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ABSTRACT

Rainfall simulation experiments were conducted in the Fifteenmile Creek drainage basin of north-central Wyoming to identify nonpoint sources of suspended sediment. A portable drop-forming rainfall simulator was chosen for reasons of low cost and low water requirements. Experiments were designed to generate 3.2 mm drops from a height of 7.5 feet (2.3 meters) with an intensity of 3 inches (7.6 cm) per hour. The simulated storms were applied over 73, 2' x 2' (.6 x .6 meter) plots for the duration of one hour. These storms, with a kinetic energy of 456 joules, were chosen as being representative of intense convective storms that occur over the basin in the summer months.

Rates of erosion and runoff were found to be most closely related to vegetation density, litter density, slope gradient, and soil texture. The possibility of altered erosion and runoff rates as a result of grazing practices was also examined. Erosion and runoff rates were then related to composite terrain types to facilitate data analysis and display in a geographic information system.

INTRODUCTION

Controlling watershed sediment production has become a focus of present day nonpoint source pollution control strategies and is of particular concern in semi-arid environments where natural rates of sediment production are at their highest. Excessive sediment concentrations can increase domestic water treatment costs, damage crops, add to maintenance costs for irrigation systems, degrade fisheries resources, and result in decreased reservoir storage capabilities. Also, nutrients, pesticides, and biological pollutants are often transported by fluvial sediments (Novotny and Chesters 1981).

The quantity of sediment discharged at the outlet of a drainage basin system is ultimately related to the supply of sediment produced by upland sources. Numerous geomorphic processes act to remove sediment from uplands including: rainsplash, sheetwash, slumping, masswasting, and rilling and gullying. Physical characteristics, especially climate, topography, living and dead vegetative cover, and soil type, can control the effectiveness of these forces. In addition, human activities can also influence the amounts of runoff and sediment produced by a watershed.

The objectives of the study are to investigate factors influencing the production of sediment and runoff in upland areas of the Fifteenmile Creek watershed of Wyoming using mapping techniques and rainfall simulation. The results of these findings will be incorporated in other concurrent studies that will eventually develop a comprehensive model for predicting the erosion, transport, and deposition of sediments in the basin. The information generated from this project will be useful to land management agencies, such as the Bureau of Land Management, by allowing them to concentrate their efforts and financial resources on those variables having the greatest influence on sediment production and on those areas of the basin which contribute disproportionately to the sediment supply.

LITERATURE REVIEW

Most relevant to this research are studies that have used rainfall simulation to evaluate rates of erosion and runoff production in semiarid watersheds.

Blackburn and Skau (1974) used a mobile type drop-forming simulator to evaluate sediment production and infiltration for 29 plant communities in Nevada rangelands. Infiltration rates and sediment production were found to vary considerably and the highest infiltration and lowest sediment production were found to be associated with well-aggregated surface soils. Using a spray-nozzle type rainfall simulator on northern Utah rangelands, Meeuwig (1970) emphasized the importance of vegetation and litter cover in maintaining infiltration capacity and soil stability. Bryan and Hodges (1981) used simulated rainfall in combination with basin lithology to evaluate sediment transport dynamics in Canadian badlands microcatchments. They concluded that rainsplash plays an important role in sediment entrainment but the dominant mode of sediment transport is surface and subsurface runoff.

DESCRIPTION OF STUDY AREA

The Fifteenmile Creek watershed is located in the Bighorn Basin of north-central Wyoming (Figure 1). The drainage basin can best be described as a cold desert environment with an area of 520 square miles (1350 km^2) and a median elevation of 4900 feet (1500 meters). Annual precipitation for the region averages 8 inches (20.3 cm) and the mean annual temperature is 45°F (7°C) (Martner 1987). Plant communities consist of shrubs, low grasses and forbs, and prickly pear cactus. However, vegetation is often sparse and the basin contains extensive badland areas where slopes are steep and plant cover is essentially absent. Eocene claystone and sandstone deposits of the Willwood Formation and Quaternary alluvial deposits underlie the lower portions of the basin while claystones and shales of the Eocene Tatman formation dominate the geology of the upper portions of the basin (Lowery et al. 1976). Uses of the basin are confined to grazing, recreational use, and oil and gas production and exploration.

