FINAL REPORT

# ALLOWABLE SOIL LOSS TOLERANCES FOR RANGELANDS BASED ON SUSTAINED PLANT PRODUCTION AND STREAM QUALITY

Submitted To
Wyoming Department of Environmental Quality
Water Quality Division
Herschler Building
Cheyenne, WY 82002

Prepared By
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Laramie, WY 82071

November 16, 1992

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## PREFACE

This report presents the results of a research and demonstration project conducted by the Civil Engineering Department, University of Wyoming, through a grant from the Nonpoint Source Program, Water Quality Division, Wyoming Department of Environmental Quality. The report is based on a thesis presented by Mr. Steven J. Linse.

All field data and the analyses are presented in this report. It should be noted that this project was originally designed to be three years rather than two, with continuing field measurements for an extended time. Actual field quantification of soil loss tolerances requires such an effort. Because funding was limited to two years, no actual field data was obtained on soil loss tolerances. The field sites and data were transferred to the Wyoming Water Research Center for continued monitoring. Soil loss tolerances used in this report are taken from applicable literature. However, based on the results of this project, soil loss tolerances may be less important on upland range sites than quantifying interactions between wind and water erosion.

Two additional activities were conducted cooperatively with this project. A major report, "A Submodel for RUSLE to Simulate Soil Loss as affected by Various Types of Cover" by L. Benkobi was previously submitted. Another research project dealing with estimating stream water quality due to upland erosion will be submitted in January. Neither of these efforts received project funds, but the work is directly related. Project data will be used to evaluate spatial variability of surface roughness under in a project funded through Colorado State University. A report of that work will be furnished.

## ACKNOWLEDGEMENTS

The Allowable Soil Loss Tolerances for Rangelands Based on Sustained Plant Production and Stream Quality project was funded by the Wyoming Department of Environmental Quality, Water Quality Division. The assistance of the Wyoming Water Research center is gratefully acknowledged. The technical effort and preparation of this report was performed by the University of Wyoming, Department of Civil Engineering.

## DISCLAIMER

Linse, Steven J., The Influence of Ground Cover on Upland Range Erosion, M.S., Department of Agricultural Engineering, December, 1992.

The relationship between ground cover and water erosion on upland rangelands was investigated. Sites were selected with different surface cover from 0 to 100% and these sites received a simulated rainfall event. A rainfall simulator was used to apply a high intensity (97.1 mm/h), short duration (5 minute) rain storm to two similar plots. Sediment leaving the plots was collected and used to determine sediment eroded as a function of percentage of ground cover. A graph of ground cover versus sediment yield showed that if ground cover was maintained above 30%, then the soil loss tolerance for poor soils (2.2 $mt \cdot ha^{-1}$) was maintained.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my Committee Chairman, Dr. James L. Smith for his guidance, support, and encouragement during this research, and to Dr. M. J. Trlica for his direction and help. I would also like to thank the other members of my graduate committee Drs. Larry C. Munn and K. James Fornstrom for their helpful suggestions and advice. I am also thankful to the Agricultural Engineering Department for their financial assistance during my studies and to the students from both Agricultural Engineering and Civil Engineering who worked on this project in the field and in the lab.

I would like to thank my family for their love, support and encouragement, together we share this accomplishment.

My deepest appreciation to my friend Tamara Tillett for her constant interest, support, encouragement, and patience during the final year of this research.

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# CHAPTER I

## INTRODUCTION

Soil erosion is a three part process that involves detachment of soil particles, movement or transport of these particles, and their deposition at a new location (Morgan, 1986). Erosion is a natural process, that has perpetually occurred throughout the earth's history. As soil is eroded, it is also continually being created through the weathering of rock and the decomposition of organics. The balance between soil erosion and new soil being created is constantly changing. Man's activities often accelerates erosion, and causes increased loss of soil.

Soil erosion has several negative environmental and economic effects (Goldman et al., 1986).

1. Erosion of topsoil leaves the less fertile subsoil for plant production. This is a serious economic concern for agricultural states.

2. Salts and other naturally occurring chemicals may move with the sediment and concentrate in a stream or in the soil. High concentrations may render the soil or stream barren.

3. Chemicals and fertilizers are often used in Agriculture. These chemicals may also concentrate in the soil or water supply, polluting them.

4. Suspended sediments increase the turbidity of

streams. Many plants and animals cannot live in turbid water. Turbid water also increases the cost of water purification for communities downstream of the erosion.

5. Deposition of sediment seldom occurs at a beneficial location. Sediment plugs irrigation structures and fills reservoirs requiring these structures to constantly be maintained.

Suspended sediment from rangelands and grazing in riparian zones is the most common source of stream pollution in Wyoming. Sediment, leached salts and chemicals, and agricultural chemicals are serious problems in Wyoming lakes (Hogan, 1988).

Soil erosion is a "non-point source" because it does not originate at a single outlet point, rather, it originates over a diffuse area and is "created or exacerbated by human activity" (Hogan, 1988). The diffuse nature of soil erosion makes control difficult.

When a raindrop falls uninterrupted to the ground, it has energy, which can be used to dislocate small soil particles. Some rain water infiltrates into the soil, the excess flows down slope regaining energy. This flow is often concentrated into small channels, or rills. The energy of the water in the rills allows it to carry detached sediment particles with it. The rills gather more water and concentrate flow that then forms gullies which are capable of carrying more sediment (Goldman et al., 1986). The gullies can carry the sediment into streams.

Stopping erosion at the stream, gully, or rill, collects sediment at that point and improves the water downstream. But, the sediment collection structure has little effect on erosion from uplands and in waterways above the point of sediment removal.

The erosion process is best stopped by minimizing soil particle detachment and increasing water infiltration. Ground cover accomplishes both of these goals (Goldman et al., 1986). The energy of the raindrop is absorbed by the cover and therefore little or no soil is detached. The ground cover causes the terrain to be rougher which also slows the formation of rills, increases the distance water flows, and allows more time for infiltration. Once water infiltrates it is no longer an erosion problem, it becomes an asset.

Infiltrated water may be available for plants. This allows for production of more ground cover and serves to perpetuate the cycle. Plant cover also has economic value as cover and food for wildlife and livestock. Groundwater provides delayed drainage to riparian zones along streams and rivers that allows them to remain in good condition.

The goal of erosion control has always been to limit the rate of soil losses at or below the rate of soil formation, the "soil loss tolerance limit" (Morgan, 1986). This maintains soil resources and plant production potential at stable levels.

