EVAPORATIVE ZONE DATA
               ----------------------------------------

 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE # 4 WITH AN
          EXCELLENT STAND OF GRASS, A SURFACE SLOPE OF  1.%
          AND A SLOPE LENGTH OF  520. FEET.

 SCS RUNOFF CURVE NUMBER            =     36.10
 FRACTION OF AREA ALLOWING RUNOFF   =    100.0     PERCENT
 AREA PROJECTED ON HORIZONTAL PLANE =     17.800   ACRES
 EVAPORATIVE ZONE DEPTH             =    120.0     INCHES
 INITIAL WATER IN EVAPORATIVE ZONE  =     26.215   INCHES
 UPPER LIMIT OF EVAPORATIVE STORAGE =     48.696   INCHES
 LOWER LIMIT OF EVAPORATIVE STORAGE =     18.192   INCHES
 INITIAL SNOW WATER                 =      0.000   INCHES
 INITIAL WATER IN LAYER MATERIALS   =     27.179   INCHES
 TOTAL INITIAL WATER                =     27.179   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                  =   5.00
          START OF GROWING SEASON (JULIAN DATE)    =     85
          END OF GROWING SEASON (JULIAN DATE)      =    311
          EVAPORATIVE ZONE DEPTH                   = 120.0  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
```

```
*******************************************************************************

      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                   0.105    0.051    0.011    0.003    0.009    0.006
                             0.006    0.004    0.009    0.006    0.001    0.000

    STD. DEVIATIONS          0.401    0.172    0.063    0.011    0.030    0.023
                             0.030    0.014    0.038    0.025    0.003    0.003

  EVAPOTRANSPIRATION
  ------------------
    TOTALS                   0.580    0.850    1.599    3.018    6.914    7.683
                             6.856    4.417    3.116    1.434    0.653    0.480

    STD. DEVIATIONS          0.164    0.269    0.395    0.550    0.560    0.871
                             2.045    2.289    1.316    0.407    0.127    0.140

  PERCOLATION/LEAKAGE THROUGH LAYER  3
  ------------------------------------
    TOTALS                   0.0248   0.0331   0.0474   0.1507   0.1470   0.1651
                             0.1288   0.1052   0.0524   0.0248   0.0164   0.0132

    STD. DEVIATIONS          0.1353   0.1590   0.1861   0.5872   0.4054   0.3965
                             0.2503   0.2151   0.1035   0.0340   0.0186   0.0133

*******************************************************************************
```

```
*******************************************************************************

     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH  100
-------------------------------------------------------------------------------
                                     INCHES           CU. FEET      PERCENT
                                ------------------  -------------  ---------
 PRECIPITATION                  38.70      (   7.401)  2500406.5     100.00

 RUNOFF                          0.211     (  0.4225)    13624.30      0.545

 EVAPOTRANSPIRATION             37.599     (  5.3578)  2429404.00     97.160

 PERCOLATION/LEAKAGE THROUGH     0.90907 (  1.84657)    58738.625     2.34916
   LAYER  3

 CHANGE IN WATER STORAGE        -0.021     (  5.4871)    -1360.40    - -0.054
*******************************************************************************
```

```
*******************************************************************************

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

         RUNOFF                                       2.239       144686.3120

         PERCOLATION/LEAKAGE THROUGH LAYER  3         0.203813     13169.17480

         SNOW WATER                                   2.25        145213.0620

         MAXIMUM VEG. SOIL WATER (VOL/VOL)                    0.3315

         MINIMUM VEG. SOIL WATER (VOL/VOL)                    0.1516
*******************************************************************************
```

```
********************************************************************************

              FINAL WATER STORAGE AT END OF YEAR  100
    ------------------------------------------------------------------------
                LAYER        (INCHES)       (VOL/VOL)
                -----        --------       ---------
                  1            6.5032         0.3613

