EFFECTS OF VEGETATION AND SOIL-SURFACE COVER TREATMENTS ON THE HYDROLOGIC BEHAVIOR OF LOW-LEVEL WASTE TRENCH CAPS

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ABSTRACT

Preliminary results are presented on a three-year field study at Los Alamos National Laboratory to evaluate the influence of different low-level radioactive waste trench cap designs on water balance under natural precipitation. Erosion plots having two different vegetative covers (shrubs and grasses) and with either gravel-mulched or unmulched soil surface treatments have been established on three different soil profiles on a decommissioned waste site. Total runoff and soil loss from each plot is measured after each precipitation event. Soil moisture is measured biweekly while plant canopy cover is measured seasonally. Preliminary results from the first year show that the application of a gravel mulch reduced runoff by 73 to 90%. Total soil loss was reduced by 83 to 93% by the mulch treatment. On unmulched plots, grass cover reduced both runoff and soil loss by about 50% compared to the shrub plots. Continued monitoring of the study site will provide data that will be used to analyze complex interactions between independent variables such rainfall amount and intensity, antecedent soil moisture, and soil and vegetation factors, as they influence water balance, and soil erosion.

INTRODUCTION

The United States Department of Energy estimates that $6x10^6 m^3$ of low-level radioactive waste (LLW) will be produced by the year 2020 (1). Disposal site designs will be required to ensure compliance with federal and state regulations. In addition, many old disposal landfills will require remedial action to correct current and/or potential problems with waste containment. Because water is the major driving force leading to LLW transport from landfills (2) current regulations are focused on control of water balance and erosion (3). In order to demonstrate compliance with the regulations, it is essential to understand and be able to model water balance and erosion as a function of the physical and biological features of the site in order to design new sites and remediation procedures that meet regulatory requirements (4).

The hydrologic response off a LLW site to inputs of precipitation is evaluated by measuring and/or modeling runoff, evapotranspiration, infiltration, soil water storage, and deep percolation. Factors that influence the response include soil type and thickness, slope and slope length of the cover, and the type and amount of vegetative cover.

The development of trench cover technology at Los Alamos has been greatly enhanced by USDA technologies utilizing rainfall simulators and experimental plots consisting of trench cap designs (2,5,6,7,8,9). Results from these studies have been used to estimate Universal Soil Loss Equation (USLE) parameters and compare the effects of various canopy and surface covers on water balance and erosion.

Water balance modeling studies were also used to design and emplace a demonstration study on a decommissioned LLW site to evaluate the performance of several trench cap designs that were subjected to natural precipitation and physical and biological features that are more typical of a LLW site. The purpose of the study was to measure runoff, erosion and soil moisture status as a function of time and to develop a cost-effective waste site closure methodology for Los Alamos that maximizes surface stability and minimizes site maintenance. The cap designs include the use of gravel mulches, different vegetation species and different soil types including a layered soil/rock profile designed as a capillary moisture barrier. This paper describes the design and construction of the demonstration plots and preliminary results on runoff and sediment yield from the first year of operation.

MATERIALS AND METHODS

Site History

The Los Alamos National Laboratory Technical Area 21 (Area B) is one of the oldest waste landfill sites at Los Alamos. It was constructed around 1944 and decommissioned in 1947 (4). During its use a wide variety of hazardous and low level radioactive wastes were discarded into trenches at Area B. A final cover of crushed Bandelier Tuff was placed over the trenches to complete closure (10). In 1982 the eastern one-third of Area B received a new trench cap as a part of a remedial-action field test (4). During the remedial action, an experimental profile designed to prevent animal and root intrusion (or biointrusion) into the waste was installed in the central part of Area B (Fig. 1). The entire experimental trench cap profile, from the bottom up, consists of 75 cm of 10 to 30-cm diameter cobble, a 25-cm gravel layer, 45 cm of crushed tuff, all overlain by 15 cm of topsoil (3). Two additional areas (east and west) received a standard trench cap cover consisting of about 75 cm of crushed tuff overlain by 15 cm of top soil (Fig. 1). This type of soil profile has been used as the standard trench cap

