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# Erosion of Earth Covers Used in Shallow Land Burial at Los Alamos, New Mexico[1]

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## ABSTRACT

**The Los Alamos National Laboratory and the USDA-ARS examined soil erosion and water balance relationships for a trench cap used for the shallow land burial of low-level radioactive wastes at Los Alamos, NM. Eight 3.05 by 10.7 m plots were installed with bare soil, tilled, and vegetated surface treatments on a 15 by 63 m trench cap constructed from soil and crushed tuff layers. A rotating boom rain simulator was used to estimate the soil erodibility and cover-management factors of the Universal Soil Loss Equation (USLE) for this trench cap and for two undisturbed plots with natural vegetative cover. The implications of the results of this study are discussed relative to the management of infiltration and erosion processes at waste burial sites and compared with similar USDA research performed throughout the USA.**



*Additional Index Words:* **overland flow, runoff, surface hydrology, tillage, Universal Soil Loss Equation, volcanic soils, water erosion.**

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The total volume of low-level radioactive wastes produced in the USA is conservatively projected to total to about 16 million $m^3$ by the year 2020 (U.S. Dep. of Energy, 1982). This increasing production rate is of major concern because new and acceptable sites will be required for the disposal of these wastes. New burial sites need to be selected in a wide range of environments throughout the USA, and actual or anticipated problems with closed shallow land burial sites must also be corrected.

The most popular current method for disposing of low-level radioactive wastes is shallow land burial. Burial trenches range in size from the 4.6-m deep, 3 by 15 m disposal pit at Oak Ridge National Laboratory to the 6.1-m deep, 30 by 300 m trench at Barnwell, SC. After waste materials are placed in these trenches, current management practices range from simple backfilling of the trench to more elaborate installation of multilayered trench caps and revegetation programs.

Once the burial trench receives its final cover, several environmental processes start influencing the configuration and integrity of the surface and subsurface of the trench cap. The most serious problems encountered in shallow land burial are related to water management (Jacobs et al., 1980), as water comes into contact with the buried wastes either from infiltration of precipitation or from trench cap erosion leading to the exposure of the buried waste. Unfortunately, most management practices that reduce erosion of the trench cap will probably enhance infiltration; thus, burial site operators must ultimately arrive at techniques that will optimize control of infiltration and erosion.

Our study investigated the water balance and erosional behavior of burial trench caps for several cover conditions. Plots were established at the Los Alamos Engineered Test Facility (ETF) and were subjected to simulated rainfall to generate infiltration, runoff, and erosion. The effects of actecedent soil water content were evaluated, and the soil erodibility factor ($K$) and the cover management factor ($C$) of the Universal Soil Loss Equation (USLE) were estimated for our trench cap configuration. Data from the study will be used in modeling the hydrologic performance and design of trench caps for specific conditions (Nyhan & Lane, 1982).

## MATERIALS AND METHODS

A 15 by 63 m simulated trench cap was constructed at the ETF in Los Alamos, NM (DePoorter, 1981) to closely match trench caps used for shallow land burial at Los Alamos (Warren, 1980). The configuration of this trench cap consisted of a 15-cm layer of backfilled Hackroy series topsoil which had been stockpiled at the site, underlain by a 90-cm layer of crushed Bandelier tuff backfill, classified as belonging to geologic mapping unit 3 (Rogers, 1977). Both layers were installed with dominant downhill slopes of 7%. We compared the hydrologic behavior of this highly disturbed system with an adjacent undisturbed soil profile with natural cover. The Hackroy sandy loam was classified as a Lithic Aridic Haplustalf (clayey, mixed, mesic family), which formed in material weathered from Bandelier tuff on

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mesa tops (Nyhan et al., 1978). The native overstory vegetation is mainly pinon pine (*Pinus edulis* Engelm.), one-seeded juniper [*Juniperus monosperma* (Engelm.) Sarg.], and scattered ponderosa pine (*Pinus ponderosa* Laws.). Our natural study plots also contained blue grama [*Bouteloua gracilis* (H.B.K.) Lag.], dropseed [*Sporobolus cryptandrus* (Torr.) Gray], snakeweed [*Gutierrezia microcephala* (DC.) Gray], pinque [*Hymenoxys richardsonii* var. *floribunda* (Gray) Parker], and prickly pear (*Opuntia polyacantha* Haw.).

