FINAL REPORT

ADAPTATION AND APPLICATION OF A SURFACE EROSION MODEL FOR NEW MEXICO FOREST ROADWAYS

by

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Technical Completion Report
Project Nos. 1423669 and 1345667
July 1983

New Mexico Water Resources Research Institute
in cooperation with the
New Mexico Natural Resources Department
State Forestry Division

and

U.S. Environmental Protection Agency
Region VI

The research on which this report is based was financed in part by funds provided through the New Mexico Water Resources Research Institute by the United States Department of the Interior as authorized under the Water Research and Development Act of 1978 (95-467) and by the State of New Mexico through State appropriations. Primary funding was provided by the United States Environmental Protection Agency, Region VI.

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ABSTRACT

The most significant source of sediment in forest environments is poorly planned, constructed or maintained roadways. Roadways change drainage patterns, expose the soil, disturb vegetation, and alter existing slope gradients. If improperly maintained, roadways can be subjected to accelerated erosion, which can cause signficant onsite and offsite impacts.

One important aspect of sediment control measures for roadways is the cost of installation and maintenance. These costs vary from year to year and roadway to roadway. The type of control measure should be selected by effectiveness in reducing erosion and associated cost.

This study was conducted to compare effectiveness of measures and associated costs. Data collected from forest roadways on four national forests in New Mexico were used to derive parameters for an existing computer based erosion and sediment yield model. The model was used to estimate sediment yields for different control measures. Yields were compared with costs of measures which were provided through a survey of forest engineers in Arizona and New Mexico. Results show the different costs of using various methods for reducing a unit of sediment yield from forest roadways, and can be used to help determine a best management method.

Keywords: computer models*, cost analysis*, data collection*, erosion control, forest hydrology, hydraulic models, hydrologic models, infiltration, parametric hydrology, roads*, runoff plot, sediment control, sediment yield, simulated rainfall, soil erosion*, water quality*.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

This study, like all field studies, required a team effort and a high degree of interaction. Dr. George O'Conner, acting director of the New Mexico Water Resources Research Institute, Raymond Gallegos, New Mexico State Forester, and Ben Longoria, New Mexico State Coordinator for the U.S. Environmental Protection Agency, provided the administrative support for this project. The field work was completed by Lynnette Barboa, Wayne Kotovsky, and Andy Missey with the assistance and direction of Keith Osantowski who "pushed and pulled" through the rough spots. Ned Elkins and David Torres assisted in processing the enormous volume of samples through the laboratory. L. R. Cooper of the USDA-ARS in Tucson, Arizona, performed the Microtrac analyses on selected soil samples. His help was most welcome. A special thanks goes out to Pam Archuleta of the NMSU Engineering Research Center who along with Dolores Mendoza were able to transform the original draft into a finished product. The role Robert Brozka played in this project can never be fully recognized unless one listened to the hours of phone and personal conversations conducted between the research team and him. Without Bob's vision and assistance, this project may never have been initiated and completed. A final word of thanks to all the USDA Forest Service personnel from ranger districts to the regional office for their physical, material, and philosophical support of this project.

INTRODUCTION

Problem

A significant source of sediment in forest environments is that associated with the layout, construction, and operation of roadways. Of particular interest are those roadways that disturb an otherwise low erosion landscape with bare soil cut slopes, fill slopes, and road surfaces. Disturbances to soil, vegetation, slope inclination, and drainage patterns further create potential avenues for accelerated erosion and increased sediment yields. If roadways carry low volumes of traffic, they are often not well maintained, thereby exacerbating any erosion problems that may initiate, such as gullying of the fill slope. In many cases, increased sediment yields are "absorbed" or "buffered" out by the surrounding undisturbed land. However, in other cases the roadway is situated so that the eroded materials easily reach streams and lakes, or the materials destroy the otherwise undisturbed surrounding lands. These offsite effects are not the only aspects of the problem. Often, if left unchecked, the roadway will erode to a point where it requires significant repair. These onsite damages are easier to quantify and, perhaps, are the most expensive to correct.

Most erosion monitoring has historically focussed on agricultural lands and related problems. In the last 25 to 30 years there has been a growing effort to address the problem of erosion from roadways, specifically those in forest environments. Empirical, long-term sediment yield studies have been conducted by government agencies in the United States concerned with this problem. More recently, mathematical modeling of long-term storm event erosion and sediment yield has been attempted.

Two general approaches are currently in vogue. One is to use empirically derived regression models and the second is to use physical process models.

A popular regression model of the erosion process is the Universal Soil Loss Equation (USLE). The term "regression" derives from the method of model development, in this case by way of regression analysis. A prerequisite for model development is a large data base containing observed erosion and watershed characteristics for numerous storms on various watersheds. From this data base, regression analysis identifies the watershed characteristics affecting erosion, and their functional relationship to the erosion process. A drawback of this method, as of any empirical method, is limited applicability. The model should only be used on watersheds and for storms similar to those used for development of the model.

A physical process model predicts erosion by interacting the various definable physical processes occuring during a storm event. These processes include infiltration, overland flow, soil detachment, and sediment transport. Each process is mathematically modeled, some by theory alone, and some using empirically derived coefficients to account for phenomena too complex to model. Empiricism, entering this model through the parameter derivations, tends to limit its application as with the regression models. However, this limitation is mitigated by the theoretical development of the process equations, which tends to make the model more flexible to different roadway designs.

Modeling of erosion with physical process models is the direction taken in this study. Although historically substantial effort has been expended in modeling, little effort has been spent in relating model results to erosion control costs. This is an important deficiency to the forest road manager who must make decisions as to the most appropriate or best practice to employ for erosion control. There is no doubt that the manager is aware that erosion occurs, and that erosion control measures cost; the primary problem is how much erosion control can be realized for a given type and level of technique. This study helps define a solution to this problem.

Goals and Objectives

The study had the goal of providing forest managers in the southwest with a methodology for estimating the relative best management choice between forest road layout alternatives. The six objectives of the study were to:

1. Adapt, update, and modify an existing mathematical model used to estimate water and sediment yield for roadways;
2. Collect field data on runoff and erosion from selected forest roadways in New Mexico using a small, portable rainfall simulator;
3. Use this runoff and erosion data to calibrate the road sediment model to soils and geology of New Mexico forests;
4. Compile applicability of existing erosion protection techniques for forest roads;
5. Use the model to assess the most effective combinations for mitigating road erosion; and
6. Demonstrate the methodology to Forestry Division personnel in a training session.

Scope of Report

This report details the approach and results of the completed study. Data collection and parameter estimation (2 and 3 above) was confined to forest roads located on four National Forests in New Mexico. A survey detailing current road erosion control techniques and associated costs was conducted for the eleven National Forests in the Southwestern Region (R3), which includes Arizona and New Mexico. These surveys provide a basis for cost estimates. Although the data and resulting model are adjusted to southwestern conditions, the general approach is applicable to other regions.

HISTORICAL PERSPECTIVE

Modeling

Quantitative studies of soil erosion were initiated around 1915 in the United States by the U.S. Department of Agriculture Forest Service. It wasn't until 1940 that an empirical relationship between soil loss and site characteristics was proposed (Zingg 1940). Numerous other relationships evolved with the culmination being the "Universal" soil loss equation (USLE) (most recently Wischmeier and Smith 1978). The equation was originally developed for agricultural lands, but its use is becoming more prevalent in other applications. The USLE has been proposed for use on forest logging roads (Curtis, Darrach, and Sauerwein 1977), roads in general (Farmer and Fletcher 1977), and other forest situations (Dissmeyer and Foster 1980). Along similar lines, the development of empirical relationships specifically for roadways has progressed. This has occurred because of the recognition of the importance of road erosion in the overall sediment budget for a watershed and the unique soil and drainage conditions which roads create. Anderson (1975), Megahan (1975), Rice, Tilley and Datzman (1979) and Reid, Dunne, and Cederholm (1981) have all estimated the overall contribution of forest roads to total basin sediment yields. Similarly, Vice, Guy, and Ferguson (1969), Reed (1980) and Gupta, Agnew, Gruber, and Kreutzberger (1981) have all studied the effects of highways on contributing suspended sediments to runoff.

Some of the earliest work related to forest roads was presented by Hoover (1945) from the Coweeta Experimental Forest in North Carolina.

In comparing loss rates between a steep skid road and a steep agricultural field, he found the skid road produced over 50 times more sediment. Weitzman and Trimble (1952) presented data from four different levels of skid roads in the Fernow Experimental Forest in West Virginia and concluded that better planning of road gradients and drainage would decrease erosion. This was followed by Trimble and Weitzman (1953) in which the field data were used to develop an erosion chart based upon slope length and gradient of the skid road. This table was compared with a modified Manning's formula, which contained variables for gradient, length, overland flow velocity, flow resistance and rainfall rate. Comparisons were good up to a 25 percent gradient where the equation gave longer allowable distances between water bars than were observed in the field. The authors noted this and rightly attributed it to the changes in normal and tangential stresses on a soil particle on steeper slopes. Trimble and Sartz (1957) developed a relationship between buffer strip width and slope gradient of the strip. They proposed that strips be a minimum of 50 feet wide plus four times the slope gradient in percent. Therefore, a buffer strip on a 10 percent slope should be 90 feet wide. This relationship was conservative and was recommended for municipal watersheds. For general situations, one half the computed value was suggested. This recommendation has persisted and is still being published as a criterion for buffer strips (Darrach, Sauerwein, and Hally 1981).

Haupt (1959) published a multiple regression equation relating buffer strip length to a side slope obstruction index, cross drain spacing, road gradient, and embankment (fill) slope length. Buffer strip gradient was not a statistically significant variable. Haupt's study area was in the Little Owl Creek basin of Idaho.

Packer (1967) presented equations for cross drain spacing and sediment transport distance away from the road (buffer strip length). The cross drain spacing to prevent one inch deep rills was found to be a function of road gradient, percent of water stable aggragates greater than 2 mm, topographic position (upper, lower, or middle third of the hillside), aspect, and steepness of the slope above the road cut. The equation for transport distances contained variables for obstructions, age of the road, fill slope cover, cross drain spacing, and percent of water stable aggragates greater than 2 mm in size. Packer suggested that addition of 60 feet to his tabulated strip values would be a conservative assumption. Packer's study was conducted in the Intermountain Forest and Range Experiment Station region.

Megahan (1974) presented a time trend model that was applied to sediment yields from roads in Idaho. His exponential decay model had site specific parameters and it fit the long term decrease in erosion quite well.

Leaf (1974) followed up on Megahan's ideas and proposed another equation that would relate unit area road erosion to total road erosion. Again his equations were site specific as were Megahan's, but he included a generalized conversion to depict total erosion.

Ohlander (1976) presented a buffer strip equation based on Packer's work. The equation contained slope, the USLE K factor, and the Soil Conservation Service curve number used for estimating runoff.

In 1977, Simons, Li, and Shiao (1977) proposed modeling road erosion using a physical process model obtained from Li (1974). This model was a break from the empirically based approaches used by earlier researchers. The model, referred to as ROSED (Road Sediment), has components for interception, infiltration, overland flow routing using a kinematic wave assumption, and sediment detachment and transport using raindrop splash and overland flow shear stress. The Meyer Peter-Müller equation is used for the bed load transport criteria and Einstein's equation for the suspended load portion. The model treats cut and fill slopes, road surfaces, ditches, and culverts. Road characteristics that are considered include gradient, lengths, width, ground cover, sediment size distribution, and infiltration characteristics. The model is an event based rainfall-runoff type. A simpler version of the complex model was presented by Simons, Li, Ward, and Shiao (1978) and is named SIRSED (Simplified Road Sediment). One or both of the models have been applied to selected road sediment yield data from forest or mine haul roads.

Case Histories

Data have been collected, analyzed, and used to validate the applicability of the complex and/or simplified models for making sediment yield estimates. Rainfall simulation data for mine haul roads in Idaho and Montana, and forest roads in California have been collected. In addition, natural rainfall events were measured at the Coweeta Experimental Watershed.

Coweeta Experimental Watershed, North Carolina. During 1976 and 1977, field data from natural rainfall events was collected from cut and fill slopes, and road surfaces in the Coweeta Experimental Watershed by Dr. Lloyd Swift. Each road segment was isolated and runoff and sediment yields sampled independently. Two sites were monitored on the same road. Road lengths were 146 and 108 feet; widths, 20 and 22 feet; and gradients, 7 and 5 percent, respectively. Nine events were measured and maximum one minute intensities varied from 0.2 to 12.6 in/hr. Further details are presented in Simons, Li, and Ward (1978).

The Coweeta data were difficult to model because of equipment errors and the natural variability in time and space of the rainfall. The ROSED model was applied and calibrated to all nine events on one road site. It was then used to estimate yields from the same nine events at the other road site. The predicted yield was, on average, 17 percent too high, but the predicted total yield for all nine storms was within 11 percent of the measured total yield.

Mine Haul Roads. During the summer of 1978, rainfall runoff simulation data were collected from selected mine haul roads in Montana and Idaho. The results of the studies have been published by Johnson, Sundberg, Burroughs, and Armijo (1980), Li, Ward, and Simons (1980), and Sundberg, Armijo and Scheer (1981). The road sections were about 75 to 150 feet long by about 33 feet wide. Slope gradients averaged 6.8 percent, and median grain sizes ranged between 0.16 and 2.2 mm. A modified CSU rainulator (Holland 1969) using 10-foot tall standpipes and pressure regulated sprinkler heads was used. This device delivers approximately 40 percent of natural rainfall kinetic energy. Average intensities varied from 1.1 to 2.4 in/hr.

Sundberg, et al., (1981) applied ROSED to nine experiments they thought were unaffected by wind or other influences. The predicted yield was, on average, 4 percent too low, and only about 2 percent too low for the nine event total.

Li, et al., (1980) also used a subset of the mine road data in applying SIRSED. Using seven events, three in common with the Sundberg, et al., (1981) events, they were able to select initial overland flow detachment coefficients and quickly converge on a calibrated value for each site. Individual values were used at each site and the model was used to estimate sediment yields.

California Forest Roads. During the summers of 1979 and 1980, rainfall simulation data were collected from forest roads in California (Simons, Li, Ward, and Schall 1980; and Simons, Li, and Anderson 1982). Data were collected from cut and fill slopes, contributing watersheds, and road surfaces. Locations were in the Klamath Mountain geomorphic province near Sonora, California.

Road sections had overland flow lengths of 20 to 89 feet, and corresponding widths of 11 to 56 feet. Gradients averaged 9.1 percent, and grain sizes ranged from 0.06 to 5.0 mm. A modified CSU rainulator using 10 foot tall standpipes and flow regulators was used. Again this device delivers approximately 60 percent of natural rainfall kinetic energy (Ward and Seiger, unpublished data). Average intensities varied from 1.4 to 3.3 in/hr.