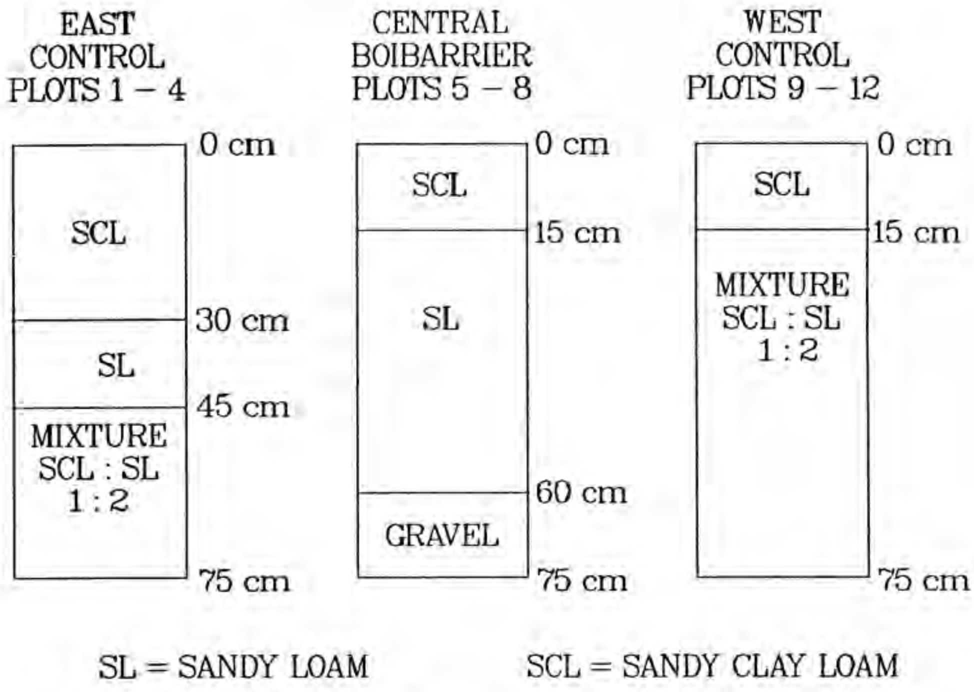

Fig. 1. Soil Profile Layers (0-75 cm) for Each Cluster at Area B.

on LLW sites at Los Alamos and a significant amount of data already exists on its physical and ecological characteristics (8,11). The topsoil used in the landfill cover at Area B is a local Hackroy sandy clay loam while the crushed tuff is classified as a sandy loam (12). The east profile has twice as much top soil and thus has a higher water holding capacity than the west soil profile (13).

Plot Installation

The plot configurations were consistent with those from earlier LLW studies at Los Alamos in order to utilize existing data bases and models (4,5,6). Twelve plots (3 x 11 m) were established at Area B with the long axis parallel to the slope (Fig. 2). Four plots were placed on each of the three soil profiles described in Fig. 1. Treatments by soil profile include two vegetative covers: two plots with a shrub overstory of rubber rabbitbrush (Chrysothamnus nauseosus) and a sparse understory of mixed grasses and forbs, and two with a mixed grass and forb cover. One plot from each pair with the same plant cover was randomly assigned a gravel mulch treatment (Fig. 2). The gravel was $\leq$1.5-cm diameter and was applied at 13 kg/m^2.

Each plot was bordered on three sides by 25-cm metal strips installed with 16 cm inserted into the soil and 9 cm extended above the soil surface. On the downslope end, a 40-cm metal end plate with a 5-cm lip was inserted into the soil so that the lip was flush with the soil surface. Total runoff from the plots was measured with the collection system described below.