                  2           17.4117         0.1707

                  3            0.9316         0.0776

              SNOW WATER       0.227

********************************************************************************
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ATTACHMENT E.2

TerreSIM MODELING

TerreSIM EVALUATION OF VEGETATION AND WATER DYNAMICS ON THE PROPOSED COVER DESIGN FOR THE SEQUOYAH FUELS CORPORATION ON-SITE DISPOSAL CELL

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September 2002

TerreSIM EVALUATION OF VEGETATION AND WATER DYNAMICS ON THE PROPOSED COVER DESIGN FOR THE SEQUOYAH FUELS CORPORATION ON-SITE DISPOSAL CELL

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1.0 SUMMARY

A simplified application of the TerreSIM model was used to evaluate the preliminary cover design for the Sequoyah Fuels Corporation (SFC) on-site disposal cell. TerreSIM simulated vegetation and water dynamics associated with the proposed cover system profile and revegetation of the cover surface with local species. The simplified application used a 2.5 acre (10,000 m^2) area with a 1% slope to simulate a portion of the top surface of the disposal cell. The simulation was conducted for a 200 year period to quantify long-term migration of meteoric water through the cover system (drainage).

The revegetation scenario for the cover was a productive plant community dominated by perennial grasses for 20 years, followed by a sycamore-hickory dominated community, which is indicative of natural succession of the system. The perennial grass community required 3-4 years for full establishment. During the first four years, drainage beyond the root zone in the cover was very high (almost 27191 m^3, or 62% of total precipitation, over the 4-year period). However, after full establishment, drainage rapidly decreased. Between the 7th and 19th year, there were only two years where drainage beyond the root zone occurred, and the drainage from these two years combined totaled only 3436m^3. Drainage began to increase as the grasses were slowly replaced by the trees (years 20-45), but ceased once again when the trees species became fully established (year 45). Because the model used a simplified community structure, the drainage in years 20-45 was most likely exaggerated, and probably would not occur under a more complex plant community.

Averaged over a 45-year period, this cover system resulted in an average of 17.2% of the precipitation received draining past the root zone in the cover. Averaged over the 200-year period, this amount decreased to 3.9%.

2.0 INTRODUCTION

Sequoyah Fuels Corporation (SFC) is in the process of decommissioning the uranium processing facility in Gore, Oklahoma. The preliminary design of the on-site disposal cell is a component of this decommissioning. Performance objectives of the cover over the disposal cell include establishing a self-sustaining vegetative community on the disposal cell. The revegetation plan used to meet this goal should 1) provide for surface stabilization of the site, 2) minimize drainage of meteoric water through the profile, and 3) provide a vegetative cover that is stable over the long-term. The layout of the preliminary disposal cell design is essentially a flattened trapezoidal mound with 5:1 side slopes and a top surface at a 1% slope.

A dynamic analysis of the effects of the variations on the successional development of the revegetated plant community is critical to the evaluation of the cover design. At a minimum, this dynamic analysis must include the continuous development of the plant community, the water balance dynamics influenced by the variations in substrate, and the interactions between the developing plant community and the impacts of daily precipitation events. Static-state plant models are therefore not appropriate. Plant community characteristics change daily, monthly, and annually, and each of these types of changes have significant impacts on water dynamics.

