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Erosion and Reclamation Plots: Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining

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16. Abstract (Limit: 200 words)

An erosion and reclamation experiment was conducted on a geologic site in east-central Ohio to determine the effect of slope and reclamation treatments on hydrologic, sediment loss, and vegetative variables. Analyses of the fallow plot data showed that a topsoiled surface significantly decreased soil loss, but was of borderline significance in affecting peak flow when compared with spoil. The application of 1 and 2 tons of mulch reduced soil loss 3.8 and 10 times, respectively, compared with no-mulch plots, but was of borderline significance in explaining runoff and peak flow changes. Treatment effects on vegetative establishment and growth were measured over a 2-year period. Mulch rates increased plant growth and vegetative canopy cover of the soil surface most during the vegetative establishment period. When plots were compared and seeded a second time, plant growth differences were smaller.

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FOREWORD

This joint report was prepared by the USDA-Agricultural Research Service, North Appalachian Experimental Watershed, Coshocton, Ohio and The Ohio State University-Ohio Agricultural Research and Development Center, Wooster, Ohio under USBM Contracts J0166055 (USDA-ARS) and J0166054 (OSU-OARDC). The contracts were initiated under the Mining Environmental Research Program. They were administered under the technical direction of the Denver Mining Research Center with Ms. Deborah P. Sherer acting as the Technical Project Officer. Ms. Gladys S. Barrera is the contract administrator for the Bureau of Mines.

The contracts were awarded for conducting the research as proposed in a document presented jointly by the USDA-ARS, North Appalachian Experimental Watershed and The Ohio State University-Ohio Agricultural Research and Development Center: A Research Proposal--Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining (May 1975). The U. S. Geological Survey, the Soil Conservation Service, the Muskingum Watershed Conservancy District, the Utah State University, and three private mining companies are participants in the studies.

This report concerns erosion and reclamation plot investigations. It presents a brief history of events, plot design and construction details, and an analysis of hydrology, erosion, and vegetation data collected at one mine site in east-central Ohio.

PREFACE

This report was prepared by:

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The coordinating committee for the joint project under which this research was supported consisted of the following members:

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ABSTRACT

An erosion and reclamation plot experiment consisting of 18 plots of one length, four slopes, three topsoil depths, and three mulch rates, in one geologic setting was conducted. The objectives were to determine the effect of slope and reclamation treatments on hydrologic, sediment loss, and vegetative variables, but the study also resulted in development of runoff measurement and sampling devices especially suited to monitoring high sediment loads with both large and small fractions.

Vegetative Cover Establishment: Vegetative cover data showed more cover on the plots having 2 t/Ac of mulch applied than on plots having less. Mulch significantly increased yields for each year measured. Neither vegetative cover nor yields were affected by topsoil depths, indicating the insignificance of the rooting medium in this study.

Runoff Volumes: Total volume of runoff was unexplainably higher on vegetated plots than on fallow plots. Runoff volume was higher from fallow spoil plots than from fallow topsoil plots, but the difference was not statistically significant. Vegetated plot runoff was unaffected by soil type (spoil or topsoil). Mulching had only a borderline effect, statistically speaking, on runoff volume, but the trend was toward higher runoff for higher mulch rates. The relationship between slope and runoff volume was erratic.

Runoff Peak Flow Rates: Vegetated plots yielded significantly lower peak runoff rates (21%) than did fallow plots. Fallow spoil tended to yield higher peak flow rates than did fallow topsoil, but the difference was only of borderline statistical significance. Peak runoff rates from vegetated plots were unaffected by either mulch rate or soil type. This response variable also erratically responded to variation in slope.

Soil Losses: Soil loss from vegetated plots was 38% less than from fallow plots, a statistically significant difference. Soil losses were significantly greater from fallow spoil plots than from fallow topsoil plots. On vegetated plots, however, soil type had no effect on soil loss. Increasing the mulch application rate had the effect of decreasing soil loss, an effect that was statistically significant. As slope increased, soil loss tended to increase, but this observation was not always consistent, and the relationship was statistically insignificant.

Universal Soil Loss Equation: Comparison of the Universal Soil Loss Equation (USLE) with one obtained using regression techniques on the plot data of this study indicated that the equation used to express the influence of slope in the USLE tended to cause overprediction of erosion from the plots.

The results from the reclamation plot investigation show the desirability and benefits of establishing a protective vegetative cover using at least 1 t/Ac of mulch during the period of seed emergence on mine soils. The presence or absence of topsoil and its depth appear to be irrelevant when hydrologic and soil loss variables are considered when fertilization in accordance with soil tests is practiced.

SUMMARY

An erosion and reclamation plot experiment consisting of 18 - 72.6 ft long plots (8 erosion and 10 reclamation) at one site in east-central Ohio was established. The objectives were to determine the effect of slope, soil type, and reclamation treatments (0, 1, 2 t/Ac mulch, and topsoil depths of 0, 6, and 12 in) on hydrologic, sediment loss, and vegetative variables.

A new composite runoff sampler type, called the diverter sampler, was designed to sample large rocks and to be very flexible in its operation. The sampler diverts the entire runoff volume at specified time intervals. Concurrent with the sampler development was the modification and development of the drop-box weir for measuring plot runoff.

Plots were established on four graded spoil slopes derived from the overburden of the Middle Kittanning (No. 6) coal seam. Spoil plots were left exposed and topsoil plots were covered with from 6 to 12 in of topsoil. Borders, shelters, weirs, samplers, etc. were installed at each plot. Two other plot sites, M09 and J11, were abandoned after a reduction in funding. The C06 site was retained, but the experimental design at the site was reduced in scope.

Soil sample data suggested that the Universal Soil Loss Equation (USLE) erodibility factors for topsoil and spoil were nearly equal. Modifying effects of large rocks are likely.

Straw mulch rates of 1 and 2 t/Ac applied at the time of seeding statistically significantly increased plant growth and vegetative cover in the establishment period. Where the 2-ton rate of mulch was applied, vegetative cover plus mulch cover, largely from the straw applied, were higher than on the plots having the 0- or 1-ton mulch rate.

Topsoil depths of 0, 6, and 12 in had no significant effect on vegetative cover or dry-matter yields, indicating the spoil was equally as good as the topsoil for plant growth.

The barren spoil plots yielded higher runoff volumes, peak flows, and soil losses than the topsoiled plots. An exception was on the 23% slope plots which showed nearly equal values for topsoil and spoil. Among the topsoiled plots, runoff volume and peak flow diminished in the order of 16, 23, 9, and 30% slopes. For the spoil plots, mean runoff volume and peak flow diminished in the order of 16, 23, 30, and 9%, and 16, 30, 9, and 23%, respectively. No distinct pattern in hydrologic variables existed with variation in slope for either soil type. The soil losses from the topsoiled plots showed a trend of increasing soil loss with increasing slope. The sediment losses from the spoil plots increased in the following slope order: 9, 23, 16, and 30%.

Fallow plot runoff volume was not significantly (statistically) affected by either slope or soil type (spoil or topsoil). The effect of soil type on peak flow rate was of borderline influence (statistically), but slope did not significantly affect peak flow. The peak flow on the spoil plots was on the average 1.3 times that on the topsoil plots. Soil loss from the fallow plots was significantly affected by soil type, spoil plots yielding 1.6 times the amount of soil yielded by the topsoil plots. Slope was not found to be significant in explaining the variation in soil losses.

Comparison of the Universal Soil Loss Equation (USLE) with one obtained using regression techniques on the plot data of this study indicated that the equation used to express the influence of slope in the USLE tended to cause overprediction of erosion from the plots.

Mulch was of borderline significance (statistically) in explaining the variation in runoff volume. Topsoil depth had no significant effect on runoff volume from vegetated plots. However, runoff volume on fallow plots was observed to be significantly higher on spoil plots than on topsoil plots. Neither topsoil depth nor mulch rate had an effect on peak flows. However, mulch rate significantly (statistically), affected soil loss (as mulch increased, soil loss decreased), but topsoil depth did not.

Statistically significant decreases in soil loss are attributable to 1 and 2 t/Ac applications as compared to no mulch. The 2 t/Ac plots showed only a borderline significance in decreasing soil loss as compared with the 1 t/Ac mulch plots. On the average, soil loss from the plots having no mulch was 3.8 times those having 1 t/Ac of mulch, and was 11 times those having 2 t/Ac mulch.

For events large enough to be sampled, vegetated plots showed significantly less soil loss (38% less), significantly lower peak rates (21% less), and higher runoff volume than did the fallow plots.

The results from the reclamation plot investigations show the desirability and benefits of establishing a protective vegetative cover using at least 1 t/Ac of mulch during the period of seed emergence on mine soils. The presence or absence of topsoil and topsoil depth appears to be irrelevant to hydrologic and soil losses, if vegetated and properly fertilized according to a soil test, as was done in this study.

The analyses reported herein were exploratory in nature. There are basically four areas that can be investigated further. The first is an investigation to tie the data collected in this study with the USLE. Specifically, erodibility (K) and cropping-management (C) factors could be quantified. Time did not permit these analyses in this study. The second is to further investigate the effect of armoring on soil loss and compare its effectiveness with vegetative cover. The third is to quantify the factors that caused a higher runoff volume for larger events on vegetated plots than from the fallow plots. A fourth area of investigation would be to partition the data sets into single, double, etc. events and by years in an attempt to reduce the variability of the data in the various analyses presented. The data used in this report were sampled runoff events having up to 12 individual events within one sample.

I. INTRODUCTION

The USDA-Agricultural Research Service, North Appalachian Experimental Watershed (NAEW), Coshocton, Ohio and The Ohio State University-Ohio Agricultural Research and Development Center (OSU-OARDC), Wooster, Ohio cooperated on a project entitled, "Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining." The project was funded by the U. S. Bureau of Mines. The erosion and plot investigations described herein are part of this larger project whose original overall objective was to obtain complete hydrologic and water quality data from four watersheds, 40 - 50 Ac in size, each for five years and subjected to surface mining and reclamation activities in order to determine the hydrologic and water quality impacts of mining and reclamation. A fifth watershed, having a long-term hydrologic record was to be monitored in its natural state for the duration of the project as a control. These study watersheds are designated as C06, M09, J11, J08, and A06. The letter preceding the coal seam is the initial of the Ohio county in which the watershed is located (Figure 1). The "C" referring to Coshocton County, the "M", Muskingum County, and the "J", Jefferson County. The exception is the "A" of Watershed A06 (the control watershed), which is located at the NAEW in Coshocton County. The number within each name identifies the coal seam (seam numbers 6, 8, 9, and 11) to be mined.

Interpretive reports for the above watershed studies can be found in U. S. Bureau of Mines (10, 11, 12, 13, 14, and 15). Other related publications include Hamon et al. (5), Hamon et al. (6), and Amerman et al. (2).

This report describes a subproject of the overall project study mentioned above, the erosion and reclamation plot investigations. These studies include those related to sediment losses from, and vegetative cover and yields on, small field plots. This chapter describes the project background, the experimental objectives and plans, and the analytical procedures used in this report. The second chapter describes the plots. The third chapter describes the instrumentation of the plots. The fourth chapter presents the results and discussion of analyses.

A. The Universal Soil Loss Equation

The present-day method of soil loss prediction is with the use of the Universal Soil Loss Equation (USLE). This is an empirical equation relating several important variables that influence soil losses due to rainfall on overland flow areas. The general form of the equation is:

$$A = R\ K\ L\ S\ C\ P$$

where,

- A = the computed loss of soil per unit area,
- R = a rainfall and runoff factor,
- K = the soil erodibility factor,
- L = the slope-length factor,
- S = the slope-steepness factor,
- C = the cover and management factor,
- P = the supporting-practice factor.

The USLE, and its use, are discussed in detail by Wischmeier and Smith (17).

