A STUDY OF RAINFALL SIMULATORS, RUNOFF AND EROSION PROCESSES, AND NUTRIENT YIELDS ON SELECTED SITES IN ARIZONA AND NEW MEXICO

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DISCLAIMER

ABSTRACT

Estimation of runoff and sediment yield from small, ungaged watersheds is a difficult hydrologic task. Process oriented mathematical models can be an important part in the solution of this task. Models, however, require some information which is directly related to the hydrologic processes occurring on the watershed. Rainfall simulation is an important experimental technique for gathering such information.

This technical report contains the results of a study on the utility of using rainfall simulation in southwestern watersheds. Two different simulators were compared on three sites. At one site, three simulators were used, and one of the simulators was used to gather data at three additional sites. A small area simulator, 1 square meter, and two large area simulators, approximately 32.5 square meters, were operated for a total of about 74 plot experiments. One of the simulators was operated as part of the USDA - ARS Water Erosion Prediction Project.

Analysis of the data indicates that the simulators provide similar results for infiltration characteristics, and that sediment yields were about 4.0 times higher for the small simulator. Numerous water chemistry samples were analyzed to determine potential nutrient loadings from forest and range lands to water bodies in New Mexico.

Keywords: computer models, data collection, hydrologic models, hydrologic processes, infiltration, parametric hydrology, runoff plot, sediment yield, simulated rainfall, soil erosion, nutrients

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The field crew was headed by Randy Foltz and included Bob Peyton and Billy Mendoza. Randy was also responsible for data processing after the experiments. His efforts on this project are greatly appreciated. Miguel Gabaldon, Kristel Gillespie, and Marvin Magee all assisted in the lab work.

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"CONSERVE NEW MEXICO'S WATER AND SOIL"

INTRODUCTION

Rainfall simulators are important devices for gathering data that can be analyzed to define the hydrologic and hydraulic characteristics of natural and disturbed lands. Information that can be obtained from rainfall simulator experiments includes infiltration characteristics, sediment yield/erosion parameters, and nutrient export indices. Because simulators are so useful, several have been built following a variety of designs. The variety of designs, however, creates some difficulties when a comparison of results is conducted between different simulators. Factors of scale (e.g. area differences, edge effects, and overland flow length), rainfall intensity and energy, sampling procedures, and analysis techniques all help to create differences among data sets obtained with various simulators.

Of particular interest to this project is a comparison of large area and small area simulators to the rotating boom simulator used by the U.S. Department of Agriculture, Agricultural Research Service (ARS), to gather data for the Water Erosion Prediction Project (WEPP). The large area and small area simulators operated by the Department of Civil, Agricultural, and Geological Engineering, New Mexico State University (NMSU), have previously been compared to each other on desert rangelands in New Mexico (Ward 1986). This study is an extension of that initial effort in which the small simulator was compared with the WEPP simulator at three sites: two desert rangeland and one forested. The large simulator was compared to the WEPP simulator at one of the desert sites.

This study was enhanced by interconnection to another, long-term project which has an overall objective of modeling fisheries habitat in New Mexico's streams and reservoirs. An additional three sites were sampled with the small simulator. Two of the sites were in forested land and one was in the prairie. Sixty plot-runs with the small simulator and two plot-runs with the large simulator were conducted at the six sites.

This report presents a summary and analyses of the data that were collected during the experiments. A comparison is made between the results from the three simulators and similarities and differences are discussed. The information provided in this report should aid resource managers in formulating policy related to land use and expand the data base scientists and engineers need for modeling complex water-soil-vegetation systems.

Goals and Objectives

The following two goals were identified for this study.

A. Collect data with the simulators to help characterize infiltration, runoff and erosion processes and nutrient yields for the selected sites.

B. Compare results obtained with the small area and large area rainfall simulators to those obtained with the WEPP simulator.

These two major goals were subdivided into five objectives related to the field sites or the simulation device. The following five objectives were considered to be important.

A. Site Studies

1. Characterize infiltration parameters at the sites
2. Characterize a soil erosion/transport parameter for the sites
3. Collect water samples for chemical analyses

B. Comparison of the Simulators

1. Compare infiltration and erosion measurements collected using the small and large area simulators with those collected using the WEPP simulator
2. Suggest changes to experimental or analytical procedures to provide a better correspondence between simulators, if needed

Scope of Report

This report is a summary and analysis of rainfall-runoff and erosion data collected from six sites on range and forest lands using large and small simulators. Data collection methods and techniques were previously presented in Ward (1986) and are only modified or reiterated in this report (Appendix A) as needed. This final report includes analyses of the data as related to the goals and objectives of the study.

Literature Review

The primary literature review for this project was presented in Ward (1986). The extension of the project to this study has added two components: comparison of small area and large area simulators with the WEPP simulator and collection and analysis of runoff water for nutrients.

The WEPP is a long-term USDA/USDI (Foster et al. 1987) study led by the ARS in cooperation with other federal and state agencies with the goal of developing an improved technology for estimating erosion and sediment yield from agricultural, range and forest lands. This improved technology will eventually replace the currently used universal soil loss equation (USLE) with a computer based, process oriented, user friendly model that can be used in land planning. The most recent papers on the subject were presented at the 1987 Winter Meeting of the American Society of Agricultural Engineers (e.g. Rawls, Lane and Nicks 1987) held in Chicago, Illinois. Because WEPP is focusing on process oriented models, the final product will require that numerous parameters be derived from field and laboratory data then related back to on-site characteristics. These parameters will then be generated by the model user with only a small amount of information such as soil texture or season of the year. The major problem lies in deriving the parameters and accurately relating them to easily measured or defined site characteristics.

The first step in this approach is to collect accurate and reliable field data. For infiltration and erosion parameters, this means that rainfall simulation must be used in order to obtain repeatable and controlled information in a realistic number of field seasons. Only rainfall simulation can be expected to aid in this step especially for semiarid and arid lands. The ARS has been and is continuing to use a Swanson rotating boom simulator for data collection. Simanton et al. (1985) provide a good overview of the ARS efforts on rangelands and Burroughs and Nordin (1987) review efforts in forested regions. The ARS plots are 3.05 m wide by 10.7 m long (length in the direction of flow). The simulator delivers either about 60 mm per hour or 130 mm per hour rainfall intensity. Most experiments are conducted at 60 mm per hour. The simulator delivers about 77% of the equivalent USLE kinetic energy.

The second step in the data collection and analysis approach is to relate field information to easily measured site characteristics of soil, vegetation, cover and topography. It is on this step that WEPP is now focusing. Of particular interest are the best techniques for estimating model parameters from the data and determining what site characteristics these parameters may be related.

Extension of these procedures to previously collected data sets using other types of simulators would be of tremendous benefit to WEPP and the agencies which have gathered the data. Two general problems and two procedural problems occur when trying to compare data from different simulators. First is the effect of scale. Ward (1986) has shown that there is a scale effect on sediment yield per unit area per unit depth of runoff between large area and small area simulators, the small area simulator producing the higher values. Ward also concluded that infiltration was comparable between the different simulators. Wicks et al. (1988 in press) used the small plot data of Devaurs and Gifford (1984) to estimate hydraulic conductivity for ARS simulator experiments at Reynolds Creek, Idaho. Wicks et al. concluded that the average of the small plot data gave good results when modeling the larger ARS plots.

The second general problem is developing an accurate and reliable method of measuring rainfall intensity for simulators and natural storms. Tracy, Renard and Fogel (1984) show that kinetic energies for rainfall at the Walnut Gulch watershed are in excess of what would be computed from the USLE algorithm. Therefore, the approach used to scale the sediment yields based on the fraction of USLE energy is open to criticism. Until a better approach is suggested, that method probably will persist. Unfortunately, as Wicks et al. (1988 in press) found, this may lead to large errors when trying to use simulator results to predict yields from field sized plots (one hectare in this instance).

The two procedural problems involve sampling methods and analysis techniques. Each investigator utilizes different techniques with different field and laboratory personnel. Therefore, the data from which the parameters are derived may not be the same for each experiment. However, comparison of techniques and standardization of those that can be modified will help in this regard.

The other extension of the project for this study was the addition of a chemical sampling component for determination of nutrient yields. This component of the study was brought about by the interconnection of the project to a long term fisheries modeling effort funded by the New Mexico Water Resources Research Institute and the New Mexico Department of Game and Fish. More details of the project and a good summary of progress and results to date can be found in Cole et al. (1987). The fisheries modeling project requires information about the loadings of water, sediment and associated nutrients to the streams and reservoirs in New Mexico.

Rainfall simulation is an excellent technique for gathering such information. Recognizing that, the simulator comparison study was expanded to include the goals of the fisheries project to the benefit of both. Similar work had previously been conducted by Cole et al. (1986) and another study had been summarized by NMSU (1982). In those studies, rainfall simulation was used to generate runoff from small plots and the chemical loads of the runoff water were measured. Although the data had high variance in most cases, the data did provide a general index of the concentrations and loads that might be expected from rainfall-runoff on several different soil and vegetation complexes in New Mexico. Given the background of those studies, this study was an attempt to expand and enhance the data base for future use in modeling.

METHODOLOGY

Location of Sample Sites

The six sites sampled in this study were located in New Mexico (five) and Arizona (one) (figure 1). The sites were, in order of sampling, Tombstone (Walnut Gulch), Arizona, and Clayton, Los Alamos, Bluewater, Cuba, and Bear Canyon, New Mexico. The small area simulator was used at all six sites, the large area simulator was used at Tombstone, and the ARS simulator was used at Tombstone, Cuba, and Los Alamos. The small and large area simulator experiments were conducted between May 24 and June 27, 1987. The ARS simulator experiments were conducted at various times according to the schedule followed by the ARS.

Tombstone, Arizona. The Tombstone site was located northeast of town in the Walnut Gulch experimental watershed. Six small plots and one large plot were sampled. The plots were located near the Lucky Hills set of ARS plots. The site can be characterized as desert scrub with very stony soils.

Clayton, New Mexico. The Clayton site was located west of Clayton Lake on land owned by Roy Kimbel. Because of high, persistent winds only four plots could be sampled during the site visit. The plots were located in short grass prairie at an elevation of about 1650 meters.

Los Alamos, New Mexico. The small plot simulations were performed next to the WEPP plots in the TA51 West area of the Los Alamos National Laboratory. Because of limited space for

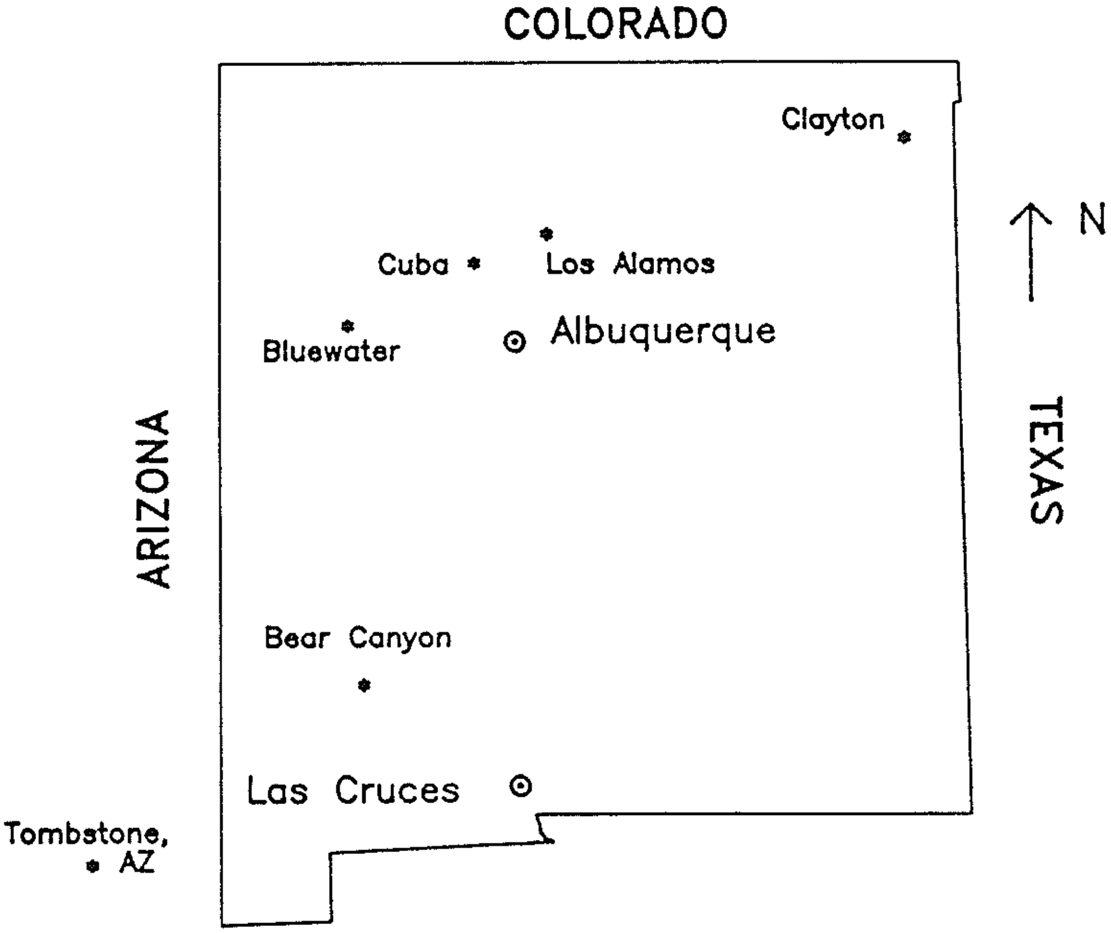

Fig. 1. Location of Sample Sites.

simulation within the exclosure at the site, only two plots could be sampled. The site was located in piñon-juniper at an elevation of about 2050 meters.