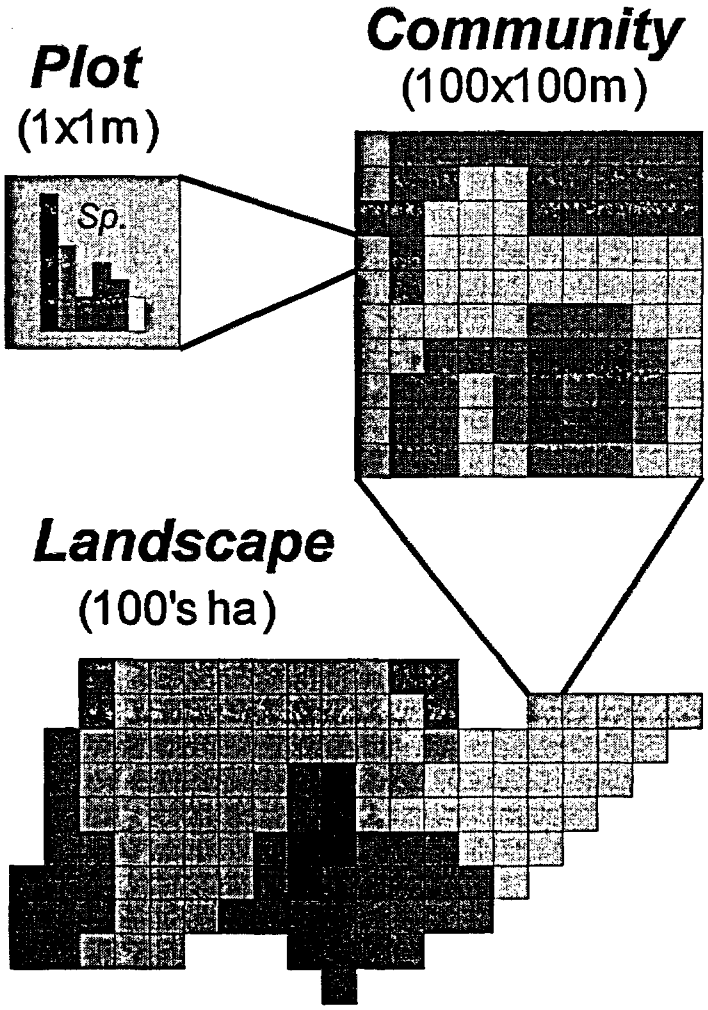
The TerreSIM (Terrestrial Ecosystem Simulation Model) model was used to evaluate the preliminary disposal cell cover design. TerreSIM is a spatially-explicit, mechanistic, computer model that is used to simulate plant community development (above- and below-ground) over time, the responses of ecological systems to environmental stressors, and the hydrological dynamics related to ecosystem dynamics. MFG ecosystem models have 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.

This report summarizes the TerreSIM evaluation of the disposal cell cover design. This evaluation is based on the TerreSIM -simulated dynamics of the simplified revegetated plant communities and the associated water dynamics over 200 years.

3.0 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-m^2 to 400 m^2). 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.