Simons, et al., (1982) used all of the California road data to derive parameters for components of SIRSED. After selecting the appropriate parameters they then compared the model results with measured values. The averages of the two groups of values were quite close (as would be expected), within 1 percent of each other. The variances of the groups were essentially identical. This was not the case for the cut and fill slopes, however, where predicted sediment yields had an average value of only 0.47 times that measured for the cuts, and 1.8 times for the fills. The calibrated parameters were used to develop a site specific model (Li, Collette, and Anderson 1982) based on SIRSED.

Erosion Treatments and Costs

Numerous erosion control techniques are available (Amimoto 1978). Interestingly, a first modeling attempt (Trimble and Weitzman 1953) considered the spacing of water bars, a classic erosion control technique (New Mexico Department of Natural Resources, Forestry Division 1980). Few studies have addressed the cost effectiveness of erosion control practices in forested watersheds. One study by Dykstra and Froehlich (1976) resulted in no one method of protection being that consistent or superior to the others. A recent report by Haber and Kadoch (1982) detailed erosion control treatment costs for several types of techniques. The report did not compare cost and resultant sediment yield reduction.

METHODOLOGY

Overview

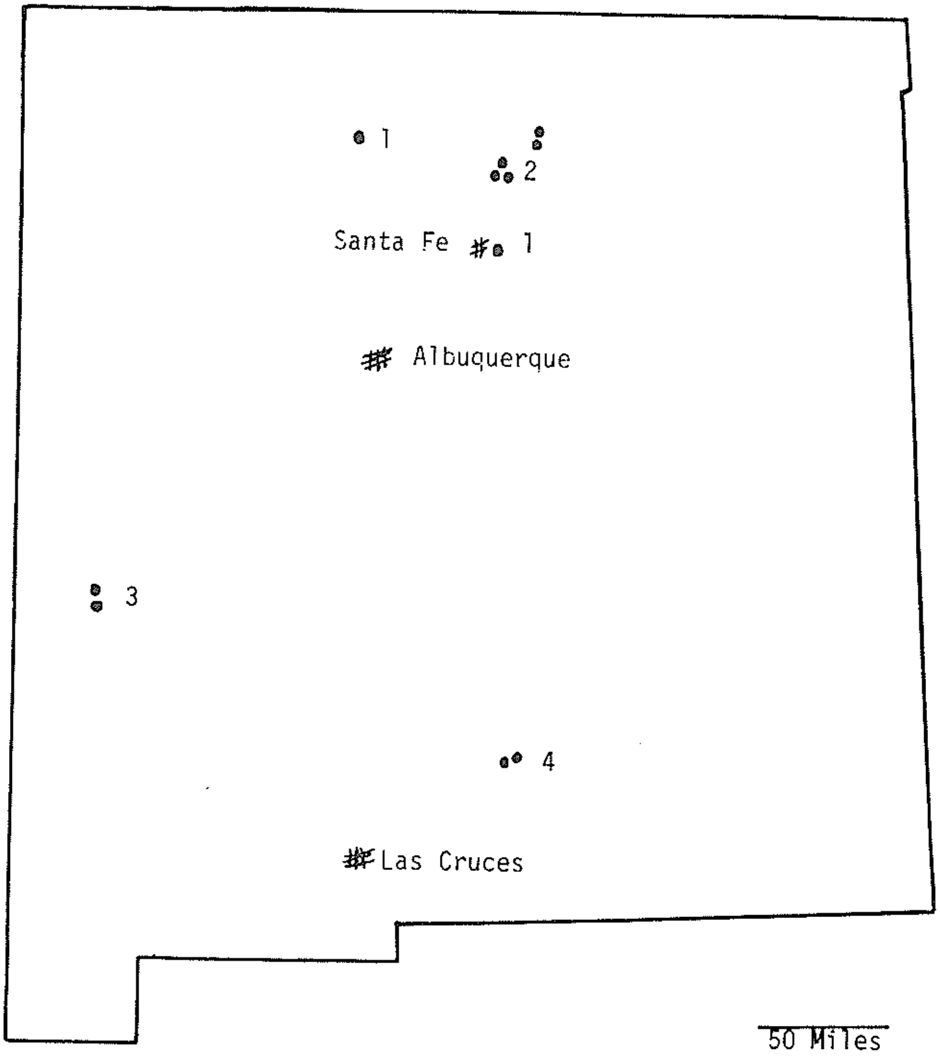
The overall goal of this study is to adapt an existing physical process model of the erosion process for use by forest managers in the southwest. Adaptation of this model, which is in the form of a computer program, is two-fold. First, the computer program will be modified to perform the specialized computations required for cost analysis of erosion protection methods on forest roads. In conjunction with this, the program must be made "user friendly" and its proper use must be documented to facilitate application by persons unfamiliar with its operation. Second, certain of the processes contained in mathematical form within the program must be calibrated to the soils and geology of New Mexico. Calibration is accomplished through empirical evaluation of site and soil dependent parameters involved in the equations for these processes. Due to the nature of these parameters, they must be evaluated from runoff and erosion data on soils similar to those that will later be modeled.

Two physical process models are involved in this study. Program ROSED predicts erosion on unprotected road surface, while program SIMSED is a simplified watershed erosion model. Both programs contain components for interception, infiltration, and sediment detachment and transport. ROSED also contains components for routing overland flow and sediment. SIMSED assumes no time or space dependent behavior of these components. Since ROSED is more precise than SIMSED and is tailored to road surfaces, ROSED was adapted to include cost calculations of erosion control methods via linked programs. SIMSED used to verify the determination of the model parameters for New Mexico soils and geology.

Calibration of the physical process models to New Mexico soils required field data collection, laboratory measures of field samples, and statistical analyses of the hydrologic, soil and surface characteristics of the roads. Program modification involved a mail survey of national forest engineers in the Southwestern Region, and adaptation of an existing road sediment yield model. A Quality Assurance Project Report detailing the sample collection techniques and analyses methods was submitted to Region VI of the USEPA (Ward 1982). A data summary report was submitted to the USEPA (Ward undated), which listed selected measurements from the experiments. Excerpts from these reports will be used in the following sections.

Locations

Field experiments were conducted on roadways of four national forests in New Mexico: Santa Fe, Carson, Gila, and Lincoln. In the Santa Fe, roads in the Coyote Ranger District (R.D.) and the Tesuque R.D. (figure 1); in the Carson, roads in the Penasco and Taos R.D.'s; in the Gila, Reserve R.D.; and in the Lincoln, the Cloudcroft R.D. The assistance obtained from U.S. Forest Service personnel at these districts was greatly appreciated. Table 1 is a listing of national forest, road designation, type of surface, and number of wet and dry runs (explained below). As the list in table 1 indicates, there were 74 plots on road surfaces, 7 plots on cut slopes and 4 plots on a road landing. This predominance of road surfaces reflects the relative importance that this portion of a roadway has in the forests. Personal observations suggest that long cut or fill slopes are not prevalent in



National Forest Sites
1 - Santa Fe
2 - Carson
3 - Gila
4 - Lincoln

Figure 1. Locations of sample sites in New Mexico

Table 1

Designation of Roadways Sampled

National Forest	Forest Road* Number or Other Designation	Surface** Type	Number of*** Plots	Total Number of Dry and Wet Plot-Runs
Carson (C)	155 W(west)	RS	4	8
	155	RS	4	8
	155 S(Spur)	RS	4	8
	778	RS	4	8
	439	RS	4	8
	697 E(East)	RS	1	2
	439 2[1]	RS	4	8
	439 S-2[2]	RS,CS	2,2	4,4
TOTALS			29	58
Gila (G)	289 1,1CS[3]	RS,CS	2,2	4,4
	289 2[3]	RS	4	8
	289 NS,NC[4]	RS,CS	4,2	8,4
	94 S	RS	4	8
TOTALS			18	36
Lincoln (L)	LOG [5]	RS	4	8
	RUS B[6]	RS	2	4
	RUS C	RS	4	8
	RUS D[7]	L	4	8
	WAT D[8]	RS	4	8
TOTALS			18	36
Santa Fe (S)	470 [9]	RS	4	8
	470 S	RS	4	8
	471 S	RS,CS	3,1	6,2
	79	RS	4	8
	79 S	RS	4	8
TOTALS			20	40
TOTALS (All Sites)			85	170

*[1] - 2-Second sampling site
[2] - S2-Spur near second sampling site
[3] - 1-First sampling site; 1CS - First sampling site cutslope
2-Second sampling site
[4] - NS-North spur; NC-North spur, cut slope
[5] - Active logging road
[6] - RUS B,C,D are designations of haul roads in the Russia Canyon area
[7] - RUS D L is a landing
[8] - WAT D - between water bars on RUS D
[9] - On road and shoulder
** - RS-Road surface; CS-Cut slope, L-Landing
***- Number for each surface, respectively.

New Mexico forests, and that most road erosion problems are associated with road surface erosion or drainage. Selections of the particular roads and locations for the sample plots was guided by a desire to obtain a variety of soil types, parent materials, and road conditions.

Data were collected during two periods. These periods were: S470 and 471 6/2/83 to 6/5/82; S79 8/17/82 to 8/19/82; C155, 778 439, and 697 6/8/82 to 6/17/82; C439 2 8/14/82 to 8/16/82; G all 6/22/82 to 6/26/82; and L all 6/30/82 to 7/12/82. The Santa Fe and Carson forests were split because of access problems during the initial visit and the desire of the New Mexico Forestry Division to measure these sites.

Field Sampling

Data were collected using a modified Purdue rainfall simulator (Bertrand and Parr 1961) contained on a 16 foot long trailer. A pair of nozzles was mounted on each of two separate booms, one boom on either side of the trailer. Both booms were of a fixed height, but adjustable in reach length and radial orientation. Suspending a plumb bob from the center of the nozzle assembly facilitated centering the nozzles over the sample plot. Once in position, the booms were locked in place. To minimize wind distortion of the rainfall, a wind screen could be supported from the boom and staked to the ground around the sample plot. The booms and windscreen are shown in figures 2 and 3.

At each parking spot it was possible to simulate rainstorms over two sample plots simultaneously. Lateral isolation of the sample plot from the surrounding soil was accomplished using a square steel frame. This frame was installed by hammering it into the soil to a depth of approximately 1 inch. One side of this frame was open, permitting runoff from the plot to flow into a collection trough. Periodically this trough was

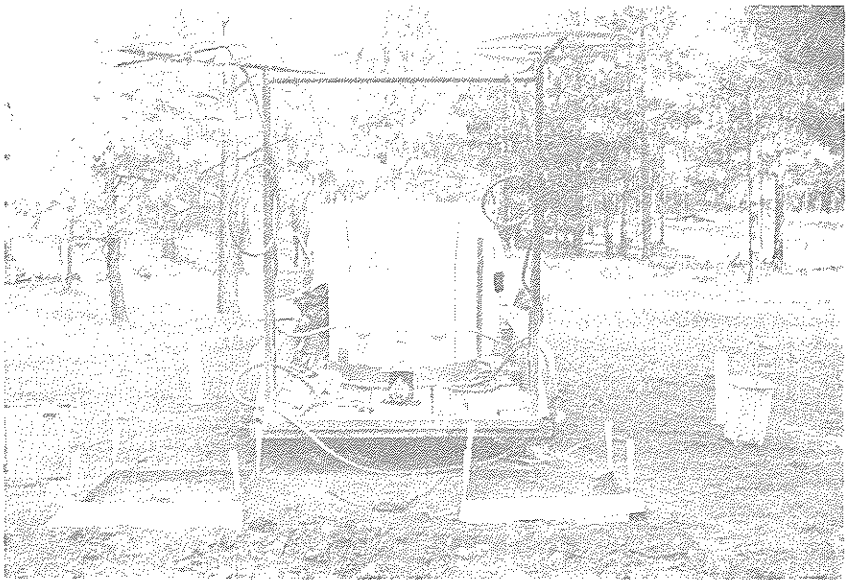


Figure 2. Booms are centered over the sample plots and locked in place in the Gila National Forest

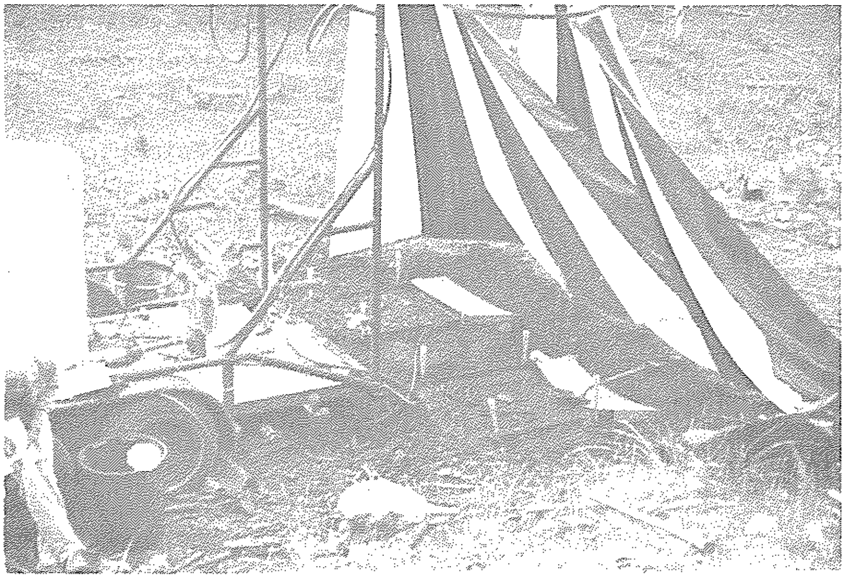


Figure 3. Wind screens installed in the Lincoln National Forest

pumped dry in order to measure the incremental volume of runoff. A cumulative depth raingage was placed at each of the four corners of the sample plot in order to measure applied rainfall.

The sample plot frame measured 38¼ inches square, providing a nominal plot area of 10 square feet. Typical installations of the sample plot and associated equipment are shown in figures 4 and 5.

This simulator delivered an average intensity of 3.5 in/hr to the level sample plot at 2.5 psi nozzle pressure. Pressure flucuations and water temperature affect the intensity at the nozzle. Land slope and wind further affect the intensity delivered to the sample plot. Kinetic energy of the nozzle spray was approximately 60 percent of that expected from natural rainfall of the same intensity (Wischmeir and Smith 1978), as determined by four pan studies conducted by Andy Seiger (unpublished data). Water was delivered simultaneously to both booms by a centrifugal pump and water tank mounted on the trailer. Figure 6 shows the layout of the various components in schematic form.

A total of 170 plot runs were conducted on the 85 sample plots. First a dry run, then a wet run, were performed as described by the following sequence:

DRY RUN

1. Select site and fill in general information on sample sheet (Appendix I).
2. Initially position one square meter plot frames.
3. Position trailer carrying rainfall simulator so that it covers the plots as desired.