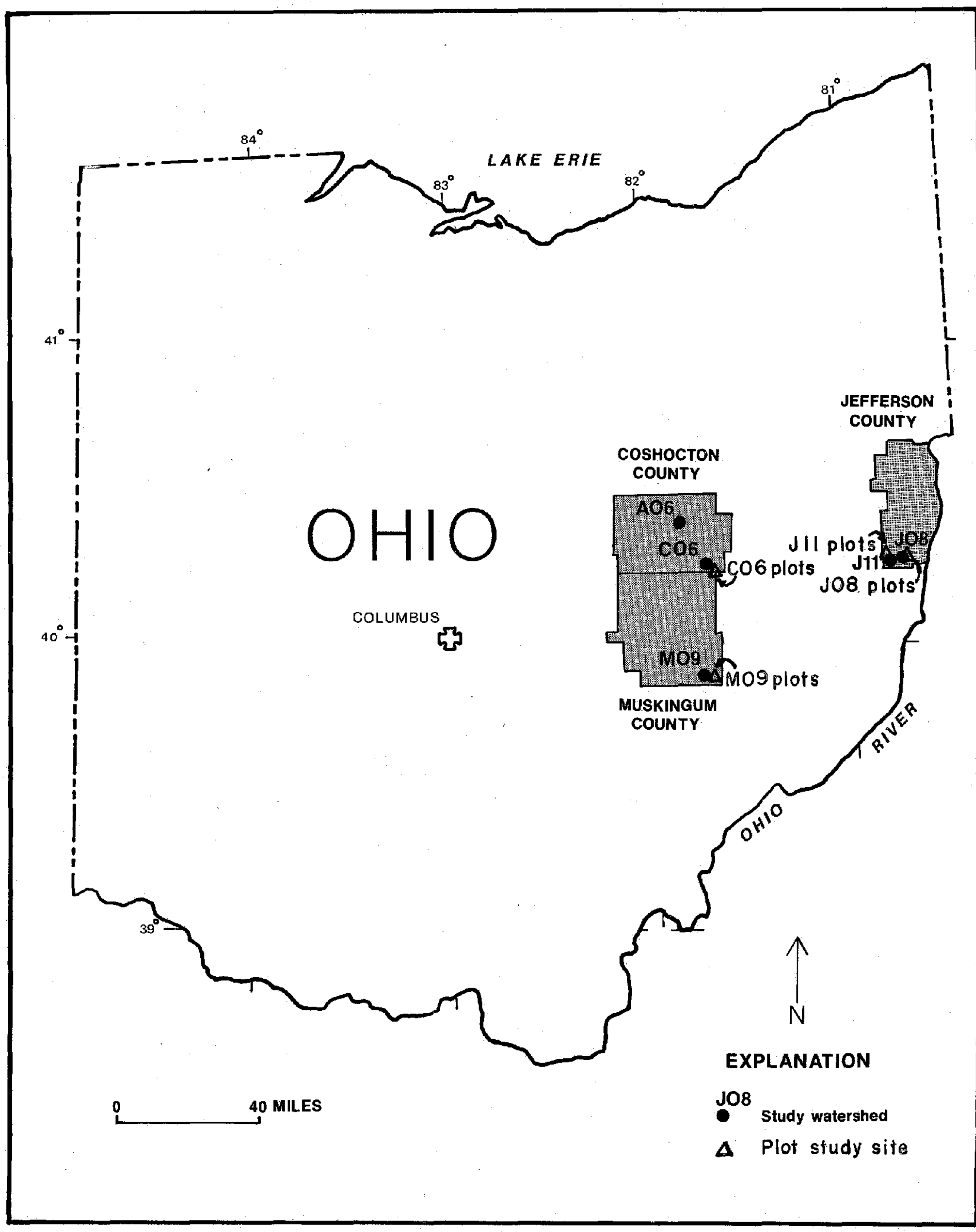

Figure 1.--Location of Watersheds Studied.

The USLE was developed for agricultural (cropland) soils having a fine granular topsoil. Mine soils, on the other hand, are characterized by having coarser textures and higher coarse fragment contents due to the blasting and grading of previously consolidated rock now exposed to the forces associated with erosion. Some of the factors of the USLE are influenced by soil characteristics such as K, L, and S (Wischmeier and Smith, 17). Many of the project objectives and plans during the project design period were oriented toward investigating the USLE and some of the important USLE factors as they apply to surface mining operations. The consideration of the USLE factors in the project design and data analyses will be apparent within this report.

B. Background

As mentioned above, the plot investigations were a part of an overall project designed to evaluate the effects of surface mining. The experimental plan and objectives originally consisted of 91 mine-soil plots, distributed among four widely varying lithologies, to investigate and quantify the effects of slope, slope length, topsoil depth, mulch rate, and cover conditions on soil losses, peak flow rates and runoff volumes, and vegetative cover and yield, to develop a mathematical model to predict soil losses, and to develop guidelines for diversion spacing on hillslopes. The four sites (lithologies) selected for instrumentation are shown in Figure 1.

Construction schedules and funding levels all varied from initial expectation, resulting in a continuing narrowing of project objectives and the elimination of three of the sites to be monitored. However, this did not occur until after a considerable amount of progress had been completed at the M09 and J11 plot sites. The remaining site, C06, was retained to advance the project at its new level, because this site was closest and most complete at the time a decision had to be made.

C. Objectives and Experimental Design

The cumulative effect of all factors affecting the plot project reduced the project to an exploratory-type study with the following objectives:

1. To determine the effect of slope on runoff peaks and volumes, and soil losses for surface mine topsoil and spoil.

2. To determine the effect of mulch and topsoil depths on vegetative cover and yields, runoff peaks and volumes, and soil losses.

Eighteen 15x72.6 ft plots were retained at the C06 site in order to accomplish the objectives. The design consisted of two sets of plots (10 and 8 plots each) called "reclamation" and "fallow" plots, respectively. Table 1 shows the experimental design of the reclamation and fallow plots (described further below). The reclamation plots consisted of nine plots on a 9% slope treated with three different topsoil depths (0, 6, and 12 in), and three different mulch rates (0, 1, and 2 t/Ac), all vegetated. In addition, one reclamation plot was maintained on a 9% slope in a fallow, no-mulch condition and had 8 in of topsoil. The eight fallow plots were established on four slopes (9, 16, 23, and 33% nominal slopes), and two soil types (spoil and topsoil, equivalent to topsoil depths of 0 and 8 in, respectively).

TABLE 1. - Plot identification and associated treatments

Within Report Plot Identification	Actual Slope	Topsoil Depth (in)	Mulch Rate (t/Ac)	Surface Vegetation
Reclamation Plots				
1[1]	0.09	0	1	Vegetated
2	.09	0	2	Vegetated
3	.09	12	1	Vegetated
4	.09	12	2	Vegetated
5	.10	6	1	Vegetated
6	.10	6	2	Vegetated
7	.09	0	0	Vegetated
8	.09	12	0	Vegetated
9	.10	6	0	Vegetated
10	.09	8	0	Fallow
Fallow Plots				
9-T[2]	.09	8	0	Fallow
9-S	.10	0	0	Fallow
16-T	.16	8	0	Fallow
16-S	.16	0	0	Fallow
23-T	.21	8	0	Fallow
23-S	.21	0	0	Fallow
30-T	.33	8	0	Fallow
30-S	.33	0	0	Fallow

[1]All reclamation plots had a target slope of 9%.

[2]Number is nominal target slope (%), and letter indicates soil type ("T" for topsoil and "S" for spoil).

Implicit in the reduced experimental design was the very narrow applicability of the results, because plots having only one topsoil type, one spoil type, and one slope length in one geologic setting were maintained.

D. Analytical Procedure

1. Data Sets and Definitions.

The erosion and hydrology data were divided (Table 2) into two experimental groups of plots, "reclamation plots" (10) and "fallow plots" (8) as described above. Subgroups of the reclamation plots called "vegetation plots" (9) and "plot 10" (1) were also made. Two subgroups of the fallow plots used herein were called "fallow topsoil" (4) and "fallow spoil" (4) plots.

Each set of data from an individual plot was comprised principally of values of runoff volume (in), peak flow rate (in/hr), and sediment load (t/Ac), called "sediment loss" or "soil loss" in this report, during the sampling period. Precipitation characteristics were not available at the time of writing. The sampling period is defined as the time interval between the times of servicing the sampler. This period may have included several events which exceeded the sampler threshold, and several that did not. The runoff volume used herein is only the runoff volume that was sampled. Similarly, the peak flow rate is the largest of the peaks that occurred during a sampling period. The sediment loss is the load of sediment that was transported off the plot only during the time the sampler threshold was exceeded and the sampler was turned on. The facts that a sample resulted from multiple events and peaks, and that unsampled runoff may have occurred between sampled events, probably affected the sediment loss data from the plots; however, these effects could not be quantified.

2. Comparisons and Statistics for Plot Data.

Analyses of the data consisted of performing an analysis of variance using a 2x4 factorial design for the fallow plots, and a 3x3 design for the reclamation plots. The response variables considered were runoff volume, peak flow rate, and soil loss. The fallow plot treatments were evaluated at two levels of soil type (spoil and topsoil), and four levels of slope (9, 16, 23, and 30%). The vegetated plots were evaluated at three levels of topsoil depth (0, 6, and 12), and three levels of mulch rate (0, 1 and 2 t/Ac). Transformations of the data were made in order not to invalidate the normality and equal variance assumptions inherent in the analysis of variance procedure. The Shapiro-Wilk test (8) was used for testing for normality, and the Burr-Foster test, as cited by Anderson (1), was used for testing for equivalent variances for the analysis of variance procedure.

Where means were to be compared, the Shapiro-Wilk test (8) was applied to determine the acceptibility of the normality assumption in order to use the t-test. Transformations of the data were also tested. It was found, however, that the normality assumption was not met for many of the cases. Therefore, a nonparametric approach was employed, in particular the Mann-Whitney U-test (Siegel, 7). This nonparametric test allows comparisons between central tendencies of 2 distributions without assuming normality as in parametric tests. A nonsignificant result means that the populations are the same with respect to central tendency, and a significant difference means that the populations are different with respect to central tendency.

TABLE 2. - Data sets used in the analysis of the data

Data Set Identification	Plot Identification[1]
Reclamation plots	1 through 10
Vegetated plots	1 through 9
Plot 10	10
Fallow topsoil plots	9-T, 16-T, 23-T, 30-T
Fallow spoil plots	9-S, 16-S, 23-S, 30-S

[1]See Table 1 for more information regarding the plot identifications and treatments.

3. Analytical Procedure for Vegetation Data.

Percent vegetative and mulch cover estimates were made October 16, 1980, May 29, 1981, and August 26, 1981. Visual estimates of plant canopy and mulch cover (straw plus plant litter) were made in 28 to 36 randomly selected small quadrangles for each plot. Means of these estimates and dry-matter yields were used in multiple linear regression analyses to evaluate the effects of applied rates of straw mulch and topsoil depths on these parameters.

II. DESCRIPTION OF THE PLOT SITE

A. Location

The C06 plot site was located approximately 14.5 miles southeast of Coshocton, Ohio (Figure 1), and in Section 22 of Linton Township of Coshocton County. Due to construction disturbances associated with instrumentation and service, the plots were located outside the study watershed, about 0.5 miles to the south.

B. Geology

The C06 plots were located in the unglaciated plateau region of Ohio. The area was underlain by stratified sedimentary rocks of the Pennsylvanian System. The prevalent rocks above and below the coal seam that was mined (the Middle Kittanning, No. 6 coal of the Allegheny Formation) were sandstone and interbedded shale (U. S. Bureau of Mines, 10). Above the coal, the principal overlying beds were the Lower Freeport of the Allegheny Formation and the Mahoning Sandstone of the Conemaugh Formation. The plots were established in spoil derived from the beds above the clay that underlaid the Number 6 coal. However, the spoil material, and, thus, the plots, were located both within the newly fractured overburden material over the underclay in the hillside, and also on top of spoil which was moved down slope from this underclay and placed on top of the original landscape during grading.

C. Soils

The area in which the erosion and treatment plots were located was not mapped prior to mining. However, the most extensive and representative undisturbed soil types present in the nearby study watershed were the Otwell, Dekalb, Coshocton, and Westmoreland series. The pH values for the top 12 in of these soils ranged from 4.5 to 6.1 (U. S. Bureau of Mines, 10).

Spoil and topsoil samples were obtained from the vegetation plots to determine the existing soil chemistry. The samples were analyzed at the OSU-OARDC, Research-Extension Analytical Laboratory. Table 3 lists the resulting chemical parameter values. These results were used for determining the quantity of amendments to be applied to the vegetated plots just prior to seeding.

Other reclamation and fallow plot soil samples were obtained and analyzed by personnel from the OSU Soil Characterization Laboratory. Due to incomplete sampling and analyses, the results of the analyses of the samples from all plots were not available at the time of writing. (Supplemental samples have since been taken.) The surface soil texture data (<2mm) are presented in Table 4 for all the plots and generally show that about 40% of spoil and topsoil samples were classified as sandy loam, whereas, about 60% of the spoil and 30% of the topsoil samples were classified as loam. Additionally, about 30% of the topsoil and none of the spoil samples were classified as fine sandy loam.