The criteria for erosion plot selection were based on the requirements set forth during the original development of the USLE on rangelands (Wischmeier & Smith, 1978) and on the constraints of the rainfall simulator (Simanton & Renard, 1982). The eight experimental plots on the simulated trench cap and the two natural plots were each 3.1 by 11 m, with the long axis parallel to the slope. Each plot pair on the trench cap was constructed on centers located 17 m apart and with metal plot borders as described previously (Simanton & Renard, 1982). Runoff from the plots was collected in troughs that diverted the runoff into a runoff-measuring flume with a FW-1 water-level recorder that measured continuous stage height.

Three treatments were imposed on the eight plots on the trench cap. Two plots received an up and down slope disking (cultivated treatment). Both standard tilled plots were comparable, except for lengthened slope, to the 22.1-m USLE unit plot of continuous tilled fallow (used to determine the USLE soil erodibility factor). Two other plots were not tilled and also had no vegetative cover (bare soil treatment). To determine the influence of vegetation on soil erosion, four plots were seeded with barley (*Hordeum vulgare* L.) at a seeding rate of 22 g $m^{-2}$, and received a simultaneous surface application of 20-10-5 (N-P-K) fertilizer at a rate of 13.5 g $m^{-2}$.

Percentages of plant cover on the plots with barley and natural cover were determined immediately after the rain simulator runs from color photographs taken above and from the side of the plots. This process involved projecting a photograph of the plot area on a grid with about 7000 intersections, and determining the number of occurrences of vegetation at these intersections. Percent plant cover was then calculated for each plot.

Rainfall simulators, such as the one used in this study, are useful to determine USLE parameters for a rapidly changing soil surface such as that found on a trench cap covering waste materials. Rainfall simulators have been used extensively to collect soil erodibility data, to measure the effect of cropping and tillage on soil erosion, and to determine the effects of various soil treatments on soil erosion (Alberts et al., 1980; Foster et al., 1968; Laflen, 1982; Meyer et al., 1972; Wischmeier & Mannering, 1969; Wischmeier et al., 1971). The rainfall simulator used in this study was a trailer-mounted rotating boom simulator capable of applying either 60 or 120 mm $h^{-1}$ of water (Swanson, 1965). Ten arms radiating from a central stem support 15 nozzles which spray downward from an average height of 2.4 m. They apply about 0.25 L $s^{-1}$ of water and produce drop-size distributions and impact velocities similar to those of natural rainfall (Swanson, 1979), resulting in rainfall energies about 80% of those of natural rainfall.

Rainfall amount and application rate were measured using a modified recording rain gauge placed between each plot pair. The rain gauge was modified for increased sensitivity by doubling the rainfall collection area and enlarging the recorded time scale. The distribution of rainfall over each erosion plot was measured with four gauges that recorded rainfall amount near each of the plot corners.

The rain simulator run sequence consisted of an initial 60 min rainfall simulation at existing levels of soil water (dry soil surface), a 30-min run 24 h later (wet soil surface), and another 30-min run after a 30-min delay (very wet soil surface). The simulated rainfall rate was always about 60 mm $h^{-1}$, and these simulated rain events were applied to the plots in late June 1982, when the barley was 1 month old, thus minimizing canopy effects on soil erosion.

Soil loss for each simulated rainstorm was calculated as the product of runoff rate and the concentration of sediment in the runoff. The flumes used to measure runoff have a capacity of about 4 L $s^{-1}$ with water level recorders modified according to Simanton and Renard (1982). During the rising and falling portions of the hydrograph, 1-L samples were collected every 30 to 60 s. After runoff rate became nearly steady, samples were collected every 10 min. The sediment concentration in each runoff sample was determined by weighing the sample, allowing about 40 d for the sediment particles to settle to the bottom of the sample jars, decanting the water, and weighing the sample jar and dried sediment after a 3-d drying period of 60°C.

## RESULTS AND DISCUSSION

### Hydrograph and Sedigraph Data

The hydrographs, sediment concentrations, and sedigraphs for the rain simulator runs are presented in Fig. 1 and 2 for the erosion plots with natural cover. During the period of gradually increasing runoff in the dry surface runs on both plots, sediment concentrations remained relatively constant (3.5 to 4.1 g $L^{-1}$) so that sediment loss rates gradually increased to a maximum of 64.9 g $min^{-1}$ (Fig. 1 and 2). In the successive wet and very wet runs, runoff occurred more promptly after the start of the rain event than previous runoff events on the plots, reflecting the decreased infiltration rate into increasingly wet soil profiles. Peak sediment concentrations, ranging from 4.0 to 5.4 g $L^{-1}$, and peak sediment loss rates, ranging from 97 to 109 g $min^{-1}$, did not occur until the final very wet run, clearly showing the effect of antecedent moisture (Fig. 1 and 2).