Bluewater, New Mexico. This site was within the watershed of Bluewater Lake near the junction of Forest Roads 178 and 180. Six plots were sampled in the ponderosa pine vegetation. The site was at an elevation of about 2370 meters.

Cuba, New Mexico. The Cuba site was originally intended to be located near the long-term plots maintained by Dr. Earl Aldon. However, the ARS plots were located in another area. The six plots sampled were next to the ARS WEPP plots. The site is midway between Cuba and San Ysidro off State Route 44. The plots are in desert grasslands at an elevation of about 1900 meters.

Bear Canyon, New Mexico. The Bear Canyon plots, although not in the watershed of Bear Canyon Lake, were located in similar soils and vegetation nearby. Six plots were sampled at a site about five miles from the junction of State Route 61 and Forest Road 151 along Forest Road 151. The plots were in piñon-juniper vegetation at an elevation of about 2250 meters.

A total of sixty plot-runs (thirty plots, dry run and wet run samples for each) were conducted using the small simulator. One dry run and one wet run were conducted using the large area simulator at Tombstone. The ARS provided data from the WEPP simulator runs at Tombstone, Los Alamos, and Cuba. The Los Alamos and Cuba samples were taken in the fall of 1987, and were observed by an NMSU project representative. Dry and wet run simulation results for the natural cover plots were provided by Dr. Roger Simanton of the ARS, Tucson, Arizona.

Procedures

Procedures (Appendix A) generally conform to those followed and reported in Ward (1986). The major exception was the collection of samples for chemical analysis. Water to be analyzed for chemical concentrations was collected from the same barrels of accumulated runoff as the sediment samples. Two 250-milliliter bottles were collected from each plot run. One bottle was preserved with sulfuric or hydrochloric acid to stop biological activity. Both samples were placed on ice. The acid treated sample was analyzed for phosphorus and nitrogen. The untreated sample was used for measuring total organic suspended solids.

These samples were taken to the Soil and Water Testing Laboratory at NMSU. The samples were analyzed on autoanalyzing equipment for total phosphorus, total Kjeldahl nitrogen, nitrate-nitrite, total suspended solids and organic suspended solids. Because the laboratory must measure total suspended solids in order to get total organic suspended solids, the lab filtration method can be compared to the centrifuge method for measuring total suspended solids.

Derivation of Parameters

Selected parameters were derived from the data using statistical and numerical techniques. For infiltration, the key model parameters are steady-state infiltration rate and a soil water parameter such as capillary suction. These values can be determined from rainfall rate and measured runoff. In the report by Ward (1986), the steady state infiltration rate was found from either a least squares fit of the incremental loss rate and the reciprocal of the infiltrated depth or by averaging the last three steady loss rates. The capillary suction parameter was then derived from the least squares parameters, the appropriate loss rate (infiltration rate), and soil characteristics of porosity and saturation. For this study, two other techniques were investigated and one of them was chosen for use in analysis. The first technique was proposed by Rawls, Brakensiek, and Savabi (unpublished manuscript) whereby the effective hydraulic conductivity could be found from

$$KE = 2(FR) - (F/T) \tag{1}$$

where:

KE = effective conductivity (L/T), (length units divided by time units, or a rate),

FR = final infiltration rate (L/T),

F = total infiltration depth at the final infiltration (L)

and

T = accumulated time corresponding to FR and F (T).

Because of surface storage effects at the beginning and end of the infiltration experiments and the difficulty in obtaining a steady final loss rate (FR), two other variations of equation (1) were investigated. None of the three different formulations was found to be acceptable as all three produced negative values of KE for different experiments. The two approaches proposed by Ward (1986) also were investigated, with the zero intercept method providing more consistent results. However, another approach was developed as a hybrid which uses the average steady state infiltration rate and the Green and Ampt steady rainfall infiltration formulation proposed by Mein and Larson (1971) and expanded upon by Li, Stevens, and Simons (1976). In this technique, the equation

$$F - a \ln(1 + Fa) = C \tag{2}$$

where:

F = total depth of infiltrated water at the end of the experiment (L),

$a = Hc(1 - Si)n$,

Hc = capillary head (L),

Si = initial soil saturation at the beginning of the experiment,

n = soil porosity,

$Fa = Fp/a$,

$Fp = i\ tp$ = infiltrated depth of water at time of ponding (L),

i = steady rainfall rate (L/T),

tp = time to ponding since beginning of effective rainfall (T),

$C = kw(T - tp) + Fp - a \ln(1 + Fp/a)$,

kw = saturated hydraulic conductivity,

T = duration of rainfall (may be effective rainfall) (T), is solved for "a" using a Newton-Raphson search. The value of kw is assumed to be known and is found by summing the volume of runoff for the last three sample periods then dividing by the total duration of the three sample periods. The search is facilitated by a first guess of "a" as

$$a = F/2(F/(kw\ T) - 1.) \tag{3}$$

The method was found to give reasonable results for Hc for most cases. However, there are certain instances when, given variations in the data or the small magnitude of "a", the method will not converge. In those cases, a direct trial and error procedure using equation (2) was employed. This was only necessary in five out of 60 plot-runs. Out of the five, some errors still persisted in two because it was impossible to reduce "a" to achieve a reasonable match between the measured and calculated values of F. However, these errors had absolute magnitudes on the order of 1 mm of infiltration. As a check, the values of kw and "a" obtained using these techniques were entered into the computational procedure presented by Simons, Li, and Ward (1977) to estimate F. As noted above, very few computations varied from the measured values.

This new procedure for estimating Hc has some advantages over the previous methods. First, the total depth of infiltration is used. This value is not affected by surface storage and routing effects as are the incremental depths. Second, the steady state loss rate is the integral of several measurements and does not rely on the last measurement. Third, once kw is determined, the method gives a value of Hc which will (in the vast majority of cases) provide an exact estimate of the the total infiltration depth. Fourth, the method can be modified to account for interception and surface retention effects on the total infiltration by reducing the apparent infiltration depth and reducing the apparent duration of the infiltration process. This last procedure was investigated which resulted in a reduction of Hc as the depth of intercepted and ponded water increased. Although these results are anecdotal, they may lead to some interesting investigations.

Erosion on overland flow surfaces comes about when there is sufficient energy to dislodge and move the soil materials. The two sources of energy present in simulator studies are from raindrop impact and overland flow. Raindrop impact works by dislodging particles and transporting them relatively short distances in splash water. In the absence of overland flow, splash is an inefficient transport mechanism. Overland flow, particularly sheet and rill flow, typically has lower energy but is more efficient at transporting sediment. In combination, the two energy inputs provide an effective method of soil erosion. It is difficult to precisely separate the two processes when analyzing soil erosion data. Instead, a balance between the two is found by analyzing data from different rainfall intensity and overland flow rate experiments. This is a primary reason for conducting a series of experiments on a site.

For surface erosion, the key parameters are raindrop splash detachment and overland flow detachment coefficients. Of primary importance for the small area simulator experiments is the raindrop splash erosion/transport parameter (Ward 1986). That parameter was determined following the procedures outlined by Ward (1986) which is summarized in Appendix A.

RESULTS AND ANALYSES

Data collected from the small and large experiments were reduced, analyzed and summarized. The results of these efforts are presented in following sections. The results are compared among the different sites in order to demonstrate differences and similarities in the hydrologic functions among areas. The results are also used to compare simulators and to provide a basis for relating the small plot data to the WEPP simulator data. Note that in the discussions the following conversions apply: 25.4 mm = 1 inch, 1 kilogram (force) = 2.205 pounds, 1 kilogram (force)/hectare = 0.893 pounds/acre, 1 kilogram (force)/ hectare-mm (unit area yield per unit of runoff depth) = 22.682 tons/acre-in.

Site Characteristics

Table 1 is a list of the summarized site measurements for the small simulator plots and the single large simulator plot. Means and standard deviations of each measured variable were determined for the small plot experiments. The measured values for each small plot are listed in Appendix B. Most information in these tables is self-explanatory. Gradation was determined by mechanically sieving the bulk soil samples and using a hydrometer analysis to determine the silt-clay division of the fine materials. Gravel percent is the average percent by total sample weight of particles larger than 4.75 mm in diameter. Sand represents the size fraction between 4.75 mm and 0.075 mm, and fines are less than 0.075 mm in size. The silt fraction is

TABLE 1

Means and Standard Deviations (in parentheses) of Plot Characteristics for Each Site

				COVER		GRADATION				AMC	
SITE	#	POROS %	SLOPE %	ROCK %	VEG %	GRAV %	SAND %	SILT %	CLAY %	DRY %	WET %
BC	6	51.4	3.0	40.8	30.0	14.7	65.6	15.7	4.1	4.2	19.6
		(4.5)	(2.7)	(25.4)	(4.4)	(7.4)	(4.4)	(7.1)	(1.4)	(0.7)	(3.0)
BW	6	44.0	3.8	0.3	30.8	3.7	55.3	34.9	6.0	2.1	24.6
		(5.9)	(1.3)	(0.5)	(6.6)	(3.6)	(3.1)	(4.5)	(0.9)	(0.5)	(5.9)
CB	6	46.2	3.2	0.0	39.2	0.0	53.5	41.0	5.5	2.2	16.2
		(7.1)	(1.3)	(0.0)	(8.6)	(0.0)	(9.7)	(9.0)	(1.0)	(0.2)	(1.3)
CL	4	54.9	3.2	1.4	81.2	4.7	66.2	23.9	5.2	6.7	23.7
		(1.4)	(0.8)	(1.1)	(6.3)	(5.1)	(8.7)	(7.3)	(2.0)	(0.6)	(0.7)
LA	2	45.0	4.3	0.2	30.0	0.0	38.1	54.6	7.3	9.5	20.9
		(0.0)	(0.6)	(0.4)	(7.1)	(0.0)	(3.3)	(0.3)	(3.0)	(0.0)	(2.9)
TS	6	42.0	10.2	75.8	19.5	29.3	64.4	4.9	1.5	4.8	15.9
		(3.9)	(2.8)	(10.7)	(6.9)	(12.4)	(12.4)	(2.7)	(1.0)	(3.6)	(1.2)
TSL	1	43.6	14.6	34.4	42.1	22.7	70.2	5.7	1.6	NA	9.5
		(9.2)	(8.2)	(6.6)	(13.6)	(4.0)	(4.2)	(1.4)	(0.7)	NA	(1.0)

# = number of plots at each site.
BC=Bear Canyon; BW=Bluewater; CB=Cuba; CL=Clayton; LA=Los Alamos;
TS=Tombstone, small simulator; TSL=Tombstone, large NMSU simulator.

defined to be between 0.075 mm and 0.002 mm. The clay fraction is below 0.002 mm in size.

Dry and wet AMCs are the antecedent water contents on a dry weight basis sampled just prior to the rainfall application. The large plot was sampled at seven locations along the centerline at 1.5 m intervals to provide the data listed in table 1. For the large plot, a topographic map and 3-D projection were prepared as shown in figures 2 and 3. These computer generated figures provide a visualization of the relative topography on the plot.

Comparisons of the small and large simulator plot characteristics at Tombstone indicate no differences between the two for most site measures. Exceptions are noted in the cover measurements of rock and vegetation where vegetative cover was lower on the small plots, but rock cover was lower on the large plot. The differences in vegetation cover are attributable to an inherent tendency to place the small plots where vegetation is sparse (easier to install) and that the small plots are a point sample while the vegetation in the large plot was sampled by a line intercept. There is also a tendency to overestimate cover on the small plot when both vegetation and rock cover the same location. This may be noted in the large simulator values for cover. Those values indicate that if there is rock cover under the vegetation, then the total rock cover would be about 76%, the same as the average for the small simulator plots. Similar differences in cover measurements were also noted by Ward (1986). Another difference between the small and large simulator plots was found in the antecedent water contents. There is no apparent reason for this difference except for natural variation.