D. Climate

The normal annual precipitation at Raingage 103 located at the NAEW, 14.5 miles from the C06 plot site, is 36.86 in, calculated from the period 1953 to 1982. The average annual air temperature is 50.1° F for the same period. The normal growing season (May - Sept., the approximate period of most of the data

TABLE 3. - Soil test values for samples taken from the reclamation plots

Parameters	Soil Type	
	Topsoil	Spoil
pH	5.2	4.2
LTI[1]	67	64
P (lbs/Ac)	34	16
K (lbs/Ac)	158	118
Ca (lbs/Ac)	630	2750
Mg (lbs/Ac)	190	1093
CEC (Meq/100g)	6	19

[1]The lime test index (LTI) is a measurement to determine the amount of liming materials required to increase the soil pH to a specified level (The Ohio State University, 9).

TABLE 4. - Soil textures (<2mm) on vegetated and fallow plots

Plot Identification	Soil Type[1]	Surface Texture[2]
1	S	L,SL
2	S	SL,SL
3	T	SL,SL
4	T	L,SL
5	T	L,SL
6	T	L,SL
7	S	L,L
8	T	L,SL
9	T	L,SL
10	T	L,L,FSL,SL
9-T	T	L,SL,SL
9-S	S	L,L
16-T	T	FSL,FSL
16-S	S	L,L
23-T	T	FSL,FSL
23-S	S	SL,SL
30-T	T	FSL,FSL
30-S	S	L

[1]S - spoil. T - topsoil.

[2]USDA textures for individual samples: L - loam SL - sandy loam FSL - fine sandy loam.

collection effort) precipitation is 16.87 in, also for the same period. The 1980, 1981, and 1982 growing season precipitation totals and departures from the NAEW normals were 27.51 (+10.64), 23.07 (+6.20), and 15.40 (-1.47) in, respectively.

E. Vegetation

As mentioned previously, fallow and reclamation plots were established for this study. The fallow plots were maintained in a bare condition by hand weeding and with the use of herbicides. The vegetative cover and fertilizer applications are described below for the vegetated plots.

To provide optimum nutrient and acidity levels for plant growth with respect to pH, P, and K, the vegetated plots were limed with agricultural limestone and fertilized with concentrated superphosphate and muriate of potash (KCl) prior to seeding. The topsoil plots were limed at the rate of 2.1 t/Ac. The spoil plots were limed at a rate of 4.7 t/Ac. These rates were recommended to raise the pH to 6.5. The phosphate fertilizer was applied to all plots at the rate of 300 lbs/Ac of P_2O_5. The topsoil plots had 263 lbs/Ac of K_2O applied. The spoil plots had 289 lbs/Ac of K_2O applied. All plots had ammonium nitrate applied at the rate of 30 lbs/Ac. The treatments were applied June 27, 1980, and incorporated into the surface just prior to seeding.

The vegetated plots were broadcast seeded with a mixture of birdsfoot trefoil (6.7 lbs/Ac), Alsike clover (4.4 lbs/Ac), ladino clover (2.2 lbs/Ac), orchardgrass (6.7 lbs/Ac), Kentucky 31 tall fescue (11.1 lbs/Ac), and timothy (4.4 lbs/Ac). After seeding, wheat straw was applied at 1 and 2 t/Ac on specified plots.

To repeat the period from seeding to vegetation establishment, the plots were prepared and seeded again on March 31, 1981. The old mulch was raked off the plots. Ammonium nitrate was applied at the rate of 30 lbs/Ac to each plot. Wheat straw at the 1 and 2 t/Ac rate was applied to the plots that had been previously mulched in 1980. Due to termination of data collection, the plots were not prepared and seeded again in 1982.

During the initial year of vegetation establishment (1980), no dry-matter yields were obtained. On October 9, 1981, strips 3 ft wide and 40 ft in length were cut and dry-matter yields obtained. All but a small sample (approximately 1 lb) for moisture determination was returned to the mowed strip.

On June 2, 1982 yield strips 3 ft wide and 50 ft in length were cut and dry-matter yields obtained as in 1981. After yield data were obtained, the entire plot was cut, and the vegetation was removed.

III. INSTRUMENTATION

A. Introduction

During the design period, the project was constrained by a short data collection period, limited human and financial resources, and the distance between the NAEW location and the study site. Thus, the criteria for an instrumentation system for the plots were:

1. Design instrumentation that would be easy and quick to fabricate.
2. Use readily available materials, components, and instruments.
3. Minimize maintenance of the system after the initiation of operations.
4. Minimize technician servicing time.
5. Minimize the cost of the system.

B. Design Parameters

During the design period, there was a potential of four years of data collection, thus, an infrequent design flow and volume had to be chosen for system component sizing. An infrequent design return period was necessary to reduce the possibility of overtopping measuring devices and containers.

A 25-year 5-min runoff event was chosen for the basis of the system design peak flow because it has a probability of 0.15 of occurring in a 4-year period, an acceptable risk. This event duration was chosen because frequency data are not available for periods smaller than 5 min, and because times of concentration from small areas are short. A 25-year, 5-min rainfall for the C06 plots is 0.63 in. Assuming 100% runoff, the design peak flow for the standard size plot was 0.19 cfs. It was decided early in the project that composite sampling of the runoff water would be the most feasible sampling technique given the laboratory, field personnel, and funding constraints. Therefore, a design storm volume was required to size the sample storage containers. A 24-hour period was chosen as a sufficient time in which to service an individual plot and drain the tanks. Therefore, assuming 100% runoff, a 25-year, 24-hour runoff volume (4.1 in, 2783 gal on a standard sized plot) was chosen.

C. Runoff Measurement

Runoff volumes and peak flow data from the plots were desired for data analyses. However, two problems had to be overcome. First, heavily sediment-laden water was expected from the plots, and, second, the flow off the plot had to be directed perpendicularly to the slope, but concentrated at the center of the plot outlet. A flow measuring device had to be used which would accommodate these two situations. Commonly used devices were not acceptable due mainly to the invalidation of the rating curves for sediment-laden water. It was decided that the drop-box weir (Copp & Tinney, 3) was suitable and could be modified for use in the erosion investigations.

It should be noted that during the design period, several plots of varying sizes were to be established. For large plots, larger design peak flows were required. Thus, several sizes of weirs were required.

During the design period it was not considered feasible to monitor hydrographs on all plots of this study due to financial, human resource, and equipment availability considerations. This will be more fully explained later.

It was considered more important to have weirs on the fallow plots than on the reclamation plots because it was thought that peak flow would help explain better the higher soil losses expected from these plots. Therefore, some of the reclamation plots did not have weirs (4). A weir was assigned to at least one plot with one of the main effect treatments. A table presented in the last chapter (Table 12) shows the distribution of weirs among the reclamation plots. On those plots without weirs, only runoff volume data were obtained using sampler catch data. This will be more fully discussed in the section titled, "Data Collection and Reduction."

The weir had been used successfully at the outlets of the previously mentioned study watersheds associated with the plot investigations. Copp and Tinney (3) noted that the rating curve was independent of upstream approach conditions (the box was the flow control) when the flow was contained in the box part of the weir, but was dependent upon the approach for high flow. Thus, the weir was modified by eliminating the upper weir lips used for gaging high flows and by sizing the weir so that the design flow would pass through only the box. A 12-in weir is shown in operation in Figure 2. The high turbulence apparent in the box keeps sediment in suspension. The resulting modified drop-box size for the design peak flow was 3.9 in for the standard size plot using the rating equation developed for the original weir. However, for several reasons discussed below, a weir 4.5 in in size was chosen.

In the new application, the drop-box weir approach condition was radically different from that of the original model study. This could affect the hydraulic behavior of the weir, in spite of Copp and Tinney's conclusion mentioned above. In the plots application, the flow enters the weir from each side; the two streams meet head-on and their directions of travel turn through 90° (Figures 2, 3 and 4). In the original weir application, the inflow had a component parallel to the weir centerline. The impact of the different approach conditions on the new weir rating was not known at the time, so choosing the 4.5-in instead of the 3.9-in size was a conservative design decision. Rating data later showed the approach condition to be important.

The design peak flow was based on a rainfall intensity attenuated over a 5-min period. Because the times of concentration were small on these plots, and there are an infinite number of rainfall patterns that can produce a 5-min design flow, the choice of the 4.5-in size was, again, conservative.

Of lesser importance is the fact that Copp and Tinney (3) found that a 3.8 in weir was the smallest size of the original weir configuration that performed consistently with large weirs of the same configuration. Consistent performance among various-sized weirs was desirable at the time of design because larger plots then in the research plan would require larger weirs. Also, the modified flow-measuring device could easily be used in other applications. By choosing the 4.5-in weir size, the weir was removed from the lower extreme of consistency of weir performance.

Another consideration in sizing the weir was that the particle size distribution of the eroded and transported surface soils was unknown. Increasing the weir size would decrease the probability of sediment clogging the V-notch section.

A Belfort FW-1 recording float-type gage was used to monitor water levels in the stilling wells of the weir.

FIGURE 2. - A 12-in modified drop-box weir in operation.

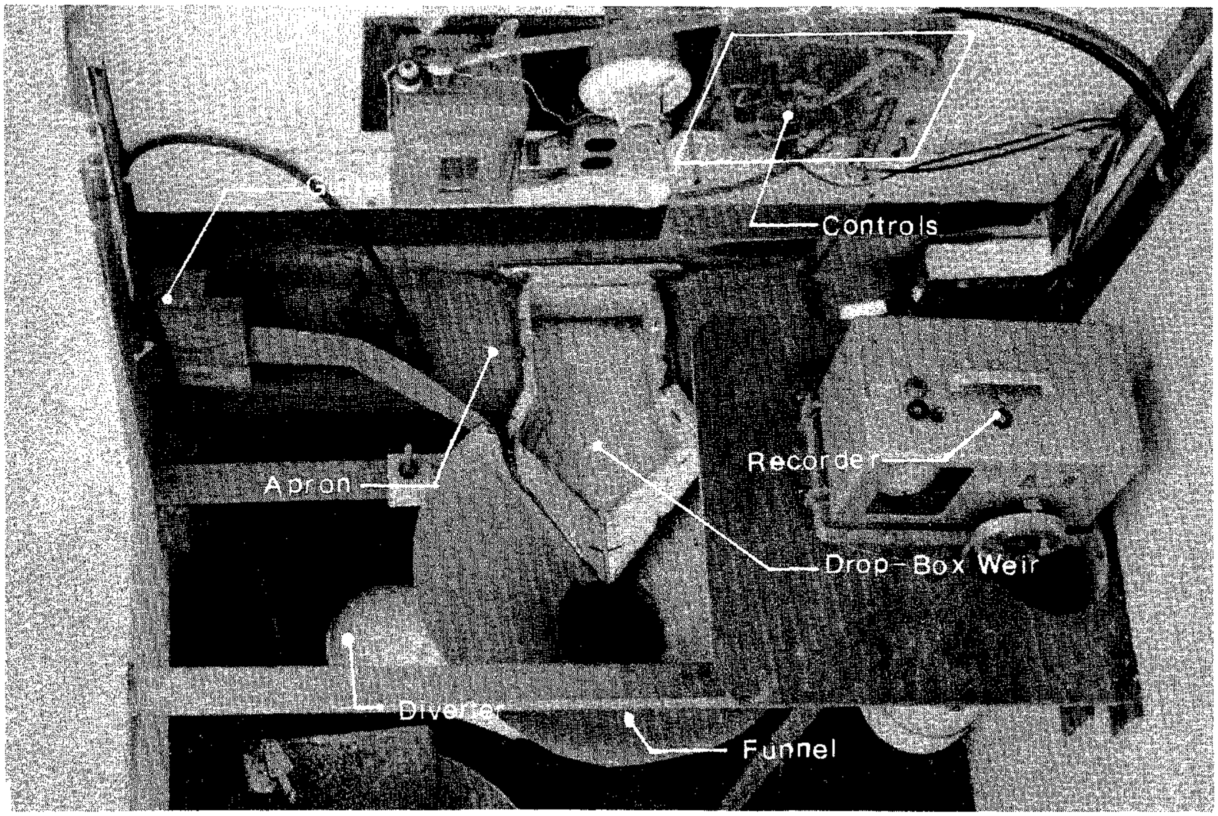

FIGURE 3. - Plan view of the drop-box weir and parts of the diverter sampler as installed in the field.