The differences between the results from these two replicated plots with natural vegetative cover (Fig. 1 and 2), located only 3 m apart, are indicative of variability in infiltration, runoff, and erosion encountered in rainfall simulator studies in rangelands (Simanton & Renard, 1982). Subtle differences in sediment concentrations, discharge rates, and times before the start of runoff in these two plots resulted in a coefficient of variation

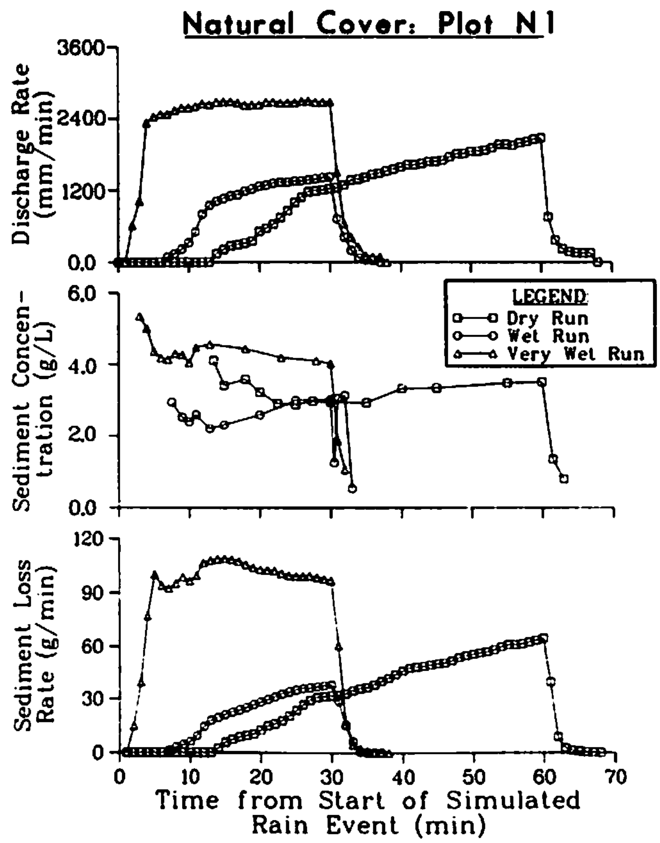


Fig. 1—Hydrograph, sediment concentration, and sedigraph data from natural cover plot N1.

[(standard deviation/mean) × 100] in soil loss rates of 39%.

Hydrograph, sediment concentration, and sedigraph data are presented in Fig. 3 through 5 for typical rain simulator runs on the trench cap with cultivated, bare soil, and barley cover treatments.

During the simulator run on the dry soil surface on the cultivated plot (Fig. 3), discharge rates quickly increased to 0.67 to 0.77 mm $min^{-1}$, and sediment concentrations ranging from 84 to 108 g $L^{-1}$ were observed. This resulted in maximum sediment loss rates of 2677 g $min^{-1}$ for this rain simulator event (Fig. 3), which exhibited sediment concentrations and loss rates on this plot that were 20 to 25 times larger than on the natural cover plots (Fig. 1 and 2). Changes in sediment concentrations during all three simulated rain events influenced the sedigraph data more than the relatively uniform discharge rate curves (Fig. 3). This suggests that sediment transport-deposition processes and interactions during the events were dynamic, which, in turn, suggests the occurrence (as was observed along the bottom 3 m of the plot after the three rainstorms applied) of sediment redistribution processes near and in the furrows formed on the plot.

Although the effect of antecedent soil water content on discharge rate was observed on the cultivated plot, a smaller difference in discharge rates occurred on this plot between the wet and very wet soil surface simulator runs (Fig. 3) than for the natural cover plots (Fig. 1 and 2). However, antecedent soil water content consistently effected the amount of time before runoff began once rainfall started.