OBJECTIVES

The majority of rangelands in Wyoming are managed by public agencies, primarily the Forest Service (USFS) and the Bureau of Land Management (BLM). These agencies are responsible for management plans that facilitate multiple use. To improve management of these high altitude, semi-arid rangelands, the relationship between surface cover, surface roughness, the Revised Universal Soil Loss Equation (RUSLE), and sediment yield are needed. The objectives of this research were to obtain more information on these relationships:

1. To measure sediment yield from a high intensity, short duration storm created with a rainfall simulator and develop a relationship between sediment yield and ground cover.

2. To measure and evaluate surface roughness on rainfall simulation plots to provide data for use in the RUSLE equation (Weitz et al., 1987).

3. To use the Revised Surface Cover (RSC) equation (Benkobi, 1992) with the cover data from the simulation plots to predict sediment yield from the simulation plots.

4. To establish relationships between total ground cover and sediment yield, actual sediment yield and predicted sediment yield using the RUSLE equation, and actual sediment yield and the predicted sediment yield using Benkobi's (1992) cover factor in RUSLE.

# CHAPTER II

## LITERATURE REVIEW

Growth of agriculture, industry, and tourism in Wyoming and the West depends on effective use of a limited water supply. Pollution of this water supply costs millions of dollars each year to clean up. Normally, suspended sediment is not thought of as water pollution; yet sediment contaminates more miles of Wyoming's rivers and streams than any other non-point source (Hogan, 1988). Erosion from cropland and rangeland also brings agricultural chemicals and biological pollutants into our rivers and streams as well as removing nutrients vital to plant growth. These chemicals along with natural salts present in the soil accumulate in the water supplies and reduce water quality (Hogan,1988).

This study was concerned with the relationship between ground cover and water erosion from upland rangelands from an individual "most damaging" rainfall event. The "most damaging" rainfall event is defined as one that causes the most sediment loss from a watershed based on its frequency, intensity, and magnitude (Huffsmith, 1988). Ground cover includes plants (Lang and McCaffery, 1984), stones (Simanton et al., 1984), crop residue or litter (Hussein and Laflen, 1982), and anything else in contact with the soil that decreases the tendency for erosion. Erosion is also caused by wind, but that was beyond the scope of this research.

Water erosion begins with a soil particle being displaced either by a raindrop impacting it or water flowing over it. Once a soil particle is detached, it may or may not reach a waterway. Gross soil erosion is the total sediment that is detached, and transported from an area, with no deposition occurring (Ponce, 1989). Some of the detached soil will only travel a short distance, be redeposited, and not reach the waterway until a future rain event.

Sediment yield is the amount of soil detached from an area that passes a point downstream (Ponce, 1989). The point that is selected to measure sediment is important to the sediment yield. A decrease in slope above the measuring point would cause a decrease in the streams' ability to carry sediment. The measurement would then indicate less erosion upstream than actually occurred. The sediment delivery ratio is the sediment yield divided by the gross sediment erosion (Ponce, 1989).

The Universal Soil Loss Equation (USLE) was developed to estimate erosion losses east of the Rocky Mountains by Wischmeier and Smith (1965). Six factors are multiplied together to estimate the soil erosion from an area in the USLE model. The factors are: rainfall (R), soil erodibility (K), slope length (L), slope steepness (S), cover (C), and practice or tillage factor (P). Slope length and slope steepness are generally combined into one factor (LS).

The Revised Universal Soil Loss Equation (RUSLE) was introduced in 1987 (Weitz, Renard, and Simanton, 1987). This revision updated the USLE equation for use throughout the West and developed equations for the cover factor, slope length-steepness factor, and the practice factor. RUSLE incorporates the new equations with erosion data from western rangelands.

RAINFALL SIMULATORS

The Purdue Rainulator was developed to study water erosion from erosion plots (Meyer and McCune, 1958). This allowed researchers to become independent of natural rainstorms, because they did not have to wait for a rainfall event with specific characteristics to occur at the right time for analysis. This improved the speed and efficiency of erosion research. It also freed researchers from interpolating between storms of different durations and intensities.

The Purdue Rainulator was large (3 m by 25 m), expensive, and relatively complicated. It's size and complexity made it difficult to move between test plots.

The next generation of simulators used rotating booms on a modified commercial irrigation carriage (Swanson, 1965). These simulators allowed large plots to be analyzed (5 m by 25 m using two simulations), while adding the advantage of greater mobility. The Swanson rotating boom simulator is the standard simulator used by the United States Department of Agriculture (USDA). Rainfall events that were consistent and repeatable could be run over a broad range of rain intensities and ground conditions.

The USDA simulator is mobile enough for a broad range of field and range conditions, but it is difficult to operate on more rugged and steep terrain found in the Rocky Mountains where some of the most severe erosion occurs. The size of the USDA simulator makes it difficult to locate in rugged, off-road areas. Once set up on the steep slopes, the rotating booms make it unstable. Another problem is the large volume of water the USDA simulator requires to maintain application rates for each simulation of from 3.78 to 7.6 $l \cdot s^{-1}$ (Swanson, 1965).

The simulator used in this project was a smaller version of the USDA simulator. It has three rotating booms, each equipped with one nozzle at the end. The simulator was constructed of aluminum and was supported by three legs. These legs could be adjusted to allow the simulator arms to be kept parallel to the surface slope. The rotation rate and pressure control the intensity of the rainstorm. The small size of the simulator allows it to be used in very rugged terrain. It can be picked up and carried manually to a new location. It requires only a limited volume of water (227 l, 0.75 $l \cdot s^{-1}$) for each simulation. This simulator greatly increases the area adaptable to simulator research.

To be effective, a rainfall simulator must simulate a natural rainfall event. The raindrop size distribution, velocity, and total kinetic energy should be represented. The raindrop distribution within a plot should be random and the storm event must be reproducible (Meyer and McCune, 1958). The University of Wyoming simulator accomplishes all of these goals.

SOIL CONSERVATION PRACTICES

Sediment eroding from rangeland can be reduced through soil conservation practices. There are three categories of conservation practices: soil management, agronomic, and mechanical (Morgan, 1986). Grazing practices are also an important management tool for soil conservation on rangelands (Ellison, 1949, Lusby, 1970). These practices can be used alone, or in any combination to limit upland erosion, increase vegetation, and improve stream water quality.

The simplest management practice is altering livestock grazing. Grazing practices of livestock are very important to range condition and the amount of erosion (Ellison, 1949). Average annual soil loss from a grazed watershed was estimated to be 50% more than that of an ungrazed watershed over a twelve year period (Lusby, 1970). Plant cover and production may decrease as the range is grazed. When soil cover decreases below 70%, erosion and runoff increases dramatically (Copeland, 1965). However, cover may decline to 40%, in some instances, and still offer some erosion protection (Shaxson, 1981).

Soil management measures involve preparing the soil to improve its structure making it more resistant to erosion (Morgan, 1986). This is generally not practical for the rangelands of the West except for isolated, small scale instances.