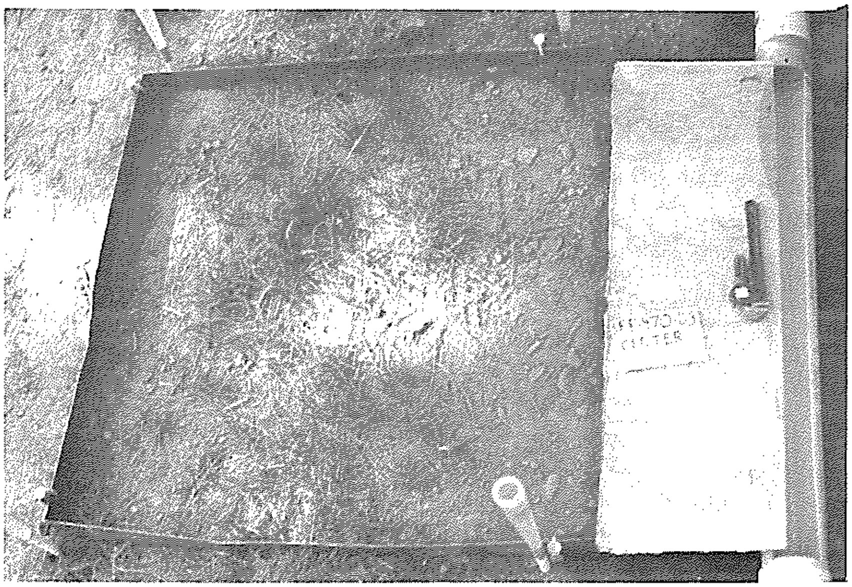


Figure 4. Plot frame, runoff flashing, and collection trough installed in the Santa Fe National Forest

Figure 5. Installation in the Lincoln National Forest shows raingages and flashing cover

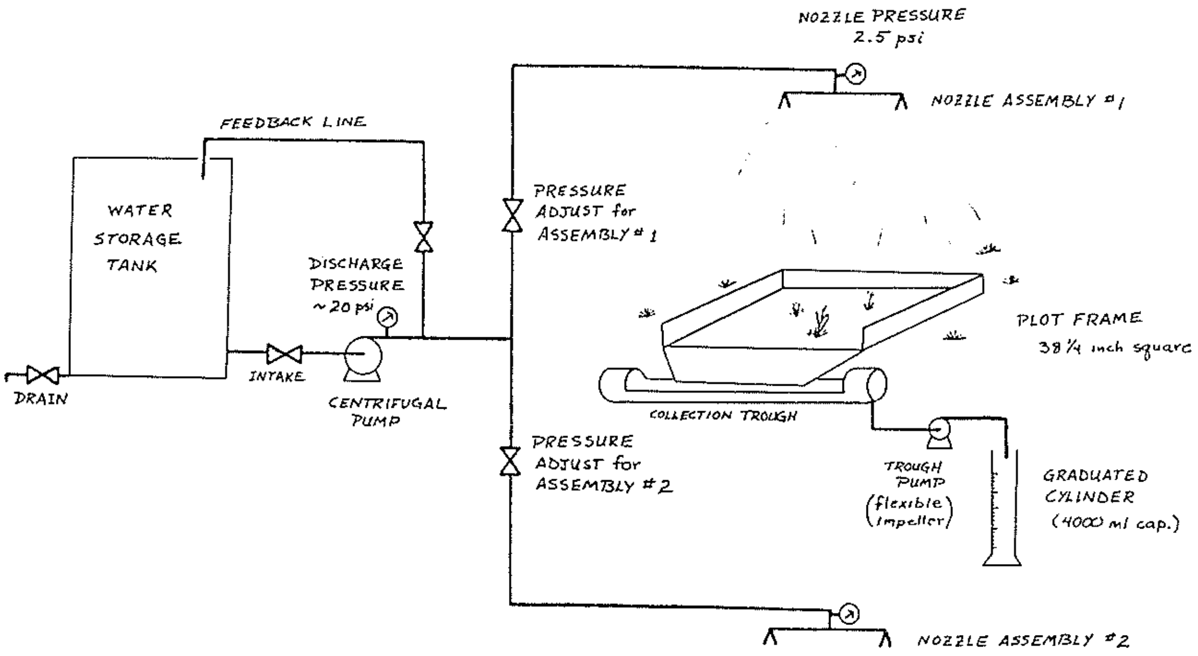


Figure 6. Schematic layout showing major elements of rainfall simulator

4. Install plot frames with trench for collection trough.
5. Seal disturbed edges of soil with bentonite.
6. Take pictures of the plots and estimate vegetation and rock cover.
7. Connect trough pumps to troughs.
8. Collect soil moisture and density samples from top ten cm of surface in the 1" I. D. sampling tube. Collect on outside edge of plot frame. Put in soil cans, label and seal. Collect sweepings of loose surface material from 1 by 1 foot area.
9. Install a nimbus raingage at each corner of each plot frame.
10. Install wind screens as needed.
11. Begin rainfall.
12. Note times of ponding and runoff into the trough.
13. Pump troughs as necessary (every three to five minutes).
14. Record pumped volume and save sample in barrel.
15. Rain for at least 30 minutes to assure a steady state runoff.
16. Stop rain and pump trough a final time.
17. Measure depths in barrels.
18. Agitate barrels and sample 500 ml of water and sediment. Preserve with 10 ml of chlorine bleach in a one quart glass jar, labelled and sealed.
19. Remove deposited material (bed load) from the runoff trough and the runoff flashing (metal flume between plot and trough). Bag material in plastic ziploc bags and label.
20. Record raingage depths in inches <u>and</u> millimeters.
21. Measure depth to wetted front on outside edge of plot.
22. Cover plot with plastic sheet, plywood, and dirt until wet run.

WET RUN (12 to 24 hours later)

23. Repeat steps 6 to 21 above except rain for 20 minutes or until steady runoff is observed.

24. Measure slope in plot with a 2" by 4" board and a Brunton compass.

25. Remove about 2 lbs. of soil for sieve analyses from the center of the plot. Save in ziploc bag.

Samples of water, sediment, and soil were transferred along with sample sheets. The transfer was from Keith Osantowski (field leader) to Andy Seiger with a check by Tim Ward to make sure all data were received. Samples were labeled as such:

1. Soil moisture cans received a label consisting of adhesive tape marked with permanent ink. We have found this method best because this tape and ink combination does not fade or burn out when dried in an oven.

2. Plastic bags containing (a) bed load, (b) sweepings and (c) bulk soil samples were labeled with masking tape and permanent ink.

3. Runoff water containers were wrapped with masking tape, so the label did not fall off, and marked with permanent ink.

Each sample container was prepared prior to the experiment. An information code distinguished samples between plots. An example of the code used is

CF - 155 - D1

where CF Carson Forest, (or other Forest)

155 road number (and surface designation)

D1 dry run, plot 1 which is on the drivers side (left) of the trailer.

Samples were then boxed and transported to the laboratory at different intervals. At the laboratory, labels were checked against data sheets, samples for each item were verified and the samples were inventoried in the data log as to code from the data sheet, soil samples (bulk and moisture), and runoff samples (suspended and bed load). This inventory is permanently affixed to the data log.

Laboratory Measurements

Once the data sheets and field samples were returned to New Mexico State University, they were measured and analyzed for several basic data including:

1. rainfall rate from the nozzle and rainfall rate on the sample plot
2. runoff rates
3. infiltration parameters
4. suspended sediment concentrations
5. bed load yields
6. erosion parameters
7. soil particle size distribution
8. soil moisture and bulk density values
9. weight of sweepings
10. percent of vegetation and rock cover

Suspended sediment was filtered following procedures for fine sediments as discussed in USGS (1977). Bed load was air dried and weighed. Cover was estimated in the field and verified by Tim Ward from photographs. Soil moisture was measured for moisture content as found in USGS (1977). Soil gradation was determined on a split sample following

ASTM specifications D42158 and D42263. Clay fraction was verified using a Microtrac (TM) analyzer. Bulk density was found from oven dried weights of measured cores. Sweepings were air dried and weighed. Rainfall rates were determined from the raingage depths, then corrected for pressure effects, boom orientation and plot slope. Corrections for these effects were determined through extensive calibration tests on the rainfall simulator. Runoff volume was determined from collected runoff increments, and checked against the accumulated volume in the barrel. Infiltration and erosion parameters were derived from the measured and the processed data as discussed in the following section.

Parameter Derivation

Overview. Field sampling of runoff-erosion data on forest roads within New Mexico was previously outlined. As mentioned above, New Mexico forest roads were the subject of the field work in order that the parameters derived from the resulting data be applicable specifically to New Mexican forest roads, and generally to forest roads within the Southwest. The procedure of parameter derivation from this data basically involves equating pertinent field data to the mathematical equation describing the process, and then solving for the empirical parameters contained within the equation.

For this study, parameters describing infiltration and sediment supply must be empirically derived. Infiltration involves two parameters, the saturated hydraulic conductivity of the soil (Kw) and the average capillary suction at the wetting from (Ψ). Sediment supply is by two separate processes, each involving one parameter. The raindrop detachment parameter (A) governs soil detachment by raindrop impact, and the overland flow detachment parameter (DOF) governs soil detachment by the shear stresses of overland flow. These four empirical parameters, along with other obtainable road surface characteristics, constitute the body of information necessary for physical process modeling of the runoff-erosion process.

Infiltration Parameters. The infiltration process is mathematically modeled by Green and Ampt (Mein and Larson 1973). Their equation relates the empirical parameters Kw and Ψ to measurable field variables in the following manner:

$$f = \frac{dF}{dt} = Kw \; (1 + \frac{\alpha}{F}) \tag{1}$$

where F = accumulated depth of infiltration

Kw = saturated hydraulic conductivity

α = Potential head parameter, further described as:

$$\alpha = \eta(S_f - S_i)\Psi \tag{2}$$

η = soil porosity

Ψ = capillary suction

S_i, S_f = initial and final degree of saturation.

Equation (1) describes a linear relationship between the field variables dF/dT and 1/F. Accordingly, a plot of these variables must define a straight line having an intercept equal to the empirical parameter Kw, and a slope equal to $Kw \cdot \alpha$. From α, the second empirical parameter for the infiltration process, Ψ, may be determined by equation (2). In this manner, evaluation of the empirical infiltration parameters is accomplished.

Field data required for this evaluation is the time-dependent accumulated infiltration (F). The valve of F on the sample plot at any time T was obtained as accumulated rainfall (P) less the accumulated runoff (Q):

$$F(T) = P(T)-Q(T)$$

Accumulated rainfall at any time T was evaluated from the constant rain intensity (RIPH) maintained over the sample plot:

$$P(T) = RIPH \cdot T$$

Runoff from the sample plot was collected and measured incrementally, the increment being recorded along with the time of measurement. At a particular time T, accumulated runoff Q was then the sum of all previous runoff increments, while P(T) and F(T) were evaluated as above. Between two consecutive times, ΔF and ΔT may be calculated; from these, infiltration rate is estimated as:

$$f \sim \frac{\Delta F}{\Delta T}$$

A plot of $\Delta F/\Delta T$ against $1/F(T)$ should display the linear character of equation (1). However, random error in the field measurements scatters the plot to some degree. The optimum line is fit to this linearly-trending data using the technique of least-squares. From this optimum line, the empirical infiltration parameters are determined (figure 7).

Transport Parameters. During a storm event, the erosion process is largely controlled by the interaction of two sub-processes. In order for erosion to occur, soil is first detached from the soil mass. Once detached, the soil can be transported from its initial position. The two sub-processes controlling erosion are then soil detachment and sediment transport.

In this study, overland flow is considered the principal agent of sediment transport. This agent transports sediment by two mechanisms, either as bed load, or as suspended load. Bed load transport results from the shear stress imparted to the soil particles by the flowing

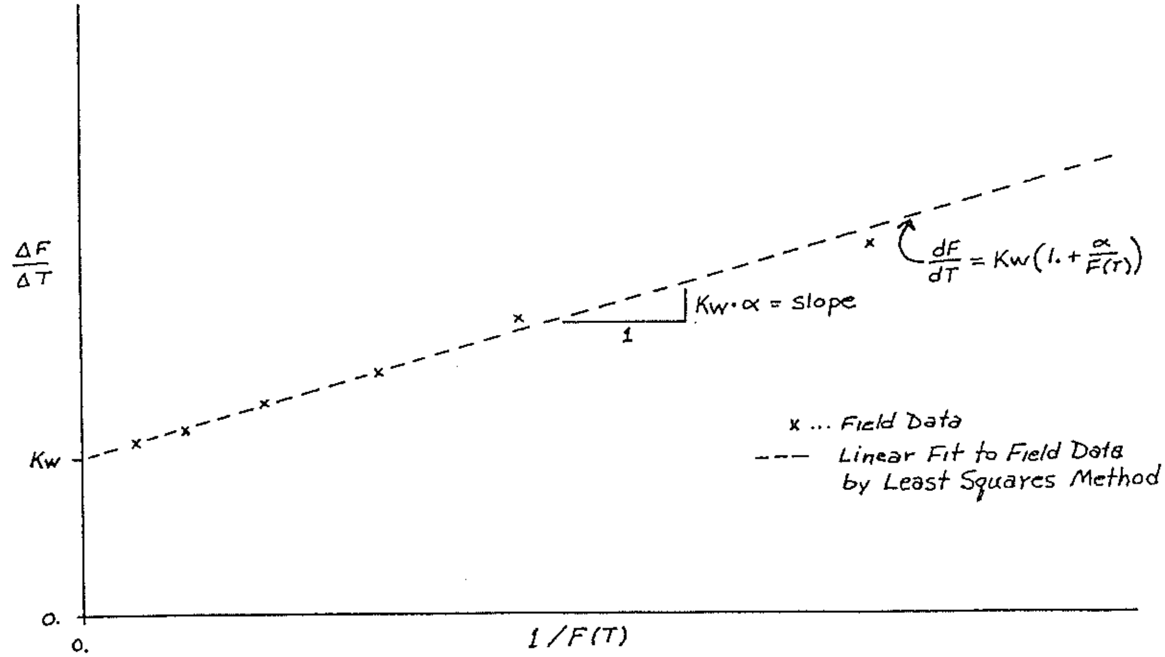


Figure 7. Evaluation of infiltration parameters from field data

water; this mode tends to drag particles along the soil surface. Suspended load transport is related to the settling velocity of particles in water, and the turbulence of the flow; this mode tends to muddy the surface flows. Typically both modes of transport are active during the erosion process.