Although discharge rates for the bare soil (Fig. 4), barley cover (Fig. 5), and cultivated (Fig. 3) treatments were similar, sediment concentrations varied considerably between treatments. Maximum sediment concentrations from the smooth bare soil plot were only 60 g $L^{-1}$, much less than the 108 g $L^{-1}$ concentration that occurred on the cultivated plot. Sediment concentrations from the plot with barley cover (Fig. 5) were lower, ranging from 15 to 22 g $L^{-1}$ during peak runoff for the dry soil surface run and from 20 to 26 g $L^{-1}$ during the wet and very wet simulator runs.

The hydrograph and sedigraph data for each rain simulator run was integrated over time and the average runoff and soil loss amounts for each surface treatment are shown in Table 1.

Only 14 mm of runoff occurred during the dry soil surface run from the plots with natural vegetative cover, resulting in a runoff/precipitation ratio of 0.26, while soil loss was 1.47 kg (Table 1). In contrast, the runoff/precipitation ratios for all of the trench cap plots ranged from 0.75 to 0.99, indicating that only 1.0 to 25% of the water infiltrated the trench cap during the simulated rain. Average soil losses for each simulator run on the natural plots ranged from 0.7 to 3.4% of the losses on the cultivated plots, whereas losses from the bare soil and barley cover treatments were 64 to 67% and 29 to 38% of the losses from the cultivated plots. The coefficient of variation (CV) in total soil loss between repli-

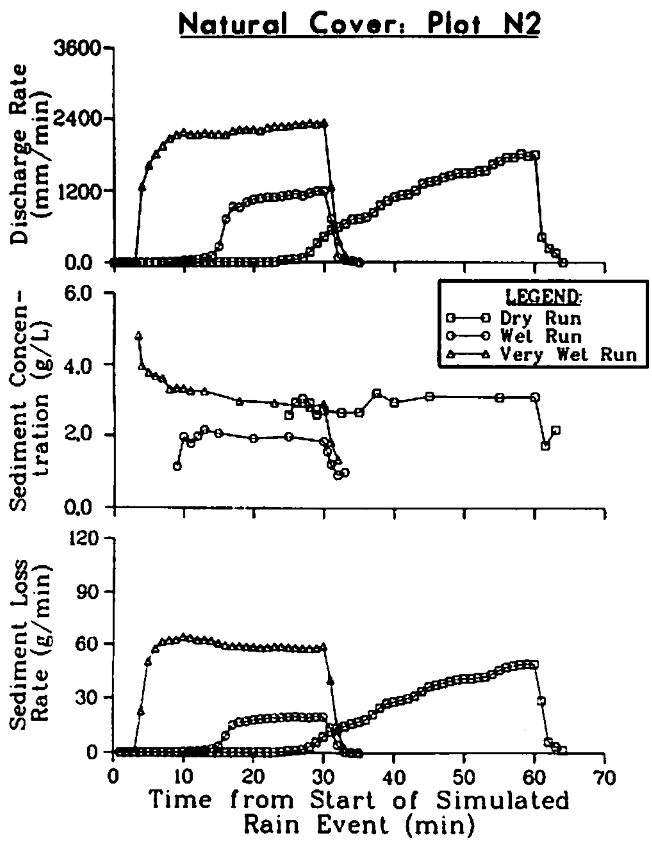


Fig. 2—Hydrograph, sediment concentration, and sedigraph data from natural cover plot N2.