The second soil conservation measure is agronomic practices. Agronomic practices involve manipulations of plant life of an area (Morgan, 1986). They may include reseeding an area, or applying fertilizer or pesticides. This may present many problems. New plants introduced to an area may out-compete native plants. The introduction of chemicals onto rangelands is becoming less acceptable than in the recent past. Agronomic methods are often expensive and time consuming on any large scale. Management and agronomic practices may decrease erosion by increasing plant canopy cover. Canopy cover absorbs the energy of the raindrop, which decreases soil particle detachment (Morgan,1986). Plant litter and plant crowns act to slow overland flow by forcing water to flow around them (Morgan, 1986). When overland flow follows a tortuous route, infiltration is increased and less water runs off.

Agronomic and management practices are often used with mechanical practices (Morgan, 1986). Mechanical methods also act to decrease overland flow and increase infiltration. This increases soil moisture which benefits agronomic practices. These practices generally involve changing the surface of the soil through some mechanical means. Examples are pitting, mulching, and terracing (Morgan, 1986). By increasing surface roughness, water can fill the small depressions rather than running off. Only the most intense storms will wash these depressions away. Mechanical treatments are very expensive and time consuming on a large scale, particularly in a rugged rocky natural rangeland.

Mechanical methods may also involve large scale projects like contouring, terracing, or shelterbelts (Morgan, 1986). These methods are expensive and better suited to the higher producing soils of the Midwest. Mechanical methods control soil particle transport, while agronomic and management methods control both particle detachment and particle transport (Morgan, 1986).

## SOIL LOSS TOLERANCE

Soil is constantly being formed by weathering, chemical action, and through the action of freezing and thawing. Organic material mixes with deteriorated rock to form soil. The rate of soil formation is important. If the erosion from a site is held at or below the formation rate, then it is below the soil loss tolerance limit and there is no net loss of soil (Morgan, 1986). The rate of soil loss can be measured, but the rate of soil formation cannot. It is easy to understand the soil loss tolerance limit, but much more difficult to quantify it. Table 1 refers to the maximum acceptable soil loss tolerance for different soils.

Table 1. Soil loss tolerance adapted from Morgan (1981).

| | | |
|---|---|---|
| Deep, fertile soils | 6.7 to 11.3 | $mt \cdot ha^{-1} \cdot y^{-1}$ |
| Thin, erodible, soils | 2.2 | $mt \cdot ha^{-1} \cdot y^{-1}$ |
| Soil Depths | | |
| 0.0 - 25.4 cm | 2.2 | $mt \cdot ha^{-1} \cdot y^{-1}$ |
| 25.4 - 50.8 cm | 2.2 to 5.2 | $mt \cdot ha^{-1} \cdot y^{-1}$ |
| 50.8 - 101.6 cm | 5.2 to 6.7 | $mt \cdot ha^{-1} \cdot y^{-1}$ |
| 101.6 - 152.4 cm | 6.7 to 9.0 | $mt \cdot ha^{-1} \cdot y^{-1}$ |
| > 152.4 cm | 11.3 | $mt \cdot ha^{-1} \cdot y^{-1}$ |

Quantifying the soil loss tolerance limit is difficult because there are many interacting factors affecting it. The erosion rate and the soil formation rate both vary with season, year, and location (Morgan, 1986). For example, water erosion decreases in the winter months because the ground is frozen in many areas. Years with higher precipitation may increase the amount of vegetation on a range which reduces raindrop impact and provides more plant biomass to form more soil. But if the precipitation occurs in large events such as is typical for some thunderstorms, runoff may increase and infiltration decrease. This results in a decrease in soil formation and an increase in erosion. Thunderstorms often are small, fast moving, and very intense. One location may receive a summer downpour, while a short distance away it remains dry.

Erosion was evaluated in the past based on the estimated soil loss tolerance (Morgan, 1986). Erosion was acceptable up to the soil loss tolerance limit. This would allow vegetation of an area to maintain itself. Since vegetation is a primary resource of rangeland, there is no net economic loss to the range.

The BLM and the USFS must try to balance multiple uses (ranching, wildlife, and recreation) on Wyoming's public rangelands, while not investing more into the land than the economic value of the land. Since the primary source of income for most of this rangeland is from grazing, the economic value of the land and improvements which can be made on the land are low.

This perspective, however ignores the problem of sediment that may concentrate in streams and rivers and pollute them. The sediment muddies the streams and destroys fisheries, costs millions of dollars in water treatment plants, plugs irrigation structures and canals, and fills reservoirs and lakes (Goldman et al., 1986; Hogan, 1988). When these costs are considered, the negative economic impacts of rangeland erosion may be greater than sustaining a constant level of vegetation.

UNIVERSAL SOIL LOSS EQUATION (USLE)

Erosion has been recognized as a problem in the fertile farmlands of the Midwest for a long time. The first erosion study plot was established at the University of Missouri Agricultural Experiment Station in 1917 (Young, 1976). The rate of soil loss constantly changes in each location because of many influences, and quantifying erosion was a difficult task. Research on erosion spread to many locations throughout the Midwest. The data gathered from these erosion plots was used to develop the Musgrave equation (Musgrave, 1947). The Musgrave equation uses slope, slope length, soil cover, conservation practices, rainfall intensity, rainfall energy, and soil erodibility to estimate the soil loss for a location.

The Universal Soil Loss Equation (USLE) was updated in 1978, simplified, and published as Agricultural Handbook No. 537 (Wischmeier and Smith, 1978). The USLE was based on the same parameters as the Musgrave equation (Musgrave, 1947), but it used a set procedure with nomographs. These nomographs were based on field data from 48 locations in 26 states, which made USLE more general, so it could be applied to most sites East of the Rocky Mountains. The USLE was developed to estimate yearly soil loss from a specific location on one slope in one field.

Since its development, USLE has been used to estimate soil loss from construction sites, mine sites, military bases, and even to estimate how rapidly plutonium fallout would reach our rivers in the form of erosion (Renard et al.,1989). The wide acceptance and general use of USLE are indicative of its value as a tool in estimating soil loss.

The USLE has limitations which the user needs to understand. USLE estimates the soil eroded from a slope, but it does not consider any deposition which occurs on that slope (Renard et al.,1989). It also does not give any sediment characteristics. USLE uses an empirically based equation to represent erosion; therefore, the actual erosion process is not represented by the equation. Rather, factors based on field conditions are multiplied together to give an estimate of erosion (Renard et al.,1989). These factors are derived from what was observed on the erosion plots.