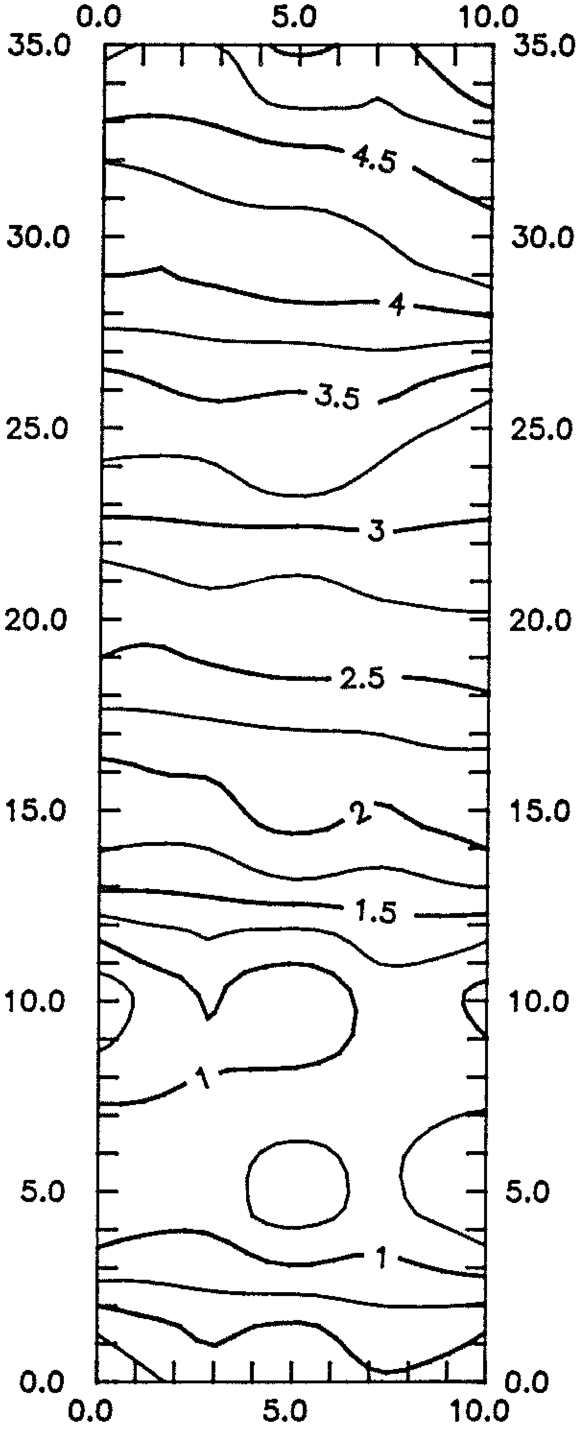

Fig. 2. Topographic Map of Tombstone Large Plot (feet)

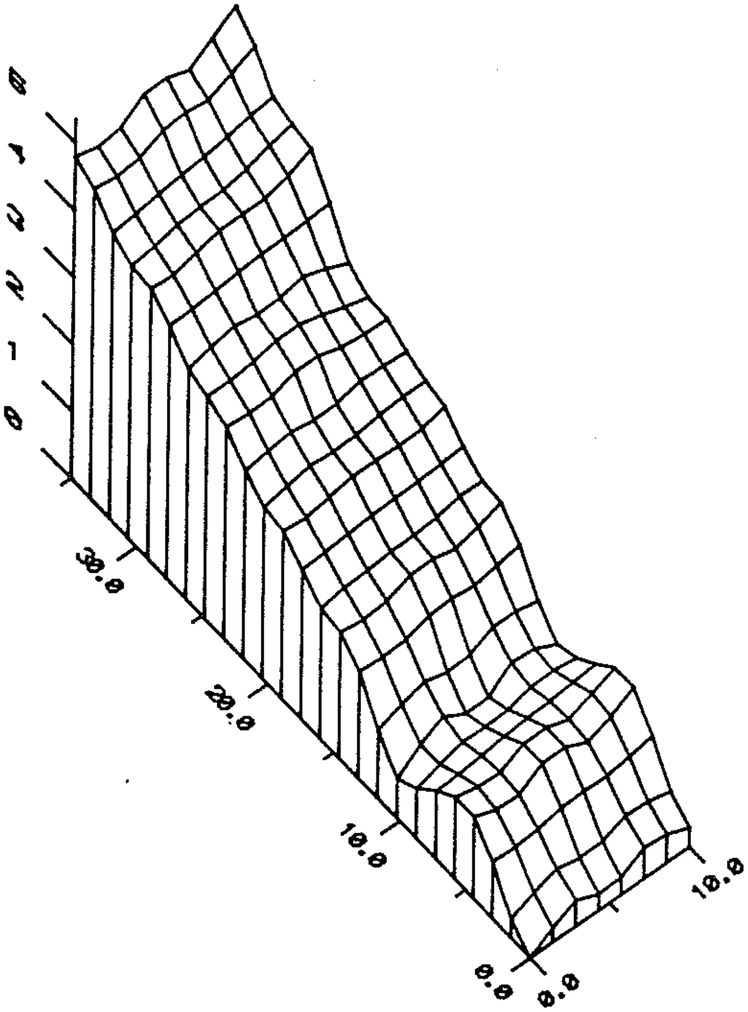

Fig. 3. Relief Projection of Tombstone Large Plot (feet)

Results from Rainfall Experiments

Table 2 lists the summarized results of the rainfall experiments for the small plots, the large plot, and the ARS WEPP plots. The ARS and NMSU large simulator data represent dry and wet runs on a single plot. The ARS data listed in this report were extracted from information provided by Roger Simanton, ARS Tucson, and are subject to revision. Individual small plot measurements are listed in Appendix C for the six sites. Notable differences among measurements for the simulators are seen in rainfall rate, duration of rainfall, runoff depth, and runoff to rainfall ratio. There are also differences among the sites for the same type of simulator and differences between dry and wet runs.

Some of these differences are caused by operational characteristics of the simulators. In general, the large simulator produces about the same rainfall intensity as the WEPP simulator. The small simulator produces much higher intensities than the other simulators. Because of the higher intensities, the small simulator tends to produce higher runoff to rainfall ratios. The greatest differences in the runoff to rainfall ratios can be seen in the Tombstone data which show that the WEPP simulator produces ratios about one-tenth the magnitude of the small and large simulators. At Cuba, the difference in ratios between the small and WEPP simulators is not significant for one WEPP plot, but it is for the other. There does not appear to be a difference at Los Alamos, but that may be caused

TABLE 2

Means and Standard Deviations (in parenthesis) of Rainfall and Runoff Characteristics for Each Site

Site	#	Intensity (mm/hr)		Duration of Rain (min.)		Duration of Runoff (min.)		Runoff (mm)		Runoff/Rainfall (percent)	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Bear Canyon	6	124.2 (8.3)	127.5 (6.3)	22.0 (1.9)	21.5 (0.9)	20.9 (2.0)	20.4 (0.7)	25.9 (6.9)	33.3 (3.3)	56.8 (13.9)	73.1 (5.4)
Bluewater	6	99.7 (27.3)	107.7 (31.4)	26.2 (3.4)	24.8 (2.7)	20.9 (3.6)	22.1 (2.7)	9.1 (6.5)	21.5 (10.6)	20.3 (13.1)	46.5 (16.3)
Cuba	6	120.0 (23.7)	124.5 (19.2)	24.6 (1.1)	22.1 (3.0)	20.8 (2.0)	20.4 (3.1)	10.4 (8.4)	17.7 (7.2)	18.8 (13.6)	38.2 (12.5)
Cuba ARS #132	1	54.8	55.0	50.0	25.0	52.8	34.3	5.1	4.5	12.1	19.6
Cuba ARS #133	1	53.7	46.7	45.0	27.0	43.5	28.3	4.8	1.3	3.7	6.2
Clayton	4	111.6 (23.0)	118.0 (21.0)	24.2 (1.5)	21.3 (1.0)	22.0 (1.3)	19.5 (0.6)	24.5 (8.7)	30.0 (10.3)	53.3 (10.1)	71.0 (17.6)
Los Alamos	2	111.2 (31.2)	110.2 (32.7)	31.4 (1.1)	19.9 (2.0)	29.5 (1.2)	18.4 (1.4)	20.2 (14.9)	19.7 (7.6)	32.8 (17.7)	53.6 (10.6)
Los Alamos ARS #128	1	56.0	52.1	45.0	25.0	50.8	35.8	16.4	8.0	39.0	36.9
Los Alamos ARS #129	1	53.2	54.5	45.0	25.0	48.1	32.8	14.6	8.8	36.6	38.8
Tombstone	6	104.2 (28.1)	106.0 (26.3)	29.9 (6.9)	23.4 (1.8)	26.8 (6.2)	21.9 (1.5)	20.1 (8.6)	23.4 (9.6)	39.6 (15.0)	55.2 (11.4)
Tombstone NMSU-large	1	58.2	58.9	29.2	32.1	46.2	33.9	6.4	6.3	22.6	20.0
Tombstone ARS #33	1	57.3	52.9	60.0	23.5	53.2	19.9	2.6	1.5	4.5	7.2
Tombstone ARS #36	1	58.7	62.0	50.0	30.0	45.6	29.1	1.0	2.5	2.0	8.1

- number of plots at each site
ARS - large rotating boom simulator

by the limited small simulator sample. The large differences at Tombstone, particularly between the large and WEPP simulators, suggest that further comparisons of these two simulators need to be conducted.

The small simulator data were analyzed for differences between dry and wet runs using a paired difference t-test. Analysis was done separately for each site. Results (table 3) show that the total amount of applied rainfall and rainfall intensity were not significantly different between dry runs and wet runs on a plot at any of the sites. The ratio of runoff to rainfall was statistically greater from the wet runs everywhere but Los Alamos where no differences were detected. The sample size at Los Alamos is very small which may confound the statistical analysis.

Hydraulic conductivity, assumed to be the steady-state loss rate, on average, is lower for wet runs than for dry runs, but is significantly lower only at Bluewater and Tombstone. Except at Los Alamos, the capillary suction head is lower for the dry runs. Significant differences between wet and dry runs for capillary suction head appear only at Bluewater.

Suspended sediment yield, deposited sediment yield and total sediment yield (the sum of suspended and deposited yields) in kilograms per hectare (kg/ha) was also analyzed with the paired difference test. The only statistical differences occurred at Clayton where the dry runs had more total sediment yield and deposited yield on average than the wet runs. This is

TABLE 3

Paired Difference t-test Results from Dry and Wet Runs for the Small Simulator at the Six Sites

	SITE					
VARIABLE	BC	BW	CB	CL	LA	TS
Applied Rainfall	0	0	0	0	0	0
Rainfall Intensity	0	0	0	0	0	0
Runoff Depth	1	1	1	1	0	0
Runoff/Rainfall	1	1	1	1	0	1
Hydraulic Conductivity	0	1	0	0	0	1
Capillary Head	0	1	0	0	0	0
Suspended Sediment Yield	0	0	0	0	0	0
Deposited Yield	0	0	0	1	0	0
Total Sediment Yield	0	0	0	1	0	0
Splash Coefficient	0	0	1	1	0	0
Tot. Phos. Yield	NA	0	0	0	0	0
Tot. Nitrogen Yield	NA	1	0	0	0	1
Tot. Volatile Susp. Yield	NA	0	0	0	0	0
Suspended Yield per mm of Runoff	0	0	1	0	0	0
Deposited Yield per mm of Runoff	0	1	0	1	0	0
Total Sediment Yield per mm of Runoff	0	1	0	1	0	0
Total Phosphorus Yield per mm of Runoff	NA	0	0	0	0	0
Total Nitrogen Yield per mm of Runoff	NA	0	0	0	1	0
Total Volatile Suspended Sed. per mm of Runoff	NA	0	0	0	0	0

Values of 0 indicate <u>no significant differences</u> between wet and dry runs; a 1 indicates significant differences at p=0.05 level.

BC=Bear Canyon; BW=Bluewater; CB=Cuba; CL=Clayton; LA=Los Alamos; TS=Tombstone; NA=data not available.

to be expected because the readily available material is usually washed off the plot during the dry run, thus decreasing the supply for the wet run. There were no clear trends at the other sites. At some sites the dry runs produced more (but not significantly more) sediment and at other sites the wet runs produced more sediment.

The splash detachment coefficient varied significantly between dry and wet runs at Cuba and Clayton. At Cuba, the coefficient was greater for the wet run and at Clayton, it was greater for the dry run. Cuba had a very heavily cracked soil surface on the dry runs which sealed up before the wet runs. Clayton had very high grass cover.

When sediment yields are standardized by dividing by the amount of runoff from the plot (units of kg/ha/mm of runoff), statistical differences appear at Bluewater and Cuba, in addition to Clayton. On average, yields per mm of runoff were greater from the dry runs which is as expected since the dry runs tend to produce more sediment and less runoff. The high rock cover at Bear Canyon and Tombstone and the small sample size at Los Alamos obscure or prevent differences from occurring.

Paired difference analysis of the chemical yields indicate a statistical difference (more from the wet runs) only in total nitrogen yields from Bluewater and Tombstone. Due to contaminated application water, the Tombstone data for nitrogen must be viewed with suspicion. The chemical values for Bear

Canyon are missing due to very low runoff volumes which precluded taking chemical samples. When chemical yields are analyzed as yields per mm of runoff, the only difference (wet runs greater than dry runs) is at Los Alamos for total nitrogen yield per mm of runoff. Because there were some differences between wet and dry runs at the sites, further analyses will consider dry and wet runs separately.