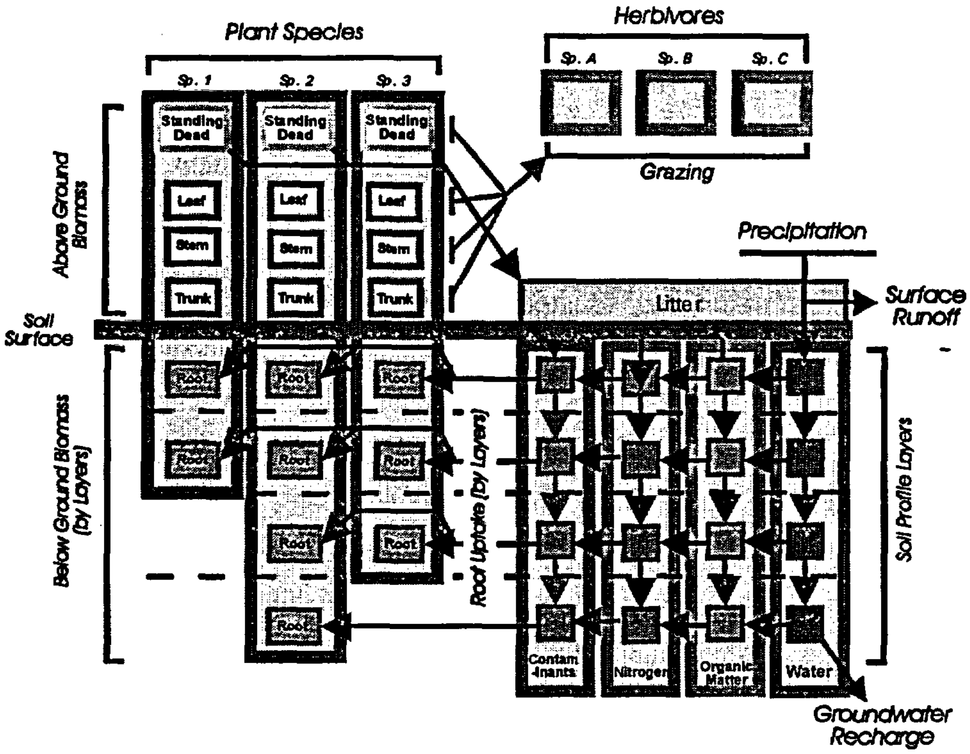


Figure 2. **TerreSIM plot-level structure**

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-m^2) 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-km^2 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.

3.1 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. Special files for rapid data exchange are now being developed to link TerreSIM with MODFLOW.

3.2 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.