Four major factors which affect erosion are included in USLE. They are: weather represented by (R), the erodibility of the soil (K), the slope characteristics (L and S), and the condition of the site (C and P) (Wischmeier and Smith, 1978). These parameters when multiplied together result in an estimate of average yearly sediment loss (A) (in tons per acre), where:

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

The USLE equation uses a standard unit plot 22.1 m (72.6 ft) long and 1.8 m (6 ft) wide (representing .01 ac). This plot is also on a 9% slope, tilled up and down slope and left fallow for at least two consecutive years. The USLE plot has been used to create an extensive data base of sediment yield with varying soil and surface conditions (Renard et al., 1978). This data base is the basis of the USLE equation.

The rainfall energy and runoff erodibility are represented by (R) in USLE (Wischmeier and Smith, 1978). The rainfall energy is the ability of the rainstorm to detach soil through the impact of raindrops. The runoff erodibility is the ability of the storm to transport sediment once it is detached and to detach more sediment through sheet flow and rill formation.

The soil erodibility is represented by (K) in the USLE equation (Wischmeier and Smith, 1978). This represents the permeability, structure, and texture of a soil. K is an index of a soils potential to erode through raindrop impact and flow over the soil. The nomograph for K was difficult to derive because of the complexity of soils and their variability with location and depth.

The first attempt to quantify soil erodibility was a cumbersome 24 term regression equation (Wischmeier and Mannering, 1969). Two years later a nomograph based on soil permeability, texture, structure, and organic makeup was developed (Wischmeier et al.,1971). This chart came from data taken from the farm belt, and was used to predict erodibility on loams and silt loams (Barfield et al.,1987).

The steepness factor and length factor are generally combined into one term, the slope length (LS) (Wischmeier and Smith, 1978). The slope length factor is 1 on a standard USLE plot. Slope length was defined as the distance from the beginning of overland flow to the point where deposition occurs or flow enters a defined channel (Smith and Wischmeier, 1957). In 1965, Wischmeier and Smith developed an equation for the slope length factor based on the slope angle and the length of the slope (Wischmeier and Smith, 1965).

The cover factor (C), is the ratio of sediment loss from a plot with some given plant and litter cover to the loss from standard a USLE plot with no cover (Wischmeier and Smith, 1978). The cover factors were developed from data gathered throughout the USLE study plots in the Midwest. Tables were developed to quantify various types and percentages of ground cover (row crop, meadow, woodland, parking lot) and the associated cover factors.

The final factor in the USLE equation is the soil practice factor (P). The practice factor is the ratio of erosion from a plot with some structural practice to the erosion from a standard USLE plot (Wischmeier and Smith, 1978). Practice factors consist of techniques like contour furrowing, terracing, pitting, or planting across the slope.

The cover factor and the practice factor are sometimes combined together into the cover management factor.

The USLE is constantly being modified and updated. The rainfall factor (R) was updated for a single storm event (Williams, 1975: Wischmeier and Smith, 1978). The (R) factor was updated for the Pacific Northwest to include values for the winter months (McCool et al., 1976) and by the Soil Conservation Service to recognize regional storm characteristics (Athesian, 1974; Soil Conservation Service, 1975; Woodward,1975). Modifications for gully erosion (Renard et al.,1974), rill and interrill erosion (Onstead and Foster, 1975), and limits on storm intensity (Hudson,1971) have improved USLE estimates of erosion.

REVISED UNIVERSAL SOIL LOSS EQUATION (RUSLE)

The most recent update of the Universal Soil Loss Equation is the Revised Universal Soil Loss Equation (RUSLE) by the Agricultural Research Service (ARS) and the BLM (Renard et al., 1989). While USLE was a very valuable tool for estimating erosion in the East, it proved inadequate for the more arid regions of the western United States. RUSLE advances the ability to analyze erosion in the West by updating the rainfall values (R), practice factors (P) used in dryland farming, a slope length (LS) table and algorithm, and a subfactor approach to the cover factor (C).

The most dramatic improvement found in RUSLE is the subfactor approach to the cover factor (Renard et al., 1989). The cover factor of USLE was based on high cover values of the eastern United States. It consisted of a table listing types of cover and their erosion relative to the standard plot. The updated, subfactor approach to RUSLE uses four factors multiplied together to get a (C) value which represents the erosion relative to a standard USLE plot. The four subfactors are: Prior Land Use (PLU), Canopy Cover (CC), Surface Cover (SC), and Surface Roughness (SR). Each of these subfactors is expressed in simple a equation providing cover factors for a broad range of land uses including some of the more arid western rangelands.

New research is continually improving RUSLE's ability to predict erosion. The subfactor approach to RUSLE allows the analysis of many different cover conditions, but RUSLE still underestimates sediment yield from sagebrush-grass rangeland by up to 20 times when the standard equation for surface cover (SC) is used (Benkobi, 1992). The standard surface cover equation is:

$$SC=\exp(-4\cdot M),$$

where SC is the surface cover subfactor, and M is the fraction of the land surface covered by mulch (Weltz et al.,1987).

The large variations in type and amount of cover on western rangelands requires a more complex method of analyzing the cover conditions. Recently, a Refined Surface Cover (RSC) equation was developed (Benkobi, 1992),

$$RSC=0.16VL+0.37R+1.02BG-.45VL \cdot R+6.97VL \cdot R \cdot BG.$$

The percent of the ground covered by vegetative litter (VL), rocks (R), and bare ground (BG) are measured to reflect the surface cover of rangelands more accurately.

Benkobi (1992) used the University of Wyoming simulator to rain on soil pans 1.0 m (length) • 0.4 m (width) • 0.1 m (depth) with a high intensity (100 $mm \cdot h^{-1}$) rainfall event for 30 minutes to develop his equation. The pans were set up on a 9% slope in a lab. The soil was placed uncompacted in the pans, saturated and then allowed to drain for 24 hours before the rainfall event. Several levels of cover in various combinations of plant litter and rocks were placed on the plots. The plots were rained on and the sediment from the plots collected.

The RSC relationship was developed using multiple linear regression techniques on the sediment yield with different cover combinations. The RUSLE surface cover equation estimated 5% of the measured sediment from an actual plot in Idaho (Benkobi, 1992). Using the RSC subfactor, RUSLE predicted 33% of the erosion from sagebrush-grass rangeland when compared to field measured values (Benkobi, 1992).

Continuing improvements in the RUSLE equation make it a promising tool for estimating soil losses from rangelands of the West. But, verification of its new algorithms needs to continue along with continued improvements in sediment yield prediction. Experience in the field will increase both RUSLE's reliability and the ability of the user to use it effectively and to recognize its limits.