Rainfall and Runoff. A least-squares means test was conducted to examine the differences in the runoff to rainfall ratio among the six small simulator sites. Results for the dry and wet runs are summarized in table 4. For the dry and wet runs, Bear Canyon and Clayton had the highest ratios of runoff to rainfall. Bluewater and Cuba had the lowest ratios and

TABLE 4

Comparison of Rainfall/Runoff Ratios for the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	1		1	0		1	1
BW	1	***		0	1	DRY	0	1
CB	1	0		***	1		0	1
CL	0	1	WET	1	***		0	0
LA	0	0		0	0		***	0
TS	1	0		1	0		0	***

Values of 0 indicate no significant differences between wet and dry runs; a 1 indicates significant differences at p=0.05 level. Values above the asterisks are for dry runs and values below the asterisks are for wet runs.

BC=Bear Canyon; BW=Bluewater; CB=Cuba; CL=Clayton; LA=Los Alamos; TS=Tombstone.

Tombstone and Los Alamos had intermediate values. For runoff to rainfall ratios on the dry runs, Bear Canyon is the same as Clayton; Clayton, Tombstone and Los Alamos are the same; and Los Alamos, Bluewater and Cuba are the same.

For the wet runs, Bear Canyon is the same as Clayton and Los Alamos; Clayton, Tombstone, and Los Alamos are the same; Tombstone, Los Alamos and Bluewater are the same; and Los Alamos, Bluewater and Cuba are the same.

Sediment Yields. Table 5 is a summary of the sediment yields collected with the small simulator. The yields are

TABLE 5

Means and Standard Deviations (in parenthesis) of the Components of Sediment Yield for Each Site

		Runoff(mm)		Suspended Yield (kg/ha)		Suspended Yield (kg/ha/mm)		Deposit (kg/ha)		Deposit (kg/ha/mm)	
Site	#	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Bear Canyon	6	25.9	33.1	387.5	581.7	14.1	17.4	881.0	860.0	34.1	26.0
		(6.9)	(3.3)	(272.9)	(325.1)	(7.4)	(9.4)	(304.6)	(515.9)	(8.9)	(15.1)
Bluewater	6	9.1	21.5	91.4	184.0	9.6	7.7	424.4	374.9	66.2	18.9
		(6.5)	(10.6)	(69.2)	(157.6)	(2.3)	(4.5)	(215.9)	(166.8)	(37.2)	(5.0)
Cuba	6	10.4	17.7	192.2	214.5	14.3	10.2	590.2	1900.2	87.6	90.7
		(8.4)	(7.2)	(185.1)	(186.4)	(6.2)	(6.2)	(457.8)	(1706.2)	(54.8)	(59.3)
Clayton	4	24.5	30.0	152.8	145.1	6.5	5.6	522.8	248.6	24.0	10.6
		(8.7)	(10.3)	(88.4)	(80.4)	(3.6)	(4.0)	(181.1)	(153.4)	(14.4)	(10.7)
Los Alamos	2	20.2	19.7	141.1	164.8	8.4	8.6	669.2	1133.4	35.9	56.6
		(14.9)	(7.6)	(48.7)	(38.4)	(3.7)	(1.4)	(380.4)	(526.1)	(7.6)	(4.8)
Tombstone	6	20.1	23.4	78.9	80.5	3.6	3.7	579.7	412.1	24.0	18.7
		(8.6)	(9.6)	(60.1)	(40.1)	(1.6)	(1.7)	(553.5)	(152.2)	(21.1)	(5.2)

- number of plots at each site

reported in weight per area (kg/ha) and weight per area per unit depth of runoff (kg/ha/mm). The latter values are equivalent to concentrations in milligrams per liter divided by 100 and are calculated to remove the effects of runoff energy from the yields. Suspended yields are sampled from the pumped runoff water while deposited yields are composed of those sediments which were deposited on the runoff tray or in the runoff trough.

The least-squares means test was conducted on the sediment yields as it was for the runoff to rainfall ratios. Unless otherwise noted, the analyses were conducted on log-transformed values to meet normality requirements. The highest sediment yields from the dry runs occurred at Bear Canyon. For the dry runs, the only differences in sediment yield (all measures) occurred at Bear Canyon (tables 6, 7, and 8) where yields were

TABLE 6

Comparison of Total Suspended Sediment Yield (kg/ha) from the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	1		1	0		0	1
BW	1	***		0	0	DRY	0	0
CB	1	0		***	0		0	0
CL	1	0	WET	0	***		0	0
LA	0	0		0	0		***	0
TS	1	0		0	0		0	***

Values of 0 indicate no significant differences between wet and dry runs; a 1 indicates significant differences at p=0.05 level. Dry values were not log-transformed.
Values above the asterisks are for dry runs and values below the asterisks are for wet runs.

BC=Bear Canyon; BW=Bluewater; CB=Cuba; CL=Clayton; LA=Los Alamos; TS=Tombstone.

TABLE 7

Comparison of Deposited Sediment Yield (kg/ha) from the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	1		0	0		0	0
BW	0	***		0	0	DRY	0	0
CB	0	1		***	0		0	0
CL	1	0	WET	1	***		0	0
LA	0	0		0	1		***	0
TS	0	0		1	0		0	***

TABLE 8

Comparison of Total Sediment Yield (kg/ha) from the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	1		0	0		0	1
BW	1	***		0	0	DRY	0	0
CB	0	1		***	0		0	0
CL	1	0	WET	1	***		0	0
LA	0	0		0	1		***	0
TS	1	0		1	0		0	***

Values of 0 indicate no significant differences between wet and dry runs; a 1 indicates significant differences at p=0.05 level. Dry values were not log-transformed.
Values above the asterisks are for dry runs and values below the asterisks are for wet runs.

BC=Bear Canyon; BW=Bluewater; CB=Cuba; CL=Clayton; LA=Los Alamos; TS=Tombstone.

higher than at some of the sites. For the wet runs, the only differences for suspended yield occurred at Bear Canyon, but for deposited yield and total sediment yield additional differences among sites appear.

When the yields per mm of runoff are analyzed, numerous differences occur among the sites (tables 9, 10, and 11). All of these differences will not be detailed here, but, it should be noted that by examining the yields as concentrations, the variance at a site decreases considerably and helps differentiate the sites from one another.

When the yields sampled from the small and large simulators are compared with the WEPP simulator data, some interesting relationships appear. Table 12 lists the total yields and total yields per mm of runoff for all the simulators. The data for the individual small simulator plots is listed in Appendix D. If the total yields per mm of runoff are used as a comparison, the small simulator produces about 2 to 5 times more sediment than does the WEPP simulator for the same depth of runoff. If the energies of the respective simulators are considered, then the factor increases by 40%. The increase is also noted between the large and small simulator values. Ward (1986), noted an increase of about 2.7 times from the large to the small simulators. These findings indicate that yields determined from the small simulator should be scaled down by a factor of 3.5 to 5 (depending on the energy adjustment) in order to be more comparable with the WEPP simulator.

<u>Infiltration and Erosion Characteristics.</u> For the small plots, hydraulic conductivity and capillary head were derived from the runoff data as detailed in the methodology section. The raindrop splash erosion/transport coefficient was derived

TABLE 9

Comparison of Total Suspended Sediment Yield per mm of Runoff (kg/ha/mm) from the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	0		0	1		0	1
BW	0	***		0	0	DRY	0	1
CB	0	0		***	1		0	1
CL	1	0	WET	0	***		0	0
LA	0	0		0	0		***	1
TS	1	0		1	0		0	***

TABLE 10

Comparison of Deposited Sediment Yield per mm of Runoff (kg/ha/mm) Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	0		1	0		0	0
BW	0	***		0	1	DRY	0	1
CB	1	1		***	1		0	1
CL	1	1	WET	1	***		0	0
LA	0	1		0	1		***	0
TS	0	0		1	1		1	***

TABLE 11

Comparison of Total Sediment Yield per mm of Runoff (kg/ha/mm) from the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	0		0	0		0	1
BW	0	***		0	1	DRY	0	1
CB	1	1		***	1		0	1
CL	1	1	WET	1	***		0	0
LA	0	1		0	1		***	0
TS	0	0		1	0		1	***

Values of 0 indicate no significant differences between wet and dry runs; a 1 indicates significant differences at p=0.05 level. Values above the asterisks are for dry runs and values below the asterisks are for wet runs.

BC=Bear Canyon; BW=Bluewater; CB=Cuba; CL=Clayton; LA=Los Alamos; TS=Tombstone.

from the total yield, cover, and rainfall data as suggested by Ward (1986). The individual plot values are listed in Appendix E

TABLE 12
Means and Standard Deviations (in parentheses) of Total Sediment Yields at Each Site with Comparisons to ARS Results

Site	#	Runoff(mm) Dry	Runoff(mm) Wet	Total Sediment Yield (kg/ha) Dry	Total Sediment Yield (kg/ha) Wet	Total Sediment Yield (kg/ha/mm) Dry	Total Sediment Yield (kg/ha/mm) Wet
Bear Canyon	6	25.9 (6.9)	33.1 (3.3)	1286.6 (519.6)	1441.6 (727.7)	48.3 (11.8)	43.4 (21.2)
Bluewater	6	9.1 (6.5)	21.5 (10.6)	515.9 (280.6)	558.9 (299.9)	75.8 (36.0)	26.6 (6.0)
Cuba	6	10.4 (8.4)	17.7 (7.2)	782.4 (626.8)	2114.7 (1889.2)	101.9 (49.9)	100.9 (65.2)
Cuba ARS # 132	1	5.1	4.5	162.4	102.9	31.9	22.9
Cuba ARS # 133	1	4.8	1.3	217.4	48.5	45.6	36.8
Clayton	4	24.5 (8.7)	30.0 (10.3)	675.5 (210.1)	393.7 (213.4)	30.6 (14.9)	16.3 (14.4)
Los Alamos	2	20.2 (14.9)	19.7 (7.6)	810.3 (429.1)	1298.2 (564.6)	44.2 (11.4)	65.2 (3.4)
Los Alamos ARS #128	1	16.4	8.0	420.4	142.7	25.7	17.7
Los Alamos ARS #129	1	14.6	8.8	238.9	149.5	16.3	16.9
Tombstone	6	20.1 (8.6)	23.4 (9.6)	658.6 (608.9)	492.7 (184.6)	27.5 (22.4)	22.4 (6.6)
Tombstone NMSU large	1	6.4	6.3	24.3	23.0	3.8	3.7
Tombstone ARS #33	1	2.6	1.5	22.4	5.5	8.8	3.8
Tombstone ARS #36	1	1.0	2.5	9.4	13.1	9.1	5.2

- number of plots at a site

and summarized in table 13. Note that splash coefficients for the suspended and deposited yields can be calculated from the values listed in Appendix E and table 13 by dividing by the total sediment yield per unit area then multiplying by the appropriate yield, suspended or deposited. The values in table 13 for the large and WEPP simulator hydraulic conductivities and capillary heads are the averages of the values calculated for the wet and the dry experiments. These values were derived using the method applied to the small simulator data. This may not be the most appropriate methodology, but it is consistent and as the table shows, it produces comparable results among the sites and simulators.

The conclusion that can be drawn from a comparison of the hydraulic parameters derived from the small and the WEPP simulators is that they are essentially the same. The conductivities for the WEPP experiments are usually within one standard deviation of the values determined from the small simulator, and the capillary head values are so variable that it is practically impossible not to be able to have an overlap between the WEPP and small simulator values. The small simulator can be used to find hydraulic parameters for the WEPP model.

Examination of the small plot data indicates that the estimated hydraulic conductivity decreases somewhat between dry and wet runs. The capillary head typically increases on the wet run but may decrease as at Los Alamos. The increase in

TABLE 13

Means and Standard Deviations (in parenthesis) of Derived Infiltration and Erosion Parameters for Each Site with a Comparison to the Large Simulators

Site	#	Est. Hydraulic Conductivity (mm/hr)		Derived Capillary Head (mm)		Splash Coefficient (kg-hr/ha-mm)	
		Dry	Wet	Dry	Wet	Dry	Wet
Bear Canyon	6	30.5	22.0	15.2	15.6	0.59	0.79
		(13.5)	(8.8)	(11.9)	(12.9)	(0.26)	(0.63)
Bluewater	6	63.3	41.8	8.0	62.6	0.18	0.17
		(19.2)	(14.8)	(4.3)	(46.2)	(0.09)	(0.08)
Cuba	6	71.1	58.0	16.5	26.3	0.18	0.54
		(12.9)	(19.9)	(12.7)	(29.2)	(0.10)	(0.41)
Cuba ARS	1	40.2		5.9		-	
Clayton	4	30.0	20.5	24.2	43.0	0.78	0.46
		(20.6)	(19.9)	(24.8)	(42.4)	(0.22)	(0.26)
Los Alamos	2	43.3	40.0	44.6	11.0	0.17	0.46
		(16.9)	(12.4)	(42.1)	(12.2)	(0.01)	(0.07)
Los Alamos ARS	1	26.2		9.9		-	
Tombstone	6	52.0	37.8	4.5	9.4	0.94	0.78
		(12.4)	(7.8)	(3.3)	(9.4)	(1.09)	(0.46)
Tombstone NMSU large	1	44.2		0.8		-	
Tombstone ARS	1	53.6		28.6		-	

Values for the large simulators are estimates for the plot with the dry run and wet run combined.
Splash coefficient is for total sediment yield.
- number of plots at a site.

capillary head may be an artifact of how it is derived from the conductivities.