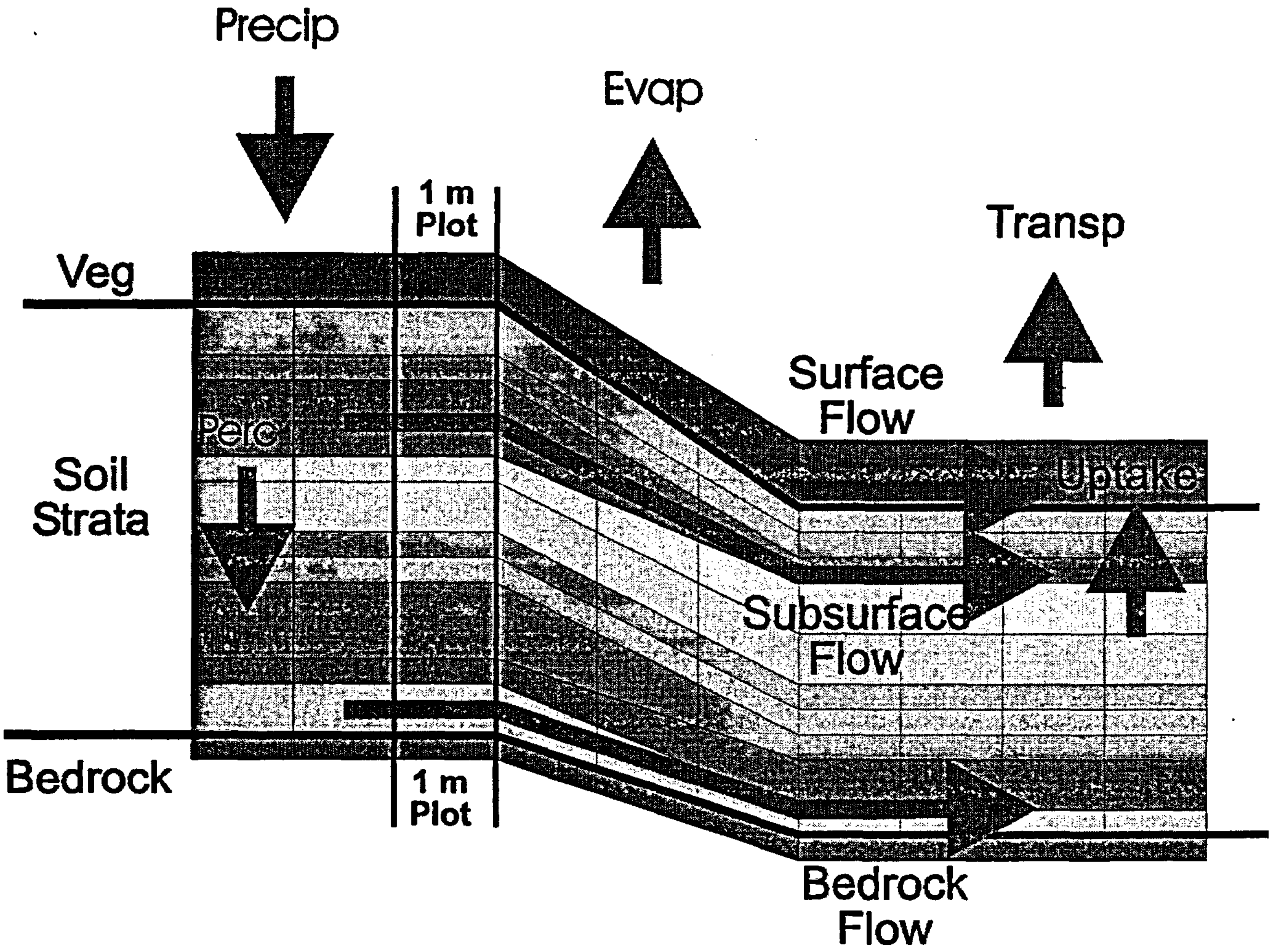


Figure 3. **Hydrological dynamics in the TerreSIM Landscape Module**

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.

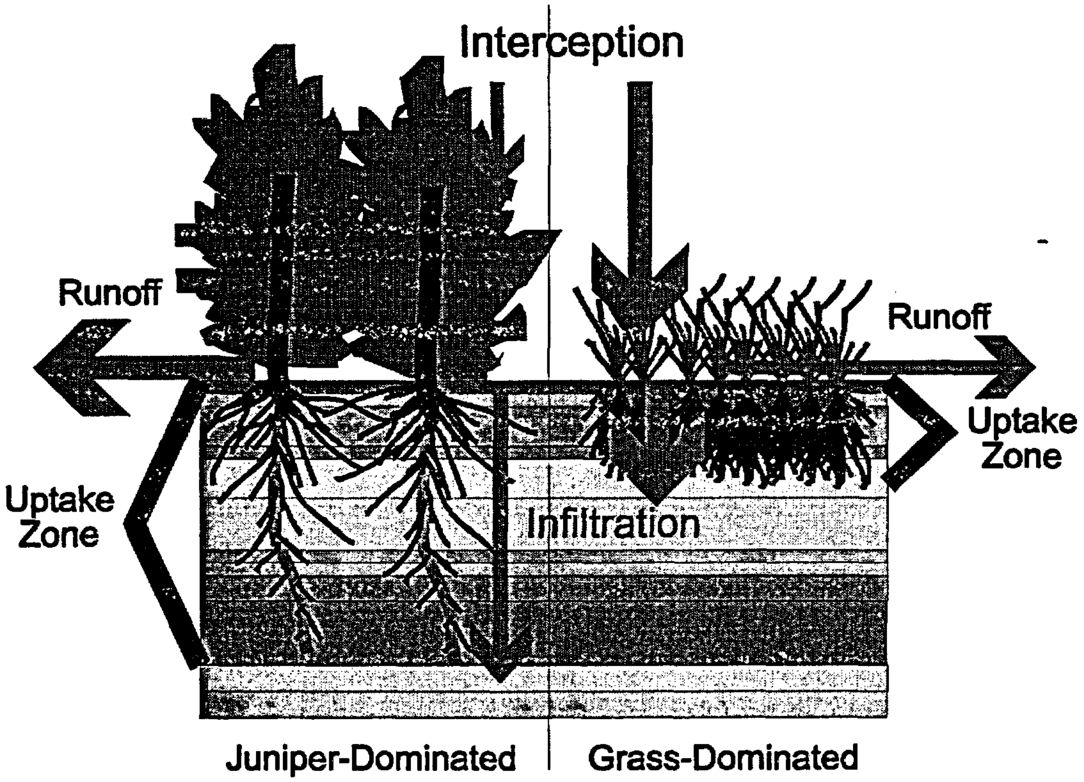


Figure 4. **Hydrological dynamics in grassland and juniper woodlands**

4.0 MODEL INPUT

4.1 Background

Application of the TerreSIM model to any management situation requires development of input parameters. 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 seasonality. 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.