Collection of Runoff Samples

Total runoff from each of the 12 study plots was collected by a gutter system at the lower end of the plot and diverted through a buried drain pipe into a recording flume equipped with a Belfort 5-FW-1 series liquid level recorder (Belfort Instrument Co., Baltimore, Maryland, 21231). The amount of runoff passing through the flume was continuously recorded for each precipitation event. Total runoff was then collected in a 180-ℓ tank. Inside the tank a 10-ℓ graduated bucket collected the runoff from small precipitation events. When the runoff was greater than 10ℓ, the total runoff volume was estimated by measuring the water level in the rectangular tank. The tanks were calibrated against volume allowing easy conversion of the water level to total runoff in ℓ. For small amounts of runoff(<5-ℓ), total runoff was collected in 1.0-ℓ tared bottles. Large amounts of runoff (>5-ℓ) were placed in large containers and allowed to sit for 24 hrs and then separated into 2 fractions. The supernatant was decanted back into the collecting tanks and the volume determined. This fraction was then vigorously agitated and 3 separate $\approx$1.0-ℓ aliquots taken to determine suspended sediment concentration in the supernatant. The settled sediment on the bottom of the container was collected in pre-tared bottles. After the sample collection was complete, all equipment was rinsed to remove all residual sediments and reinstalled to collect runoff from the next precipitation event.

The collected samples were screened to remove insects, debris, and pebbles and weighed. A minimum settling time of 1.5 days (or until the sample was clear) allowed

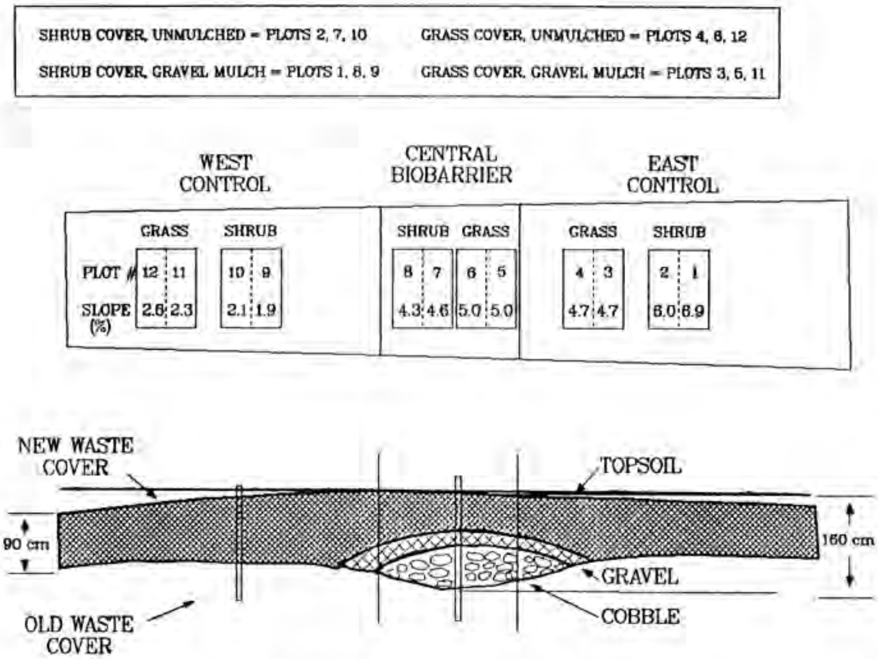

Fig. 2. Plan View of Area B Showing Experimental Plot Locations, Surface Treatments, Average Percent Slope and Showing Cross Section of Soil Profile Characteristics.

larger particles ($\geq 2\mu m$) to settle. The supernatant was then siphoned off and the sediment samples were dried to a constant weight at 105°C. Total soil loss from each plot was calculated by adding the settled sediment weight and the suspended sediment load calculated for the runoff supernatant.

Additional Measurements

Three moisture access tubes for a Campbell Pacific Model 503 neutron moisture probe, (CPN Corp, Pacheco, California, 94553) were installed to a depth of 1 m on each of the 12 plots. Soil moisture was measured biweekly at depths of 20, 40, 60, 80, and 100 cm below ground level using a probe that had been previously calibrated (14). In addition, soil moisture in the top 15 and 30 cm was measured using time-domain reflectrometry probes (IRAMS Model 6000, Soil Moisture Equipment Co., Santa Barbara, California, 93105) emplaced at three locations on each plot.

Measurements and estimates of plant cover were performed periodically by two previously developed methods (13). The shrub cover and canopy spherical volume of each shrub were estimated three times during the growing season from shrub dimensions. Canopy cover and ground cover (plant crowns, litter, and gravel) were also estimated using a point-frame. A complete record of vegetation and mulch cover was obtained at the end of the 1987 growing season. These additional measurements will continue during the course of the study and will allow us to assess the influence of vegetation and surface treatments on soil moisture storage. The effects of the season and status of plant canopy coverage and antecedent soil moisture conditions on runoff and erosion will also be analyzed.