## CHAPTER III

## METHODOLOGY

### CALIBRATING THE SIMULATOR

The purpose of a rainfall simulator is to create an artificial and controlled rainfall event. Rainfall simulators cannot duplicate all the variables of a natural rainfall event as nozzles do not produce a drop pattern or rain intensity that varies over time. It is also difficult to make a nozzle produce large enough drops to match a natural rainstorm. The drop size, drop distribution, intensity, duration, kinetic energy, and size of a storm in Wyoming are unique to a given storm and are difficult to duplicate.

Broader generalizations of storms in Wyoming are available. Storms that have a high intensity (25.4 $mm \cdot h^{-1}$ (1 $in \cdot h^{-1}$)), short duration (15 minutes), and return period of two to four years cause the most erosive damage in terms of soil loss (Huffsmith, 1988). The intensity of these storms often exceeds the infiltration rate of the soil. The excess water runs off, washing the soil surface pavement clean of loose sediment. Once the loose sediment is carried away, the erosion slows because more energy is required by the runoff to dislodge the more cohesive surface pavement. The storm intensity may then remain the same, but less erosion occurs. Therefore, a short duration (5 minute), high intensity (97 $mm \cdot h^{-1}$ (3.8 $in \cdot h^{-1}$)) storm was used in this research. This combination produced approximately the same rainfall amount (8.1 mm (.31 in)) per storm as the most damaging storm in Wyoming (Huffsmith, 1988).

The University of Wyoming simulator was assembled in the lab to run tests on its performance. This simulator was designed to produce consistent, easily reproducible storms. The secondary consideration was to duplicate natural rainfall events. The data gathered under consistent, controlled conditions can be extrapolated to other conditions.

The selection of a nozzle and its placement over the plot was the first consideration. Seven flat spray nozzles from Spraying Systems Incorporated were tested. The Veejet 80150, 80100, 8070, and 95100 nozzles produced rain intensities too high for this study. The Veejet 8060, and the Veejet 9560 nozzles produced drop sizes too small to provide adequate kinetic energy. The Veejet 9570 nozzle selected produced intensities between 76.2 $mm \cdot h^{-1}$ and 101.6 $mm \cdot h^{-1}$ and the largest raindrop size (1.9 mm).

The nozzles are located 1.57 m from the center of the simulator. The Veejet 9570 nozzle operating at 41.4 kPa (6 psi), makes an oval spray pattern. The intensity at the center of the oval is nearly uniform, but intensity decreases at the edges. Below 41.4 kPa (6 psi), the pattern becomes less uniform and more circular. Above 41.4 kPa (6 psi), the oval becomes wider, but intensity does not become significantly more uniform. At 41.4 kPa (6 psi) and 1.57 m from the center, the uniform section of the spray pattern consistently covers two symmetrically located plots entirely (Figure 1).

Rainfall intensity was measured in the lab. Thirteen 200 ml beakers were placed side by side in a rack radially under the simulator, starting 0.5 m from the center. Screens were placed around the rack of beakers to minimize raindrop splash off of the floor. The beakers covered the full arc of the plots. The nozzles were 2.76 m (109 in) above the beakers. The tests were run in the lab to prevent wind drift, but the ceiling in the lab prevented reaching the full height of 2.95 m (116 in) used in the field. The simulator was run at 41.4 kPa (6 psi) and four rpm for five minutes, and the volume of water collected in each beaker was measured. The exposed area of the beakers and the duration of the event were constants. The average intensity for eight simulations was 97 $mm \cdot h^{-1}$ (3.8 $in \cdot h^{-1}$).

The duration of the simulation was chosen to represent the amount of rain produced from a natural most damaging event and to allow several simulations to be run in the

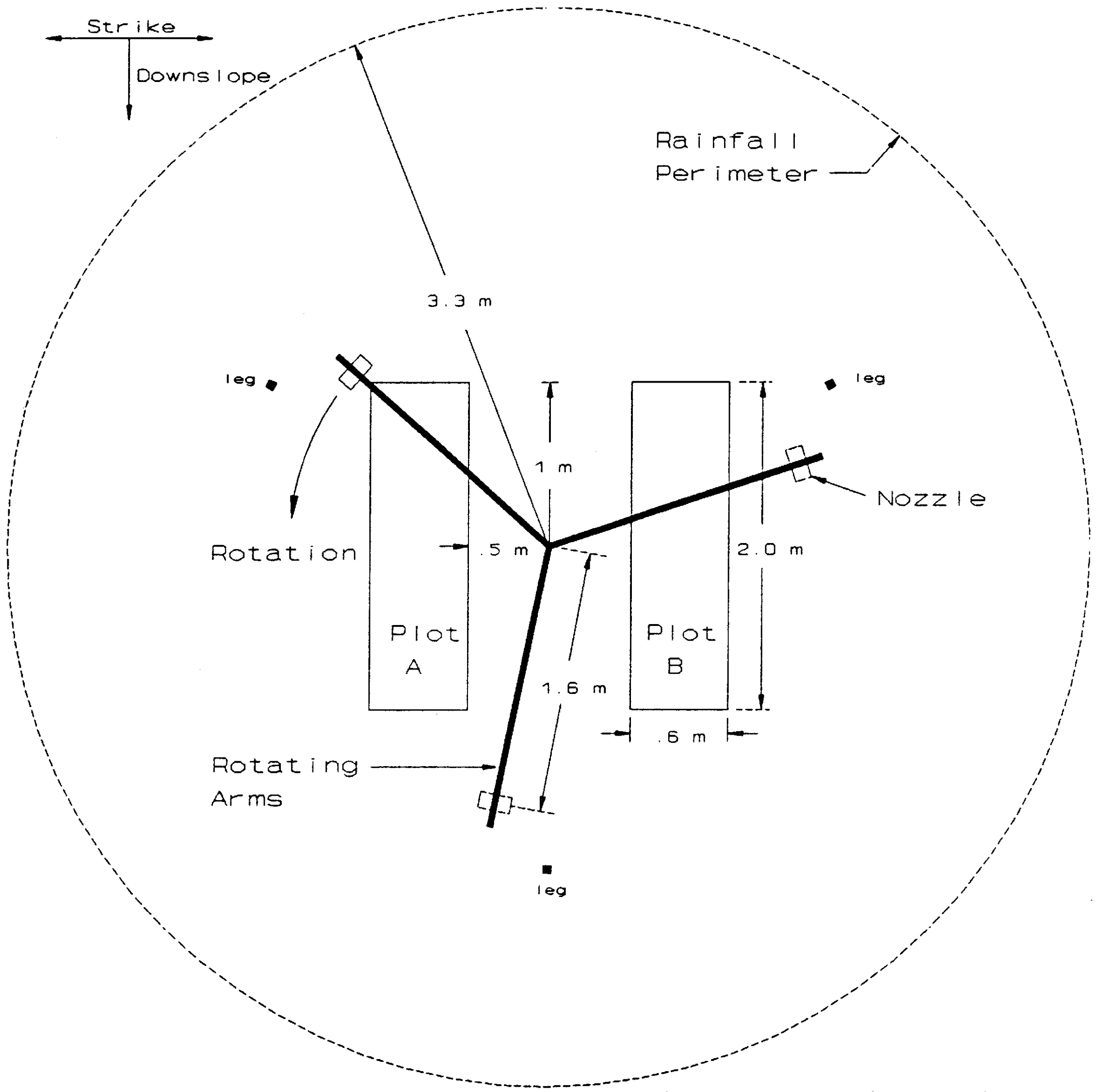


**Figure 1.** Plan View of the University of Wyoming rainfall simulator shown over the plots.

field in one day. The amount of water applied for each simulation of five minutes was 8 mm (.3 in) ± .2 mm, and the simulator used only 227 l per simulation.