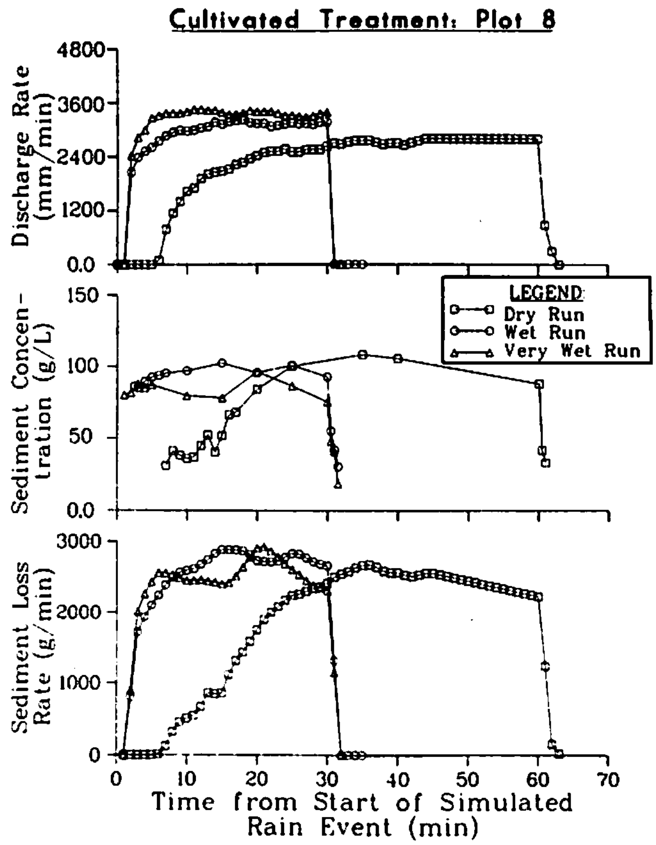


Fig. 3—Hydrograph, sediment concentration, and sedigraph data from plot 8 with cultivated treatment.

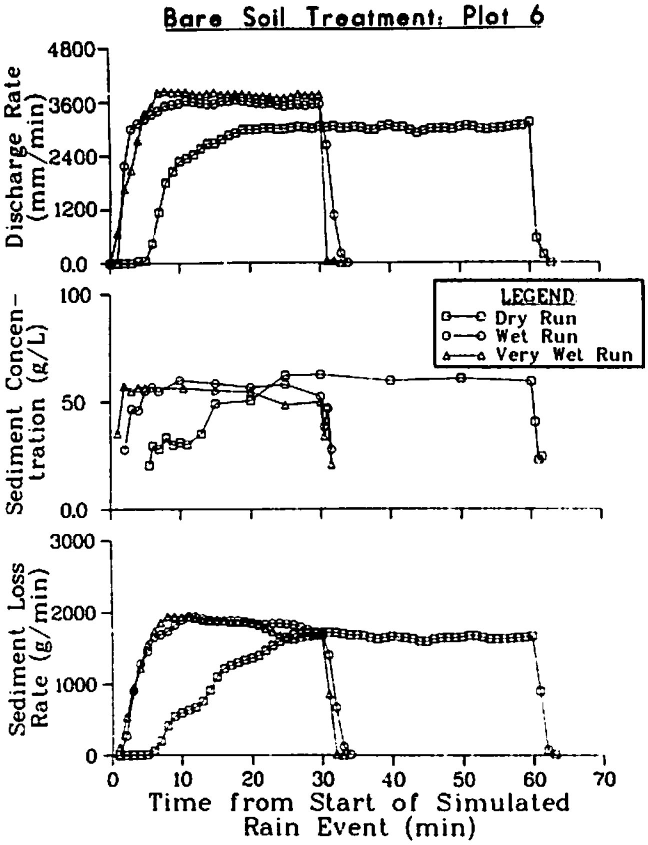


Fig. 4—Hydrograph, sediment concentration, and sedigraph data from plot 6 with bare soil treatment.

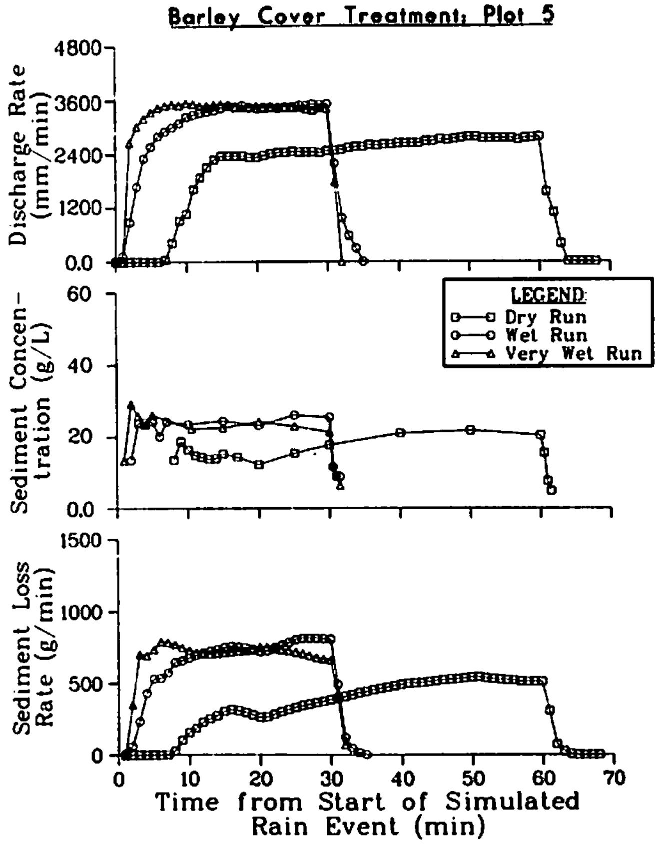


Fig. 5—Hydrograph, sediment concentration, and sedigraph data from plot 5 with barley cover.

cated plots ranged from only 14 to 23% on these plots, compared with the larger variation observed on the natural plots.