RESULTS

During the 1987 summer growing season, 39 storms with measurable precipitation were recorded at Area B. Of these, 29 events resulted in runoff from at least one plot and data on these were recorded for 21 events. Precipitation per storm varied from 2 to 14 mm for a total precipitation addition of 105 mm for the 21 events. Six events were either missed partially or entirely at the start-up of the study when equipment installation was not complete. Two more events have incomplete data due to insufficient capacity of the runoff collecting tanks or other equipment failure. Capacity of the runoff tanks has been increased to prevent further loss of data due to overflow problems.

As shown on Table I, the percent ground cover on plots with a grass cover were much higher. Estimated ground cover on the plots (gravel, litter, grass crowns, and shrub stems) ranged from 75 to 90% on the gravelled plots, from 27 to 40% on the unmulched grass plots, and from 19 to 21% on the unmulched shrub plots (Table I). Unmulched grass plots had higher ground cover than the comparable unmulched shrub plots because of the high cover attributable to the grass crowns. Percent of ground covered by plant canopies (foliar cover in Table I) ranged from 31 to 62% on the grass plots, and from 37 to 56% on the shrub plots.

Preliminary data on runoff and erosion from each plot, for the 21 events where data are complete, are shown in

TABLE I

Ground and Foliar Cover, Runoff, and Soil Loss in 1987.

	SHRUB, UNMULCHED			SHRUB, GRAVEL MULCH			GRASS UNMULCHED			GRASS, GRAVEL MULCH		
PLOT	2	7	10	1	8	9	4	6	12	3	5	11
LOCATION	EAST	CENTRAL	WEST	EAST	CENTRAL	WEST	EAST	CENTRAL	WEST	EAST	CENTRAL	WEST
SLOPE (%)	6.0	4.6	2.1	6.9	4.3	1.9	4.7	5.0	2.6	4.7	5.0	2.3
GROUND COVER (%)[a]	20	21	19	81	78	81	40	39	27	90	75	86
FOLIAR COVER (%)[b]	44	46	37	56	53	42	31	62	41	40	53	47
TOTAL RUNOFF (l)[c]	904	829	557	78	24	117	667	35	514	209	28	81
RUNOFF/PRECIP (%)[d]	23.2	21.6	14.8	2.0	0.7	3.1	17.5	0.9	13.3	5.8	0.7	2.2
(coeff. variation)	0.92	1.03	1.12	1.49	0.49	1.13	1.07	0.51	1.22	1.16	0.52	1.07
TOTAL SOIL LOSS[c] (g/plot)	7909	4718	3065	347	317	658	4630	381	2583	955	232	388
TOTAL SOIL LOSS[c] (Mg/ha)	2.43	1.45	0.94	0.11	0.10	0.20	1.42	0.12	0.79	0.29	0.07	0.12
SEDIMENT CONC. (g/l)[e]	6.73	7.26	6.86	3.98	6.80	4.37	5.68	6.12	7.50	4.99	4.21	3.75
(coeff. variation)	0.99	1.47	1.64	1.55	1.53	1.09	1.07	1.43	1.30	1.32	1.53	1.37

[a]Percent ground cover by gravel, litter, and plant crowns.

[b]Percent soil surface covered by plant canopies.

[c]Totals of 21 storm events.

[d]Mean and coefficient of variation (standard deviations/mean) for runoff as percent of precipitation.

[e]Mean and coefficient of variation (standard deviation/mean) for sediment concentration (soil loss/runoff).

Table I. Total runoff collected on the unmulched shrub plots ranged from 557 to 904*l*, with the highest runoff occurring on the plot having the steepest slope. On the other three surface treatments, runoff was lower on plots on the central soil profile that incorporated a cobble-gravel layer under a shallow soil and crushed tuff layer. The greatest differences were seen among plots with the grass, unmulched surface treatments, where the central plot had only 35*l* runoff collected over the season compared with 667*l* on the east plot. This large difference may be partly attributable to the higher foliar cover (62% compared to 31%) on the central plot.