The capacity for transport by overland flow is modeled using hydraulic principals. Bed load is modeled by the Meyer-Peter, Müller formulation (USBR 1960), and suspended load is modeled by the Einstein method (1960). Parameters used in these models appear only mildly sensitive to road surface characteristics, and are thus evaluated from representative values reported in the literature. These parameters include the overland flow friction (K_ℓ and K_h), the grain resistance parameter (Ko), and the critical shear stress parameter (δ_s). Values chosen for these parameters are listed below:

Parameter	Value
K_ℓ	100.
K_h	400.
Ko	50.
δ_s	.047

Detachment Parameters. Soil detachment results from two erosive agents: the impact of falling raindrops, and the shear stress of overland flow. Equations for both these sub-processes include empirical parameters. Two assumptions facilitate evaluation of these parameters from field data. First, it was assumed that the erosion process observed on the sample plots was not limited by the transport capacity of the overland flow. In other words, all detached soil was transported off the plot and collected. This sediment collection was according to mode of transport, either bed load or suspended load. Bed sediment was equated to the overland flow process, while suspended sediment was equated to the process of raindrop detachment. This equivalence between measured sediment and detachment process constitutes the second assumption. With these assumptions, the suspended sediment and bed sediment collected on the sample plot may be used to evaluate the raindrop detachment parameter (A) and the overland flow detachment parameter (DOF), respectively.

Raindrop Detachment. This detachment process is modeled to be proportional to the square of the rain intensity (Meyer 1971) or:

$$\text{Raindrop Sediment Supply} = A \cdot I^2 \tag{4}$$

where

A = raindrop detachment coefficient

I = rainfall intensity, in/hr

The parameter A was evaluated for each rain event on each plot, with the assumption that the measured suspended load represented raindrop detachment. Since rain intensity was constant during a rain event, parameter A was taken as the ratio of suspended sediment to I^2, after adjusting this measured sediment for the deficient energy of the simulated rainfall.

Kinetic energy of natural rainfall is assumed to be related to the rain intensity according to the relation used in Wischmeier and Smith (1978):

$$KE = 916 + 331 \text{ LOG}_{10}(I) \tag{5}$$

where

KE = rainfall energy, $\frac{\text{ft-tons}}{\text{acre-inch}}$

I = rainfall intensity, in/hr

This relation is difficult to reproduce using simulated rainfall; a simulated rainfall of a certain intensity will typically have an energy below that of a natural rainfall of the same intensity. A consequence of this reduced energy is a decrease in sediment supply from raindrop detachment; the measured suspended load should be lower than that observed under natural rainfall. To adjust A for this effect, the measured suspended load was increased by multiplication with the ratio of natural rainfall energy to the simulated rainfall energy (Young and Burwell 1972).

The rainfall intensity used in both equations (4) and (5) was that delivered by the nozzles; this nozzle intensity was slightly higher than the rainfall intensity reaching the sample plot due to land slope effects. The effect of surface cover on the parameter A was removed by multiplying A by the ratio of total plot area to bare in the area plot. Finally, coefficient A was converted into units of porous depth of sediment through division by the bulk density of the soil mass.

Overland Flow Detachment. The model used for this process is that common to the physical process models developed at Colorado State University. In these models, overland flow detachment is a fraction of excess sediment transport capacity. The parameter describing this process represents the ratio of overland flow detachment to the excess sediment transport capacity. Excess sediment transport capacity is capacity in excess of that necessary to transport sediment supply created by raindrop detachment. In equation form:

$$\begin{matrix}\text{overland flow}\\ \text{sediment supply}\end{matrix} = \text{DOF (transport capacity - raindrop supply)} \tag{6}$$

where DOF = overland flow detachment coefficient.

Measured bed load was used to represent the overland flow sediment supply, and the energy-adjusted measured suspended load was equated to the raindrop sediment supply. Transport capacity was calculated as the sum of the bed load and suspended load capacities calculated from measured plot and soil characteristics. Bed load capacity was determined from the Meyer-Peter Müller bed load relation (USBR 1960) and suspended load capacity was predicted using Einstein's equation (Einstein 1950).

By following the above procedures, parameters used in the ROSED model were derived. Therefore there needed to be no further reinterpretation of the parameters before use in the model.

Cost Survey

An important part of this study was to acquire cost estimates of commonly used erosion control measures. To meet that objective, a mail questionnaire was developed in conjunction with Robert Brozka of the New Mexico State Forestry Division. A copy of the questionnaire can be found in Appendix II. The questionnaire was sent to forest engineers at the eleven National Forests in the Southwestern Region. Responses from ten of these were received and processed.

The forest engineers were asked to respond to five specific questions and comment on pertinent road erosion problems they must consider. Three questions dealt with miles and types of roadways, one asked about miles treated and cost of 19 specfic treatments, and one asked what was the most serious road erosion problem on the forest. Data were tabulated and estimated costs were converted to common base units using realistic factors. The tabulated values served as a guideline for estimating erosion control technique use and costs.

Computer Model Analyses

Analysis of the field data produced surface and soil characteristics, and parameter values for each sample plot. This information was arranged as input data for program SIMSED, and the resulting predicted sediment yield was compared to that actually measured. The purpose of this was to verify the parameter estimates from the field data. The modified ROSED model was then used to predict erosion on a hypothetical forest road. For this, rainfall inputs were selected based on data taken from Miller, Frederick, and Tracey (1973) and temporal distributions determined by other studies (Ward and Sedaghian, unpublished data). ROSED results were then combined with cost estimates for specific treatments to provide a matrix of costs for specific road layouts and treatments. The ROSED model was then reconfigured into an interactive mode allowing the potential user a variety of choices for analyzing road erosion control techniques.

RESULTS AND DISCUSSION

Field Measurements

A provisional set of field data was previously presented in the data summary report (Ward undated). The data have been reviewed and rechecked and are presented in Appendix III for the different forests. Statistics for the entire data set are listed in table 2.

Table 3 presents results of a paired plot difference t test to statistically investigate the dependence of the field variables on antecedent surface condition (dry or wet). In this test, the difference between measured values for dry and wet runs on each sample plot were computed and then treated as a random sample from a normal distribution. For each field variable, the mean and variance of this difference were used to construct a t test statistic. Under a null hypothesis of no surface moisture dependence, this statistic follows a student's t distribution.

Table 3 shows statistically significant differences at the 1 percent level for moisture content, average runoff rate, sediment yield, and runoff to rainfall ratio. Significant differences were expected for soil moisture and average runoff rate. The difference in runoff rate also causes a difference in the runoff to rainfall ratio. Test results for total sediment yield show the dry surface condition produced significantly greater sediment, expressed as tons of sediment per acre of surface per inch of runoff. The runoff has been introduced to account for differing volumes and runoff rates between plots and runs. It should be cautioned that the yields are expressed on the basis of acres for comparison purposes only and do not suggest that the listed value is what might be expected from one acre of road surface.

TABLE 2

STATISTICS FOR FIELD MEASUREMENTS ON ALL SAMPLE PLOTS BY ANTECEDENT SURFACE CONDITION

M = MEAN SD = STANDARD DEVIATION
DRY, WET = SURFACE CONDITION

	DRY		WET	
	M	SD	M	SD
NUMBER OF SAMPLES	85	85	85	85
MOISTURE CONTENT, FR.	0.08	0.06	0.19	0.09
POROSITY, FR.	0.52	0.08	0.51	0.07
SLOPE GRADIENT, FR.	0.14	0.16		
ROCK COVER, FR.	0.13	0.20		
VEGETATIVE COVER, FR.	0.07	0.15		
GRAVEL (>4.75MM), FR.	0.16	0.14		
SAND (.074-4.75MM), FR.	0.35	0.18		
FINES (<.074MM), FR.	0.49	0.23		
RAIN RATE ON PLOT, IPH	3.68	0.90	3.84	0.85
AVERAGE RUNOFF RATE, IPH	2.38	0.75	2.79	0.60
FINAL INFILTRATION RATE, IPH	1.12	0.70	1.06	0.58
RUNOFF / RAINFALL, FR.	0.58	0.18	0.69	0.15
SEDIMENT YIELD, T/AC,IN *	1.99	2.92	1.53	1.66
SURFACE DUST, T/AC	19.10	15.50		

* VALUES STANDARDIZED TO TONS / ACRE / INCH OF RUNOFF FOR COMPARISON PURPOSES; YIELD IS UNADJUSTED FOR DEFICIENT RAINFALL ENERGY

TABLE 3

TEST FOR DEPENDENCE OF PLOT CHARACTERISTICS ON SURFACE MOISTURE ROAD SURFACES ONLY

H.: NO DEPENDENCE OF PLOT CHARACTERISTICS
T = MEAN/SQRT(VAR/N)

	DIFFERENCE BETWEEN DRY, WET SURFACE			TEST STATISTIC	
CHARACTERISTIC	N	MEAN	VAR	T	PROB>=T
MOISTURE CONTENT, FR.	78	-.099	.0032	-15.56	.0001
POROSITY, FR.	78	.099	.0050	1.15	.2547
RAIN RATE ON PLOT, IN/HR	78	-.125	.2812	-2.09	.0401
AVERAGE RUNOFF RATE, IN/HR	78	-.360	.4982	-4.50	.0001
FINAL INFILTRATION RATE, IN/HR	78	.033	.5436	0.40	.6919
RUNOFF / RAINFALL, FR.	78	-.092	.0315	-4.57	.0001
SEDIMENT YIELD, T/AC.IN	78	.191	.3394	2.90	.0049

The wet-dry data pairs were also divided into two groups, those from road surfaces (78 pairs) and these from cut slope sufaces (7 pairs). The statistical test between wet and dry surface was repeated on these two groups. The difference tests were equivalent between the 78 pairs and 85 pairs, as expected. The 7 cut slope pairs indicated that there was not a significant difference in the sediment yields, but there was a significant difference at the 5 percent level in the final infiltration rates. The small sample size of 7 for the cut slope tests greatly reduces confidence in these results.

A grouping of the data by forest and dry or wet run for road surfaces provides insight into the different characteristics of each forest. This breakdown is listed in table 4.

An analysis-of-variance (ANOVA) test was used to compare the average plot characteristics for the four forests. The aim of this test was to identify different forest characteristics. Only vegetative cover, fraction of gravel in the soil sample, and rainfall rate applied to the plots were not found to be different between the forests. All other characteristics yielded F-values which were significant at the 1 percent (usually) or 5 percent levels. No differences in rainfall rate is reassuring because it indicates that rainfall rate was consistent (as designed) for the field studies. Although not significantly different, the dry run rainfall rates tended to be a bit lower than wet run rates. This is judged to be a function of run time (dry runs were longer) over which wind, mechanical, and other factors could affect the rate. The ANOVA test results for vegetation cover and gravel fractions indicate that the sample plots were located in areas of low vegetation, and on

TABLE 4

STATISTICS FOR FIELD MEASUREMENTS ON ROAD SURFACES ONLY BY ANTECEDENT SURFACE CONDITION AND FOREST

M = MEAN SD = STANDARD DEVIATION WET, DRY = ANTECEDENT SURFACE CONDITION

	CARSON				GILA				LINCOLN				SANTA FE			
	DRY		WET		DRY		WET		DRY		WET		DRY		WET	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
NUMBER OF SAMPLES	27	27	27	27	14	14	14	14	18	18	18	18	19	19	19	19
MOISTURE CONTENT, GM/GM	.060	.026	.146	.036	.053	.030	.199	.068	.159	.073	.279	.120	.065	.041	.127	.052
POROSITY	.483	.076	.484	.067	.555	.045	.535	.046	.577	.069	.559	.066	.489	.067	.481	.063
SLOPE GRADIENT, FT/FT	.069	.031			.076	.028			.152	.087			.092	.043		
ROCK COVER, FR.	.056	.054			.073	.114			.276	.321			.131	.186		
VEGETATIVE COVER, FR.	.070	.158			.009	.022			.131	.220			.062	.128		
GRAVEL (>4.75MM), FR.	.165	.128			.174	.180			.148	.181			.178	.121		
SAND (.074–4.75MM), FR.	.351	.154			.345	.107			.175	.104			.520	.134		
FINES (<.074MM), FR.	.483	.181			.480	.172			.676	.277			.302	.128		
SURFACE DUST, T/ACRE*	18.97	20.46			29.43	14.21			12.44	9.56			17.62	8.02		
PLOT RAIN RATE, IPH	3.78	0.39	3.91	0.41	3.98	0.35	4.02	0.35	3.85	0.42	4.01	0.40	3.78	0.65	3.93	0.21
AVERAGE RUNOFF RATE IPH	2.42	0.52	2.57	0.56	2.03	0.53	2.55	0.42	2.56	0.77	3.31	0.62	2.81	0.75	2.97	0.45
FINAL INFILTRATION, IPH	1.08	0.53	1.26	0.63	1.55	0.66	1.29	0.56	0.98	0.66	0.67	0.37	0.86	0.44	0.95	0.40
RUNOFF / RAINFALL	0.59	0.16	0.64	0.16	0.47	0.13	0.61	0.11	0.61	0.17	0.79	0.10	0.69	0.14	0.72	0.11
SEDIMENT YIELD, T/AC.IN**	1.18	0.76	1.10	0.72	1.24	0.65	1.08	0.63	2.76	2.12	2.32	1.64	0.71	0.72	0.58	0.59

* VALUES STANDARDIZED TO TONS PER ACRE FOR COMPARISON PURPOSES

** VALUES STANDARDIZED TO TONS / ACRE / INCH RUNOFF FOR COMPARISON PURPOSES; SEDIMENT UNADJUSTED FOR DEFICIENT ENERGY surface soils containing similar gravel fractions, but as shown in table 4 not the same sand and fine material fractions.

What is most striking in table 4 is predominance of the Lincoln National Forest in delimiting a characteristic on the high or low end. Although the characteristics are not all independent, this does imply that results from the Lincoln Forest tend to be different from the rest. A Duncan's multiple range test between pairs of forests was not conducted for all pairs because the data were collected to have differences and variation. The variation permits any regression equations developed to be applicable to a wide range of data. A similar ANOVA was not conducted for cut slopes because cut slopes were not sampled in all forests.

The values in table 4 tend to confirm the results presented in table 3. One notable exception is the final infiltration rates. For the 78 pairs, the rates were not significantly different between the dry and wet runs. However, examination by forest reveals a significant difference between dry run and wet run final infiltration rate for the Lincoln National Forest. This may be caused by the higher proportion of fine materials in the soil and its response to initial wetting.

Table 4 shows roads in the Carson and Gila National Forests respond similarly in terms of runoff and sediment yields. The Lincoln and Santa Fe National Forests differ from these two by significant amounts. They both have higher runoff, but the Lincoln National Forest roads yield more sediment and the Santa Fe National Forest roads less sediment than the other two forests. The sediment yields are strongly related to the fine soil material fraction (primarily silts) while the runoff is related to a combination of factors. Relationships between variables are discussed in more detail in the next section on parameter derivation.