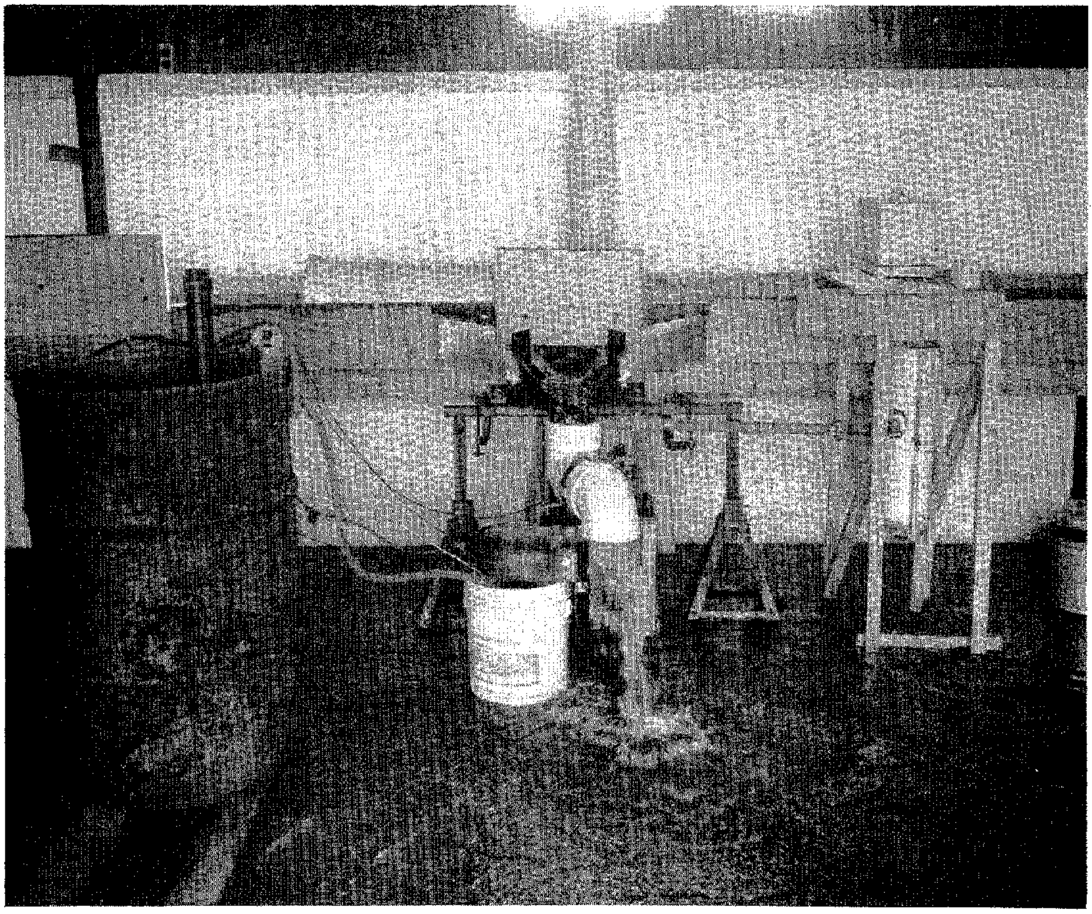

FIGURE 4. - Experimental apparatus for testing the diverter sampler. (Sampler is in waste position).

D. Sediment Samples

As mentioned previously, composite sediment samples of the runoff events were to be obtained for each plot. The criteria for the selection of a type of sampler were as follows. The sampler had to be:

1. Inexpensive because of the large number of samplers required.
2. Easy and quick to fabricate and install.
3. Easy to service and maintain.
4. Able to catch the large soil particles expected in the runoff water.
5. Able to catch different fractions of the runoff water to permit, as experience was gained in the operation of the plots at the four sites, adjustment of the fraction sampled.
6. Capable of adjustment to start sampling at any threshold flow.
7. Compatible with the drop-box weir.
8. Capable of frequent sampling so that sediment transported in the flashy flows expected from the plots is adequately sampled.
9. Capable of providing an estimate of runoff volume for each event.

Several existing sampler types were considered, but none met all the above criteria. A new sampler type was therefore designed.

The new sampler, termed the diverter sampler (Figures 3-6), was designed according to a rearranged form of Equation 1.

$$V_s = fV_r, \tag{1}$$

where: V_s = volume of water collected,
f = fraction of the runoff volume sampled, and
V_r = volume of runoff to be sampled.

Since either volume of water (V) in Equation 1 can be expressed as:

$$V = Qt,$$

where: Q = flow rate, and
t = time,

then:

$$Q_s t_s = fQ_r t_r,$$

where the subscripts s and r denote sampler and runoff variables, respectively.

If all water is diverted, then

$$Q_s = Q_r, \text{ and}$$

$$t_s = f\ t_r. \tag{2}$$

A sampler designed according to Equation 2 is a composite sampler for all flows. The fraction caught can be adjusted by varying the time of sampling.

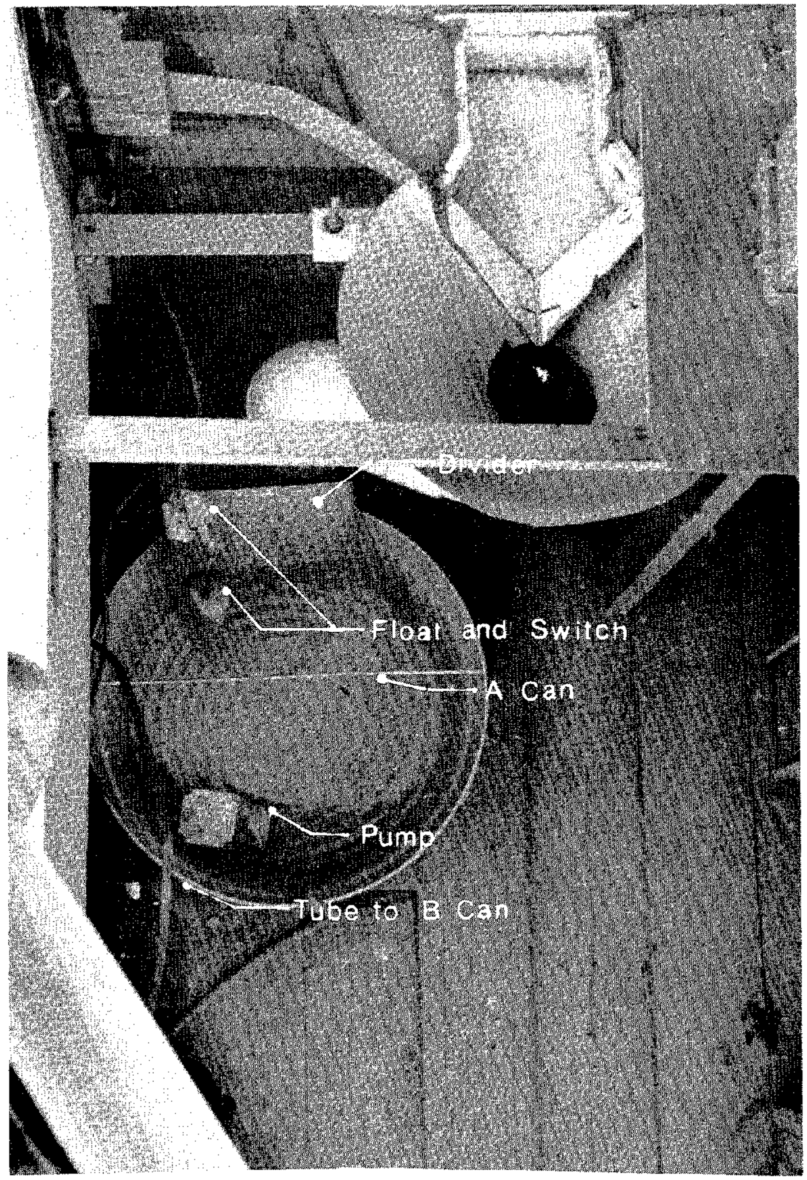

FIGURE 5. - Plan view of drop-box weir and diverter sampler showing the A can as installed in the field.

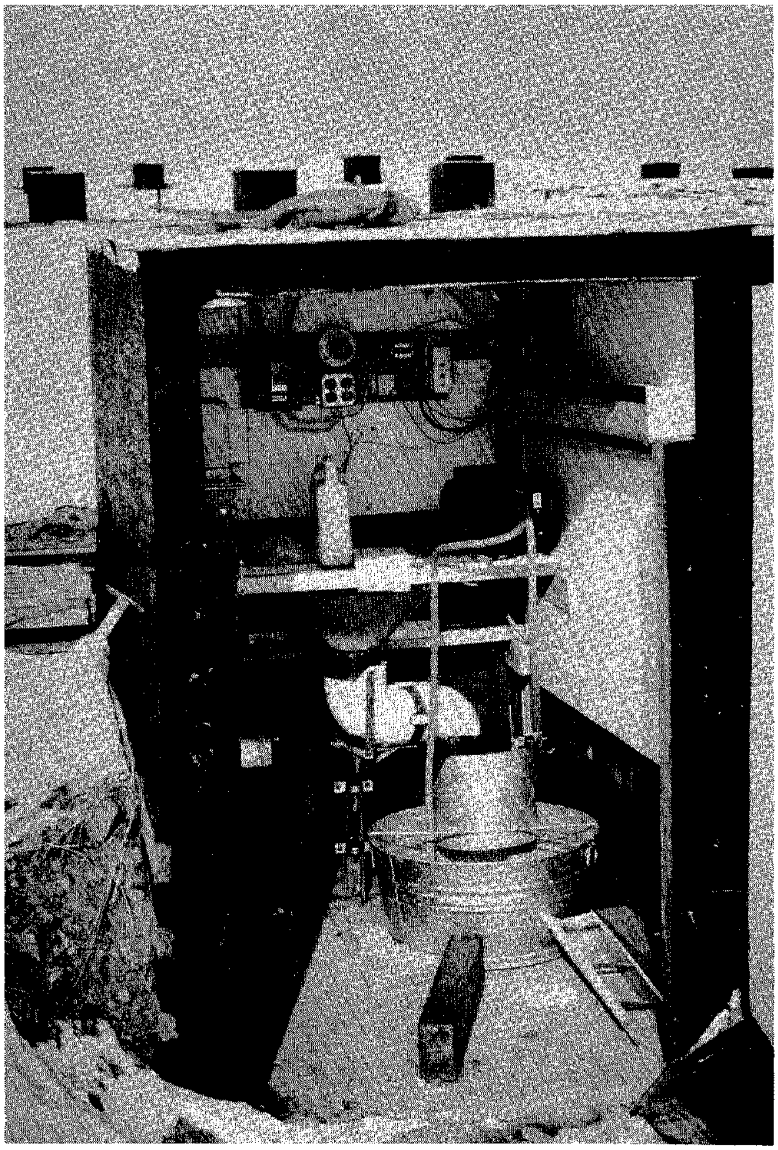

FIGURE 6. - A typical diverter sampler in a shelter at the C06 plot site.

The diverter sampler was designed using Equation 2 and the criteria listed earlier. Briefly, all water and sediment from the drop-box weir (Figures 3-6) flows into a diverter made of PVC pipe, which is electrically controlled to divert all plot runoff water from a waste position to a sampling position for, a small, but constant, fraction of the time.

Because the fall from the flume to the floor of the sampling shelter had to be small, as will be explained in the "Plot Construction" section, the sampled water was diverted into a shallow temporary holding tank called the A-can (Figure 5). When water filled this tank, to an adjustable level, the water and some of the retained sediment was pumped from the A-can to the B-can. The B-can, when full, overflowed into a C-can, if there was one, etc. Sediment samples were obtained from each container when each plot was serviced.

Most materials used in the fabrication of the sampler were readily available. For example, PVC pipes and 90° ells were used for the diverter; angle iron, pillow blocks, steel rod, and flat metal were used for the diverter and support. Sheet metal was used for the funnel above the diverter (Figure 3), and sheet rubber was used to align the funnel and diverter (Figure 6).

Plastic buckets and galvanized wash tubs were used for the A-cans, and 55-gal drums with plastic drum liners to prevent rust contamination of the sample were used for the B-, C-, etc., cans. Other tanks, as available, were used for the B-, C-, etc., cans, also. Readily available and inexpensive pumps and linear actuators for the diverter were also used. A typical sampler is shown in Figures 3, 5, and 6.

E. Plot Construction

1. Grading.

The plots were to be established on graded spoil with a veneer of topsoil on selected plots according to the plans mentioned in the first chapter of this report. The original hillside consisted of cast overburden from mining operations. As the area in which the proposed plot site was being reclaimed, small areas of the spoil were graded with a large bulldozer and grader to the target slopes listed in Table 1 (Figure 7). Figure 8 shows the location of the small C06 plot areas on the reclaimed landscape. On these small areas, topsoil was spread to the specified depths with a pan (Figure 9), and the final grading was performed with a road grader and bulldozer. After grading, the individual plots were roughly located on the plot areas and covered with plastic to minimize erosion during the subsequent construction period. Figure 10 shows the graded plots without plastic coverings at Plot Site M09. This plot site was later abandoned.