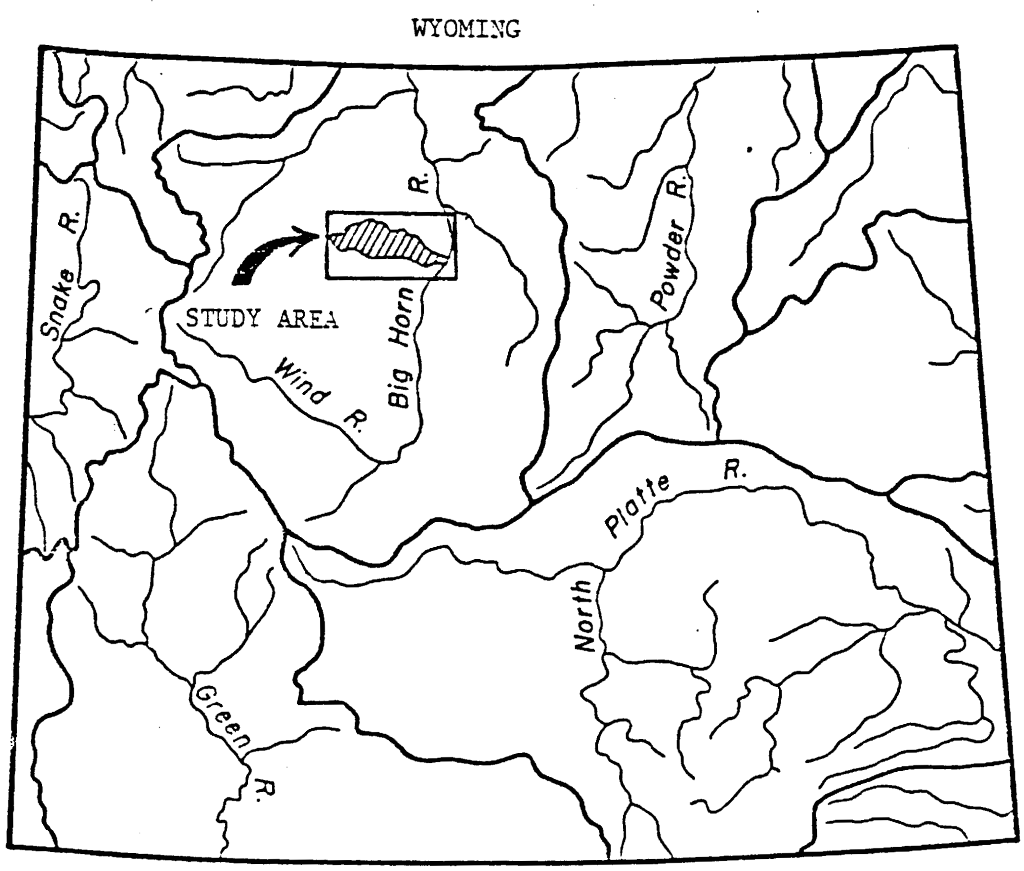

Figure 1. Study Area.

Although the watershed contributes only 0.8 percent of the mean annual flow to the Big Horn River, it contributes 75 percent of the sediment supply to the stream (Cooper, 1979). During the 1950s and 1960s, the Bureau of Land Management (BLM) addressed this problem with an aggressive watershed improvement program to control sediment production in the basin. Work undertaken by the program included the installation of sediment retention structures, water spreaders and drift fences, and also included revegetation attempts and altered grazing management practices. Using 20 years of streamflow and sediment data from a gaging station located on Fifteenmile Creek near its confluence with the Bighorn River, Yochem and Rosenlieb (1978) evaluated changes in downstream suspended sediment concentrations in response to these measures. They concluded that a 25 percent reduction in sediment concentrations could be directly related to the watershed improvements. However, recent on-site inspections revealed that many of the structures are failing, possibly effecting the present and future sediment transport dynamics of the stream.

METHODS

Because of the large size of the watershed, field experiments were limited to the 41.8 square mile (108 km^2) Middle Fork subbasin. Thirty-seven study sites were selected on the basis of soils, vegetation, slope, and range condition by on-site inspection and mapping techniques. Slope maps were constructed from U.S. Geological Survey topographic maps by delineating areas of similar slopes into five categories. Bureau of Land Management site write-up area (SWA) maps, containing information on soil types, and vegetation conditions and densities, were used to create soil texture and vegetation density maps. The sites were selected to comprehensively include the varying slopes, plant communities and soil types found in the basin.