Trends in runoff versus treatment were explored in more detail by normalizing runoff as a percent of precipitation for each event. Mean values of percent runoff (Table I) had high coefficients of variation (C.V.). The central plots 5, 6, and 8 had very uniform C.V. values from 0.49 to 0.52, with the remaining plots having C.V. values ranging from 0.92 to 1.49. Means of percent runoff by treatment (Table II) showed strong trends which were tested for significance in an analysis of variance (ANOVA) using a split-split plot design (15). Mean percent runoff was significantly different between plot location, between vegetation treatments, and between mulch treatments. The mulch treatment had the greatest effect on percent runoff, causing a runoff reduction of 90% on the shrub plots and 73% on the grass plots over unmulched treatments. Using grass as a cover on the unmulched plots reduced runoff by about 50% in comparison to the shrub cover likely as a result of the much higher ground cover on the grass plots. With a gravel mulch, the shrub cover (which also has a sparse grass understory) resulted in runoff reduced to 67% of that observed on the grass plots. This could be attributable to the slightly higher foliar cover on the shrub/gravel plots than on the grass/gravel plots, and also to the more complex canopy structure on the shrub plots that would mitigate raindrop impact more efficiently than the grass canopy.

Soil loss for the events recorded showed wide variability between storms and between treatments. Overall totals (Table I) are presented both as g/plot and Mg/ha. Inspection of means of soil loss by treatment (Table II) shows that soil loss on the gravelled plots was only 7 to 17% of that observed on the unmulched plots. Unmulched grass plots had about 50% of the soil loss observed on the unmulched shrub plots. A three-way ANOVA using plot totals as the variable, showed significant differences (P 0.01) in total soil loss between gravelled and unmulched plots. Type of plant cover was not a significant ($P = 0.01$) treatment effect. It should be noted that these totals do not represent yearly soil loss since runoff from several storm events (including two that produced high runoff and soil loss) was not collected.

The sediment concentration in each runoff collection (total sediment/total runoff) and the mean per plot was calculated (Table I) to allow more detailed statistical analysis. Considering treatment means, sediment concentration was reduced by 23 to 33% by the gravel mulch (Table II). Differences between treatment means were analyzed using an ANOVA with a split-split plot design (15). Soil surface treatment was a significant effect, but plot profile and vegetative cover treatment effects were not significant.

There are many factors contributing to the high variability in both runoff and erosion that are not addressed in these preliminary results. The degree of disturbance of the soil and vegetation in setting up the plots and applying the gravel mulch was about the same for all plots. However, slopes and soil profiles vary among the plots, and plant cover variability throughout the year is largely undocumented. These factors will be addressed in future analyses of data over the entire three-year study period.

DISCUSSION

Much of the variability in runoff and erosion between events is undoubtedly due to the differences in intensity and duration of the storms, as well as the differences in antecedent moisture conditions on the plots at different times of the season. These factors, along with the variation between plots with respect to slope, vegetation, and soil profiles, make it difficult to form conclusions, especially after only one season of data collection. However, this complexity is also the source of one of the greatest values of a study of this nature, which is to document the range of variation likely to be found on actual waste sites receiving only natural precipitation.

The effects of the storm intensity on runoff and erosion can be seen by comparing the event of 7/17/87 with that of 7/23/87, the most severe event for which complete data were recorded in 1987 (Table III). The 7/17/87 storm had a higher total precipitation (14.1 mm compared to 10.1 mm on 7/23/87) but much lower intensity and longer duration. The resulting maximum runoff observed (78.6*l* on plot 2) and total sediment load (87 g) were much less than those observed for the 7/23/87 storm when plot 2 produced 147*l* runoff and 1741 g total sediment load. Extremes of plot-to-plot variation within one surface treatment were also seen during high intensity storms. During the 7/23/87 event, plot 4 had over 20 times the runoff volume and over 18 times the sediment load recorded on plot 6. Such variation is likely to occur on closed waste sites that will inevitably have areas with widely different slopes and vegetative cover. The implication is that erosion may be concentrated in very local parts of the waste site leading to rapid failure of the cover in such areas.

A study in Missouri demonstrated that spatial variability of runoff over a series of 40 contiguous plots with uniform management was high under natural precipitation (16). For example, a precipitation event of 96 mm produced

TABLE II

Mean Runoff, Sediment Concentrations, and Total Sediment Loss for 1987.