The relationship between average characteristics for wet and dry runs for the road surfaces can be compared with results from other studies. These results are listed in table 5. As expected, the prewetted soil produced more runoff. However, the effects on sediment yield were quite varied. For the mine haul roads, there was a slight increase in yield for the wet runs but it is not significantly different. The California data show a drop in yield. It should be noted that the California wet run intensities averaged (by design) 64 percent of the dry run rainfall intensities, which may account for some of the decrease. A decrease in the New Mexico data can also be noted; however, this may be caused by a winnowing of surface materials during the dry run because the wet run rainfall intensities were the same as in the dry runs.

Comparison between sites reveals no outstanding behavior among the Coweeta, California, and New Mexico road surfaces. The mine haul roads responded with a bit more runoff from rainfall, and significantly smaller sediment yields. One reason that the yields were lower is because of gravel cover on the mine haul road sites. The Idaho forest roads (Burroughs, Haber, Watts and Kadoch 1983) tended to produce more sediment and runoff than any other area. This is primarily as a response to decomposed granitic materials in the watershed. Ward (1983) compared the Coweeta study to other areas and found good agreement. This indicates that the simulator results for this study are representative of natural erosion and sediment yield. In contrast to these yields, a study by Buckhouse and Gaither (1982) for natural forest and range land showed average yields of 0.05 tons per acre.

Table 5

Comparison of Runoff and Sediment Yields for Different Roads

Location	Number of Observations	Runoff to Rainfall Ratio		Sediment Yield Tons/Acre	
		Dry Soil	Wet Soil	Dry Soil	Wet Soil
Coweeta[1]	18	0.57 ± 0.30*		1.8 ± 1.6	
Mine haul roads[2]	8 Dry 5 Wet	0.59 ± 0.13	0.74 ± 0.14	0.4 ± 0.4	0.7 ± 0.3
California[3]	10 Pairs	0.51 ± 0.27	0.66 ± 0.28	1.7 ± 1.1	1.3 ± 1.2
Idaho[4]	4 Dry 2 Wet	0.60 ± 0.15	0.79 ± 0.08	3.1 ± 1.5	2.1 ± 0.03
New Mexico (this study)	78 Pairs	0.58 ± 0.18	0.69 ± 0.15	1.6 ± 1.7	1.2 ± 1.4

* No clear distinction in data between "dry" or "wet" events.

NOTE: All data have been converted to a unit area basis. Scale effects may be important in some cases.

[1] - Simons, Li, and Ward 1978
[2] - Sundberg, Armijo, and Scheer 1981
[3] - Simons, Li, and Anderson 1982
[4] - Burroughs, Haber, Watts and Kadoch 1983

Parameter Derivation

Estimates of parameter values were calculated for each rain event on each sample plot. These estimates represent point samples of the parameter values for the road or cut slope surface in the vicinity of the plots. Generally, four sample plots were examined on each surface selected for study, each plot being exposed to two rain events. Average parameter estimates for each road surface under both surface conditions are tabulated in Appendix III.

Dual rainfall events were performed on each plot in order to investigate the dependence of the parameters on initial surface moisture. The difference between parameter estimates on each of these paired runs, averaged over all plots, can be transformed into a suitable test statistic. Under a null hypothesis of no parameter dependence on surface moisture, this statistic follows a student's t distribution. Results of testing this hypothesis are presented in table 6. A statistically significant difference at the 1 percent level was found for the capillary suction and overload flow detachment parameters only. This result conforms to theory which defines capillary suction as moisture dependent. Hydraulic conductivity and raindrop detachment appear independent of surface moisture.

Table 6

Test for Dependence of Parameters on Surface Moisture Road Surfaces Only

H_o: No dependence of parameters

T = Mean/SQRT (Var/N) ~t(N-1)

	Difference Between Dry, Wet Surface			Test Statistic	
Parameter	N	Mean	Var	T	Prob > T
Kw, in/hr	78	-.035	.51	-.39	.7008
ψ, in.	72	1.15	5.14	3.87	.0002
A, ft/hr*	78	-.33E-5	.61E-7	-.12	.9067
DOF*	77	.66E-2	.30E-4	3.16	.0023

*Parameters adjusted for deficient rainfall energy

Additional information on the parameter estimates was revealed through an ANOVA. Parameter variation among forests was significant (<2 percent) for hydraulic conductivity and raindrop detachment coefficient; capillary suction showed no significant variation among the forests. The overland flow detachment coefficient varied only on the wet plots; on dry plots the coefficient appeared to be independent of the forest.

Apparent parameter relationships with measured plot characteristics were examined using a linear stepwise least-squares regression technique. The resulting relationships may be useful in obtaining parameter estimates for road surfaces having characteristics similar to those examined under this study. The relationships obtained were:

$$\mathrm{Kw} = 0.145 + 2.12\,(\mathrm{NU}) - 1.18\,(\mathrm{VFR} + \mathrm{RFR}) \qquad r^2 = .52^* \qquad (7)$$

$$\Psi = -0.022 + 3.73\,(\mathrm{FFI}) - 8.00\,(\mathrm{MST}) + 2.49\,(\mathrm{VFR} + \mathrm{RFR}) \qquad r^2 = .34 \qquad (8)$$

$$\mathrm{A} = 0.0000022 + 0.00129\,(\mathrm{VFR}) + 0.00063\,(\mathrm{RFR}) \qquad r^2 = .46 \qquad (9)$$

$$\mathrm{DOF} = 0.137 - 0.207\,(\mathrm{NU}) \qquad r^2 = .40 \qquad (10)$$

where:

Kw = hydraulic conductivity, in/hr
Ψ = average capillary suction, inches
A = raindrop detachment coefficient
DOF = overland flow detachment coefficient
FFI = fines, fraction of total soil sample (dia < .074 mm)
FSA = Sand, fraction of total soil sample (.074 mm < dia < 4.75 mm)
MST = Soil moisture, fraction
NU = Soil porosity, fraction
RFR = Rock cover on road surface, fraction
VFR = Vegetation cover on road surface, fraction
* = All relationships significant at 1 percent level.

The above predictive equations for hydraulic conductivity and capillary suction agree with infiltration theory. Hydraulic conductivity is shown to vary with porosity and total cover in a manner that would be expected, considering total cover is composed primarily of rock cover. Capillary suction is shown decreasing with soil moisture as capillary suction should. An increase of suction with fraction of fines agrees with the theory of capillary action.

The predictive equation for the raindrop detachment coefficient can be explained by noting vegetation cover is strongly correlated in a positive sense with fines, and rock cover is strongly and positively correlated with gravel fraction of the soil sample. These cover variables then act as pseudo-variables for soil gradation.

The overload flow detachment coefficient is related to only porosity. This mirrors a fundamental relationship of DOF with clay fraction; as clay increases, also porosity. High clay soils possess cohesion which resist shear stresses, hence show low values of DOF.

A note of caution on the use of these relations: regression equations are best applied in situations similar to those used to derive the relations. Use of these relations in areas strikingly different from the forest sites studied is not advised. Finally, these relations may occasionally produce a negative parameter estimate; since this is unrealistic, a value of zero should be used instead.

Cost Survey

The mailed questionnaire (Appendix II) was returned by 10 of the 11 forest engineers in the Southwestern Region. Not all questions were answered, and units for expressing costs varied. The information supplied by the questionnaire, and adjusted as needed to common units, is listed in table 7.

Table 7

Responses to Erosion Control Questionnaire

	Miles of Road Constructed Per Year	% of Roadway Miles Built For					% of Roadway Miles are			Inslope Road		Outslope Road		Crowned Road	
		Commerical Haul	Recreation	Fire	Admin.	Other	Permanent	Seasonal	Single Use them Closed	Estimated Miles	Cost ($/mile)	Estimated Miles	Cost ($/mile)	Estimated Miles	Cost ($/Mile)
Apache - Sitgreaves	120	95	5	-	-	-	5	80	15	0	-	100	2000-8000	20	17500
Carson	80-100	90	3.3	3.3	3.3	-	20	40	40	30	20000	60	14000	10	35000
Cibola	23	82	7	-	-	11	21	32	47	34.6	41000	51.56	5000	12.01	87000
Coconino	190 R 10 C	99	1	-	-	-	-	95	5	60	14000	135	10000	5	24000
Coronado	2 R	-	60	-	40	-	100	-	-	0	-	0	-	0	-
Gila	100 R 30 C	100	-	-	-	-	-	20	80	0	-	30	9000-1500	0	-
Kaibab	230	79	9	6	6	-	3.8	62.7	33.5	0	-	230	-	0	-
Lincoln	8.7	91	5	1	3	-	4	92	4	50	286	285	214	50	286
Santa Fe	100 R 10 C	95	-	-	-	5	70	20	10	0	-	100	8000	10	35000
Tonto	10	70	20	-	-	10	30	70	-	2	20000	2	20000	1	20000

R - Reconstructed
C - Constructed
X - Value received but unable to be converted realistically
* - Converted from values given on questionnaire.
Only use as an approximation.
** - Includes seeding, fertilizing and mulching

NOTE: Missing questions or values indicate no response.

Table 7 (Continued)

Responses to Erosion Control Questionnaire

	Gravel		Oil		Pavement		Grading		Seeding Grass		Fertilizing		Mulching	
	Estimated Miles	Cost ($/yd^3)	Estimated Miles	Cost ($/Mile)	Estimated Miles	Cost ($/Ton)	Estimated Miles	Cost ($/Mile)	Estimated Miles	Cost ($/Acre)	Estimated Miles	Cost ($/Acre)	Estimated Miles	Cost $/Acre
Apache - Sitgreaves	60	8-15	2	5000	-	-	-	-	100	100-400	-	-	-	-
Carson	10	12	-	-	-	-	40	2500	100	150	10	50	10	75
Cibola	41	10.36	22.8	2100	7.96	26.30	64.43	110	113.39	95	-	-	6	900**
Coconino	50	6.40	5	2100	-	-	620	100	200	300	-	-	-	-
Coronado	0	-	-	-	-	-	300	150	-	-	-	-	-	-
Gila	10	8*	-	-	-	-	-	-	130	27	-	-	-	-
Kaibab	15	4*	-	-	9.14	27*	-	-	1230	-	-	-	-	-
Lincoln	165	10	-	-	74	40	1072	230	1275	250	-	-	-	-
Santa Fe	10	15	10	4000	-	-	90	200	80	120	-	-	-	-
Tonto	0	-	-	-	-	-	-	-	-1	1200**	-	-	-	-

R - Reconstructed
C - Constructed
X - Value received but unable to be converted realistically
* - Converted from values given on questionnaire.
Only use as an approximation.
** - Includes seeding, fertilizing and mulching

NOTE: Missing questions or values indicate no response.

Table 7 (Continued)

Responses to Erosion Control Questionnaire

	Culverts		Rip Rap Around Culverts		Lead Off Ditches		Water Bars		Grade Dips	
	Estimated Miles	Cost $/lin ft	Estimated Miles	Cost ($/yd^3)	Estimated Miles	Cost $/lin ft	Estimated Miles	Cost ($/each)	Estimated Miles	Cost ($/each)
Apache - Sitgreaves	20	30	10	40	60	.15-.35	20	20 - 50	100	80-100
Carson	70	25	10	15	50	1.25	0	-	50	95
Cibola	51.05	27	0	-	100	1.33	0	-	62.34	100
Coconino	65	32	0	-	135	0.35	0	-	135	80
Coronado	0	-	0	-	0	-	0	-	0	-
Gila	10	20	0	-	20	0.80	0	-	120	85
Kaibab	0	-	0	-	230	-	0	-	230	-
Lincoln	105	23	5	100	100	0.10	50	50	335	80
Santa Fe	10	X	0	33*	20	1.00	0	-	90	75
Tonto	2	-	0	-	0	-	-	-	1	100

R - Reconstructed
C - Constructed
X - Value received but unable to be converted realistically
* - Converted from values given on questionnaire.
Only use as an approximation.
** - Includes seeding, fertilizing and mulching

NOTE: Missing questions or values indicate no response.

It is clear from the responses tabulated in table 7 that each forest has different needs, approaches, and costs. It appears that grade dips, gravel, grading, grass, and lead off ditches are common techniques. Outsloped roads are a favorite, with 79 percent of the miles estimated to be of that type. Commercial haul roads are the major type of road, as expected. Although the values do vary, they are comparable with those presented by Haber and Kadoch (1982) for the Silver Creek study area of Idaho. A comparison is shown in table 8. An inspection of these values indicates that the cost estimates from the questionnaire responses are reasonable and can be used for modeling purposes.

Table 8

Comparison of Erosion Treatment Costs

Treatment	Units	Range in Cost This Study	Haber & Kadoch (1982) for Idaho*
Aggregate on Surface	\$/cu. yd.	4-15	59
Dust oil	\$/mile	2100-5000	2500
Pavement	\$/ton	26-40	40-70
Seeding	\$/acre	27-400	130
Seeding & Fertilizer	\$/acre	200-800	200
Seeding & Fertilizer & Mulch	\$/acre	275-1200	500

* Converted to Units of table 7.

Computer Model Analyses

Overview. Throughout the preceeding text, a method was demonstrated for estimating model parameters for the physical process models SIMSED and ROSED. Parameter evaluation by this method indirectly calibrates these computer models to the soils targeted by the field study.

Also described was a cost study via questionnaire which established a data base of erosion control methods and their associated costs, for forest roads in the southwest. Finally, various statistical tests on the field data from this study were used to investigate the physical character of the four National Forests studied. This information will provide the forest manager with parameter values, forest characteristics, and cost estimates for use in program ROSED. Additional information required by program ROSED must also be derived from basic hydraulic and hydrologic principals.

Input data to program ROSED is described in the training session outline. Input data falls into three categories: (1) the arrangement, dimensions, and hydraulic response of the road surface, runoff conveyance structures, and erosion control measures; (2) the physical characteristics of the soil, road surface, vegetative and canopy cover, and conveyance structures; and (3) the hydrologic characterization of the design storm. Cost information on erosion control methods under investigation might be put into a fourth category.

Data for category (1) is developed from an engineering view of the road design. The breakdown of the design problem into input data for program ROSED is described in the original user's manual (Simons, Li, and Shiao, 1977). This manual also contains a wealth of information and suggestions pertaining to the use of program ROSED.

Category (2) requires data which is available from a variety of sources, the source being dictated by the required accuracy of the program results. Data for this category may be obtained from field studies similar to those described in this report. Less accurate, but relative results, may be obtained using representative data from field studies performed by others, including those summarized in this report. Hydrologic information, the third category, is available in a variety of government publications, and is strongly dependent on location, season, and economic life of the roadway.

Prior to presenting an example application of program ROSED, model calibration through parameter evaluation is verified. This is accomplished using the SIMSED model, along with parameter estimates by methods outlined in this study. SIMSED is used to predict sediment yield on the sample plots which were the subject of the field study.

Erosion Model Results. In order to validate the parameter evaluation, the SIMSED model was executed to predict sediment yields from each sample plot. Equations (7) through (10) were used with measured plot characteristics to predict the model parameters. These parameters were introduced into the model along with the other data from the field study, including rainfall rate, slope, cover, and sediment size distribution. The results are shown in figure 8.