The splash detachment coefficients are indices of the rainfall erosion at a site per unit area of bare ground. Sites with higher values indicate higher erosivities of the exposed soils. These values tend to complement the yield values but also incorporate rainfall and cover effects. Although differences exist among sites as shown by the data tables, there is no significant difference between dry and wet runs because the variability of this coefficient is so high. The splash coefficient derived from small simulator data should be useful in the WEPP effort in order to provide an estimate for modeling.

Least-squares means tests on untransformed values were used to investigate differences in hydraulic conductivity, capillary head, and splash coefficients among sites (tables 14 through 16). There were differences in hydraulic conductivity (table 14) among sites for dry and wet runs. For both runs, the highest conductivities were at Cuba and the lowest at Clayton. Differences (table 15) in capillary head for the dry runs occurred mostly in comparison with Los Alamos and Tombstone which had the highest and lowest capillary head values, respectively. There were fewer differences among sites for the wet runs.

Splash coefficients at Tombstone (highest coefficient) were significantly greater (table 16) than at Bluewater and Cuba which had the lowest coefficients for the dry runs. For wet

TABLE 14

Comparison of Hydraulic Conductivities (mm/hr) from the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	1		1	0		0	1
BW	1	***		0	1	DRY	0	0
CB	1	0		***	1		1	1
CL	0	1	WET	1	***		0	1
LA	0	0		0	0		***	0
TS	0	0		1	0		0	***

TABLE 15

Comparison of Capillary Suction Heads (mm) from the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	0		0	0		1	0
BW	1	***		0	0	DRY	1	0
CB	0	1		***	0		1	0
CL	0	0	WET	0	***		0	1
LA	0	1		0	0		***	1
TS	0	1		0	0		0	***

TABLE 16

Comparison of Sediment Detachment Coefficients from the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	0		0	0		0	0
BW	1	***		0	0	DRY	0	1
CB	0	0		***	0		0	1
CL	0	0	WET	0	***		0	0
LA	0	0		0	0		***	0
TS	0	1		0	0		0	***

Values of 0 indicate no significant differences between wet and dry runs; a 1 indicates significant differences at $p=0.05$ level. Values above the asterisks are for dry runs and values below the asterisks are for wet runs.

BC=Bear Canyon; BW=Bluewater; CB=Cuba; CL=Clayton; LA=Los Alamos; TS=Tombstone.

runs, the high coefficients at Tombstone and Bear Canyon were significantly greater than the low coefficient at Bluewater.

Correlation of Parameters. The hydraulic and sediment yield values presented above were correlated to site and rainfall characteristics and soil moisture content in an attempt to better understand the factors controlling the runoff and erosion processes. Runoff was positively correlated with rainfall intensity, initial water content, rock cover and percent sand in the soil. Sediment yields are positively correlated with rainfall intensity and runoff for the suspended, deposited and total loads. Yields per mm of runoff appear to be inversely correlated to runoff, but not related to rainfall intensity.

Conductivity, capillary head, and the detachment coefficient are derived parameters, therefore some correlations are spurious. Conductivity is negatively correlated to rock cover, initial water content, and the ratio of clay to total fines in the soil. Capillary head is positively correlated with the percent of clay in the soil, and the detachment coefficient is negatively correlated with the percent of total fines in the soil. Regression relationships were not developed for these parameters as that was beyond the scope of this study.

Chemical Concentrations and Yields. Water chemistry data collected with the small simulator is summarized in table 17 and individual values are listed in Appendix F. Before analysis, chemical concentrations in the simulator rainwater (background

TABLE 17

Means and Standard Deviations (in parenthesis) of Chemical Yields for Each Site

Site	#	Total Phos. (kg/ha)		Total Phos. (kg/ha/mm)		Total Nitrogen (kg/ha)		Total Nitrogen (kg/ha/mm)		Total Volatile Suspended (kg/ha)		Total VSS (kg/ha/mm)	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
BC	6	0.483	NA	0.018	NA	0.392	NA	0.0153	NA	55.6	NA	2.06	NA
		(0.234)	NA	(0.007)	NA	(0.417)	NA	(0.0148)	NA	(27.4)	NA	(0.64)	NA
BW	5 dry	0.321	0.292	0.0314	0.014	0.453	0.597	0.0435	0.0272	10.9	21.3	1.15	0.867
	6 wet	(0.237)	(0.185)	(0.014)	(0.009)	(0.249)	(0.428)	(0.0188)	(0.0110)	(8.8)	(20.9)	(0.74)	(0.666)
CB	5 dry	0.479	0.353	0.0223	0.0178	0.479	0.240	0.0300	0.0137	22.1	23.5	1.59	1.13
	6 wet	(0.546)	(0.306)	(0.0067)	(0.0117)	(0.546)	(0.118)	(0.024)	(0.0057)	(16.1)	(21.9)	(0.43	(0.80)
CL	4	0.208	0.153	0.0088	0.0061	1.728	1.968	0.0724	0.0732	17.9	18.2	0.765	0.720
		(0.153)	(0.080)	(0.0066	(0.0041)	(0.850)	(0.713)	(0.0274)	(0.0344)	(8.3)	(6.5)	(0.291)	(0.508)
LA	2	0.109	0.090	0.0076	0.0047	1.927	2.138	0.0975	0.107	15.7	21.4	0.985	1.115
		(0.007)	(0.022)	(0.0059	(0.0007)	(1.326)	(0.984)	(0.0064)	(0.009)	(3.1)	(5.6)	(0.573)	(0.148)
TS	4 dry	0.070	0.081	0.0038	0.0037	0.159	0.329	0.0078	0.0159	14.62	12.35	0.795	0.540
	6 wet	(0.042)	(0.024)	(0.0010)	(0.0012)	(0.225)	(0.373)	(0.0070)	(0.0163)	(9.34)	(7.96)	(0.103)	(0.297)

BC=Bear Canyon; BW=Bluewater; CB=Cuba; CL=Clayton; LA=Los Alamos;
TS=Tombstone.

NA - Runoff too low at Bear Canyon to collect chemical sample.
- number of plots at a site.

concentrations) were subtracted from the runoff concentrations (Appendix G). Some problems occurred in the background measurement of chemicals at Tombstone which resulted in negative concentration when the backgrounds were subtracted. These problems could not be corrected.

After log-transforming the data, a least-squares means test was conducted on the chemical yields to check for differences among sites. Tables 18 through 20 give the results of the

TABLE 18

Comparison of Total Phosphorus Yield (kg/ha) from the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	0		0	0		1	1
BW	0	***		0	0	DRY	0	1
CB	0	0		***	0		0	1
CL	0	0	WET	0	***		0	0
LA	0	0		0	0		***	0
TS	0	1		1	0		0	***

TABLE 19

Comparison of Total Nitrogen Yield (kg/ha) from the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	0		0	0		0	0
BW	0	***		0	0	DRY	0	0
CB	0	0		***	1		1	0
CL	1	1	WET	1	***		0	1
LA	1	1		1	0		***	1
TS	0	0		0	1		1	***

TABLE 20

Comparison of Total Volatile Suspended Sediment Yield (kg/ha) from the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	1		1	1		0	1
BW	1	***		0	0	DRY	0	0
CB	1	0		***	0		0	0
CL	1	0	WET	0	***		0	0
LA	0	0		0	0		***	0
TS	1	0		0	0		0	***

Values of 0 indicate no significant differences between wet and dry runs; a 1 indicates significant differences at p=0.05 level. Values above the asterisks are for dry runs and values below the asterisks are for wet runs.

BC=Bear Canyon; BW=Bluewater; CB=Cuba; CL=Clayton; LA=Los Alamos; TS=Tombstone.

least-squares means tests for yields in kilograms/hectare (kg/ha). For dry and wet runs, total phosphorus yield (kg/ha) was significantly lower at Tombstone (table 18). Tombstone had the lowest average yield and the highest average yield was at Bear Canyon (table 17).

For total nitrogen yield, Bear Canyon and Bluewater were the same as all other sites for the dry runs. Some differences appeared at the other sites (table 19). For the wet runs, numerous differences appeared among sites. For dry and wet runs, Bear Canyon had significantly greater yields of total volatile suspended sediment (organic carbon) (table 20) than most other sites.

Chemical differences among sites were also investigated as yield per mm of runoff. Tables 21 through 23 have the results of the least-squares means test for chemical yield per mm of runoff. For dry and wet runs, there were many differences among sites for total phosphorus (table 21) and total nitrogen (table 22). There were few differences (table 23) for volatile suspended sediment as kg/ha/mm on the dry runs and none on the wet runs.

Spearman correlation analysis was used to investigate relationships between chemical yields from the plots and site characteristics. A one percent level of significance was used in the analysis. Chemical yields were not significantly correlated with initial soil saturation. Therefore, subsequent analyses were conducted with dry and wet runs combined.

TABLE 21

Comparison of Total Phosphorus Yield (kg/ha/mm) from the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	0		0	1		1	1
BW	0	***		0	1	DRY	1	1
CB	0	0		***	1		1	1
CL	0	1	WET	1	***		0	0
LA	0	0		0	0		***	0
TS	0	1		1	0		0	***

TABLE 22

Comparison of Total Nitrogen Yield (kg/ha/mm) from the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	0		0	1		1	0
BW	0	***		0	0	DRY	0	1
CB	0	0		***	1		1	0
CL	1	1	WET	1	***		0	1
LA	1	1		1	0		***	1
TS	0	0		0	1		1	***

TABLE 23

Comparison of Total Volatile Suspended Sediment Yield (kg/ha/mm) from the Small Simulator at the Six Sites

	BC	BW		CB	CL		LA	TS
BC	***	1		0	1		0	1
BW	0	***		0	0	DRY	0	0
CB	0	0		***	1		0	0
+L	0	0	WET	0	***		0	0
LA	0	0		0	0		***	0
TS	0	0		0	0		0	***

Values of 0 indicate no significant differences between wet and dry runs; a 1 indicates significant differences at p=0.05 level. Values above the asterisks are for dry runs and values below the asterisks are for wet runs.

BC=Bear Canyon; BW=Bluewater; CB=Cuba; CL=Clayton; LA=Los Alamos; TS=Tombstone.

Total phosphorus yield was not correlated with any site characteristics. It was related to total sediment yield, the two components of total sediment yield (suspended and deposited yield) and total organic suspended sediment yield. Total nitrogen yield was correlated with total suspended sediment yield, total organic suspended sediment yield and percent vegetation cover.

Total phosphorus yield is closely related to the amount of soil that washes off of the plots. Total nitrogen yield is related to the suspended sediment yield, but is also dependent upon the amount of vegetation present. The higher the organic fraction of suspended sediment yield, the more phosphorus and nitrogen that are present.

Comparison of Techniques for Estimating Total Suspended Solids

Two independent measures of total suspended solids (TSS) were available for almost every plot-run. Only in those cases when samples were not collected for chemical analysis is a second estimate of TSS missing.

A paired difference t-test was run on the differences between the centrifuge measurement of TSS and the measurement (filtration method) from the Soil and Water Testing Laboratory at New Mexico State University. The mean of the differences was 15.02 mg/l with the centrifuge values slightly higher than the lab values. A t-test of the hypothesis indicated that the mean of the differences was not significantly different ($p = 0.05$)

from zero. The Spearman correlation coefficient between the two measurements of TSS was 0.97.

At two sites, there is also a comparison of the ARS technique for measuring TSS and the centrifuge technique. When the ARS used the large rotating boom simulator at Cuba and Los Alamos, a field assistant from NMSU was present and collected samples of runoff from the plots. The Tucson ARS unit measures TSS by oven drying the total sample of runoff water and sediment collected at each time period.

A t-test on the differences between the ARS samples and the NMSU samples gave a mean difference of 0.13 percent by weight. This value is significantly different (p=0.001) from zero. The ARS values are higher than the NMSU values. Regression analysis on the log values shows that the NMSU values are about 70 percent of the ARS values with an R-squared value of 0.87.

In order to investigate further the differences in techniques, six mixtures containing known sediment weights were subjected to all three methods. As before, the agreement between the centrifuge method and the New Mexico State University Soil and Water Testing Laboratory filtration technique was good (r=0.92). Both of these techniques underestimated the known concentration of the samples. One reason for this is the difficulty of subsampling a perfectly mixed volume from the sample jar. Heavy materials settle very quickly in the sample jars and are easily underrepresented in the analysis container. The known concentrations were made with material that passed a #60 sieve and tended to settle very quickly in the jars. In the field, samples typically have a wider range of materials and do not settle as quickly.