4.2 Climate, Landscape, and Soils

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 about 20 miles to the east. This data set includes 44 yr of complete daily precipitation data over the period 1949-1993, with an average annual precipitation of approximately 45 inches. TerreSIM simulation runs utilize this data set beginning in year 1949 through however many years the simulation continues.

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: 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 design topography for the facility and the immediate surroundings was developed from the preliminary disposal cell design. The total area for containment of 10 million cubic feet of material is approximately 17.8 acres (773,736 ft^2) with approximately 8 acres (346,487 ft^2) on the top surface, and the remainder of the area encompassing the four sides with 5:1 slopes. The simplified community scale TerreSIM application modeled a portion of the top section of the preliminary disposal cell design. This modeled area was $10{,}000 m^2$, or 2.5 acres with a 1% slope. Infiltration would be the greatest on the flatter slopearea, therefore the simplified model application estimates infiltration for the entire mound conservatively. The planned cover materials on the top surface of the cell consist of a sandy silt topsoil over a gravelly clay subsoil. Beneath the subsoil is a coarse zone of gravel to provide a lower limit on root penetration and moisture extraction. The thickness of the topsoil zone in this model run was 2 feet and the thickness of the subsoil zone was 9 feet.

4.3 Plant Community

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.

5.0 SIMULATION RESULTS

In this report, the results of one scenario are presented in a summary table for annual plant community and hydrological dynamics over the 200-year simulation period. The single scenario was based on no disturbance options, such as fire, grazing, crop production. This provides a view of the successional development of the plant community for evaluation. A 200-year summary is presented for water dynamics.

5.1 Plant Community Dynamics

This simplified application modeled plant species from the seed bank, and did not include any plantings. The TerreSIM simulation indicates that a productive plant community should develop on the cover within five years (Table 1). As would be expected, the perennial grasses dominate for the first 20 years as the trees are becoming established. The trees then dominate and continue to dominate the system over time. No annual grasses or any type of forbs or shrubs were included in this simplified application, otherwise a more complete plant community would have developed. However, the grasses and the trees used in this application satisfy the need for a general overview of what can be expected for the vegetation development on the disposal cell.

5.2 Water Dynamics

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. Drainage is percolation of water through the cover profile, past the rooting zone.

Table 1. **TerreSIM simulation results for end-of-growing season aboveground biomass (g/m^2) over 200 years**

Year	Total	Total Trees	Total Grass	Sycamore	Hickory	Ash	Red oak	Post oak	Big bluestem	Indian grass	Little bluestem
1	96	82	13	24	23	13	10	13	2	3	7
5	467	128	339	48	42	14	10	13	180	12	147
10	1731	171	1559	76	59	14	10	13	878	45	636
15	1648	215	1433	106	74	14	10	12	777	67	590
20	1952	268	1684	143	91	13	9	12	843	131	710
25	1899	380	1519	224	124	12	9	11	739	176	604
30	1933	553	1380	354	169	11	9	10	693	136	552
35	2072	800	1272	544	229	10	8	9	649	118	504
40	2351	1182	1170	851	304	10	8	9	607	103	460
45	2805	1732	1073	1302	406	9	8	8	566	89	418
50	3151	2260	891	1755	482	8	7	8	474	72	345
55	3709	2902	807	2304	577	8	7	7	436	62	309
60	3930	3279	651	2632	626	7	7	6	352	50	250
65	4128	3593	535	2918	657	7	6	6	292	40	203
70	4613	4151	462	3409	724	6	6	6	255	33	174
75	4782	4418	364	3653	748	6	6	5	201	26	137
80	4972	4672	300	3884	772	5	5	5	168	21	112
85	5216	4974	242	4165	793	5	5	4	135	17	90
90	5451	5256	195	4436	806	5	5	4	110	13	72
95	5430	5277	153	4464	800	5	5	4	87	10	56
100	5568	5441	127	4617	812	4	5	4	72	8	46
150	6397	6384	13	5592	785	2	3	2	8	1	4
200	6853	6851	1	6139	708	1	2	1	1	0	0