The rotation rate for the simulator was set at four revolutions per minute in a counter-clockwise direction. This rate was easy to set and check with a stopwatch, allowed some temporal variation of intensity, and produced negligible centrifugal effects in the drops. As the nozzle passed over a spot, the intensity increased until the nozzle was directly overhead, then decreased to a mist until the next nozzle passed. The soil surface appeared to seal and less percolation occurred, when higher rotation rates were tested.

The average drop size was measured using the oil method (Eigel and Moore, 1983). A mixture of 2:1 mineral oil and STP was placed in a petri dish. This mixture is viscous enough to allow the rain drops to become spherical, yet not too viscous so droplets splash when they hit the surface. The drops which hit the oil mixture slowly settle to the bottom. This allows the petri dish to be placed on a table and a picture taken of the spherical drops. The setup included a metric scale, so when the picture was developed, the diameter of the sphere was measured. The drop sizes were measured from four pictures from each nozzle.

All the drops which could be measured were measured in each picture. This produced an unnaturally small estimate of the raindrop size for the simulator because there was a mist which accompanies any spray nozzle. The large number of mist droplets, when averaged with the larger raindrops, brought the average drop size down. The average measured drop diameter was 1.09 mm ± 0.04 mm. This is smaller than the desired drop size of 2 to 4 mm, but, again, the estimate may be low. The temperature of the water was measured, the average volume of the raindrops was calculated (.67 $mm^3$), and the mass of the raindrops was calculated (.067 mg). Using the manufacturer's (Spraying Systems Incorporated) data, median drop diameter is 1.98 mm at 41.4 kPa (6 psi)(Appendix B). This is a much more realistic value that does not reflect the mist associated with the spray. It is also very close to the minimum recommended drop size.

The average velocity was estimated using a photographic method. A sheet of plywood was painted flat black. The plywood was placed 1 m behind the nozzle, and the floor was covered with screen to minimize splash. A meter scale was placed directly under the stationary nozzle and used to focus a camera. Four pictures were taken under each nozzle at different shutter speeds. At a speed of 125 th of a second, the raindrops appear as streaks against the black plywood. Several streak lengths were measured in each picture and the average velocity was found to be 7.42 $m \cdot s^{-1}$. Only streaks that appeared independent of each other were measured.

The kinetic energy of the raindrops was calculated using the equation:

$$Kinetic\ Energy = 0.5 \cdot (Mass \cdot Velocity^2).$$

The average mass of the drops produced by the University of Wyoming simulator was 0.67 mg. The average velocity was 7.42 $m \cdot s^{-1}$. The kinetic energy was 0.018 mj.

Using the median drop diameter from the manufacturer, the kinetic energy is 0.099 mj.

DESCRIPTION OF STUDY AREA

Once the operating parameters were defined, sites were chosen for field simulations. The Fifteen Mile Creek drainage west of Worland, Wyoming, the Ten Mile Creek drainage north of Worland, Wyoming, and areas on Beaver Creek and Little Jack south of Rawlins, Wyoming, were selected for study.

The first site west of Worland was the Fifteen Mile drainage, a cold desert environment in northwestern Wyoming. The annual precipitation of the region averages 203 mm (8 in) with a mean annual temperature of 7 C (45 F)(Martner, 1987). The lower elevations of Fifteen Mile Creek receive an average of 152 mm (6 in) of annual precipitation (Hogan,1988). The soil belongs to the Greybull-Persayo association. The area is sparsely vegetated with saltbush (<u>Atriplex</u> spp.), pricklypear cactus (<u>Opuntia</u> sp.), blue gramma (<u>Bouteloua gracilis</u>), and shrubs (Soil Conservation Service, 1983). Badlands cover a large amount of the drainage area with steep slopes. The primary uses are grazing, recreation, and some oil and gas exploration. This area provided the lowest total ground cover amounts.

Fifteen Mile drainage has severe soil erosion problems. The watershed empties into the Bighorn River where it contributes only 0.8% of the mean annual flow, but 75% of the sediment of the river (Cooper,1979). The BLM recognized the problem and installed sediment retention structures, water spreaders, drift fences, and a revegetation program in the 1950's and 60's. The program was not completed, but about 25% reduction of sediment was realized (Yochem et al., 1978). High costs of construction and seeding prevented the project from being completed. Revegetated areas are prospering relative to natural vegetation, but the erosion control structures have not been maintained.

The second site in the Bighorn Basin was located in an area on the Ten Mile Creek drainage. The average annual precipitation of this area was also 203 mm (8 in) with a mean annual temperature of 7 C° (45 F°) (Martner, 1987). This site had a much higher amount of ground cover than the Fifteen Mile Creek area. The vegetation cover consisted of wheatgrasses (Agropyron spp.), needle-and-thread (Stipa comata), and big sagebrush (Artemisia tridentata) with some blue gramma and pricklypear cactus also present. There was no visible evidence of grazing during the period before rainfall simulations were run. The soil in this area was a Uffens-Rairdent complex (Soil Conservation Service, 1983).

The third research area south of Rawlins was on the Stratton Sagebrush Hydrology Study area located 29 km west of Saratoga, Wyoming. This area is a higher, wetter area with more vegetation than the Worland study areas. The average annual rainfall is 516 mm (20.3 in) with 117 mm (4.6

in) falling as summer precipitation. The average elevation was 2225 m (7300 ft). The vegetation consisted of big sagebrush and grasses (Fescues, bluegrasses, and needlegrasses). The soil belonged to the Youga series, a fine-loamy, mixed Argic Cryoboroll (Sturges, 1991).

The first site in the Stratton Hydrology Study Area was on Beaver Creek. It was located in an exclosure on a north facing slope. This exclosure was not grazed by livestock from 1961 to 1991, and received a higher amount of moisture from wind deposited snow than the surrounding area. The site had high cover with values from 85 to 100% cover. The plots with 100% cover had a mat of litter several centimeters thick.