2. Borders.

The individual plot boundaries were surveyed and borders were constructed and installed on each of the smaller slope areas. Borders were made of 1/2 in exterior plywood sections 8 ft long and 12 in wide spliced to form one long continuous border on a side of each plot. Support stakes were used along the borders where necessary.

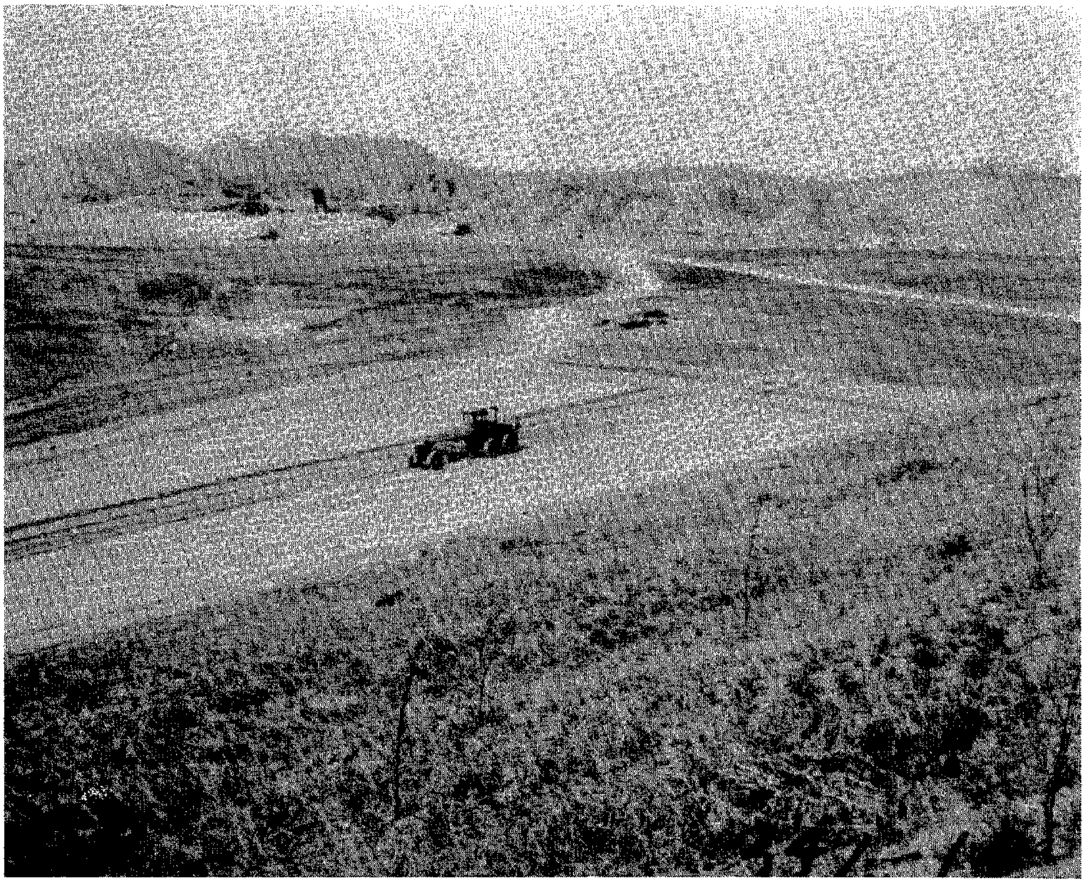

FIGURE 7. - Grader leveling the spoil to a uniform 9% slope at plot site C06.

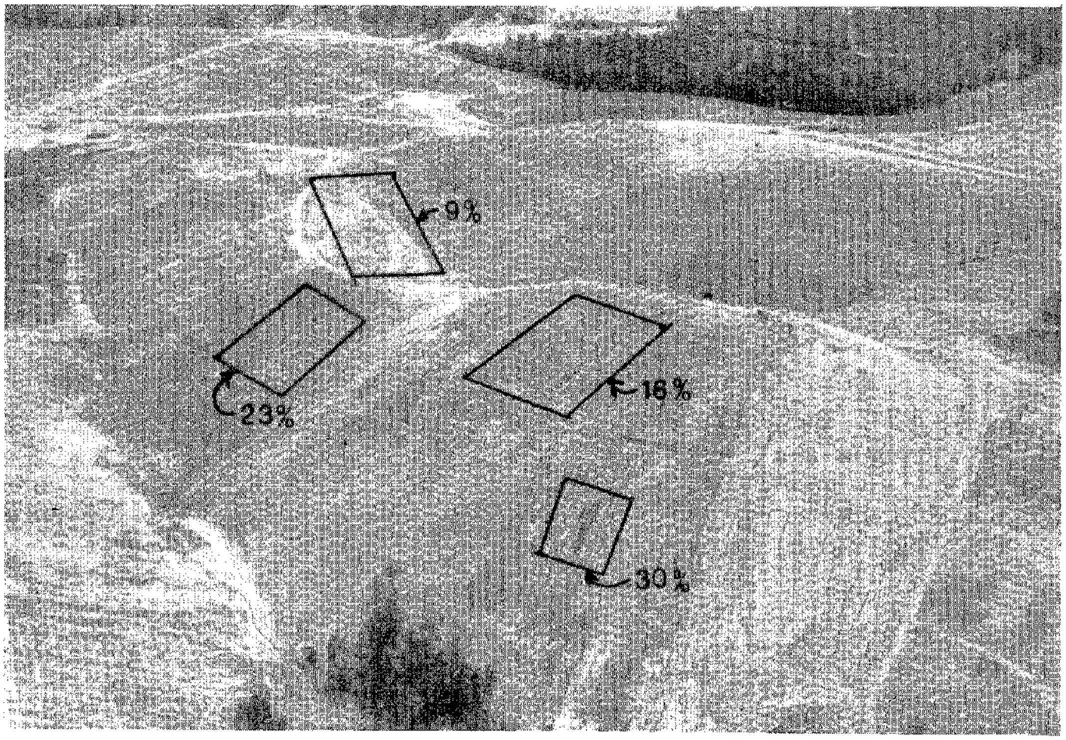

FIGURE 8. - Aerial view of the plot site C06 showing plot-slope areas after initial grading.

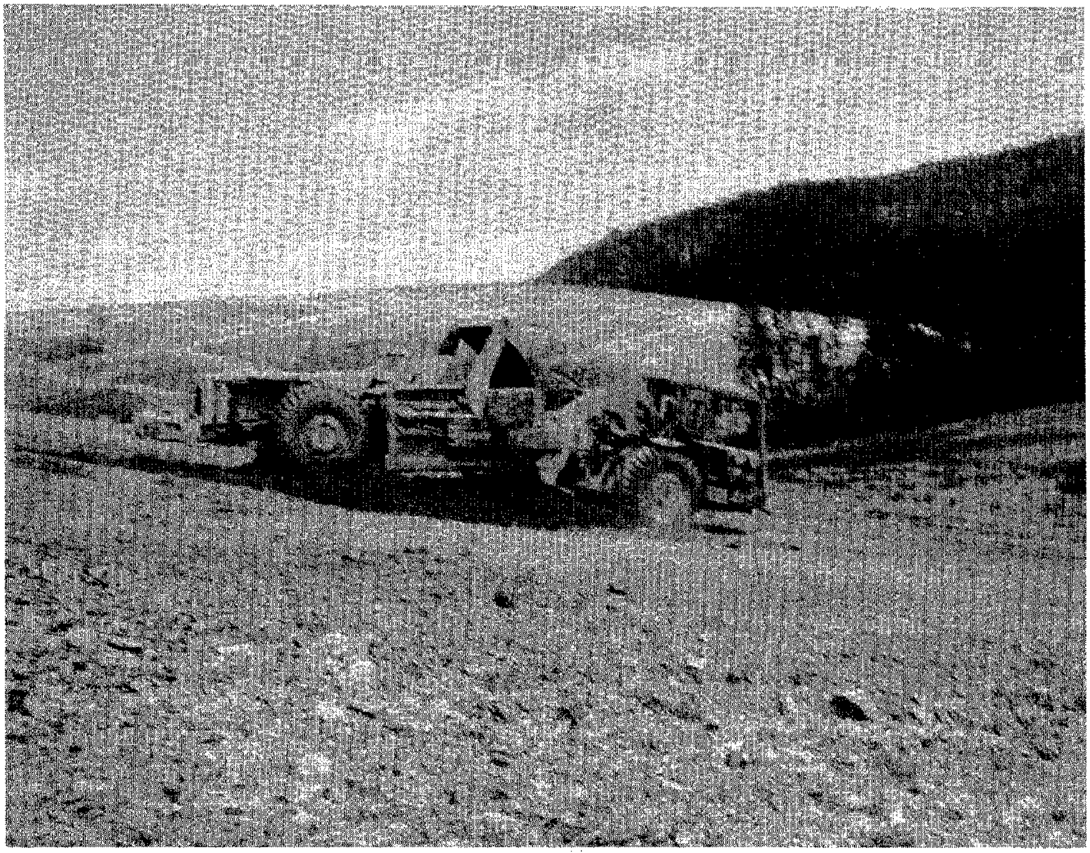

FIGURE 9. - Pan spreading topsoil on a graded spoil area.

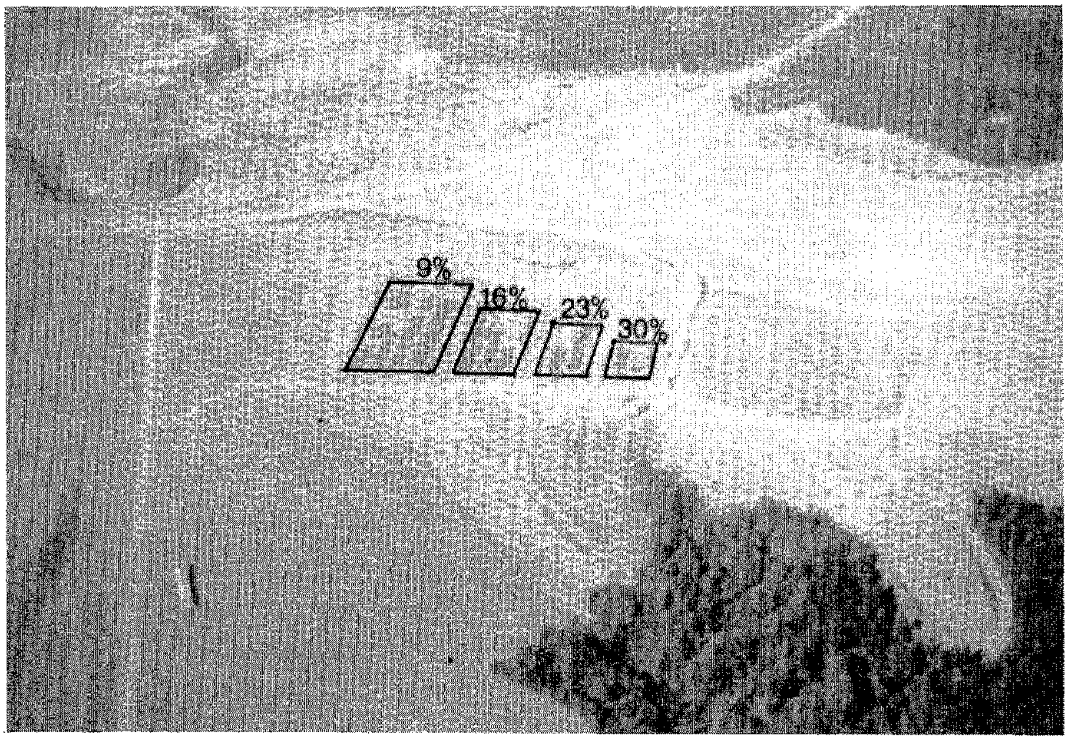

FIGURE 10. - Aerial view of plot site M09 after initial grading.

3. Cutoff Walls and Shelter.

At the base of each plot, a cutoff wall and shelter foundation was constructed of 2x8 in treated tongue and groove boards, supported by 4x6 in treated posts set into concrete. The tongue and groove joint was filled with a sealant prior to assembling to prevent leakage. The spoil material that was to be excavated had a high large rock content, precluding a deep excavation with the equipment available. As a result, the cutoff wall was not as deep across the ends of the plot as it was in the center where a deeper excavation was required to house the sampling and monitoring equipment. The large rocks, the resulting longer time required to excavate, the higher material expense, and close spacing of some of the individual plots on a graded area also limited the depth of the excavation for the shelter foundation. As a result, the sampling system required the use of a shallow holding tank (the A-can) and a small pump to pump the water into a large storage container (B-can), as mentioned previously. The treated tongue and groove boards were used below grade for the shelter foundation and plywood above grade for the shelter proper.