For the simulated 10,000 m^2 subset of the top area of the disposal cell, total drainage equals 88,566 m^3 (23,399,800 gal) of water over a 200 year period (Table 2). The first 30% of total drainage occurs within 4 years, which corresponds to the initial development of vegetation, and 50% in 22 years. Drainage ceases from years 10-20, while the grass community is dominant, and then occurs again in years 20-45, as the trees are becoming more dominant and shade out the grasses. Drainage ceases by year 45, when the tree component of the vegetation is established successfully. The years of drainage from 20-45 are most likely a relic of the simplified plant community that was modeled, and are not completely indicative of real world values, where an understory of many species of forbs and grasses would exist under the trees, which would utilize the excess water. Only eight species were used in this simplified application, so complete community dynamics could not be included. However, the numbers are indicative of general trends that would be expected as the plant community developed over the disposal cell.

Development of the vegetation results in increased water use from two sources, transpiration and evaporation (Table 2). Increased transpirational water use during succession occurs because of 1) increases in total plant biomass and 2) changes water-use efficiencies related to changes in species composition. In addition, there is an increase in structure of the plant community that occurs during succession. This results in an increase in plant height and leaf area. Both of these structural aspects increase the amount of precipitation that is caught by vegetated surfaces and therefore evaporated directly back into the atmosphere. Few models are able to simulate these structural-induced changes in evaporation.

The TerreSIM simulations indicate that evaporation does increase as the plant community develops (Table 2). This is especially important when a significant amount of the precipitation received occurs as relatively small precipitation events. In those years, the amount lost via evaporation from plant surfaces may equal or exceed the amount transpired.

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

Year	Precipitation	Evaporation		Transpiration	Runoff	Cover Drainage
		Canopy	Soil			
1	11371.58	538.66	697.94	3573.56	0	3764.52
2	11414.76	575.63	422.71	439.23	12.53	8387.03
3	12453.62	585.62	49.54	640.42	0	9080.96
4	8801.1	672.21	38.94	1312.55	0	5957.82
5	10248.9	1058	45.76	2799.96	0	5933.47
6	7762.24	1091.12	44.32	4810.68	0	1697.17
7	7683.5	2178.5	65.62	5868.61	0	353.93
8	8135.62	1984.78	74.07	4563.68	0	0
9	17363.44	4356.05	67.39	7878.12	0	3082.79
10	14711.68	5219.13	89.23	8255.57	18.11	0
11	13032.74	5381.88	89.5	7017.94	0	0
12	10398.76	4267.58	87.3	5100.38	0	0
13	13634.72	5267.29	82.89	6937.68	57.67	0
14	9349.74	4456.02	77.62	4052.35	0	0
15	6670.04	3615	84.58	2625.54	0	0
16	9733.28	4153.65	65.43	4333.81	0	0
17	9309.1	4143.59	78.96	4288.79	0	0
18	9636.76	4028.91	64.1	3294.21	0	0
19	9903.46	4976.71	88.84	3482.84	0	0
20	14066.52	5524.54	71.26	4338.71	0	1227.37
21	12448.54	4793.25	78.13	3935.65	38.06	572.72
22	12608.56	5494.96	55.84	3404.25	26.13	3562.98
23	12344.4	5356.85	56.83	3043.42	28.72	1077.57
24	8968.74	3929.28	53.92	2853.66	0	1080.31
25	18435.32	7371.92	69.29	2730.96	28.29	4687.02
26	12796.52	4963.66	60.78	2652.09	8.54	4079.55
27	11468.1	5293.3	47.78	2525	0	2535.06
28	10038.08	5300.43	59.72	2468.9	0	2248.31