	Shrub Plots			Grass Plots		
	Unmulched	Gravel	Gravel/Unmulched[1]	Unmulched	Gravel	Gravel/Unmulched
Runoff/Precip. (%)	19.84[a,2]	1.94[b]	0.10	10.58[c]	2.89[d]	0.27
Sediment Conc. (g/ℓ)	6.95[a]	5.05[b]	0.73	6.43[a]	4.32[b]	0.67
Total Soil Loss (Mg/ha)	1.37[a]	0.09[b]	0.07	0.65[a]	0.11[b]	0.17

[1]Ratio of gravel/unmulched shows the average effect of a gravel mulch on each vegetation type.

[2]Means with the same letter are not significantly different at $P < 0.01$.

TABLE III

Total Runoff Volume and Total Sediment Load for Two Precipitation Events in 1987.

		7/17/87 (14.12 mm)		7/23/87 (10.05 mm)	
Plot	Treatment	Runoff Volume (ℓ)	Soil Loss (g)	Runoff Volume (ℓ)	Soil Loss (g)
2	S/U	78.6	87	147.0	1741
7	S/U	65.8	93	135.3	1418
10	S/U	30.3	69	112.9	1401
1	S/G	1.7	13	26.3	100
8	S/G	2.3	8	3.1	55
9	S/G	5.5	18	35.0	276
4	G/U	34.4	108	116.0	1300
6	G/U	3.5	19	5.3	71
12	G/U	14.5	44	118.7	1159
3	G/G	6.1	18	45.0	361
5	G/G	3.5	8	4.2	28
11	G/G	5.4	22	21.5	93

[a]S/U = shrub unmulched
S/G = shrub gravel mulch
G/U = grass unmulched
G/G = grass gravel mulch

a mean runoff value of 48 mm, with the range in runoff over the 40 plots being from 18 mm to 72 mm. It is not surprising, therefore, that similar or greater variability was observed in the Area B data given the differences in site factors between the three clusters of plots at the site.

Laflen (17) has shown that the effect of mulches on erosion rates can be highly dependent on soil types and slopes, and that runoff amounts are not necessarily correlated with surface cover in the form of crop residues. Laflen concluded that the use of standardized simulated rainfall to study runoff and erosion characteristics may be masking complex interactions between independent variables such as rainfall amount, intensity, antecedent moisture, and soil and vegetation factors. Continued monitoring of the Area B study will result in a data base that can be used to analyze such interactions and evaluate the validity of using results from simulated experiments to infer erosion and runoff characteristics under natural conditions.

The reduction in total soil loss resulting from the application of a gravel mulch (0.17 to 0.07, Table II) is comparable to the cover management factors (0.016 to 0.050) observed using simulated rainfall on experimental trench cap plots with gravel mulches at Los Alamos (8). Additional data over the next two years will allow us to calculate, independently, the factors needed to predict soil loss at a waste site using the USLE model (9). Comparisons will then be made with all the factors estimated from rainfall simulation studies as well as with the actual runoff and sediment transport measured on sites in the southwest (5,6,18).

It is anticipated that the comparison between the effects of summer and winter precipitation will provide valuable data on the differences in erosion rates resulting from short duration, high intensity storms of the summer monsoon, and the longer, less intense, winter storms that often consist largely of snow. The multiplicity of factors operating in natural field systems (precipitation intensity and duration, soil conditions, soil temperatures, vegetation seasonality and spatial variability) have previously made it extremely difficult to predict effects of natural precipitation with accuracy. The use of predictive models is a necessary step in trench cap design and currently several hydrologic models are in use at Los Alamos to aid in the assessment of different trench cap configurations (12). The data obtained from this ongoing project at Los Alamos will be invaluable in verifying such models for the design of trench caps in semi-arid regions.