As figure 8 indicates, most of the estimates cluster around a 1:1 line representing perfect agreement between the model and field measurements. The simple correlation coefficient between predicted and measured values is 0.67, significant at the 1 percent level. This result is encouraging considering that the parameter estimating equations (equations 7 through 10) are based on average plot characteristics, and do not fully account for all of the variation in the parameters. The correlation appears to validate use of the parameter values within program ROSED for sediment yield estimates on the soils studied.

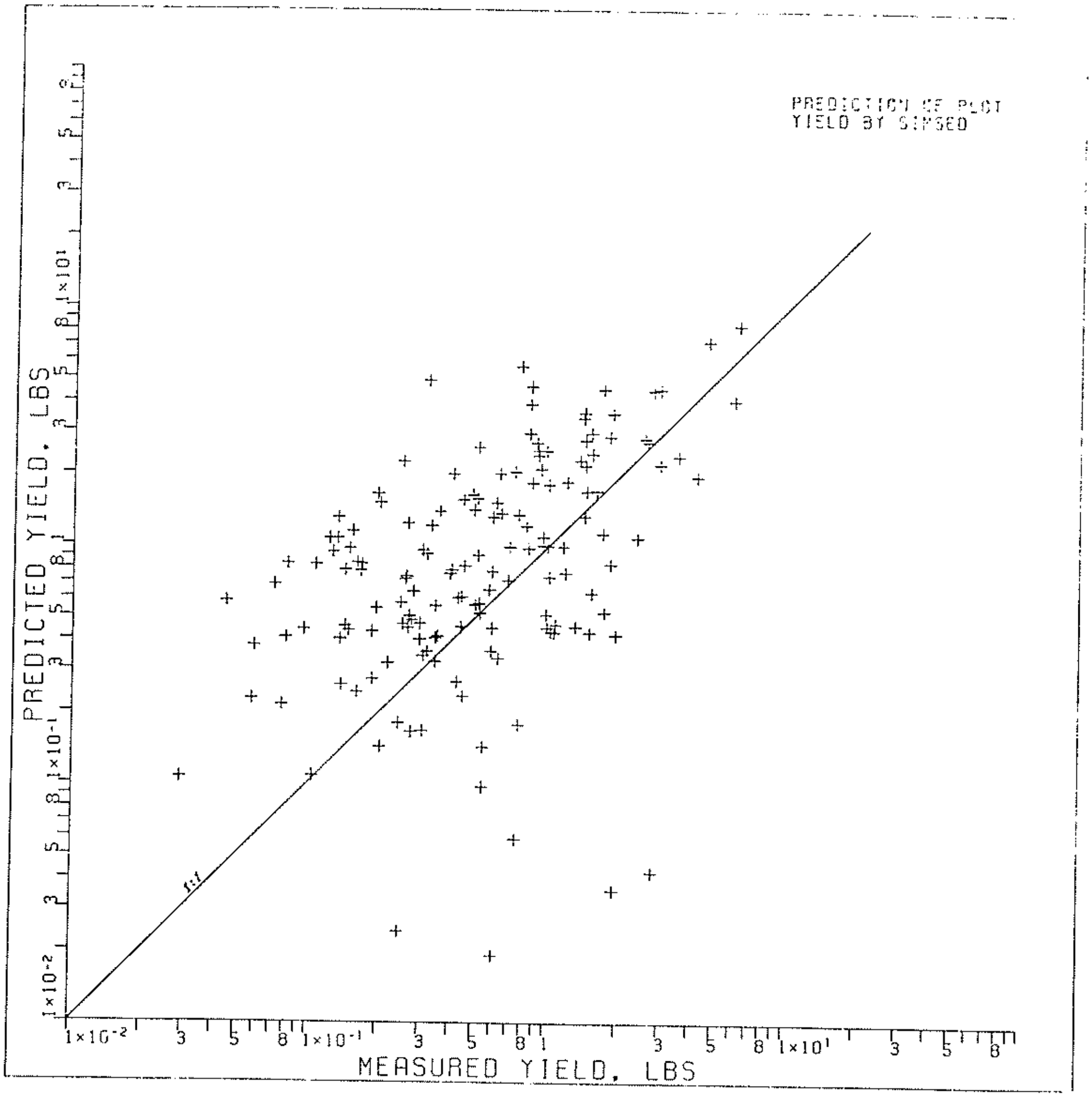


Figure 8. Comparison of measured sediment yield from sample plots, and predicted sediment yield by program SIMSED. Yield is adjusted for deficient rainfall energy

Example of Model Application. The road erosion survey indicated that many engineers were familiar with road dips and gravel. Therefore, as an example of the type of information available from the ROSED model, the following hypothetical, but realistic, situation was employed.

Data used in this example were extracted (in part) from the Carson Forest road 439. The pertinent road characteristics, model parameters, and other information are listed in table 9.

Program ROSED was executed using the information in table 9 while varying the number of grade dips and percent of surface covered by gravel. The number of grade dips determines the effective overland flow length and the gravel cover protects the soil from raindrop and overland flow erosion. The sediment yield was used as a surrogate for erosion, and, if the road was divided by two or more grade dips, the sediment yields for each subsection were added as were the water yields. For the cost estimates, grade dips were assumed to cost $90 each and gravel was assumed to cost $10 per cubic yard. These values were taken from the road questionnaire previously discussed. Costs were computed on a marginal basis. The base cost for a 500 foot long, ungraveled road was that of one grade dip or $90. As grade dips and gravel were added, the cost increased but the sediment yield decreased. For the example storm, which is a recorded 60 minute duration event temporally patterned after a storm of July 25, 1945 (Ward and Sadeghian unpublished), the base sediment yield was 411.1 pounds and the base water yield is 215.9 cubic feet. The number of grade dips was varied from one to five (flow lengths of from 500 feet down to 100 feet) and gravel cover varied from

Table 9

Example Input to Program ROSED

Road surface: length = 500 feet, varied for demonstration in the model
width = 14 feet
slope = 6.6%
Hydraulic conductivity = 1.12 in/hr
Capillary suction = 1.0 inch
Porosity = 0.53
Antecedent moisture = 5% by dry weight
Overland flow resistance = 100 to 400
Ground Cover = 14% (measured), varied for demonstration in the model
Raindrop detachment coefficient = 0.00005
Overland flow detachment coefficient = 0.064

Representative Soil Particle Size, mm	Percent of Soil Represented
3.1	5.84
1.4	6.46
0.71	13.85
0.35	20.78
0.18	17.77
0.97	8.62
0.057	4.80
0.037	6.14
0.026	3.46
0.019	2.41
1.013	2.67
0.0093	1.33
0.0065	1.07
0.0046	1.60
0.0005	3.20

Table 9 (Continued)

Rainfall duration = 60 minutes (12 five-minute blocks)

Rainfall Intensity in Each Five-Minute Block (in/hr)											
2.64	3.72	4.92	2.46	0.72	0.59	0.73	1.15	0.12	0.12	0.12	0.12

0 to 100 percent of the soil surface covered. The gravel cover was assumed to be a function of the gravel volume according to the relation:

$$CY = e^{z} \qquad (11)$$

where CY = cubic yards of gravel needed per 1000 square feet of surface area

$e = 2.7183$

$z = 2.94$ (cover fraction - 0.59)

This relation is for cover greater than 10 percent. Gravel volume varied from 0.0 to 23.4 cubic yards. The cost varied from $90 (no treatment) to $684 for 5 grade dips and 23.47 cubic yards of gravel. The results for a matrix of measures are presented in table 10.

The cost estimates are based on marginal values or the difference between treatment and base level (untreated) costs divided by the difference between treated and untreated sediment yields. For the road conditions examined in this example, the use of grade dips is less effective than gravel because raindrop splash detachment greatly exceeds overland flow detachment. Gravel also decreases sediment yield by reducing the erosive capacity of the flowing water. This type of response may not be the same for other road conditions and is a specific example of the need for a detailed process model. The most effective erosion protection technique is surface gravelling. A relatively small investment ($47 per 100 ft length of road) will essentailly eliminate erosion for these conditions. Note that the marginal cost increases as more cover is added beyond about 50 percent cover, but relative sediment yield decreases. Using this type of table, a forest engineer would correctly choose to use gravel instead of more grade dips for these conditions. Note that although this example is only for one one storm, as more storms are accumulated the relative costs will vary accordingly.

Table 10
Marginal Costs of Protection Per Pound of Sediment Reduced Below Base Level

Number of Grade Dips		Percent of Surface Covered by Gravel						
		0	10	25	50	75	90	100
1	C*	0.22	.64	.27	.24	0.42	.57	.72
	SR	1.0**	.94	.77	.45	.34	.26	.21
2	C	3.85	2.18	.98	.59	.69	.83	.97
	SR	.94	.88	.71	.41	.28	.22	.18
3	C	5.35	3.31	1.58	.93	.95	1.08	1.21
	SR	.92	.86	.68	.39	.25	.20	.17
4	C	6.41	4.22	2.15	1.26	1.21	1.33	1.45
	SR	.90	.84	.67	.37	.23	.19	.16
5	C	7.29	4.45	2.67	1.58	1.46	1.58	1.70
	SR	.88	.82	.65	.36	.22	.18	.15

* - C - Cost \$ per lb of sediment reduction based on untreated condition
SR - Ratio of sediment yield treated/untreated condtions

** - Base level 411.1 lbs sediment, \$90 cost

Numerous other examples can be developed. However there are an infinite variety of cases that could be examined. Fortunately, many situations can be rapidly analyzed with the computer program adapted for this study.

SUMMARY AND CONCLUSIONS

Poorly designed, constructed or maintained roads can be a major source of sediment in forests. The choice of the most efficient and cost effective method for reducing erosion is difficult. This study was conducted to provide forest managers in the southwest with a methodology for estimating the relative best management choice between forest road layout alternatives. An existing computer model for estimating road surface erosion was adopted for this methodology and adapted for this study. Field data collection from four national forests was conducted to provide estimates of model parameters, and a survey questionnaire was used to gather information on forest road erosion control costs. This information was used in the model with the field data to demonstrate an application of the model.

There is no overall best management technique for all road conditions. As conditions change so will the technique. The model adopted in this study will be helpful in making a correct choice based on reduction in sediment yield and associated cost.

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APPENDICES

Appendix I

Data Collection Sheet

Plot ID Number____________________Date__________Observer_____________

Sunny_________ Windy__________ Air Temp____________

Cloudy________ Calm___________

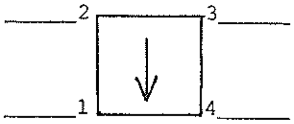
% vegetation cover_________ % rock cover___________

Before every run:

soil moisture, 0-5cm______

5-10cm______

Raingage readings:



After every run:

Depth to wetted front________

Suspended sample (pint)______

Bed Load (total)____________

After wet run:

Soil sample_________________

Slope______________________

Clock time at start of rainfall______________________

All other times measured from start of rainfall, hr:min:sec.

Time to ponding_____________________

Time to runoff______________________

Time	Volume, ml	Time	Volume, ml	Time	Volume, ml

Depth in collection bucket_________________________

Appendix II

Road Erosion Control Questionnaire

COLLEGE OF ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING
Box 3CE/Las Cruces, New Mexico 88003
Telephone (505) 646-3801

NEW MEXICO STATE UNIVERSITY

I am currently conducting a research contract with the U.S. EPA and the New Mexico State Division of Forestry. Under this contract, I need to define costs of certain erosion control practices employed on forest roadways. I have enclosed a brief questionaire which I was hoping you could take the time to complete. There is space on the form for any additional comments you think should be included. I have also provided a self addressed envelope for your convenience. I am coordinating this study with the regional office in Albuquerque, where I obtained your name and address.

Thank you in advance for your assistance. If possible I would like to have the form returned by February 18, 1983.

Sincerely,

Timothy J. Ward by Gloria R. Chavarria
Associate Professor
Civil and Geological Engineering

cc: Noel Larson - R.O.

Questionaire on Forest Road Erosion Control Costs

Name of Respondent: ______________________
Date: ______________
National Forest: ______________________

1) On average, how many miles of road are constructed in your forest each year? __________

2) Approximately what percentages of the roadway miles were built for:

Commercial haul	______________
Recreation	______________
Fire	______________
Administration	______________
Other (Please designate each)	______________

3) Approximately what percentages of the roadway miles are:

Permanent (year road)	______________
Seasonal	______________
Single use then closed	______________
Other (Please designate each)	______________

4) For the following road practices, could you please provide estimates of roadway miles treated and cost per mile? Please try stating your cost in dollars per mile, per acre, or per device, or some other common units. Use zeros if no miles treated by the practice.

Practice	Estimated Miles	Estimated cost $ units
inslope road	______	________
outslope road	______	________
crowned road	______	________
crossroad culverts	______	________
open to culverts	______	________
rip rap around culverts	______	________
lead off ditches	______	________
water bars	______	________
grade dips	______	________
gravel	______	________
soil binders	______	________
oil	______	________
pavement	______	________
grading	______	________
planting trees	______	________
seeding grass	______	________
fertilizing	______	________
mulching	______	________
debris removal from streams	______	________
other (please designate each)	______	________

5) What is your most serious problem in terms of road erosion?

6) Please use the space below or the back of this questionaire to provide any pertinent comments on road erosion problems.

Appendix III

Results of Data Collection and Analyses for Each Plot

Appendix III-a

Plot Characteristics

Notes: Plot ID is plot identification by road-site-replication

Antecedent Soil Moisture (AMC) is reported on a dry weight basis

Soil Gradation is reported on a dry weight basis

Gravel is percent of soil greater than 4.75 mm in diameter

Sand is percent of soil between 0.074 mm and 4.75 mm in diameter

Fine is percent of soil less than 0.074 mm in diameter

Poros is soil porosity.