4. Collection Gutters.

The runoff water and sediment were conveyed from the downslope edge of the plot to the weir located at the center of the lower boundary of each plot. The gutters were fabricated of longitudinally split PVC pipe of varying diameters depending on the plot size. For mounting purposes, the split pipe was attached to two pieces of plywood with support braces beneath on a 4% slope. At the weir a transition apron was required where the flow cross section changed from a semicircle to a relatively flat rectangular cross section. The transition piece made of thin galvanized sheet metal (Figure 3), also provided enough flexibility to properly align the gutters with the weir. Where there was no weir, a longitudinally split PVC tee was used at the center to convey water directly to the sampler diverter.

F. System Test

The time period for testing the sampling system prior to full scale production was short. To accelerate the testing, a model of the diverter sampling system was constructed indoors at the NAEW (Figure 4). The sampler was operated over a range of steady flows. The flow rate and the sampler catch were measured for various periods of sampling. The fraction of the flow sampled was calculated and plotted against the steady flow rate during the test. Additionally, the average diversion fraction, measured with a stopwatch and using Equation 2 was determined. The results are shown in Figure 11. The data show a large positive slope indicating that the sampling mechanism acted slightly more slowly at the higher flows when a large volume of water had to be diverted. The error was too small to be considered significant. The stopwatch fraction was about 6% greater than the actual fraction measured, indicating a bias that must be accounted for in runoff volume calculations on plots where weirs were not installed. This will be discussed in the next section.

After the indoor testing was completed, a prototype was installed on one of the plots. Soil with large particles was placed on a plastic surface temporarily placed on the plot. This was done to create large runoff volumes and large sediment loads when the plot was exposed to natural precipitation events. The indoor and field tests resulted in slight modifications of the original concept.

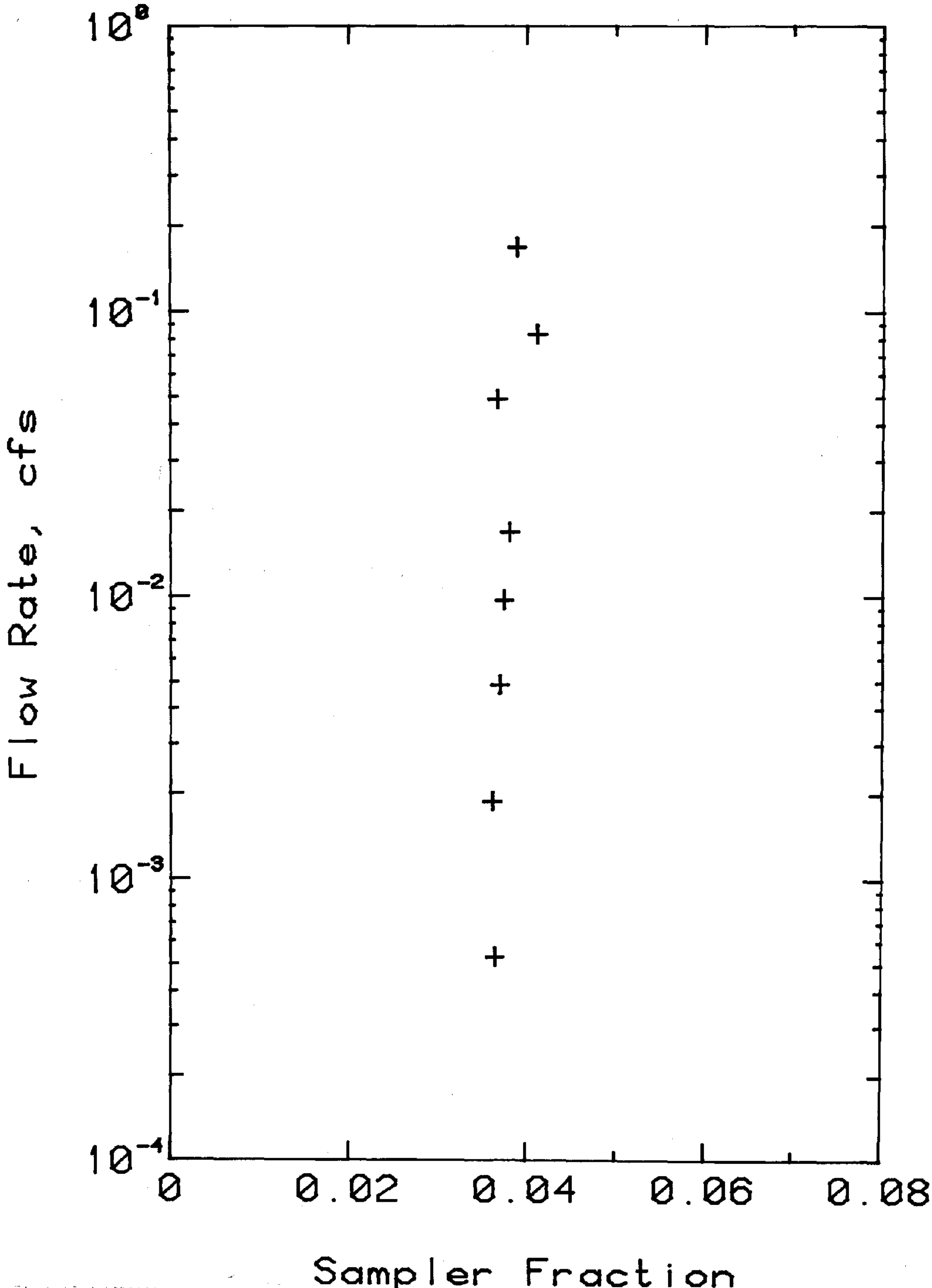

FIGURE 11. - Results of laboratory test of diverter sampler proportionality.

The samplers were installed on each plot. Field experience with all the plots operating pointed out other problems as time progressed. These problems were remedied as they arose.

G. Data Collection and Reduction

1. Data Collection.

The data collected in the field at the time of sampling by a technician included the pit precipitation gage volume, the chart time traces of accumulated precipitation from the two precipitation gages, the runoff chart time traces of stage from the weirs, the depths to the water surface in each sample storage container, field comments, a sample from each container, all the sediment deposited in the weir, aprons, and gutters, and occasionally sampler diversion times. The plots were sampled as soon after the occurrence of precipitation events as possible. During periods of prolonged precipitation, several precipitation-runoff events were sampled into one composite sample as mentioned earlier in the report.

After experience was gained in the field, the sampler threshold switch was activated to sample when the gage height equalled or exceeded 0.05 ft. This gage height was established because the sampler would sample only the larger events (the ones of interest), and less frequent attention would be required at the plot sites.

The sampling threshold for the plots without weirs were activated by the threshold switch at adjacent plots of similar surface treatment.

2. Data Reduction.

In order to process the field data after runoff events, other data were required. These are discussed briefly below.

A rating curve had to be developed for the drop-box weir. The rating was performed indoors at NAEW using steady flow rates (maintained by a constant head tank), calibrated containers, and a stopwatch. The weir exhibited four separate rating curves for the range of flows that would pass through the weir without overtopping.

It was not feasible to obtain calibrations on each sample storage container. Therefore, calibrations of representative sample storage containers were obtained indoors at the NAEW. Where the containers were unique, the individual calibrations were obtained.

The depths to the bottom and to the overflow point were measured from an established datum for each sample storage container in the field. These data were used to further define the container calibrations.

A computer program was developed to process all the hand tabulated chart runoff and sampler data. The program was designed so that all field data for sampled runoff events would be entered together. Provisions for time shifts due to clock errors and chart expansion, and for gage height adjustments were also made.

The drop-box weir rating and data reduction program were not available until the end of the reporting period of the plot project. When some data were processed, errors in the runoff chart traces were observed. During the course of data collection, a subtle instrument error was detected which affected the zero settings of the weirs. The problem was corrected using field data, and diversion times where other information was not available. The gage zero was adjusted in increments of 0.005 ft until the slope of the sample catch vs sampled runoff volume line equaled the diversion time. This error may bias some of the individual plot data.

The diverter sampler allows estimates of the runoff volume from the plot without weirs to be made by rearranging Equation 1:

$$V_r = V_s/f.$$

V_s and f are known from field data. The fraction, f, is the recorded diversion time ratio divided by 1.06 as explained earlier.

IV. RESULTS AND DISCUSSION

A. Soil Physical Characteristics

The soil characterization data available were the soil textures (Table 4) and the particle size distributions less than 2 mm (Table 5). The data were compared by vegetation type-soil type-particle size class categories. The results show, that, visually, on the average when total percentage classes are compared, there is no difference between the spoil and topsoil particle size distributions of the vegetated and fallow plots, respectively. However, the fallow and vegetated topsoil plots show slightly larger differences in sand particle size classes. The most critical particle classes for soil erodibility determination include those spanning the 0.1 to 2 mm, 0.002 - 0.05 mm, and 0.05 - 0.1 mm particle size ranges (Wischmeier and Smith, 17). Percent organic carbon data were not available, so a K-factor could not be determined from the K-factor nomograph (Wischmeier and Smith, 17). However, the data suggest nearly equal K-factors for spoil and topsoil in the range of 0.3 to 0.4 for the <2 mm particle size range. These soils have a 15% to 70% large rock content and, thus, the K-values may be different from the above range. On the average, the data showed that spoil plots had more coarse fragments than the topsoil plots. It appears that the erodibility of the topsoil and spoil may not shed light on the differences in soil losses observed (see later sections), however, this will require further study.

B. Results of Vegetation Surveys

1. Cover.

Listed in Table 6 are the estimates for vegetative and mulch cover. After seeding, the mulched plots had more plant growth which resulted in a higher percent vegetative canopy cover. The mulch cover from plant litter was not measured in the unmulched plots until the August 26, 1981 measurement.

The straw mulch significantly increased the vegetative cover (Table 7). The multiple regression analysis for the May 29, 1981 vegetative cover measurements indicate the straw mulch had a smaller effect which was not significant. The mulch treatments did not influence (straw and plant litter) plant residue cover. Topsoil depths had no significant effect on either vegetative or mulch cover.

2. Yields.

Listed in Table 8 are dry-matter yields for harvests made in both 1981 and 1982. The additions of 6 and 12 in of topsoil did not increase plant yields which indicates the spoil was equally as good for plant growth when fertilizer was applied (Table 9). The straw mulch during the establishment year of 1981 significantly increased dry-matter yields. Although significant, the yield differences were much smaller for the second year. This indicates the importance of a mulch on plant growth during the establishment period.

C. Hydrology and Soil Loss From Fallow Erosion Plots

1. Comparisons.

The fallow topsoil and spoil erosion plots were examined to detect possible differences among the plots due to slope and soil type using the response

TABLE 5. - Comparison of particle size distributions of spoil and topsoil plots

	Sand (mm)					
						Total
	1-2	0.5-1	0.25-0.5	0.1-0.25	0.05-0.1	0.05-2
Mean (Spoil - Vegetated, %)	5.4	12.1	9.8	15.1	8.1	50.7
Mean (Topsoil - Vegetated, %)	3.9	9.4	12.2	18.2	7.4	51.0
Mean (Spoil - Fallow, %)	5.5	12.6	10.8	17.4	8.2	54.5
Mean (Topsoil - Fallow, %)	3.0	8.7	11.0	22.7	7.5	52.8

	Silt (μ)			Clay (μ)		
			Total			Total
	2-20	20-50	2-50	<0.2	0.2-2	<2
Mean (Spoil - Vegetated, %)	24.1	11.4	35.5	2.7	11.1	13.8
Mean (Topsoil - Vegetated, %)	22.5	13.6	36.1	2.9	10.1	13.0
Mean (Spoil - Fallow, %)	21.7	9.8	31.5	3.5	10.5	14.0
Mean (Topsoil - Fallow, %)	22.2	13.7	35.9	1.7	9.6	11.3

TABLE 6. - Effect of topsoil depth and mulch rate on estimated percent vegetative and mulch (straw and plant litter) cover

Treatments		Percent Cover for Date Indicated					
		10-16-80		05-29-81		08-26-81	
Topsoil Depth (in)	Mulch Rate (t/Ac)	Vegetation	Mulch	Vegetation	Mulch	Vegetation	Mulch
0	1	51	14	65	17	81	17
0	2	53	36	57	31	86	14
12	1	62	18	74	9	87	11
12	2	55	35	50	34	83	16
6	1	50	18	70	16	66	31
6	2	36	42	50	34	75	22
0	0	18	0	33	0	37	12
12	0	19	0	28	0	29	10
6	0	10	0	29	0	30	12

[1] Plot had been cultivated June 3, 1982.