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REFERENCES

1. U. S. Department of Energy, Office of Nuclear Energy, "Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics," Department of Energy Report DOE/NE-0017-1, Nat'l Technical Inf. Service, Springfield, VA (1982).
2. J. W. Nyhan, G. L. DePoorter, B. J. Drennon, J. R. Simanton, and G. R. Foster, "Erosion of Earth Covers Used in Shallow Land Burial at Los Alamos, New Mexico," p. 361-366, Journal of Environmental Quality, Vol. 13, no. 3 (1984b).
3. R. J. Lutton, G. L. Regan, and L. W. Jones, "Design and Construction of Covers for Solid Waste Landfills," U. S. Environmental Protection Agency, EPA-600/2-79-165, p. 250 (1979).
4. T. E. Hakonson, "Evaluation of Geologic Materials to Limit Biological Intrusion into Low-Level Radioactive Waste Disposal Sites," Los Alamos National Laboratory Report LA-10286-MS (1986).
5. J. R. Simanton and K. G. Renard, "Seasonal Change in Infiltration and Erosion From USLE Plots in Southeastern Arizona," Proceedings of the 1982 Meetings of the Arizona Section American Water Resources Assn. and the Hydrology Section - Arizona Academy of Science, Tempe Arizona, April 24, 1982, Vol. 12, p. 37-46 (1982).
6. J. R. Simanton, C. W. Johnson, J. W. Nyhan, and E. M. Romney, "Rainfall Simulation on Rangeland Erosion Plots," Proceedings of the Rainfall Simulator Workshop, Tucson, Arizona, January 14-15, 1985, p. 11-17 (1985).
7. W. H. Wischmeier and D. D. Smith, "Predicting Rainfall Erosion Losses--A Guide to Conservation Planning," USDA Handbook 537, (US Government Printing Office, Washington, DC (1978).
8. J. W. Nyhan and L. J. Lane, "Rainfall Simulator Studies on Earth Covers Used in Shallow Land Burial at Los Alamos, New Mexico," Proceedings of the Rainfall Simulator Workshop, Tucson, Arizona, January 14-15, 1985, Vol. 12, p. 39-42 (1985).
9. J. W. Nyhan and L. J. Lane, "Erosion Control Technology: A User's Guide to the Use of the Universal Soil Loss Equation at Waste Burial Facilities," Los Alamos National Laboratory Report LA-10262-M (1986).

10. M. A. Rogers, "History and Environmental Settings of LASL Near Surface Land Disposal Facilities for Radioactive Wastes (Areas A, B, D, C, E, F, G and T) A Source Document," Los Alamos National Laboratory Informal Report LA-6848-MS, Vol. I., p. B-1 - B-9 (1977).

11. W. V. Abeele, M. L. Wheeler, and B. W. Burton, "Geohydrology of Bandelier Tuff," Los Alamos National Laboratory Report LA-8962-MS (1981).

12. J. W. Nyhan, L. W. Hacker, T. E. Calhoun, and D. L. Young, "Soil Survey of Los Alamos County, New Mexico," Los Alamos Scientific Laboratory Report LA-6779-MS (1978).

13. F. J. Barnes and J. C. Rodgers, "Evaluation of Hydrologic Models in the Design of Stable Landfill Covers," IAG. No. DW899930235-01-1, Final Report, U. S. Environmental Protection Agency, Cincinnati, Ohio (1987).

14. J. W. Nyhan, B. J. Drennon, J. C. Rodgers, and W. V. Abeele, "Spatial Resolution of Soil Water Content By Three Neutron Moisture Gauges," Los Alamos National Laboratory Report LA-UR-83-2863 (1983).

15. R. J. Freund and R. C. Littell, "SAS for Linear Models, A Guide to the ANOVA and GLM Procedures," SAS Institute, Cary, NC (1985).

16. T. A. Hjelmfelt and R. E. Burwell, "Spatial Variability of Runoff," J. Irrigation and Drainage Engineering 110, p. 46-54 (1984).

17. J. M. Laflen, "Interpretation of Rainfall Simulator Data," Proceedings of the Rainfall Simulator Workshop, Tucson, Arizona, U.S.D.A. Science and Education Administration Report ARM-W-10, p. 101-107 (1979).

18. G. E. Hart, "A Test of the USLE on Bare and Sagebrush Plots in Utah," Proceedings of the Workshop on Estimating Erosion and Sediment Yield on Rangelands, Tucson, Arizona, March 1981, U.S.D.A. Agricultural Research Service Report, ARM-W-26, p. 101-105 (1982).