The second site south of Rawlins was on a north facing slope on a State section (Sec.36,T17N,R87W). This site received an average annual precipitation of approximately 381 mm (15 in). This site had slightly more sand in the surface soil than the exclosure site. The ground cover for the State section ranged from 40 to 70%, and had been grazed by cattle at the time of the simulations.

SIMULATION EXPERIMENTS

The design of this experiment involved ground cover as the controlled variable. Plots were chosen with a range of cover from 0 to 100%. Slope, plot size, rain intensity, and storm duration were all maintained as constants for all simulations. The soils were not the same, but surface texture was shown to be similar based on grain size analysis. All the soils had high percentages of silt and very fine sand which are highly susceptible to erosion. Surface roughness was not a controlled variable. Surface roughness was measured for each plot, but it was not a decision criteria for this experiment.

EROSION PINPLOTS

Specific sites for running rainfall simulations were identified in the study areas. The original plan involved conducting the simulations on erosion pinplots. These pinplots were established at each study area. These plots were standard USLE plots with thirty randomly placed pins. The height of the pins projecting above the ground could be accurately measured over the next five years. A simulation would be run on either side of the pinplots and the sediment yield would be calculated. The simulations and the pinplots would have about the same cover, soil, grazing, and weather. In the future, the pinplot data could be compared with the simulation data allowing the actual erosion data from the pinplots to be compared with simulation data.

The first task was to select pinplot locations, which would automatically locate the first simulations. Twelve pinplot locations were selected and placed outside of Worland and twelve outside of Rawlins. The goal for this project was to measure the relationship between total ground cover and sediment yield.

A constant slope of approximately 9% for 22.1 m (72.6 ft) was required for the erosion pinplots. The slope was measured using a 3.05 m (10 ft) section of PVC pipe placed parallel to the dip and measured using a hand held inclinometer. The cover had to be relatively uniform over the length of the plot and each pinplot had to represent a part of the total range of cover (0 to 100%). Preferred sites would be close together allowing easier pinplot measurement in the future and minimizing the time required to move the simulator.

Ideally, the soil would be the same at each simulation and pinplot site. Unfortunately, the percentage of ground cover also reflected the soil type and environmental conditions. The sites with the lowest cover had higher amounts of clay, the middle cover ranges had higher amounts of sand, and the highest cover was found on soil that was silty loam. All the sites were in areas that have shown a tendency to be highly erodible.

The sites were all on native rangeland. Some of the sites were ungrazed, some were grazed, and some were heavily grazed. None of the sites had ever been tilled. Range was not classified by the relative terms good or poor. Excellent ranges for sites near Worland involved cover greater than 50%, but 50% cover on the sites near Rawlins would be listed as fair to poor based on species composition. Sites were graded strictly on percentages of ground covered by plants, litter, and rocks. Additional simulations were run both in Worland and Rawlins to fill in gaps in cover values.

SIMULATION PROCEDURES

The simulation sites beside the erosion pinplots were checked to make sure they represented the same percentage of cover, type of soil, and maintained the 9% slope. Each simulation site had two plots 0.6 m wide and 2 m long. The two plots were separated by 1 m (Figure 1). The long axis of the plots was oriented parallel to the slope with plot A on the left and plot B on the right when facing up slope. Two plots were used to account for the rotating action of the rotating sprayer arms. As the sprayer nozzles rotated counter-clockwise down plot A, sediment movement might be accelerated down the slope. As the sprayer arms rotated upward over plot B, sediment movement was slowed.

Two plots were chosen instead of one large plot centered under the simulator so that access to the center of the simulator site was available without disturbing the plots. Each plot was located by a rigid frame made of aluminum angle iron. The frame was placed in the location for simulation and a 20 cm (8 in) spike located the center of the site between plot A and plot B. A border of sheet metal 10.1 cm (4 in) high by 0.6 m (23.6 in) wide by 2 m (78.7 in) long surrounded each plot on the uphill and two sides. These sheet metal strips were driven into the ground

2.5 to 5 cm (1 to 2 in) using a hammer and block of wood. This prevented sediment from outside the plot from entering the plot or detached sediment from within the plot from not being collected. It also decreased the amount of splash erosion entering and leaving the plot.

The surface roughness of each plot was measured using an elevation table. The elevation table is a table manufactured of aluminum with four adjustable legs. The elevation table was made to fit snugly inside the sheet metal of a plot. One hundred pins 80 cm (31.5 in) long slide in holes made in the top of the table. The pins are arranged in twenty rows of five (Figure 2).

The table is placed inside each plot as far uphill as possible. The legs are extended as far as possible, then the highest leg on the top and bottom of the slope is lowered until the table is level across the top and bottom edge. The table is now parallel with the slope and one leg on the upslope side and one leg on the downslope side is fully extended. This allows the table to be placed in the exact same position after a simulation.

The height of each pin was measured using a digital depth gauge mounted in a sliding bracket. The gauge was raised to its maximum height, zeroed, slid over the pin, the distance down to the pin was then recorded electronically with a Polycorder notebook. Once all the elevations for the pins were recorded, the type of cover (plant, rock, or bare

Figure 2. The elevation table being used to measure elevations over the plots.

soil) touched by each pin was logged. Data collected from the elevation table allows for the future analysis of the effect of surface roughness on sediment yield.

After the surface roughness data were gathered, sediment collecting pans were placed at the bottom of each plot. The pans were 0.6 m (23.6 in) wide and 5 cm (2 in) high and fabricated from galvanized sheet metal. They fit across the bottom of the sheet metal side tins, collect all the sediment, and funneled it down into a PVC pipe 3.05 m (10 ft) long (Figure 3). The pans were flat on the bottom so they collected the suspended sediment and the bedload. A lid of sheet metal prevented water drops which would fall on the pan from splashing the sediment samples.