TABLE 7. - Multiple regression analyses for percent vegetative cover and percent mulch cover

	Multiple and partial correlation coefficients for percent vegetative cover		
	Measurement Dates		
Independent Variables	10-16-80	5-29-81	8-26-81
Mulch	.73[1]	.55	.86[2]
Topsoil	.15	-.03	-.05
R	.74	.55	.86[1]

	Multiple and partial correlation coefficients for percent mulch cover		
	Measurement Dates		
Independent Variables	10-16-80	5-29-81	8-26-81
Mulch	.57	.39	.52
Topsoil	.15	.23	-.41
R	.58	.44	.60

[1] Significant at the 0.05 probability level.

[2] Significant at the 0.01 probability level.

TABLE 8. - Effect of topsoil depth and mulch rate on dry-matter yields

Treatments		Harvest Dates (lbs/Ac)	
Topsoil (in)	Mulch (lbs/Ac)	10-09-81	06-02-82
0	0	105	1011
6	0	33	1037
12	0	68	1198
0	1	1475	1589
6	1	1208	1264
12	1	1402	1623
0	2	1161	1597
6	2	977	1354
12	2	1417	1441

TABLE 9. - Multiple regression analyses for dry-matter yields

Independent Variables	Multiple and partial correlation coefficients for dry-matter yields Harvest Dates 10-9-81	 6-2-82
Mulch	.78[1]	.70[1]
Topsoil	.05	.06
R	.78	.70

[1]Significant at the 0.05 probability level.

variables of peak runoff, runoff volume, and sediment loss for the sampled events.

First, the means of the response variables of the fallow plot data set were tabulated in Table 10. Possible differences and patterns due to slope and soil type were examined. The data show that the higher runoff-producing plots were those on the 16% slope for both topsoil and spoil plots and on the 23% topsoil slope. The other slopes yielded approximately the same amount of runoff within each soil type. The topsoil plots with the highest mean runoff values also had the highest mean peak flows. The 16% and 30% spoil plot slopes had the highest peak flows, while the 23% spoil plot had the smallest. The mean sediment loss data for the different slopes showed that the soil loss from the topsoil plots increased with slope as one would expect. However, the data for the spoil plots did not follow such a pattern. These data showed the minimum and maximum sediment loss values were associated with the minimum and maximum slopes, respectively. However, the values for the 16% and 23% slopes were reversed from what one would expect. The topsoil and spoil soil loss results indicate that other factors beside flow volume and peak flow affected the soil losses. Among the factors that can be considered as candidates for further study are precipitation energy, intensity, and amounts for each event, soil erodibilty differences between plots, antecedent conditions, and other soil characteristics. In summary, generally, the spoil plots had higher values of the response variables considered. The two exceptions (mean peak flow rate and soil loss on the 23% slope) were nearly identical. The absence of a pattern of the various response variables may reflect some unknown, site-specific factors.

Next, an analysis of variance for the individual data for each of the three response variables was performed to determine the extent of the variability of the data as summarized in Table 10, and to determine whether there were significant differences between the levels of the two factors considered, and if an interaction between the factors existed. First, the issue of the type of data set to use had to be resolved. There are two ways in which the data can be examined. One is to form a data set by extracting all the sampled events having experienced the same rainfall and perform an analysis of variance. The other is to use the entire data set regardless of the synchronization of the precipitation periods. Both methods were attempted. The data set resulting from the former approach had a small sample size and, therefore, results from this data set would not have been reliable; the entire data set was therefore analyzed.

Three data sets resulted from using all the data collected, one for each response variable. Before performing an analysis of variance (ANOVA) on each data set, the data were subjected to tests for the implied equal variance and normality assumptions as mentioned in Section 1 of this report. The results of these tests were that the two ANOVA assumptions were violated. A logarithmic transformation was applied to the data because the variances were observed to generally increase with the means of the data. Tests of the two assumptions on the transformations resulted in the acceptance of the normality and equal variance assumptions for all levels of all transformed response variables. The results from the ANOVA were that there was no significant influence of the two factors (soil type and slope) on runoff volume; there was a borderline dependence of peak flow rate upon soil type (probability $>F = 0.04$); and there was a significant effect of soil type on soil loss (probability $>F = 0.0003$). Interactions between the two factors were not apparent. Means of the spoil and topsoil data calculated across slopes showed that on the average, soil losses

TABLE 10. - Mean runoff volumes, peak flows, and soil losses from fallow topsoil and spoil plots on varying slopes

	Mean Runoff Volume		Mean Peak Flow (in/hr)		Mean Soil Loss (t/ac)	
	Topsoil Depth (in)		Topsoil Depth (in)		Topsoil Depth (in)	
Slope%	0	8	0	8	0	8
9	0.47	0.29	2.5	1.6	0.96	0.32
16	.64	.63	2.8	2.5	3.0	1.5
23	.51	.48	2.2	2.3	1.5	1.7
30	.50	.29	2.8	1.3	3.2	1.8

from the spoil plots were 1.6 times those of the topsoil plots, and that peak flows from the spoil plots were 1.3 times those of the topsoil plots.

In summary, the spoil plots showed higher values of the three response variables in general. An ANOVA on the logarithms of the original data showed effects due to soil type of varying significance on the three response variables; a significant effect on soil loss, an effect bordering on significance on peak flow rate, and an insignificant effect on runoff volume. A significant effect of slope on the three response variables was not evident. This means that soil type (spoil or topsoil) affected soil loss more than slope (ranging from 9% to 33%) on the plots studied, notwithstanding the coarser nature and higher large rock content of the spoil than the topsoil. It also suggests that peak flow rate is an important factor causing the soil loss difference observed above.

2. Regressions.

a. USLE Slope Factor.

The design of the experiment allows a qualitative comparison between the slope factors of the USLE and one derived from the data collected. The USLE slope factor(s) is the ratio of the soil lost from an area of a specified slope to that from a standard plot having a 9% slope, all other factors remaining the same. It is given by Wischmeier and Smith (17) as Equation 3,

$$S = 65.41 \sin^2 T = 4.56 \sin T + 0.065, \tag{3}$$

where,

T = the angle of the slope.

Soil loss ratios were calculated using data from topsoil and spoil plots and the definition of the S factor. A least-squares fit to an equation of the form of Equation 3 was made to the data. The two least-squares equations, the USLE equation for S, and the range of scatter for the two least squares equations are shown in Figure 12. The two least-squares equations show remarkable similarity. Also, they both lie well below the USLE curve, indicating that much more erosion would be computed by the USLE for the same slope than that shown by the mine-soil curves. However, the large variability in the data maintained low levels of explainable variation in the data. The lower position of the soil loss ratio curve may indicate an effect due to the exposed large rock content of the soil surface and the near surface or to inherent erodibility factors due to the high large rock content of the soils. The small average slope of the two mine-soil curves lends graphical support to the conclusion of insignificance of the effect of slope on soil loss found in the ANOVA of the last section.

b. Soil Loss and Peak Flow Rate Equations.

The analysis of variance for the response variables of peak flow rate and soil loss from the fallow plots suggested a causal relation between peak flow rate and soil loss. Other investigators have been successful in using peak flow as an independent variable also. Williams (16) suggested the use of a USLE

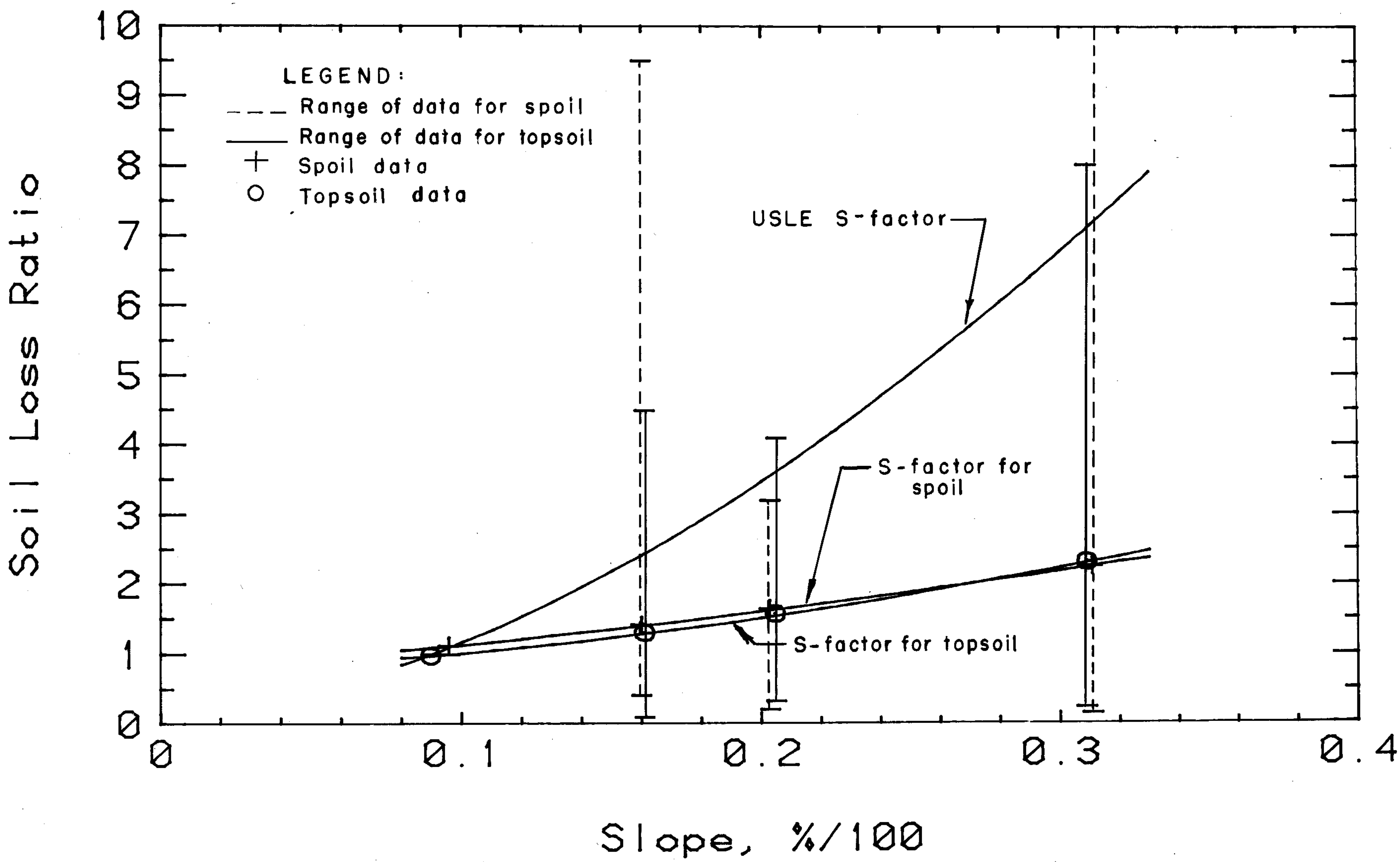

FIGURE 12. - Slope factor equations from mine soil data and for the USLE.

runoff energy factor (R) as:

$$R = 95\ (VQ)^{0.56} \tag{4}$$

where, V = runoff volume, and

Q = peak flow,

Foster et al. (4) suggested the form of a USLE rill erosivity function as:

$$R = aVQ^{1/3}, \tag{5}$$

Here, a is a constant, and the other terms are as defined above. In both cases, R is an erosivity coefficient as used in the USLE, and is fixed for all slopes. Varying slopes are accounted for by the slope factor of the USLE.

In order to examine the apparent observed causal relation, the peak flow rate and soil loss data for each plot were graphed in logarithmic coordinates, and an equation of the form $y = ax^b$ was fitted to the data, where y = soil loss and x = peak flow rate. Runoff volume was not included as was done by other investigators because soil loss was calculated using runoff volume and spurious correlation would result. The graphs of the data having the minimum and maximum coefficients of determination (r^2) are shown in Figures 13 and 14, respectively. The r^2 values for the other regressions are summarized in Table 11. The table shows a weak to fair correlation between the two variables, suggesting other factors besides peak flow are important in determining soil loss. However, peak flow rate did explain the major part of the variability of the soil losses observed.

D. Hydrology and Soil Loss of Reclamation Plots

1. Comparisons.

The reclamation plot data were examined to compare plots having different topsoil depths, mulch application rates, and vegetation by using the same response variables as were used for the fallow plots, runoff volume, peak flow rate, and sediment loss. The analyses in this section apply to runoff events that were sampled (the larger of all possible events) because of the setting of the sample threshold switch. The results may not apply to smaller events.