A rainfall simulator design was chosen and a simulator built in the spring of 1987. The device utilizes a rainfall chamber similar to the one developed by Chow and Harbough (1965) which produces 3.2 mm drops by use of polyethylene tubing. A variable area flow meter regulates water entering the rainfall chamber. The apparatus is portable and similar in design to the "Tahoe Basin" rainfall simulator developed by Munn and Huntington (1976). The drops fall 7.5 feet (2.3 meters) to a 2' x 2' (.61 x .61 meter) plot. A frame defines the border of the plot and the resulting runoff and sediment is funneled into containers at the downslope end of the plot. Because of the head of water required for adequate drop formation, 3 inches (7.65 cm) per hour was found to be the minimum rate of intensity for the above described rainfall simulator. The total kinetic energy produced by the simulated storm under these conditions is 456 joules (0.168 foot-tons).

In July and August, 1987, artificial rainstorms having an intensity of 3 inches (7.64 cm) per hour were applied to plots on the 37 study sites for a duration of one hour. The experiments were duplicated on adjacent plots at all but one study site for a total of 73 experiments. During each experiment four 500 ml water samples were collected, with the time for the sample bottles to fill recorded to later determine runoff from the site. Also sediment captured in the downslope collection trough was placed into a fifth sample container. Percent canopy cover and litter cover, number of plants, percent slope, type of plants, and slope aspect were recorded for the 73 plots. A surface soil sample was also collected at each study site and photographs taken of both the study area and experimental plots.

Runoff samples were analyzed in the fall of 1987 using the evaporation method to determine runoff volumes and sediment concentrations. Total runoff (liters) and sediment loss (grams) from the plots for the individual storms was then calculated by interpolating between these data with the weight of sediment collected at the downslope trough added to determine total sediment eroded from a plot. Soil samples were analyzed using the hydrometer method with the percents (1) sand, (2) coarse silt, (3) fine silt, and (4) clay recorded. Soil texture was then expressed on a scale of 1 to 4 using the above assigned numbers and percent of the sample in each size category.

RESULTS

Step-wise procedures were used to develop multiple linear regression equations identifying those variables most influential in determining runoff and erosion and to predict soil loss from rainsplash and sheetwash erosion, and surface runoff. Variables tested in the two analyses were vegetation density (percent canopy cover), vegetation frequency (number of plants), litter density (percent ground cover), slope (percent), and soil texture (scale: 1-4). The regression equations for soil loss (grams) and runoff production (liters) by simulated rainstorms from the 2' x 2' (.61 x .61 meter) study plots are presented below.

Soil loss: $$\text{Log } Y = 1.90 + 0.0340X_1 + -0.00916X_2 + 0.191X_3$$

where: X_1 = slope
X_2 = vegetation density
X_3 = soil texture

R2 = 0.79
N = 71

Runoff: $$Y = 3.63 - 5.52(\text{Log}X_1) + 31.24(\text{Log}X_2) + 3.84(\text{Log}X_3)$$

where: X_1 = litter density
X_2 = soil texture
X_3 = slope

R2 = 0.67
N = 71

All relationships are significant at the .001 alpha level.

The regression equations illustrate that slope, indices of vegetative cover, and soil texture are good indicators of runoff and soil erosion. Soil erosion is most strongly correlated with slope which predicts 63 percent of the variation in soil loss alone. However, percent slope was not as strong a predictor of runoff. Vegetation was found to be a strong predictor of soil loss while litter predicted 48 percent of the variability in runoff. The soil texture variable was a good predictor of runoff and had a significant correlation with soil loss. The results also show a fairly strong degree of multicolliniarity between the predictors (Table 1).