The influence of antecedent soil water content on water erosion can also definitely be shown for all of the trench cap plots. Thus, soil loss rates increased by 19 to 53% between the dry and wet soil surface simulator runs, and only increased 1 to 7% between the wet and very wet soil surface runs (Table 1).

## Soil Erodibility and Cover Management Factors

We used the soil loss data to estimate values for the soil erodibility (*K*) and soil loss ratios for the cover-management (*C*) factors of the USLE. Values for *K* were calculated from the measured soil losses from the cultivated plots and the energy and intensity of the simulated rainstorms applied to these plots. Soil losses from the three rain simulator runs on the cultivated plots were summed and adjusted for soil loss from the standard unit plot (22.1 m length, 9% slope) according to USDA agricultural handbook 537 (Wischmeier & Smith, 1978), using the recommended conversion to metric units (Foster et al., 1981). The storm energy × rainfall intensity (EI) factor (storm erosivity factor) for the runoff of the three simulated rainstorms was calculated (Meyer & McCune, 1958) as the product of the energy of the rainstorms (MJ $ha^{-1}$) and the simulated rain intensity (mm $h^{-1}$). The average *K* factor for all three simulator runs on both tilled plots was then calculated by dividing the total unit-plot adjusted soil loss for the three simulator runs by the estimated total EI factor. This gave a *K* value of 0.085 Mg ha h $ha^{-1}$ $MJ^{-1}$ $mm^{-1}$ with a CV of 16% ($n$ = 6). This *K* value agrees quite well with the estimate of 0.079 Mg ha h $ha^{-1}$ $MJ^{-1}$ $mm^{-1}$, which we determined from the soil erodibility

Table 1—Average runoff, runoff-precipitation ratios, and soil loss for rain simulator runs on dry, wet, and very wet soil surfaces on erosion plots as a function of surface treatment.†

| Treatment (no. of plots) | Average runoff | | | Average runoff/precipitation ratios | | | Average soil loss | | |
|---|---|---|---|---|---|---|---|---|---|
| | Dry surface | Wet surface | Very wet surface | Dry surface | Wet surface | Very wet surface | Dry surface | Wet surface | Very wet surface |
| | mm | | | | | | kg | | |
| Natural cover (2) | 14.5 | 6.0 | 18.7 | 0.26 | 0.28 | 0.65 | 1.47 | 0.46 | 2.24 |
| Cultivated (2) | 44.1 | 25.0 | 27.2 | 0.82 | 0.93 | 0.94 | 104.93 | 65.37 | 66.09 |
| Bare soil (2) | 46.7 | 26.8 | 28.4 | 0.90 | 0.92 | 0.99 | 70.55 | 41.88 | 44.58 |
| Barley cover (4) | 37.9 | 26.5 | 27.6 | 0.75 | 0.92 | 0.95 | 30.56 | 23.43 | 24.84 |

† Represents an initial 60-min rainfall simulation (dry surface), a 30-min run 24 h later (wet surface), and another 30-min run after a 30-min delay (very wet surface), all performed at a nominal target rainfall rate of about 60 mm $h^{-1}$.

Table 2—Soil loss, cover management factor (C), and plant cover estimates for the trench cap plots with barley cover and the natural plots.

| Plot number | Total soil loss† | C factor‡ | Plant cover |
|---|---|---|---|
| | Mg ha⁻¹ | | % |
| | Trench cap plots with barley cover | | |
| 2 | 45 | 0.43 | 62 |
| 4 | 28 | 0.27 | 84 |
| 5 | 28 | 0.27 | 78 |
| 7 | 39 | 0.37 | 62 |
| | Natural plots | | |
| N1 | 2.4 | 0.023 | 63 |
| N2 | 1.3 | 0.013 | 78 |

† Sum of soil losses from plot during dry, wet, and very wet soil surface rain simulator runs, adjusted for losses from a standard USLE unit plot.
‡ Total soil loss from the vegetated plot/average total soil loss from the cultivated erosion plots.

nomograph (Wischmeier et al., 1971; Wischmeier & Smith, 1978).