The means of the response variables are presented in Table 12. From the table there appear to be no patterns with respect to topsoil depth, except that runoff volume is higher from spoil plots than topsoiled plots as was found for the fallow plots. There also appear to be no patterns with respect to mulch rate, except for soil loss. Here, there are noticeable reductions in soil loss with increasing mulch rate.

Analysis of variance was performed on only the vegetated plots in order to determine if a significant difference existed between the levels of the two factors considered, and if an interaction between the factors was apparent. The classification variables were mulch rate, topsoil depth, and the interaction of mulch rate and topsoil depth. The data were examined two ways as was done for the fallow plot data. However, a balanced data set could not be extracted from the entire data set, so the analyses used the entire data set.

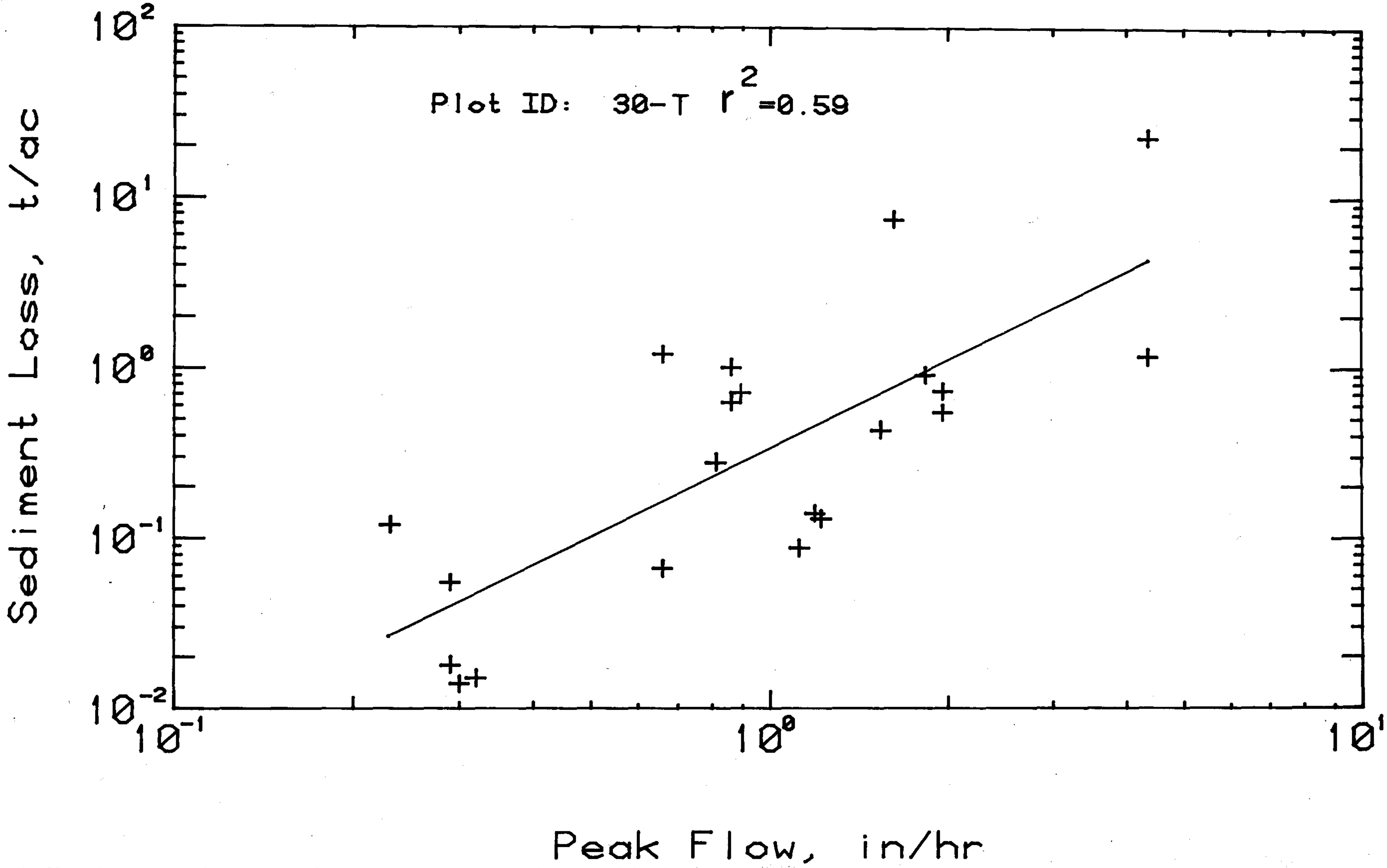

FIGURE 13. - Graph of sediment loss vs peak flow for plot having the lowest r^2 value.

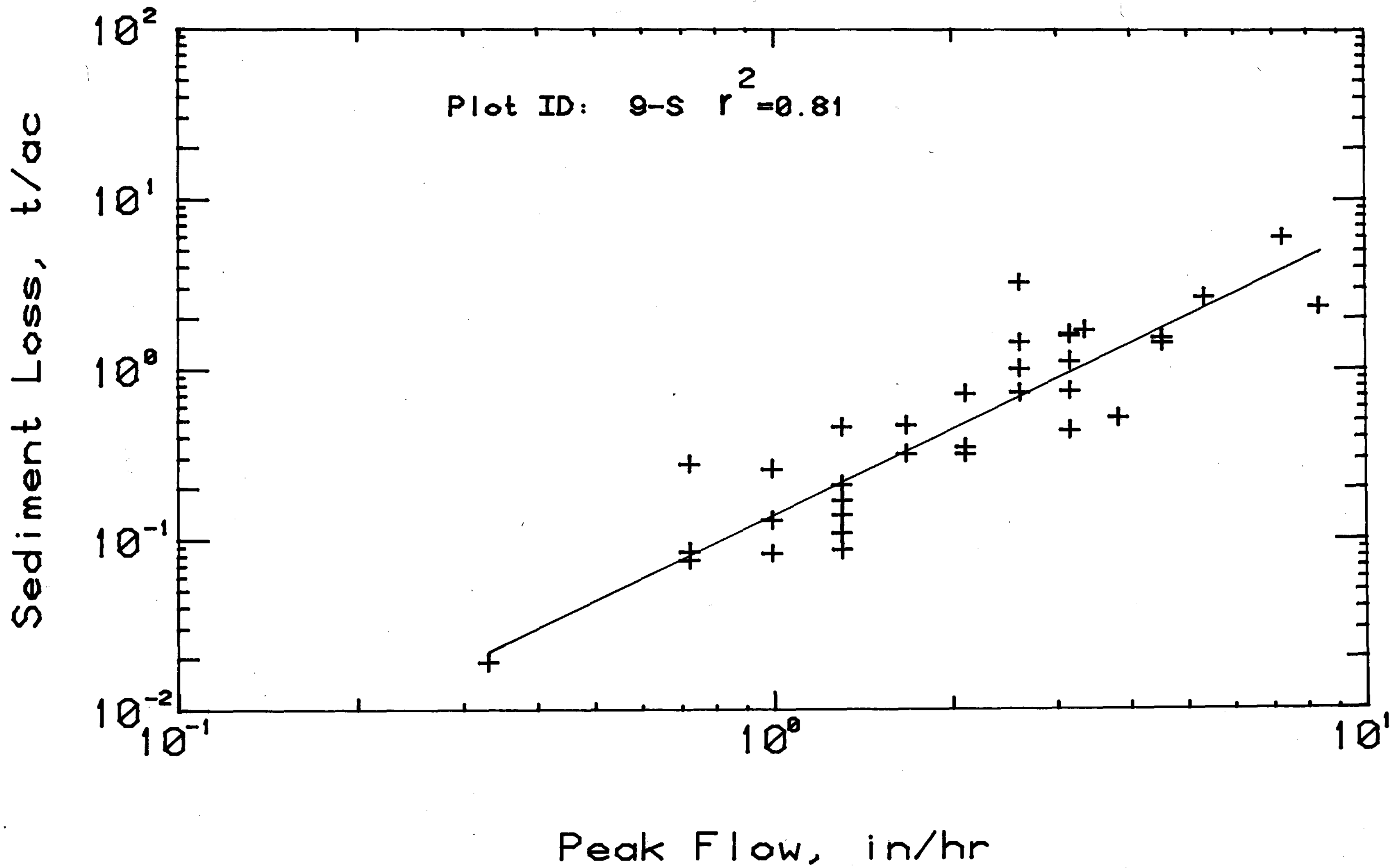

FIGURE 14. - Graph of sediment loss vs peak flow for plot having the highest r^2 value.

TABLE 11. - Regression summary for soil loss vs peak flow

Regression Variables		Coef. of Determination		Number of r^2 Values in the Range Indicated			
Dependent	Independent	Minimum	Maximum	0.50-0.60	0.60-0.70	0.70-0.80	0.80-0.90
Peak Flow	Runoff Volume	.52	.73	3	4	1	0

TABLE 12. - Mean runoff volumes, peak flows, and soil losses from vegetated topsoil and spoil plots

	Mean Runoff Volume (in)			Mean Peak Flow (in/hr)			Mean Soil Loss (t/Ac)		
	Topsoil Depth (in)			Topsoil Depth (in)			Topsoil Depth (in)		
Mulch (t/Ac)	0	6	12	0	6	12	0	6	12
0	0.70	0.56	0.53	2.4	1.5	ND[1]	0.53	0.66	0.79
1	.90	.45	.67	ND	ND	1.6	.23	.10	.27
2	1.1	1.0	.53	ND	1.7	1.5	.072	.076	.038

[1] ND - No data due to method of instrumentation.

The data sets resulting after the ANOVA grouping were subjected to tests of normality and equivalence of variances as was done for the fallow plots. The results showed that the large majority of the data failed the tests. A logarithmic transformation of the data resulted in all the individual plot data passing the two tests. The results of the analysis of variance for each response variable showed that there was no effect due to topsoil depth and none due to the interaction of topsoil depth and mulch rate for all three response variables. However, a borderline effect on runoff volume (probability >F = 0.08), significant effect on soil loss (probability >F = 0.0001), and an insignificant effect on peak flow rate due to mulch rate was observed. The significant effect due to mulch was investigated further.

The data were averaged across slopes, resulting in three levels of mulch rate for each response variable. The original data were found to be nonnormal, therefore, other schemes for comparing the data were investigated. A logarithmic transformation of the new data sets resulted in mixed results, some variables becoming normally distributed and some retaining their nonnormality, as determined by the Shapiro-Wilk W-test for normality. The data were then subjected to the Mann-Whitney U-test to avoid the normality assumption inherent in the statistical t-test procedure. This is a nonparametric statistical method for testing for differences between central tendencies (Siegel, 7), as explained in the first chapter of this report. The results of these tests showed the sources of the differences found in the analysis of variance tests performed above. First, there was a significant decrease (probability >t = 0.0005) between the means of soil loss due to the effects of 0 and 1 t/Ac of mulch (the 1 being approximately 74% less than the 0 t/Ac plots). Also, the effect of applying 2 t/Ac vs 1 t/Ac of mulch was of borderline significance on runoff volume (probability >t = 0.08), runoff averaging 1.4 times more runoff than the 2 t/Ac plots. The reason for the apparent anomally in runoff volume is not known. There was no significant effect due to 2 t/Ac of mulch as compared with no mulch on peak flow. Runoff volume and soil loss were significantly different at higher levels of the t statistic than in the 0 and 1 and 1 and 2 t/Ac comparisons.

The effect of the presence of vegetation and mulch on an originally bare plot on the three response variables was investigated next. The data were examined for compliance with the normality assumption inherent in the statistical t-test procedure. Neither the original data nor different transformations of the data were found to be distributed normally as determined by the Shapiro-Wilk test. The data were next subjected to the Mann-Whitney U-test, as above. The results of this test for each of the three response variables were that significant differences between the vegetated plots and the fallow plot existed for peak flow rate (probability >t = 0.009), and soil loss (probability >t = 0.0001), due to the presence of mulch and vegetation on the plots. On the average, peak flow and soil loss from the fallow plot were 1.3 and 1.6 times higher than from the vegetated plots, respectively. There was no significant effect on runoff volume due to the above factors.

It is evident from the data that at least 1 t/Ac of mulch applied at the time of seedbed preparation with fertilization according to a soil test significantly improved the soil loss problem on the mine soils studied.

2. Regressions.

Regressions of sediment loss vs runoff volume and peak flow and peak flow vs runoff volume were performed for the vegetated plots similar to the analyses of the fallow plots. Generally, the coefficients of determination were smaller than those of the fallow plots. The regression coefficients apparently varied independently of treatment type, thus, no further investigation of these regressions was made.

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