Known concentrations were also sent to the ARS in Tucson. Their analysis agreed closely with the known concentrations. The samples were mixed with distilled water, but, in the field the simulator water usually contains various salts. The Tucson technique would include these salts in the estimate of suspended solids, but the centrifuging and filtration techniques would not. Depending on the amount of salts in the simulator rainwater, we would expect the ARS technique to report higher sediment concentrations than the centrifuge method. The differences between the ARS values and the NMSU values are less at Los Alamos than at Cuba. This may be related to the difference in water quality between the sites.

Summary

Sixty plot-runs using the small simulator and two using the big simulator were conducted for this study. A tremendous amount of data was gathered and analyzed. Information was developed for rainfall rate, runoff rate, types and percent of ground cover, size and slope of the sampled plots, soil particle size gradation, soil water content, soil porosity, sediment yield, infiltration parameters, erosion parameters, and water chemistry. The analyses presented here compare site characteristics, how the sites respond to simulated rainfall, how results from the two simulators compare, and how those simulators compare with the ARS WEPP simulator. The data base developed in this study will provide information for further research and analyses.

CONCLUSIONS AND RECOMMENDATIONS

There were two goals and five objectives for this study. The first goal was to collect data and use it to characterize the rainfall-runoff-erosion processes at selected sites. Sixty plot-runs (number of plots times number of experiments on each plot) produced an extensive data set that was used to define site characteristics including slope, cover, soil gradation, infiltration parameters, and erosion measures. This type of information is essential for future hydrologic studies.

The second goal was to compare the information gathered with the small area and large area rainfall simulators with the ARS WEPP simulator. Comparison of the small and WEPP simulator results at three different sites indicated that infiltration parameters were similar, and that sediment yields on a per unit of runoff and area basis were higher for the small plots by a factor of about 4.0 times after differences in energy are taken into consideration. The higher yields are most likely related to the shorter distance the sediment must travel on the small plot before it is sampled.

In order to provide a better comparison of the small simulator to the WEPP simulator, the following are suggested:

1) Change the way cover is measured to correspond to the techniques used for WEPP.

2) Investigate the reasons why the centrifuge and filtration methods produce different results than those found from drying the suspended sediment samples.

3) Investigate nozzle modifications to the small simulator to come nearer to WEPP energy delivery.

4) Conduct further large simulator experiments adjacent to the WEPP plots at selected sites in order to determine why two simulators with the same rainfall rate should produce such different runoff to rainfall ratios.

In conclusion, this study provided an extensive data set and clearly demonstrated the utility of simulated rainfall in examining and measuring runoff and erosion processes.

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APPENDICES

Appendix A. Field and Laboratory Procedures for Small Simulator Experiments

The following standardized procedures have been developed for collecting and processing data from the small plot rainfall simulator. These procedures are followed except as modified for specific needs.

Data are collected using a modified Purdue simulator (Seiger 1984) mounted on a 4.9 meter (16 feet) long trailer. A pair of nozzles is mounted on two separate booms, one boom on either side of the trailer. At each parking spot, it is possible to collect simultaneously two samples from the one square meter (10 square feet) target shape with one side driven flush with the soil surface. That side is where runoff exits the plot, enters a collection trough and is sampled with a small aquarium pump. Water is delivered simultaneously to both booms by a pump and water tank mounted on the trailer. First a dry run, then a wet run, is conducted as described by the following sequence.

DRY RUN

1. Select site and fill in general information on sample (data) sheet.
2. Initially position one square meter plot frames.
3. Position trailer carrying rainfall simulator so that it covers the plots as desired.
4. Install plot frames with trench for collection trough.
5. Repair disturbed edges of soil with gravel and water as needed.

Appendix A. (cont.)

6. Take pictures of the plots and estimate cover.
7. Connect suction pumps to troughs.
8. Collect soil moisture and density samples from top ten cm of surface in a 1" inside diameter sampling tube. Collect on outside edge of plot frame. Put in soil cans, label and seal.
9. Place impervious rainfall collection cover on plot.
10. Install rain gages.
11. Install wind screens as needed.
12. Begin rainfall.
13. Measure rainfall rate using runoff from impervious cover.
14. Remove cover.
15. Note times of ponding and runoff into the trough.
16. Pump troughs as necessary (every one to five minutes).
17. Record pumped volume and save sample in barrel.
18. Rain for 25 to 45 minutes until a steady-state runoff is achieved.
19. Replace cover and again measure rainfall rate.
20. Stop rain and pump trough a final time.
21. Measure depths in barrels.
22. Agitate barrels and collect a quart jar of water and sediment. Label the jars as to site and run. These samples are for the analysis of total suspended solids.
23. At selected representative sites, agitate barrels and collect two, 250 ml samples of water and sediment. Preserve one of the 250 ml samples with sulfuric or hydrochloric acid and place both 250 ml samples in an ice chest. (These samples are for the analysis of phosphorus, nitrogen, and organic solids).

24. Remove deposited material from runoff trough and runoff tray (metal flume between plot and trough). Bag material in sealable plastic bags and label.

25. Record rain gage depths.

26. Measure depth to wetted front on outside edge of plot.

27. Cover plot with plastic sheet, plywood, and dirt until wet run.

28. Collect two 250 ml samples of the rainwater from the trailer after the water has passed through the filters, usually from impervious runoff tray. Treat as in step 23.

<u>WET RUN</u> (12 to 24 hours later)

29. Repeat steps 8 to 28 above as necessary except rain for minimum of 20 minutes or until steady runoff is observed.

30. Measure slope in plot with a Brunton compass.

31. Remove about 1 kilogram of soil for sieve analyses from the center of the plot (destructive sampling) or from an undisturbed area near the plot (nondestructive sampling).

Samples of water, sediment, and soil are transferred along with sample sheets. Once the data sheets and field samples are returned to New Mexico State University, they are measured and analyzed for several basic items including:

1. Rainfall depth and duration.
2. Total runoff.
3. Suspended sediment concentration and yield.
4. Deposited sediment yield.
5. Final infiltration rate.

6. Infiltration parameters.
7. Soil moisture and porosity.
8. Depth to wetted front.
9. Soil particle size distribution.
10. Percent and type of cover.
11. Erosion parameters.

Suspended solid samples are centrifuged in a Beckman J2-21 centrifuge. After centrifuging, the water is poured out of the bottles into preweighed dishes. Distilled water is used to wash all of the soil particles out of the bottle into the sample dish. The dish and soil is dried in a 105 degree C oven for 24 hours then weighed again. Since a known volume of sample was centrifuged, and the weight of soil in the sample is known, the concentration of total suspended solids can be computed. When water chemistry samples are collected, those samples are filtered and sediment concentrations are computed. When this is done, the two types of measurements are compared.

The samples in the 250 ml bottles are taken to the Soil and Water Testing Laboratory at NMSU. The samples are analyzed on auto-analyzing equipment for total phosphorus, total Kjeldahl nitrogen, nitrate-nitrite, and organic suspended solids. Cover estimates from the field are checked with photographs of the plots. Soil moisture is measured following procedures found in USGS (1977). Soil gradation is determined on a split sample following ASTM specifications D421-58 and D422-63. Bulk density is measured from oven dried weights of measured cores.

The primary hydrologic parameters that can be derived from the field and laboratory data include final infiltration rate, the Green-Ampt parameters of hydraulic conductivity and capillary suction head, and a rainfall splash/transport coefficient. Approaches for determining the desired parameters have previously been used by Ward (1986) and will be employed in this study. The techniques for determining the hydrologic parameters are detailed in the following paragraphs.

The Green-Ampt infiltration model can be rewritten as:

$$f = Kw \frac{(F + Hc)}{F} \qquad \text{(A1)}$$

where f is infiltration rate, Hc is a grouping of soil parameters which is computed as the difference between final and initial soil saturation times the porosity times the capillary suction head and F is the infiltrated volume and Kw is hydraulic conductivity. Using rainfall simulator data, the following method can be used to obtain estimates of hydraulic conductivity, Kw, and capillary suction head, Yc.

1. Plot the infiltration rate and infiltrated volume as a function of time. The infiltration rate is the measured rainfall rate minus the measured runoff rate, in inches per hour.

2. Plot the infiltration rate versus the reciprocal of the infiltrated volume using the curves plotted in Step 1 of the procedure.

3. The curve of infiltration rate as a function of the reciprocal of infiltrated volume is nearly a straight line, to the extent that the Green-Ampt equation represents the actual soil process. If a straight line is fitted to these data (excluding the first point and the last point as they include rainfall simulator operation and non-infiltration effects), then the y-intercept is Kw and the slope is (Kw)(Hc). Thus estimates of Kw and Yc can be obtained by measuring the slope and intercept of the line fit to the data.

This approach does not always work as negative intercepts can be obtained which do not have a physical interpretation. Therefore, this alternative approach is suggested :

1. Plot and examine the data as suggested in the first approach.

2. Use an average infiltration rate calculated from the last three steady rate values. This average value is assumed to be Kw.

3. Calculate a revised set of data pairs as $y = (f - Kw)/Kw$ and $x = 1/F$. Note that the first data point is not used since it represents an amount of water that has been infiltrated and intercepted. The last data point also is excluded from the analysis because it represents water that was on the soil surface and ran off after the rainfall stopped.

4. Fit a no-intercept straight line to the revised data (a no-intercept line passes through the data point (0,0)). The slope of this line is (Kw)(Hc).

Both approaches are suggested as a method of obtaining the necessary soil hydrologic characteristics. The standard approach should be used first, then if the intercept Kw is negative, the time approach should be used.

A rainfall erosion/transport (detachment) coefficient also can be derived from rainfall simulation data. This coefficient is used as a measure of sediment supply. The coefficient is determined from the following equation:

$$Dr = Y/(I^2*t*Ab) \tag{A2}$$

where Dr is the detachment coefficient, Y is the sediment yield, I is the rainfall intensity, t is the duration of rainfall on the plot, and Ab is the fraction of the plot soil which is exposed to the rainfall. The detachment coefficient is dimensional depending on the units used to derive it. The rainfall splash detachment coefficient is a function of soil type, soil structure, moisture conditions, and cohesion.

The measured and derived data and parameters are subjected to a wide variety of statistical tests. As a first step, the data are subjected to a frequency distribution analysis to determine the form of their distribution curves (normal, log-normal, etc.). This enables a more appropriate selection of parametric or non-parametric tests for later analyses. Correlation analyses is performed on the original and transformed data to check for anticipated and spurious correlations. Paired difference t-tests are run on the variables using the dry and wet data sets as the different experiments on the same subject (plot). An appropriate ANOVA is run among the sites on selected variables to determine site/soil differences. Statistical analyses and practical considerations will help in determination of which type of equation should be used for predictive purposes.

Appendix A. (cont.)

The following system is used to identify plots in the appendices. Plots are identified by a two letter code for site, a number indicating pairs of plots and a letter indicating each side of a plot pair. Simulation occurs on two plots at once. For example, BC 1-E is Bear Canyon, pair one, even plot and BC 1-O is Bear Canyon, pair one, odd plot. Even and odd refer to the two plots that make up a pair. Each pair of plots was rained on in a dry state and a wet state. Antecedent moisture condition (AMC) is referred to as dry or wet.

The following codes are used for site identification:

BC - Bear Canyon, New Mexico
BW - Bluewater, New Mexico
CB - Cuba, New Mexico
CL - Clayton, New Mexico
LA - Los Alamos, New Mexico
TS - Tombstone, Arizona

Appendix B. Physical Characteristics for Each Plot.