Table 1. Correlation Matrices (r values).

a. Soil Loss

	Y	X_1	X_2	X_3
Y	1.0	.763	-.735	.513
X_1	.793	1.0	-.525	.343
X_2	-.735	-.525	1.0	-.357
X_3	.513	.343	-.357	1.0

b. Runoff

	Y	X_1	X_2	X_3
Y	1.0	-.691	.683	.467
X_1	-.691	1.0	-.479	-.413
X_2	.683	-.479	1.0	.170
X_3	.467	-.413	.170	1.0

CONCLUSIONS

In the Fifteenmile Creek watershed, slope, living and dead vegetative cover, and soil texture exert strong control on erosion and runoff production, although the relative influence of each is complicated by the multicolliniarity. Steep slopes often have low vegetative and litter cover which in turn leads to less protection of the soil surface from erosive forces. Soils which erode more easily can produce steeper slopes, are less desirable for plant growth and, as a result, are poorly protected from rainsplash and sheetwash erosion. Finer textured soils are also associated with lower rates of infiltration and, therefore, produce greater amounts of runoff which can be available for rill, gully, and stream channel erosion.

The results of this research point out that establishing dense vegetative cover, particularly on steep slopes, would decrease soil erosion and surface runoff. Managing grazing in such as way as to provide optimal vegetative cover could lessen rates of sediment production, although it is unlikely that sufficient vegetative cover could be established in many areas of the basin do poorly developed soils, inadequate moisture, and pre-existing steep topography. Portions of the watershed are presently divided into numerous small grazing allotments, a management scheme that encourages concentration of livestock in small areas with heavy impacts on vegetation. Closely monitoring off-road vehicle use, especially in areas with steep slopes, provides another possibility for increasing vegetative cover and decreasing erosion. The results also imply that natural erosion in the extensive badland areas of the basin is contributing disproportionally to the watershed sediment budget. This problem is further amplified by the extremely high drainage density (length of streams per unit area) that was measured in these areas of the basin, providing for an efficient means to transport the eroded sediments into stream channels.

In the past, structural measures were undertaken to control sediment production in the Fifteenmile Creek watershed. Concentrating such structures in areas of high sediment yield could be a way of decreasing the sediment production of the basin, although the cost-benefit ratio of such measures is often high and the effective life of many sediment control structures in the harsh environment of the watershed may be relatively short.

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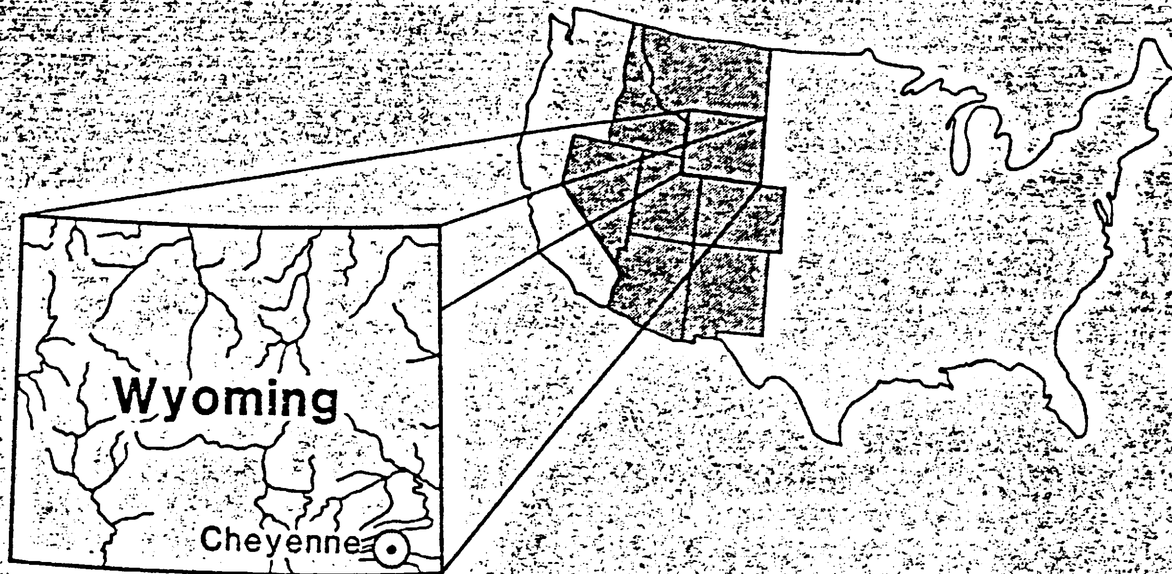

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