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 (continued)**

Year	Precipitation	Evaporation		Transpiration	Runoff	Cover Drainage
		Canopy	Soil			
29	9070.34	4191.1	42.81	2415.21	0	1507.37
30	9316.72	3747.31	31.29	2492.31	0	1955.57
31	9900.92	4964.12	56.17	2477.9	0	1399.66
32	7706.36	4091.2	50.92	2575.67	0	468.43
33	13703.3	6701.77	59.6	2563.81	36.93	3464.54
34	10063.48	4500.23	49.63	2685.37	0	1380.28
35	14046.2	6475.75	59.57	2676.31	7.73	2214.27
36	12951.46	5870.51	44.47	2825.96	0	2220.1
37	12633.96	6085.99	64.82	2820.02	0	2959.84
38	14135.1	5421.68	49.39	2991.57	0	1733.49
39	8524.24	4578.44	37.04	2910.1	0	1964.18
40	11386.82	5557.21	46.37	3190.69	0	377.47
41	19281.14	8458.4	64.19	3207.76	2.51	3124.78
42	14051.28	5690.58	61.1	3478.17	0.63	2367.24
43	11551.92	5754.95	55.98	3468.1	0	969.63
44	12600.94	5496.03	60.61	3788.37	0	525.47
45	11371.58	6315.26	45.49	3702.19	0	605.22
46	11414.76	6680.97	49.3	4037.23	0	0
47	12453.62	6864.35	41.25	3026.42	0	0
48	8801.1	5672.7	35.96	2864.53	0	0
49	10248.9	6692.33	51.46	3099.71	0	0
50	7762.24	3987.78	37.94	2336.9	0	0
60	9733.28	6008.85	25.39	2521.91	0	0
70	12796.52	7747.92	29.3	3966.4	0	0
80	12951.46	7905.1	24.85	2794.24	0	0
90	11414.76	7976.4	25.15	2241.97	0	0
100	10398.76	7110.17	23.81	2333.08	0	0
110	12608.56	10107.73	27.26	2850.17	0	0
120	7706.36	6089.37	12.7	847.61	0	0
130	14051.28	9880.19	27.09	1960.25	0	0
140	8135.62	5189.22	11.83	1542.69	0	0
150	9636.76	6258.56	12.11	1100.82	0	0
160	10038.08	8591.55	19.86	1413.4	0	0
170	14135.1	8229.49	15.7	1763.24	0	0
180	8801.1	6560.82	11.21	1426.29	0	0
190	9349.74	7175.5	11.31	1514.7	0	0
200	8968.74	6556.16	14.68	1350	0	0
Total	2284907.80	1433128.61	7109.02	474803.50	349.66	88566.12
% of Ppt	100	62.72	0.31	20.77	0.015	3.87

For the first 45 years, the average cover drainage (past the root zone) is approximately 7.75 inches/yr, or 17.2% of the total precipitation over the 45 years. For the last 155 years of the simulation, cover drainage is zero.

6.0 CONCLUSIONS

The preliminary TerreSIM application run indicates that the vegetative community easily becomes successfully established and thrives on the Sequoyah Fuels disposal cell. The perennial grasses become fully established by year 4, and the trees begin to dominate by year 20, becoming fully established by year 45. Because of the simplified plant community, and limited area used within this simplified application of the TerreSIM model, estimates of not only plant growth, but also water infiltration, are very coarse. A more diverse plant community would be planted and would establish at this site, and infiltration in years 20-45 would be greatly reduced, if it occurred at all, with the understory species that would develop with the trees. In addition, the limited footprint utilized is estimated to be a very conservative approach in estimating infiltration, because the entire disposal cell design would initiate much more runoff due to the sloping sides, than the 1% slopes of the top of the disposal cell. Therefore, this simplified application overestimates the total infiltration that would occur at the site.