SITE	INITIAL WATER CONTENT %		SLOPE %	POROS %	ROCK %	VEG %	GRAVEL %	SAND %	SILT %	CLAY %
	dry	wet								
BC 1-E	4.63	15.1	2.3	51.6	65.0	25	16.8	67.8	11.1	4.3
BC 1-O	3.24	20.4	1.7	57.9	25.0	30	28.0	61.5	7.6	2.9
BC 2-E	4.67	16.6	8.3	46.6	70.0	25	9.0	69.2	18.4	3.4
BC 2-O	4.57	21.3	0.9	47.1	15.0	30	14.1	69.9	13.5	2.5
BC 3-E	3.36	22.6	1.7	50.2	55.0	35	7.0	59.0	28.0	6.0
BC 3-O	4.86	21.8	2.4	55.3	15.0	35	13.4	65.9	15.4	5.3
BW 1-E	2.60	29.2	3.2	37.6	1.0	30	4.1	56.5	33.1	6.4
BW 1-O	1.44	16.5	4.1	35.6	0.0	35	1.1	56.8	36.3	6.0
BW 2-E	2.00	20.9	4.8	47.8	0.0	20	10.4	56.4	27.9	5.4
BW 2-O	2.30	21.1	5.2	50.0	0.0	40	1.8	59.2	34.2	4.7
BW 3-E	2.70	30.4	1.7	46.0	0.0	30	4.5	52.0	36.4	7.0
BW 3-O	1.85	29.7	3.5	47.0	1.0	30	0.6	51.0	41.6	6.8
CB 1-E	2.40	18.5	2.3	50.0	0.0	55	0.0	47.5	46.6	5.9
CB 1-O	2.40	16.9	1.4	50.0	0.0	40	0.0	55.5	37.8	6.7
CB 2-E	1.95	15.1	4.4	49.1	0.0	40	0.0	48.4	46.4	5.3
CB 2-O	1.95	15.6	4.4	53.5	0.0	35	0.1	44.7	49.1	6.2
CB 3-E	2.16	16.0	4.1	37.2	0.0	30	0.0	53.1	41.7	5.2
CB 3-O	2.16	15.3	2.6	37.2	0.0	35	0.0	71.6	24.7	3.7
CL 1-E	6.77	24.4	4.1	55.7	3.0	80	0.2	77.2	18.8	3.7
CL 1-O	6.77	24.3	2.9	55.7	1.0	90	11.6	68.7	16.5	3.2
CL 2-E	5.95	23.0	2.3	52.8	1.0	75	1.7	61.6	29.9	6.8
CL 2-O	7.44	23.2	3.5	55.5	0.5	80	5.2	57.4	30.5	7.0
LA 1-E	9.49	18.9	3.9	45.0	0.5	35	0.0	40.4	54.4	5.2
LA 1-O	9.49	23.0	4.7	45.0	0.0	25	0.0	35.8	54.8	9.4
TS E1-E	9.45	15.2	8.7	41.6	75.0	12	13.8	75.7	7.7	2.8
TS E1-O	9.45	18.2	10.5	41.6	60.0	15	21.3	69.8	6.6	2.4
TS W1-E	2.63	15.2	8.7	46.5	70.0	15	47.5	45.3	5.8	1.4
TS W1-O	2.63	15.8	7.0	46.5	75.0	30	39.5	53.3	5.9	1.4
TS W2-E	2.34	15.2	14.9	37.9	90.0	20	24.0	75.0	0.8	0.2
TS W2-O	2.34	15.8	11.4	37.9	85.0	25	29.8	67.2	2.5	0.6

POROS=soil porosity; ROCK=rock cover; VEG=vegetation cover; GRAVEL=percent soil fraction that is gravel; SAND=percent soil that is sand; SILT=percent soil that is silt; CLAY=percent soil that is clay.

Appendix C. Rainfall-Runoff Characteristics for Each Plot

SITE	AMC	INTMM	TIMEMIN	RAINMM	RUNMM	RORAIN
BC 1-E	DRY	115.6	19.53	37.6	20.6	0.55
BC 1-O	DRY	133.6	20.50	45.6	31.9	0.70
BC 2-E	DRY	122.4	23.43	47.8	29.7	0.62
BC 2-O	DRY	129.5	21.03	45.4	31.9	0.70
BC 3-E	DRY	113.5	23.33	44.2	14.8	0.33
BC 3-O	DRY	130.3	24.25	52.7	26.5	0.50
BC 1-E	WET	121.2	23.10	46.6	34.5	0.74
BC 1-O	WET	131.1	21.05	46.0	37.1	0.81
BC 2-E	WET	133.6	21.75	48.4	34.9	0.72
BC 2-O	WET	130.3	20.73	45.0	34.8	0.77
BC 3-E	WET	130.6	21.05	45.8	30.5	0.66
BC 3-O	WET	118.1	21.05	41.4	28.1	0.68
BW 1-E	DRY	75.2	27.52	34.5	7.0	0.20
BW 1-O	DRY	143.8	23.17	55.5	13.8	0.25
BW 2-E	DRY	70.4	30.55	35.8	2.7	0.08
BW 2-O	DRY	100.6	28.67	48.1	16.5	0.34
BW 3-E	DRY	92.2	25.55	39.3	0.9	0.02
BW 3-O	DRY	115.8	21.70	41.9	13.7	0.33
BW 1-E	WET	90.7	26.42	39.9	25.1	0.63
BW 1-O	WET	140.5	25.87	60.6	30.2	0.50
BW 2-O	WET	82.0	21.72	29.7	9.6	0.32
BW 2-O	WET	140.2	24.75	57.8	31.4	0.54
BW 3-E	WET	68.1	28.30	32.1	6.8	0.21
BW 3-O	WET	124.7	21.50	44.7	26.2	0.59
CB 1-E	DRY	93.7	23.62	36.9	0.7	0.02
CB 1-O	DRY	143.8	24.28	58.2	19.0	0.33
CB 2-E	DRY	97.3	24.67	40.0	1.7	0.04
CB 2-O	DRY	137.4	23.50	53.8	13.5	0.25
CB 3-E	DRY	105.4	26.00	45.7	7.5	0.16
CB 3-O	DRY	142.7	25.82	61.4	20.1	0.33
CB 1-E	WET	113.8	19.68	37.3	8.6	0.23
CB 1-O	WET	144.3	22.70	54.6	25.8	0.47
CB 2-E	WET	109.7	24.22	44.3	12.2	0.28
CB 2-O	WET	148.1	17.60	43.4	13.2	0.30
CB 3-E	WET	101.3	25.88	43.7	22.4	0.51
CB 3-O	WET	129.8	22.42	48.5	24.0	0.49

AMC=antecedent moisture condition; INTMM=rainfall intensity in mm/hr; TIMEMIN=duration of rainfall in minutes; RAINMM=rainfall in mm; RUNMM=runoff in mm; RORAIN=runoff/rainfall.

Appendix C. (cont.)

SITE	AMC	INTMM	TIMEMIN	RAINMM	RUNMM	RORAIN
CL 1-E	DRY	92.2	25.50	39.2	15.1	0.38
CL 1-O	DRY	130.6	23.33	50.8	28.7	0.56
CL 2-E	DRY	91.2	22.67	34.4	19.7	0.57
CL 2-O	DRY	132.3	25.50	56.2	34.4	0.61
CL 1-E	WET	103.6	22.50	38.9	17.6	0.45
CL 1-O	WET	138.2	21.70	50.0	38.7	0.77
CL 2-E	WET	96.5	20.83	33.5	25.5	0.76
CL 2-O	WET	133.6	20.12	44.8	38.2	0.85
LA 1-E	DRY	89.2	32.17	47.8	9.7	0.20
LA 1-O	DRY	133.3	30.58	68.0	30.8	0.45
LA 1-E	WET	87.1	21.38	31.0	14.3	0.46
LA 1-O	WET	133.3	18.50	41.1	25.1	0.61
TS E1-E	DRY	75.2	36.88	46.2	12.5	0.27
TS E1-O	DRY	114.0	39.25	74.6	20.4	0.27
TS W1-E	DRY	68.6	27.52	31.5	8.6	0.27
TS W1-O	DRY	128.8	24.35	52.3	30.4	0.58
TS W2-E	DRY	100.8	29.92	50.3	20.0	0.40
TS W2-O	DRY	137.9	21.62	49.7	28.7	0.58
TS E1-E	WET	84.6	22.75	32.1	18.0	0.56
TS E1-O	WET	132.6	22.50	49.7	26.3	0.53
TS W1-E	WET	75.9	21.78	27.6	12.3	0.44
TS W1-O	WET	133.1	22.02	48.8	29.7	0.61
TS W2-E	WET	86.6	26.17	37.8	16.2	0.43
TS W2-O	WET	122.9	25.08	51.4	37.9	0.74

AMC=antecedent moisture condition; INTMM=rainfall intensity in mm/hr; TIMEMIN=duration of rainfall in minutes; RAINMM=rainfall in mm; RUNMM=runoff in mm; RORAIN=runoff/rainfall.

Appendix D. Sediment Yields from Each Plot

SITE	AMC	INTMM	RUNMM	SY	SYMM	DEPYLD	DEPMM	YIELDMM
BC 1-E	DRY	115.6	20.6	246.7	12.0	376.4	18.3	30.2
BC 1-0	DRY	133.6	31.9	314.2	9.8	972.9	30.5	40.3
BC 2-E	DRY	122.4	29.7	351.9	11.8	1099.8	37.0	48.8
BC 2-0	DRY	129.5	31.9	911.5	28.6	1145.3	35.9	64.5
BC 3-E	DRY	113.5	14.8	120.6	8.2	645.3	43.6	51.7
BC 3-0	DRY	130.3	26.5	380.3	14.4	1046.6	39.5	53.8
BC 1-E	WET	121.2	34.5	805.6	23.4	663.8	19.2	42.6
BC 1-0	WET	131.1	37.1	146.5	4.0	652.9	17.6	21.5
BC 2-E	WET	133.6	34.9	909.1	26.0	1784.2	51.1	77.2
BC 2-0	WET	130.3	34.8	701.2	20.2	311.3	8.9	29.1
BC 3-E	WET	130.6	30.5	728.3	23.9	1090.0	35.7	59.6
BC 3-0	WET	118.1	28.1	199.5	7.1	657.3	23.4	30.5
BW 1-E	DRY	75.2	7.0	68.8	9.8	410.0	58.6	68.4
BW 1-0	DRY	143.8	13.8	177.7	12.9	544.5	39.4	52.3
BW 2-0	DRY	70.4	2.7	26.3	9.7	215.8	79.9	89.7
BW 2-0	DRY	100.6	16.5	115.5	7.0	609.5	36.9	43.9
BW 3-E	DRY	92.2	0.9	6.2	6.9	121.5	135.0	141.9
BW 3-0	DRY	115.8	13.7	154.1	11.2	645.3	47.1	58.4
BW 1-E	WET	90.7	25.1	188.2	7.5	592.3	23.6	31.1
BW 1-0	WET	140.5	30.2	427.3	14.2	491.3	16.3	30.4
BW 2-E	WET	82.0	9.6	59.0	6.2	195.2	20.3	26.5
BW 2-0	WET	140.2	31.4	95.8	3.0	365.5	11.6	14.7
BW 3-E	WET	68.1	6.8	23.6	3.5	169.2	24.9	28.4
BW 3-0	WET	124.7	26.2	309.8	11.8	436.0	16.6	28.5
CB 1-E	DRY	93.7	0.7	5.0	7.2	98.7	141.0	148.2
CB 1-0	DRY	143.8	19.0	419.4	22.1	1167.0	61.4	83.5
CB 2-E	DRY	97.3	1.7	12.3	7.2	275.5	162.0	169.3
CB 2-0	DRY	137.4	13.5	207.9	15.4	244.0	18.1	33.5
CB 3-E	DRY	105.4	7.5	105.4	14.0	667.0	88.9	103.0
CB 3-0	DRY	142.7	20.1	403.0	20.0	1088.9	54.2	74.2
CB 1-E	WET	113.8	8.6	41.9	4.9	175.7	20.4	25.3
CB 1-0	WET	144.3	25.8	406.4	15.8	3680.0	142.6	158.4
CB 2-E	WET	109.7	12.2	60.6	5.0	823.2	67.5	72.4
CB 2-0	WET	148.1	13.2	73.9	5.6	851.4	64.5	70.1
CB 3-E	WET	101.3	22.4	238.6	10.6	1519.5	67.8	78.5
CB 3-0	WET	129.8	24.0	465.6	19.4	4351.4	181.3	200.7

AMC=antecedent moisture condition;INTMM=rainfall intensity in mm/hr; RUNMM=runoff in mm; SY= suspended sediment yield in kg/ha; SYMM=suspended sediment yield in kg/ha/mm; DEPYLD=deposit yield in kg/ha; DEPMM=deposit yield in kg/ha/mm; YIELDMM=total sediment yield in kg/ha/mm.

Appendix D. (cont.)

SITE	AMC	INTMM	RUNMM	SY	SYMM	DEPYLD	DEPMM	YIELDMM
CL 1-E	DRY	92.2	15.1	87.2	5.8	683.3	45.2	51.0
CL 1-O	DRY	130.6	28.7	66.7	2.3	372.0	13.0	15.3
CL 2-E	DRY	91.2	19.7	217.2	11.0	360.1	18.3	29.3
CL 2-O	DRY	132.3	34.4	239.9	7.0	675.7	19.6	26.6
CL 1-E	WET	103.6	17.6	188.3	10.7	467.5	26.6	37.3
CL 1-O	WET	138.2	38.7	40.6	1.0	120.4	3.1	4.2
CL 2-E	WET	96.5	25.5	126.9	5.0	170.3	6.7	11.7
CL 2-O	WET	133.6	38.2	224.4	5.9	236.4	6.2	12.1
LA 1-E	DRY	89.2	9.7	106.7	11.0	400.2	41.3	52.3
LA 1-O	DRY	133.3	30.8	175.6	5.7	938.2	30.5	36.2
LA 1-E	WET	87.1	14.3	137.6	9.6	761.4	53.2	62.9
LA 1-O	WET	133.3	25.1	192.0	7.6	1505.4	60.0	67.6
TS E1-E	DRY	75.2	12.5	22.2	1.8	143.2	11.4	13.2
TS E1-O	DRY	114.0	20.4	32.1	1.6	181.1	8.9	10.4
TS W1-E	DRY	68.6	8.6	28.0	3.2	0.0	0.0	3.3
TS W1-O	DRY	128.8	30.4	159.6	5.2	1343.8	44.2	49.5
TS W2-E	DRY	100.8	20.0	95.0	4.8	1064.0	53.2	57.9
TS W2-O	DRY	137.9	28.7	136.3	4.8	746.2	26.0	30.8
TS E1-E	WET	84.6	18.0	36.0	2.0	383.9	21.3	23.3
TS E1-O	WET	132.6	26.3	44.7	1.7	314.5	11.9	13.7
TS W1-E	WET	75.9	12.3	76.9	6.3	273.3	22.2	28.5
TS W1-O	WET	133.1	29.7	133.6	4.5	693.1	23.3	27.8
TS W2-E	WET	86.6	16.2	68.8	4.2	343.8	21.2	25.5
TS W2-O	WET	122.9	37.9	123.2	3.2	464.2	12.2	15.5

AMC=antecedent moisture condition;INTMM=rainfall intensity in mm/hr; RUNMM=runoff in mm; SY= suspended sediment yield in kg/ha; SYMM=suspended sediment yield in kg/ha/mm; DEPYLD=deposit yield in kg/ha; DEPMM=deposit yield in kg/ha/mm; YIELDMM=total sediment yield in kg/ha/mm.