PLOT CHARACTERISTICS

CARSON NATIONAL FOREST

	AMC		Slope	Poros	Cover		Gradation		
Plot ID	Dry (%)	Wet (%)	(%)	(%)	Rock (%)	Veg (%)	Gravel (%)	Sand (%)	Fine (%)
155-W -1	5.0	15.0	7.5	47.8	5.0	0.0	21.8	39.7	38.5
155-W -2	3.0	15.0	5.0	52.3	5.0	1.0	12.1	22.0	65.9
155-W -3	7.0	15.0	7.8	44.2	5.0	5.0	16.3	21.1	62.6
155-W -4	4.0	16.0	12.0	47.3	9.0	20.0	3.6	23.3	73.1
155- -1	4.0	12.0	3.9	53.6	5.0	0.0	4.4	17.5	78.1
155- -2	6.0	16.0	5.8	57.5	15.0	0.0	6.4	19.0	74.6
155- -3	4.0	14.0	2.0	31.4	7.0	0.0	32.8	30.0	37.2
155- -4	7.0	18.0	7.6	52.6	15.0	15.0	55.7	18.4	25.9
155-S -1	9.0	25.0	9.6	53.5	0.0	10.0	26.5	13.4	60.1
155-S -2	10.0	20.0	7.6	48.6	1.0	4.0	5.2	17.6	77.2
155-S -3	5.0	20.0	11.5	57.0	2.0	66.0	4.9	19.3	75.8
155-S -4	11.0	18.0	15.4	49.2	5.0	5.0	7.4	18.4	74.2
778- -1	4.0	13.0	3.8	56.1	2.0	0.0	3.3	60.1	36.6
778- -2	3.0	15.0	4.3	52.6	1.0	0.0	3.3	42.1	54.6
778- -3	2.0	15.0	4.8	43.4	22.0	0.0	8.5	61.0	30.5
778- -4	3.0	10.0	7.7	50.4	5.0	50.0	21.8	40.0	38.2
439- -1	2.0	8.0	5.8	50.5	5.0	0.0	10.5	65.5	24.0
439- -2	4.0	8.0	3.8	47.0	1.0	0.0	17.5	54.8	27.7
439- -3	5.0	12.0	6.6	53.9	2.0	12.0	16.0	40.3	43.7
439- -4	7.0	13.0	1.9	51.8	0.0	0.0	9.2	43.0	47.8
697-E -1	6.0	15.0	6.6	54.1	3.0	0.0	21.7	29.7	48.6
439- 2-1	11.0	13.0	7.9	52.0	5.0	0.0	13.0	48.4	38.6
439- 2-2	8.0	13.0	9.6	42.0	5.0	0.0	43.1	29.3	27.6
439- 2-3	6.0	12.0	7.7	30.0	0.0	0.0	24.6	38.6	36.8
439- 2-4	9.0	15.0	7.6	31.0	10.0	0.0	26.4	39.4	34.2
439-CS-1	8.0	19.0	71.3	46.0	15.0	0.0	3.9	57.5	38.6
439-S2-2	8.0	12.0	4.7	53.0	5.0	0.0	15.4	47.4	37.2
439-CS-3	6.0	15.0	90.8	37.0	5.0	0.0	13.3	48.9	37.8
439-S2-4	8.0	15.0	3.8	42.0	10.0	0.0	13.3	48.9	37.8

PLOT CHARACTERISTICS

GILA NATIONAL FOREST

	AMC		Slope	Poros	Cover		Gradation		
Plot ID	Dry (%)	Wet (%)	(%)	(%)	Rock (%)	Veg (%)	Gravel (%)	Sand (%)	Fine (%)
289-1 -1	9.0	35.0	5.8	56.3	5.0	0.0	6.8	27.0	66.2
289-CS-2	10.0	40.0	31.8	61.0	40.0	2.0	2.3	12.4	85.3
289-1 -3	14.0	31.0	7.7	59.7	2.0	0.0	0.4	11.8	87.8
289-CS-4	10.0	33.0	36.2	64.1	10.0	3.0	24.2	12.5	63.3
289-2 -1	4.0	15.0	9.4	58.1	1.0	0.0	11.9	38.4	49.7
289-2 -2	4.0	17.0	5.8	56.8	0.0	0.0	8.3	42.7	49.0
289-2 -3	6.0	15.0	5.5	58.4	0.0	0.0	5.4	41.4	53.2
289-2 -4	3.0	14.0	11.5	46.5	0.0	0.0	3.9	44.4	51.7
289-NS-1	5.0	15.0	7.6	57.2	7.0	0.0	30.4	34.3	35.3
289-CS-2	4.0	19.0	57.5	65.1	35.0	0.0	23.1	48.9	28.0
289-NS-3	5.0	17.0	7.0	46.9	5.0	0.0	21.3	43.8	34.9
290-NS-4	4.0	17.0	5.8	57.1	1.0	0.0	22.0	42.5	35.5
289-NS-5	2.0	18.0	5.8	51.8	4.0	0.0	25.2	39.8	35.0
289-CS-6	2.0	24.0	42.5	61.9	7.0	0.0	18.0	43.9	38.1
94 -S -1	3.0	16.0	11.5	53.3	7.0	5.0	5.8	37.5	56.7
94 -S -2	5.0	16.0	9.6	56.7	25.0	7.0	6.4	33.2	60.4
94 -S -3	4.0	26.0	2.0	61.8	5.0	0.0	27.1	34.2	38.7
94 -S -4	6.0	27.0	9.5	56.7	40.0	0.0	69.9	12.4	17.7

PLOT CHARACTERISTICS

LINCOLN NATIONAL FOREST

Plot ID		AMC		Slope	Poros	Cover		Gradation		
		Dry (%)	Wet (%)	(%)	(%)	Rock (%)	Veg (%)	Gravel (%)	Sand (%)	Fine (%)
LOG-	-1	4.0	12.0	5.8	51.8	90.0	0.0	45.9	38.1	16.0
LOG-	-2	6.0	4.0	7.1	37.2	95.0	0.0	36.9	42.7	20.4
LOG-	-3	5.0	7.0	7.9	55.3	42.0	0.0	50.7	32.1	17.2
LOG-	-4	5.0	6.0	3.8	55.3	50.0	0.0	39.3	25.1	35.6
RUS-B	-1	18.0	35.0	29.7	64.6	50.0	0.0	2.3	11.2	86.5
RUS-B	-2	13.0	33.0	25.7	58.7	80.0	5.0	31.3	20.5	48.2
RUS-C	-1	12.0	26.0	6.6	54.4	10.0	5.0	0.0	11.0	89.0
RUS-C	-2	12.0	28.0	9.2	55.2	5.0	22.0	3.5	10.0	86.5
RUS-C	-3	23.0	37.0	12.8	55.9	15.0	5.0	0.7	8.3	91.0
RUS-C	-4	24.0	34.0	13.1	59.1	5.0	7.0	0.0	13.6	86.4
RUS-D	-1	19.0	42.0	28.3	63.7	5.0	10.0	0.0	14.3	85.7
RUS-D	-2	16.0	38.0	29.6	67.6	2.0	90.0	2.7	13.5	83.8
RUS-D	-3	22.0	33.0	17.6	63.3	5.0	20.0	0.1	12.3	87.6
RUS-D	-4	18.0	30.0	23.0	59.5	15.0	10.0	0.0	13.3	86.7
WAT-D	-1	22.0	33.0	17.9	53.3	10.0	0.0	2.8	8.8	88.4
WAT-D	-2	17.0	33.0	10.6	59.3	10.0	2.0	11.1	12.8	76.1
WAT-D	-3	23.0	36.0	13.4	58.6	7.0	20.0	14.2	8.2	77.6
WAT-D	-4	27.0	36.0	10.1	64.6	0.0	40.0	25.4	19.4	55.2

PLOT CHARACTERISTICS

SANTA FE NATIONAL FOREST

	AMC		Slope	Poros	Cover		Gradation		
Plot ID	Dry (%)	Wet (%)	(%)	(%)	Rock (%)	Veg (%)	Gravel (%)	Sand (%)	Fine (%)
470- -1	10.0	13.0	5.8	54.8	12.0	1.0	24.1	46.3	29.6
470- -2	3.0	9.0	13.5	50.7	80.0	1.0	10.9	54.3	34.8
470- -3	7.0	20.0	17.3	59.1	20.0	32.0	5.8	44.6	49.6
470- -4	13.0	18.0	8.3	49.9	5.0	5.0	17.1	39.8	43.1
470-S -1	17.0	21.0	17.4	58.3	5.0	0.0	17.8	42.0	40.2
470-S -2	11.0	16.0	13.9	54.8	7.0	0.0	8.1	55.6	36.3
470-S -3	8.0	12.0	14.0	55.4	5.0	37.0	16.0	49.2	34.8
470-S -4	4.0	18.0	11.6	52.5	10.0	35.0	51.9	21.2	26.9
471- -1	9.0	23.0	9.6	50.6	1.0	1.0	6.4	34.4	59.2
471-CS-2	18.0	26.0	89.0	54.1	2.0	0.0	0.0	14.3	85.7
471- -3	8.0	12.0	5.5	49.5	15.0	0.0	4.3	59.5	36.2
471- -4	4.0	13.0	7.7	50.0	32.0	5.0	3.7	66.3	30.0
79 - -1	5.0	8.0	10.5	50.0	10.0	0.0	17.7	69.5	12.8
79 - -2	7.0	6.0	7.9	49.0	5.0	0.0	23.5	63.4	13.1
79 - -3	4.0	8.0	7.6	36.0	0.0	0.0	28.1	59.0	12.9
79 - -4	4.0	7.0	8.5	40.0	20.0	0.0	18.7	69.3	12.0
79 -S -1	3.0	11.0	5.6	40.0	0.0	1.0	34.3	37.3	28.4
79 -S -2	3.0	8.0	3.1	49.0	5.0	0.0	28.1	52.2	19.7
79 -S -3	2.0	9.0	1.9	41.0	7.0	0.0	11.6	55.2	33.2
79 -S -4	2.0	10.0	6.4	39.0	10.0	0.0	8.9	70.3	20.8

Appendix III-b

Simulated Storm Characteristics and Sediment Yield

Notes: RO/RA is the ratio of depth of runoff to depth of rainfall

PLOT ID is plot identification by road-site-surface (Dry or Wet) and replication

Sediment yield contains both bed load and suspended load. The suspended load is unadjusted for deficient kinetic energy of the simulated rainfall.

Rainfall rate is based on the actual volume of precipitation on the plot. Since the effect of land slope is to reduce the projected area of the plot, the actual rainfall rate delivered by the nozzles is somewhat higher.

STORM CHARACTERISTICS
CARSON NATIONAL FOREST

PLOT ID	RAINFALL INTENSITY (IN/HR)	RAINFALL DURATION (MIN)	DEPTH OF RAINFALL (IN)	DEPTH OF RUNOFF (IN)	TOTAL SEDIMENT (T/AC.IN)	RO / RA
155-W -D1	3.79	30.0	1.89	0.98	1.203	0.52
155-W -D2	3.96	30.0	1.98	0.99	1.047	0.50
155-W -D3	3.99	40.0	2.66	1.19	1.092	0.45
155-W -D4	3.49	45.0	2.62	1.14	1.291	0.44
155-W -W1	3.76	30.0	1.88	1.16	1.592	0.62
155-W -W2	3.84	20.0	1.28	0.74	1.126	0.58
155-W -W3	3.98	20.0	1.33	0.91	1.505	0.68
155-W -W4	3.42	20.0	1.14	0.60	1.053	0.52
155- -D1	3.77	25.0	1.57	1.23	1.779	0.78
155- -D2	3.83	25.0	1.59	0.68	0.761	0.42
155- -D3	2.86	30.0	1.43	1.26	0.661	0.88
155- -D4	3.83	30.0	1.92	1.06	0.465	0.55
155- -W1	2.97	15.0	0.74	0.71	1.308	0.96
155- -W2	3.86	17.5	1.13	0.82	1.414	0.73
155- -W3	4.37	15.0	1.09	0.70	0.514	0.64
155- -W4	4.48	15.0	1.12	0.49	0.257	0.44
155-S -D1	4.25	30.0	2.12	1.05	0.603	0.49
155-S -D2	3.14	30.0	1.57	1.22	1.362	0.77
155-S -D3	3.87	30.0	1.94	1.11	0.439	0.57
155-S -D4	3.51	25.0	1.46	1.16	2.981	0.79
155-S -W1	4.18	17.0	1.18	0.54	0.556	0.46
155-S -W2	4.01	15.0	1.00	0.73	0.834	0.73
155-S -W3	4.18	20.0	1.39	0.90	0.255	0.65
155-S -W4	3.49	17.0	0.99	0.58	1.872	0.59
778- -D1	3.63	35.0	2.12	0.89	0.976	0.42
778- -D2	3.47	35.0	2.02	0.72	0.672	0.35
778- -D3	3.67	30.0	1.83	0.59	0.099	0.32
778- -D4	3.92	30.0	1.96	0.74	0.678	0.38
778- -W1	4.18	21.2	1.48	0.70	0.888	0.47
778- -W2	3.92	21.2	1.39	0.55	0.494	0.40
778- -W3	3.19	20.0	1.06	0.84	0.394	0.79
778- -W4	3.87	20.0	1.29	0.77	0.389	0.59
439- -D1	4.52	30.0	2.26	1.29	1.520	0.57
439- -D2	3.45	30.0	1.73	1.46	0.998	0.84
439- -D3	4.18	30.0	2.09	1.12	0.405	0.53
439- -D4	3.11	30.0	1.56	1.12	0.857	0.72

STORM CHARACTERISTICS
CARSON NATIONAL FOREST

PLOT ID	RAINFALL INTENSITY (IN/HR)	RAINFALL DURATION (MIN)	DEPTH OF RAINFALL (IN)	DEPTH OF RUNOFF (IN)	TOTAL SEDIMENT (T/AC.IN)	RO / RA
439- -W1	4.15	15.0	1.04	0.63	0.906	0.61
439- -W2	4.04	20.0	1.35	0.49	1.209	0.36
439- -W3	4.18	17.0	1.18	0.86	0.511	0.73
439- -W4	3.27	20.0	1.09	0.76	0.448	0.69
697-E -D1	3.49	30.0	1.75	1.09	0.000	0.63
697-E -W1	3.89	15.0	0.97	0.41	0.538	0.42
439- 2-D1	3.89	30.0	1.95	1.44	2.258	0.74
439- 2-D2	4.35	30.0	2.18	1.53	2.784	0.70
439- 2-D3	4.00	30.0	2.00	1.35	1.817	0.67
439- 2-D4	3.79	30.0	1.90	1.32	1.909	0.70
439- 2-W1	3.30	20.0	1.10	1.06	1.930	0.96
439- 2-W2	4.00	20.0	1.33	1.20	2.499	0.90
439- 2-W3	4.21	20.0	1.40	0.89	3.105	0.63
439- 2-W4	4.50	20.0	1.50	0.98	2.055	0.65
439-CS-D1	3.90	30.0	1.95	1.05	6.991	0.54
439-S2-D2	3.92	30.0	1.96	1.22	2.138	0.62
439-CS-D3	2.24	30.0	1.12	0.61	22.403	0.54
439-S2-D4	4.36	30.0	2.18	1.32	0.958	0.60
439-CS-W1	3.90	20.0	1.30	0.72	3.699	0.55
439-S2-W2	3.92	20.0	1.31	0.89	1.041	0.68
439-CS-W3	2.30	20.0	0.77	0.74	10.780	0.96
439-S2-W4	4.45	20.0	1.48	1.13	0.971	0.76