The cover management factor in the USLE is an average soil loss ratio weighted according to the distribution of the soil loss ratio throughout the year in conjunction with the distribution of erosivity throughout the year. This factor reflects the ratio of the soil loss at a specific crop stage to the corresponding loss from the clean-tilled, unprotected soil of a unit plot. Thus, we calculated soil loss ratios for the barley cover and natural cover treatments by dividing the total soil loss from all three simulator runs for these treatments, adjusted for soil loss from the standard unit plot (Wischmeier & Smith, 1978), by the corresponding soil loss from the tilled plots (Table 2). Soil loss ratios ranged from 0.27 to 0.43 for the barley plots and from 0.013 to 0.023 for the plots with natural vegetative cover. These soil loss ratios agreed quite well with standard soil loss ratios for barley cover at crop stages 1 and 2, having soil loss ratio values of 0.31 to 0.60 (Table 5, Wischmeier & Smith, 1978), and for the natural vegetation in local rangelands, having soil loss ratio values of 0.01 to 0.08 (Table 10, Wischmeier & Smith, 1978).

Soil loss ratios are obviously more than just a function of vegetative cover as evidenced by the large difference between soil loss ratios for the barley on the trench cap and the cover on the natural plots (Table 2). Plant cover on the barley plots increased from 62 to 84%, as soil loss decreased from 44.9 to 28.4 Mg ha$^{-1}$. The plant cover on the natural plots, which included some additional protection by canopy, also ranged from 63 to 78% cover, yet much smaller soil losses were observed on these plots than on the barley plots.

Several subfactors of the cover-management factor should be considered in making a comparison of the soil loss ratios in the plots with natural cover and the barley plots on the trench cap. The *C* factor is directly influenced by variations in subfactors involving not only plant and canopy cover, but also residue mulch, incorporated residues, plant roots, and changes in soil structure, density, biological activity, and many other properties (Wischmeier & Smith, 1978). Shallow land burial site preparations, such as those that occurred on our trench cap plots, remove vegetation, the root zone of the soil, residual effects of prior vegetation, and partial covers of mulch and vegetation, all of which substantially increase soil erosion. Another observed difference was the large amount of dark green lichens and algae (cryptogams) growing in erosion-resistant pedestals throughout the natural plots. An additional contributing factor was the difference in the texture of the surface soils in the two plots: the fine-textured subsoil in the natural soil series was mixed into the soil surface layer of the trench cap plots, compared with the sandier topsoil found on the natural plots. These factors influenced the infiltration-runoff relationships on these two plot types (Table 1).

As time proceeds, succession and soil formation processes will make the erosional and hydrologic properties of the disturbed soil surfaces at the shallow land burial site more similar to those of our undisturbed natural plots. Thus, the time required for the revegetated trench cap surfaces to reduce soil erosion as effectively as the natural systems has major implications in waste management decisions at these sites. Clearly, more research is needed to investigate how the subfactors of the cover management factor and the soil erodibility factor change with time on the trench cap to ensure successful, long-term management of infiltration and soil erosion processes in a wide range of trench cap environments.

## SUMMARY

Soil erosion and hydrologic relationships of a trench cap used for shallow land burial of radioactive wastes were investigated and compared with similar data for an undisturbed, natural soil system. The hydrograph and sedigraph measurements generated during simulated rain events demonstrated that antecedent soil water content of the surface soils significantly affected infiltration and erosion rates for all erosion plots. Values of runoff/precipitation ratios were much lower on the plots with natural cover (0.26–0.65) than plots on the highly disturbed trench cap (0.82–0.99). Soil losses from the plots were influenced more by variations in sediment concentrations than by discharge rates. Variation in soil loss between replicated plot treatments was less on the trench cap plots (14–23%) than on the natural plots (39%). Soil loss from the plots with natural cover was about 2% of that from the cultivated plots on the trench cap, and the soil loss from plots with the bare soil and barley cover treatments on the trench cap had 66 and 33%, respectively, of the soil loss from the cultivated plots.

The soil erodibility (*K*) factor and soil loss ratios for the cover management (*C*) factor of the USLE were quantified from the soil loss data. An average *K* value of 0.085 Mg ha h ha$^{-1}$ MJ$^{-1}$ mm$^{-1}$ was estimated from our cultivated plot data, with a CV of 16%. Soil loss ratio values for the barley plots on the trench cap were about 20 times larger than corresponding soil loss ratios for the natural plots.

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