Appendix E. Estimated Hydraulic Parameters for Each Plot

SITE		AMC	AKW	PSI	ACOEFF
BC	1-E	DRY	35.7	6.4	0.55
BC	1-O	DRY	21.3	9.4	0.40
BC	2-E	DRY	24.8	16.4	1.10
BC	2-O	DRY	20.7	11.6	0.59
BC	3-E	DRY	55.7	8.9	0.52
BC	3-O	DRY	25.1	38.6	0.38
BC	1-E	WET	18.1	11.0	0.99
BC	1-O	WET	17.2	4.2	0.25
BC	2-E	WET	18.3	26.5	1.85
BC	2-O	WET	16.8	19.1	0.29
BC	3-E	WET	21.7	33.2	1.04
BC	3-O	WET	39.7	< 0.01	0.32
BW	1-E	DRY	50.2	6.0	0.27
BW	1-O	DRY	89.2	9.8	0.14
BW	2-E	DRY	54.2	7.1	0.13
BW	2-O	DRY	48.8	9.0	0.25
BW	3-E	DRY	86.8	1.5	0.05
BW	3-O	DRY	50.8	14.4	0.24
BW	1-E	WET	19.6	64.0	0.31
BW	1-O	WET	50.8	69.2	0.17
BW	2-E	WET	38.7	19.6	0.13
BW	2-O	WET	62.1	0.7	0.10
BW	3-E	WET	46.7	122.7	0.13
BW	3-O	WET	33.1	99.6	0.19
CB	1-E	DRY	89.2	1.0	0.07
CB	1-O	DRY	63.0	19.0	0.32
CB	2-E	DRY	85.2	3.6	0.12
CB	2-O	DRY	68.8	17.2	0.09
CB	3-E	DRY	62.3	22.7	0.23
CB	3-O	DRY	58.4	35.3	0.26
CB	1-E	WET	69.0	12.2	0.11
CB	1-O	WET	61.0	8.7	0.86
CB	2-E	WET	57.4	17.9	0.30
CB	2-O	WET	85.7	6.2	0.22
CB	3-E	WET	26.5	83.6	0.57
CB	3-O	WET	48.4	29.2	1.18

AKW=estimated hydraulic conductivity in mm/hr; PSI=derived capillary suction in mm; ACOEFF= splash coefficient in kg-hr/ha-mm.

Appendix E. (cont.)

SITE		AMC	AKW	PSI	ACOEFF
CL	1-E	DRY	57.0	< 0.01	1.10
CL	1-O	DRY	35.1	11.2	0.67
CL	2-E	DRY	13.5	28.8	0.74
CL	2-O	DRY	14.5	57.0	0.62
CL	1-E	WET	39.1	13.9	0.84
CL	1-O	WET	36.2	< 0.01	0.24
CL	2-E	WET	4.3	72.4	0.37
CL	2-O	WET	2.4	85.8	0.39
LA	1-E	DRY	55.3	14.8	0.18
LA	1-O	DRY	31.4	74.4	0.16
LA	1-E	WET	31.3	19.7	0.51
LA	1-O	WET	48.8	2.4	0.41
TS	E1-E	DRY	50.9	2.8	0.22
TS	E1-O	DRY	74.4	7.1	0.07
TS	W1-E	DRY	48.2	0.4	0.05
TS	W1-O	DRY	35.9	9.5	1.28
TS	W2-E	DRY	51.8	4.8	2.86
TS	W2-O	DRY	50.8	2.6	1.14
TS	E1 E	WET	30.7	5.3	0.70
TS	E1 O	WET	50.9	13.5	0.16
TS	W1 E	WET	38.8	1.3	0.66
TS	W1 O	WET	41.3	6.8	0.73
TS	W2 E	WET	35.6	26.5	1.58
TS	W2 O	WET	29.7	2.8	0.83

AMC=antecedent moisture condition; AKW=estimated hydraulic conductivity in mm/hr; PSI=derived capillary suction in mm; ACOEFF= splash coefficient in kg-hr/ha-mm.

Appendix F. Sediment and Chemical Concentrations of Runoff in mg/l for Each Plot

SITE	AMC	RUNMM	CTSS	FTSS	TVSS	TP	TKN	NO2-3	WATER*
BC 1-E	DRY	20.6	1197.5	1292	188.00	1.88	2.55	-0.20	A
BC 1-O	DRY	31.9	985.0	1104	185.00	1.52	2.95	-0.22	A
BC 2-E	DRY	29.7	1185.0	1291	171.00	1.32	2.15	-0.09	A
BC 2-O	DRY	31.9	2857.5	2112	321.00	2.00	1.55	-0.11	A
BC 3-E	DRY	14.8	815.0	823	140.00	1.07	2.05	-0.09	A
BC 3-O	DRY	26.5	1435.0	2684	233.00	3.17	2.25	-3.62	A
BC 1-E	WET	34.5	2335.0	475	113.00	0.35	0.75	0.07	B
BC 1-O	WET	37.1	395.0	.	.	.	.	.	B
BC 2-E	WET	34.9	2605.0	.	.	.	.	.	B
BC 2-O	WET	34.8	2015.0	.	.	.	.	.	B
BC 3-E	WET	30.5	2388.0	.	.	.	.	.	B
BC 3-O	WET	28.1	710.0	.	.	.	.	.	B
BW 1-E	DRY	7.0	982.5	960	197.00	2.16	6.5	0.42	C
BW 1-O	DRY	13.8	1287.5	1411	23.00	5.04	4.9	0.27	C
BW 2-E	DRY	2.7	972.5	997	117.00	4.26	2.5	0.36	C
BW 2-O	DRY	16.5	700.0	743	61.00	2.45	1.9	0.30	C
BW 3-E	DRY	0.9	692.5	.	.	.	.	.	D
BW 3-O	DRY	13.7	1125.0	1230	178.00	1.77	4.55	0.04	D
BW 1-E	WET	25.1	750.0	1085	155.00	2.44	3.2	0.26	C
BW 1-O	WET	30.2	1415.0	913	165.00	0.94	3.8	0.31	C
BW 2-E	WET	9.6	615.0	559	46.00	2.61	2.95	-0.07	D
BW 2-O	WET	31.4	305.0	327	9.00	0.81	1.05	-0.09	D
BW 3-E	WET	6.8	347.5	301	32.00	0.57	2.05	-0.02	D
BW 3-O	WET	26.2	1182.5	787	113.00	1.20	2.95	-0.05	D
CB 1-E	DRY	0.7	717.5	.	.	.	.	.	E
CB 1-O	DRY	19.0	2207.5	2258	166.00	3.29	3.5	0.04	E
CB 2-E	DRY	1.7	722.5	522	94.00	2.38	0.6	0.14	E
CB 2-O	DRY	13.5	1540.0	1506	174.00	2.11	1.0	0.04	E
CB 3-E	DRY	7.5	1405.0	1352	151.00	1.54	2.9	0.06	E
CB 3-O	DRY	20.1	2005.0	1419	211.00	1.85	3.4	3.31	E
CB 1-E	WET	8.6	487.5	429	32.00	0.84	0.85	0.095	F
CB 1-O	WET	25.8	1575.0	1563	138.00	2.05	1.25	0.095	F
CB 2-E	WET	12.2	497.5	479	47.00	0.55	0.95	0.095	F
CB 2-O	WET	13.2	560.0	1321	116.00	2.52	2.35	0.095	F
CB 3-E	WET	22.4	1065.0	945	92.00	1.11	0.85	0.075	F
CB 3-O	WET	24.0	1940.0	2725	255.00	3.62	1.35	0.115	F

AMC=antecedent moisture condition;RUNMM=runoff in mm; CTSS=total suspended solids, centrifuge method; FTSS=total suspended solids, filtration method; TVSS=total volatile (organic) suspended solids; TP=total phosphorus; TKN=total Kjedahl nitrogen; NO2-3=nitrate-nitrite; WATER=Letters refer to Appendix G which lists values for background analysis of rainwater. Chemical values have the rainwater values subtracted, sediment values do not have rainwater values subtracted.

Appendix F. (cont.)

SITE	AMC	RUNMM	CTSS	FTSS	TVSS	TP	TKN	NO2-3	WATER*
CL 1-E	DRY	15.1	577.5	610	85.00	0.56	6.9	0.02	G
CL 1-O	DRY	28.7	232.5	211	35.00	0.23	3.6	0.06	G
CL 2-E	DRY	19.7	1102.5	978	103.00	1.75	10.3	-0.09	G
CL 2-O	DRY	34.4	697.5	765	83.00	0.98	8.1	0.06	G
CL 1-E	WET	17.6	1070.0	1135	146.00	1.07	10.3	0.09	G
CL 1-O	WET	38.7	105.0	117	30.00	0.09	2.6	0.05	G
CL 2-E	WET	25.5	497.5	548	56.00	0.71	9.3	0.02	H
CL 2-O	WET	38.2	587.5	497	56.00	0.55	6.9	0.01	H
LA 1-E	DRY	9.7	1100.0	1184	139.00	1.18	10.2	0.00	I
LA 1-O	DRY	30.8	570.0	527	58.00	0.34	9.3	0.00	I
LA 1-E	WET	14.3	962.5	1054	122.00	0.52	10.1	-0.02	I
LA 1-O	WET	25.1	765.0	985	101.00	0.42	11.3	-0.01	I
TS E1-E	DRY	12.5	177.5	102	81.00	0.49	2.45	-1.59	K
TS E1-O	DRY	20.4	157.5	91	67.00	0.37	1.45	-1.57	K
TS W1-E	DRY	8.6	325.0	387	78.00	0.24	0.50	0.27	J
TS W1-O	DRY	30.4	525.0	609	92.00	0.40	1.40	0.20	J
TS W2-E	DRY	20.0	475.0	.	.	.	.	.	J
TS W2-O	DRY	28.7	475.0	.	.	.	.	.	J
TS E1-E	WET	18.0	200.0	94	11.00	0.26	2.25	-1.77	K
TS E1-O	WET	26.3	170.0	71	25.00	0.29	1.35	-1.77	K
TS W1-E	WET	12.3	625.0	607	86.00	0.54	5.35	-1.69	K
TS W1-O	WET	29.7	450.0	451	73.00	0.33	5.25	-1.95	K
TS W2-E	WET	16.2	425.0	457	72.00	0.52	3.05	-1.27	K
TS W2-O	WET	37.9	325.0	286	57.00	0.30	2.15	-1.41	K

AMC=antecedent moisture condition;RUNMM=runoff in mm; CTSS=total suspended solids, centrifuge method; FTSS=total suspended solids, filtration method; TVSS=total volatile (organic) suspended solids; TP=total phosphorus; TKN=total Kjedahl nitrogen; NO2-3=nitrate-nitrite; WATER=Letters refer to Appendix G which lists values for background analysis of rainwater. Chemical values have the rainwater values subtracted, sediment values do not have rainwater values subtracted.

Appendix G. Sediment and Chemical Concentrations of Simulator Rain Water in mg/l for Each Plot

I.D. LETTER*	TOTAL PHOSPHORUS	KJELDAHL NITROGEN	NITRATE-NITRITE	TOTAL VOLATILE SUSPENDED SOLIDS	TOTAL SUSPENDED SOLIDS
A	0.06	< 0.1	3.78	2	6
B	0.06	< 0.1	3.69	< 1	10
C	< 0.01	0.1	1.24	< 1	2
D	0.07	< 0.1	1.61	< 1	< 1
E	< 0.01	0.2	0.08	5	8
F	0.04	< 0.1	< 0.01	< 1	32
G	0.01	0.8	0.32	< 1	2
H	< 0.01	1.0	0.10	< 1	< 1
I	0.06	0.6	0.26	< 1	< 1
J	0.29	2.3	0.27	< 1	< 1
K	0.34	< 0.1	9.52	76	94

*See previous appendix for key to I.D. letters