STORM CHARACTERISTICS
GILA NATIONAL FOREST

PLOT ID	RAINFALL INTENSITY (IN/HR)	RAINFALL DURATION (MIN)	DEPTH OF RAINFALL (IN)	DEPTH OF RUNOFF (IN)	TOTAL SEDIMENT (T/AC.IN)	RO / RA
289-1 -D1	3.86	30.0	1.93	0.69	2.222	0.36
289-CS-D2	4.36	30.0	2.18	0.31	7.159	0.14
289-1 -D3	4.11	30.0	2.05	0.51	2.642	0.25
289-CS-D4	3.55	30.0	1.77	0.39	5.543	0.22
289-1 -W1	3.86	20.0	1.29	0.53	1.154	0.41
289-CS-W2	4.27	20.0	1.42	0.63	3.813	0.44
289-1 -W3	3.98	20.0	1.33	0.71	2.448	0.53
289-CS-W4	4.10	20.0	1.37	0.82	4.308	0.60
289-2 -D1	3.75	30.0	1.87	1.26	1.377	0.67
289-2 -D2	3.95	30.0	1.97	0.80	0.571	0.41
289-2 -D3	3.88	25.0	1.61	0.63	1.077	0.39
289-2 -D4	4.47	25.0	1.86	1.08	1.560	0.58
289-2 -W1	4.49	20.0	1.50	1.06	1.441	0.71
289-2 -W2	3.64	20.0	1.21	0.74	0.365	0.61
289-2 -W3	4.21	20.0	1.40	0.81	1.038	0.58
289-2 -W4	4.00	16.5	1.10	0.70	1.333	0.64
289-NS-D1	4.30	30.0	2.15	0.80	0.699	0.37
289-CS-D2	4.07	30.0	2.03	0.30	3.087	0.15
289-NS-D3	3.89	40.0	2.59	1.26	1.150	0.48
289-NS-D4	4.52	25.0	1.88	0.80	0.898	0.42
289-NS-D5	3.20	30.0	1.60	0.92	1.398	0.58
289-CS-D6	2.12	35.0	1.23	0.86	1.728	0.69
289-NS-W1	4.10	25.0	1.71	1.16	0.664	0.68
289-CS-W2	4.12	25.0	1.72	1.00	3.063	0.58
289-NS-W3	4.40	20.0	1.47	0.74	0.721	0.51
289-NS-W4	3.86	20.0	1.29	0.74	0.832	0.57
289-NS-W5	4.14	16.0	1.10	0.68	1.071	0.62
289-CS-W6	3.89	20.0	1.30	0.90	1.362	0.70
94 -S -D1	3.85	20.0	1.28	0.85	1.654	0.66
94 -S -D2	3.68	26.0	1.59	0.92	1.055	0.58
94 -S -D3	4.37	35.0	2.55	0.90	0.891	0.35
94 -S -D4	3.85	34.0	2.18	0.99	0.171	0.46
94 -S -W1	3.37	20.0	1.12	0.87	2.240	0.78
94 -S -W2	4.50	20.0	1.50	0.73	0.802	0.49
94 -S -W3	4.19	20.0	1.40	0.98	0.809	0.70
94 -S -W4	3.51	20.0	1.17	0.88	0.206	0.75

STORM CHARACTERISTICS
LINCOLN NATIONAL FOREST

PLOT ID	RAINFALL INTENSITY (IN/HR)	RAINFALL DURATION (MIN)	DEPTH OF RAINFALL (IN)	DEPTH OF RUNOFF (IN)	TOTAL SEDIMENT (T/AC.IN)	RO / RA
LOG- -D1	3.90	25.5	1.66	1.13	0.339	0.68
LOG- -D2	3.69	25.0	1.54	1.31	0.259	0.85
LOG- -D3	4.07	30.0	2.04	1.95	0.249	0.96
LOG- -D4	4.20	30.8	2.16	1.55	0.372	0.72
LOG- -W1	4.44	20.1	1.48	1.31	0.257	0.88
LOG- -W2	4.16	20.0	1.39	1.15	0.162	0.83
LOG- -W3	4.46	20.0	1.49	1.20	0.160	0.81
LOG- -W4	4.25	20.1	1.42	1.24	0.268	0.87
RUS-B -D1	3.87	30.0	1.94	0.97	1.871	0.50
RUS-B -D2	4.27	30.0	2.14	1.22	0.879	0.57
RUS-B -W1	3.80	20.0	1.27	1.09	2.191	0.86
RUS-B -W2	4.26	20.0	1.42	1.08	0.797	0.76
RUS-C -D1	3.58	30.0	1.79	0.98	1.785	0.55
RUS-C -D2	4.17	30.0	2.09	1.07	2.490	0.52
RUS-C -D3	4.42	30.0	2.21	1.28	3.998	0.58
RUS-C -D4	2.95	35.0	1.72	1.07	5.057	0.62
RUS-C -W1	3.90	20.0	1.30	0.97	1.934	0.75
RUS-C -W2	3.91	20.1	1.31	0.91	3.043	0.70
RUS-C -W3	4.37	20.0	1.46	1.13	2.976	0.77
RUS-C -W4	3.80	20.0	1.27	1.02	2.727	0.80
RUS-D -D1	3.73	30.0	1.86	0.74	5.889	0.40
RUS-D -D2	3.45	29.3	1.69	0.79	0.459	0.47
RUS-D -D3	3.17	30.0	1.58	0.83	4.341	0.52
RUS-D -D4	3.81	30.0	1.90	1.48	3.793	0.78
RUS-D -W1	4.00	20.0	1.33	0.82	3.564	0.61
RUS-D -W2	3.21	20.1	1.07	0.78	0.368	0.73
RUS-D -W3	4.19	20.0	1.40	0.88	3.268	0.63
RUS-D -W4	3.19	20.0	1.07	0.71	3.361	0.66
WAT-D -D1	3.42	30.0	1.71	1.41	6.705	0.82
WAT-D -D2	4.24	30.1	2.13	1.56	3.968	0.73
WAT-D -D3	3.87	30.0	1.93	0.52	4.819	0.27
WAT-D -D4	4.44	30.0	2.22	1.09	2.437	0.49
WAT-D -W1	3.66	20.0	1.22	1.14	5.467	0.94
WAT-D -W2	4.14	19.7	1.36	1.25	2.945	0.92
WAT-D -W3	3.77	23.6	1.49	1.22	4.390	0.82
WAT-D -W4	4.63	28.0	2.16	2.13	3.795	0.99

STORM CHARACTERISTICS
SANTA FE NATIONAL FOREST

PLOT ID	RAINFALL INTENSITY (IN/HR)	RAINFALL DURATION (MIN)	DEPTH OF RAINFALL (IN)	DEPTH OF RUNOFF (IN)	TOTAL SEDIMENT (T/AC.IN)	RO / RA
470- -D1	3.56	25.0	1.48	0.81	0.213	0.54
470- -D2	3.69	25.0	1.54	1.00	0.831	0.65
470- -D3	2.73	25.0	1.14	0.84	2.714	0.74
470- -D4	3.84	25.0	1.60	1.13	1.316	0.71
470- -W1	3.87	15.0	0.97	0.52	0.498	0.54
470- -W2	3.78	15.0	0.94	0.72	0.698	0.76
470- -W3	3.92	20.0	1.31	1.15	2.356	0.88
470- -W4	3.88	20.0	1.29	0.90	1.401	0.70
470-S -D1	3.70	30.0	1.85	1.29	1.709	0.70
470-S -D2	3.93	30.0	1.96	1.06	0.978	0.54
470-S -D3	5.23	30.0	2.61	2.46	0.454	0.94
470-S -D4	3.83	30.0	1.91	1.09	0.306	0.57
470-S -W1	3.61	20.0	1.20	0.77	1.195	0.64
470-S -W2	3.79	25.0	1.58	1.51	0.789	0.95
470-S -W3	3.90	25.0	1.62	1.13	0.306	0.70
470-S -W4	3.77	20.0	1.26	0.82	0.333	0.65
471- -D1	3.86	30.0	1.93	0.85	0.959	0.44
471-CS-D2	1.49	30.0	0.74	0.61	9.872	0.82
471- -D3	2.00	25.0	0.83	0.77	0.694	0.93
471- -D4	4.05	25.0	1.69	0.94	0.598	0.56
471- -W1	4.08	15.0	1.02	0.56	0.741	0.55
471-CS-W2	1.77	15.0	0.44	0.42	5.830	0.95
471- -W3	4.00	30.0	2.00	1.42	0.795	0.71
471- -W4	3.70	30.0	1.85	1.27	0.680	0.68
79- -D1	3.21	30.0	1.60	1.34	0.086	0.83
79- -D2	4.34	30.0	2.17	1.69	1.740	0.78
79- -D3	3.90	30.0	1.95	1.28	0.223	0.65
79- -D4	3.87	30.0	1.94	1.65	0.096	0.85
79- -W1	4.40	20.0	1.47	1.03	0.090	0.70
79- -W2	3.87	20.0	1.29	1.00	0.650	0.78
79- -W3	4.22	20.0	1.41	0.98	0.116	0.70
79- -W4	3.98	20.0	1.33	1.05	0.043	0.79
79-S -D1	3.97	30.0	1.99	1.23	0.139	0.62
79-S -D2	4.38	30.0	2.19	1.57	0.143	0.72
79-S -D3	3.93	30.0	1.96	1.19	0.156	0.60
79-S -D4	3.85	30.0	1.92	1.45	0.178	0.76

STORM CHARACTERISTICS
SANTA FE NATIONAL FOREST

PLOT ID	RAINFALL INTENSITY (IN/HR)	RAINFALL DURATION (MIN)	DEPTH OF RAINFALL (IN)	DEPTH OF RUNOFF (IN)	TOTAL SEDIMENT (T/AC.IN)	RO / RA
79-S -W1	3.70	20.0	1.23	0.96	0.097	0.77
79-S -W2	4.32	20.0	1.44	1.10	0.073	0.76
79-S -W3	3.91	20.0	1.30	0.78	0.073	0.60
79-S -W4	3.92	20.0	1.31	1.12	0.080	0.86

Appendix III-c

Calculated Model Parameters

Notes: Parameter values reported herein are averages of the parameter values calculated for each replicated sample plot.

NPLOT is number of sample plots contributing to the average.

Kw is hydraulic conductivity in in/hr

PSI is capillary suction in inches

A is raindrop detachment coefficient in ft. poros depth per hour over bare soil

DOF is overland flow detachment coefficient.

AVERAGE PARAMETER ESTIMATES
BY SURFACE CONDITION FOR EACH SITE IN EACH FOREST

FOREST	ROAD	SITE	SURFACE	KW (IN/HR)	PSI (IN)	A (FT.PD/HR)	DOF	NPLOT
CARSON	155		DRY	0.86	1.40	0.000073	0.0268	4
CARSON	155		WET	1.23	0.38	0.000051	0.0225	4
CARSON	155	S	DRY	0.70	3.79	0.000063	0.0140	4
CARSON	155	S	WET	1.27	0.04	0.000060	0.0098	4
CARSON	155	W	DRY	1.14	3.50	0.000042	0.0227	4
CARSON	155	W	WET	1.18	0.64	0.000078	0.0268	4
CARSON	439		DRY	0.95	0.67	0.000049	0.0635	4
CARSON	439		WET	1.47	0.00	0.000030	0.0590	4
CARSON	439	CS	DRY	0.79	1.10	0.000317	0.0789	2
CARSON	439	CS	WET	0.78	0.00	0.000275	0.0350	2
CARSON	4392	S	DRY	1.22	0.48	0.000115	0.0958	2
CARSON	4392	S	WET	1.18	0.00	0.000062	0.0538	2
CARSON	4392		DRY	0.95	0.08	0.000120	0.0668	4
CARSON	4392		WET	0.84	0.00	0.000113	0.0687	4
CARSON	697	E	DRY	0.83	0.90	0.000000	.	1
CARSON	697	E	WET	2.15	0.00	0.000000	0.0111	1
CARSON	778		DRY	1.09	2.77	0.000017	0.0446	4
CARSON	778		WET	1.10	2.76	0.000023	0.0403	4
GILA	289	CS	DRY	1.59	0.33	0.000153	0.0242	2
GILA	289	CS	WET	1.28	0.00	0.000186	0.0200	2
GILA	289	NS	DRY	1.36	1.39	0.000106	0.0307	4
GILA	289	NS	WET	1.27	0.09	0.000076	0.0228	4
GILA	2891		DRY	1.63	1.30	0.000033	0.0251	2
GILA	2891		WET	1.93	0.05	0.000048	0.0157	2
GILA	2891	CS	DRY	2.41	0.51	0.000052	0.0284	2
GILA	2891	CS	WET	1.60	0.25	0.000116	0.0137	2

AVERAGE PARAMETER ESTIMATES
BY SURFACE CONDITION FOR EACH SITE IN EACH FOREST

FOREST	ROAD	SITE	SURFACE	KW (IN/HR)	PSI (IN)	A (FT.PD/HR)	DOF	NPLOT
GILA	2892		DRY	1.51	1.26	0.000067	0.0169	4
GILA	2892		WET	1.10	1.12	0.000043	0.0135	4
GILA	94	S	DRY	0.99	1.41	0.000086	0.0242	4
GILA	94	S	WET	0.80	1.80	0.000116	0.0211	4
LINCOLN	LOG		DRY	0.49	3.55	0.000305	0.0513	4
LINCOLN	LOG		WET	0.58	1.02	0.000251	0.0334	4
LINCOLN	RUSB		DRY	0.92	2.42	0.000437	0.0124	2
LINCOLN	RUSB		WET	0.58	0.90	0.001024	0.0118	2
LINCOLN	RUSC		DRY	0.50	3.15	0.000243	0.0158	4
LINCOLN	RUSC		WET	0.78	0.37	0.000151	0.0127	4
LINCOLN	RUSD		DRY	1.03	2.22	0.000900	0.0153	4
LINCOLN	RUSD		WET	0.76	0.60	0.000600	0.0104	4
LINCOLN	WATD		DRY	1.18	5.11	0.000525	0.0276	4
LINCOLN	WATD		WET	0.51	2.06	0.000848	0.0255	4
SANTA FE	470		DRY	0.53	1.65	0.000089	0.0290	4
SANTA FE	470		WET	0.95	0.61	0.000098	0.0253	4
SANTA FE	470	S	DRY	1.15	0.00	0.000099	0.0122	4
SANTA FE	470	S	WET	0.94	0.00	0.000059	0.0092	4
SANTA FE	471		DRY	0.93	0.64	0.000041	0.0277	3
SANTA FE	471		WET	0.99	0.60	0.000033	0.0264	3
SANTA FE	471	CS	DRY	0.72	0.00	0.000549	0.0203	1
SANTA FE	471	CS	WET	0.02	0.00	0.000235	0.0114	1
SANTA FE	79		DRY	0.39	2.20	0.000020	0.0615	4
SANTA FE	79		WET	0.82	0.08	0.000007	0.0254	4
SANTA FE	79	S	DRY	1.14	0.00	0.000016	0.0200	4
SANTA FE	79	S	WET	0.63	0.78	0.000011	0.0097	4