A square spade was used to cut a line across the bottom of the sheet metal tins to place the pans. Care was taken to not disturb the soil within the plots. The soil was removed below the plots to a point level with the lowest spot across the bottom. The pans were then butted against the soil flush with the bottom edge of the tins. Once the pans were ready to place, a shallow trench was made for the PVC pipe so that it maintained the 9% slope. At the end of the pipe, a hole was excavated approximately 30 cm (1 ft) deep and 1 m (3 ft) in diameter for a collection tub. The pans, attached to the PVC pipe, were then placed against the tins and several small piles of soil were placed over the PVC and around the pans to hold them in place. Any holes across the edge of the pan were filled with soil and water was applied to the entire edge. Wetting this edge minimized the effect of water washing the disturbed edge sediment into the pan and eliminated undercutting of the pans. Two sets of pans were used so that once the pans were set and the edge wet, they had several hours to dry before the simulation was run. The pans and PVC pipe were rinsed of

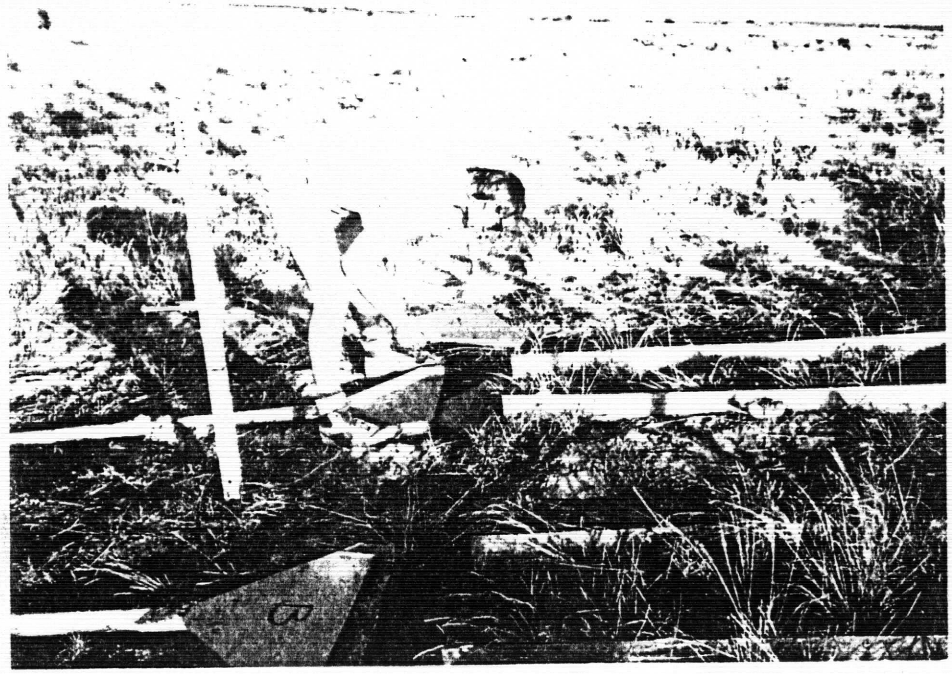

Figure 3. The collection pans funnel sediment from the plots into PVC pipes. The sheet metal around each plot prevents sediment from moving into or out of the plots.

all sediment and the lids were placed over the pans prior to each run.

The simulator was centered over the two plots using the pin placed in the center of the site as a reference. Two legs of the simulator were placed uphill approximately in line with the back of the tins. One leg was placed downhill about 1 m (39.4 in) below the bottom of the tins and centered between them. The simulator was then raised using its adjustable legs until the bottom of all three nozzles was at 2.95 m (116 in), ± 2.5 cm (1 in). The plane of the rotating nozzle arms was parallel to the slope of the ground. Two guide ropes were tied to the top of the upper two legs to two steel fence posts driven in the ground to compensate for the slope of the ground and to add some stability to the simulator (Figure 4).

The two plots were covered with a tarp prior to the start of the simulated rainfall. This protected the plots from any unexpected disturbance or rainstorm. The nozzle arms were rotated through the use of an electric motor and gear reducer controlled by a rheostat. A generator was started and the rotation rate of the nozzle arms checked using a stopwatch. The rotation rate chosen in the field was four rpm. Since there were three arms each with one nozzle, this allowed 60 passes of the nozzles over each plot in a five minute rainfall simulation.

A water pump was connected to a 756 l (200 g) tank and then to the simulator. One l sample bottles were tagged with the site number, plot A or B, sample collection time, and arranged at the end of the PVC pipe. Two clean 11.3 l (3 gal) tubs were placed under the bottom end of both PVC pipes to collect all the runoff water and suspended sediment from each plot.

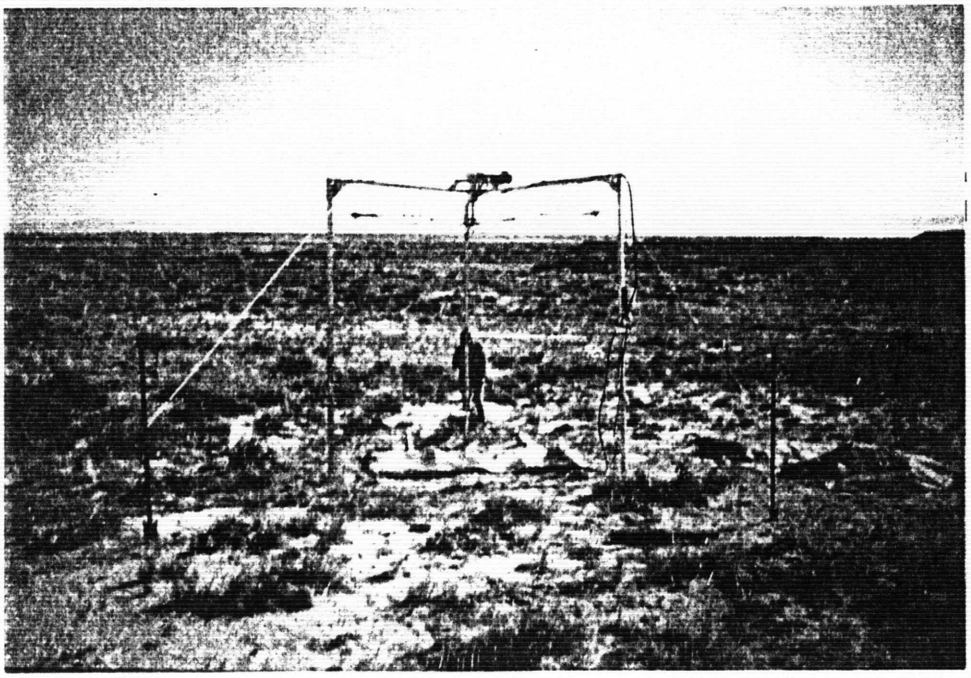

Figure 4. The rainfall simulator, over the plots, ready for a simulation.

A soil sample from the top 2 or 3 cm (1 to 1.5 in) of soil was taken from between the two plots. These soil samples were used for soil grain size analysis. Finally, the date, time, nozzle height, and weather conditions were recorded along with any relevant observations. The initiation of runoff, total runoff time, total water and suspended sediment collected in the tub, and any comments or observations made during the simulation were recorded.

An estimation of wind speed was made before the simulation began. If the wind was considered too strong, wind screens were put up, or the simulation canceled until a later time. Winds less than 16.1 $km \cdot h^{-1}$ (10 mph), had little effect on the drop pattern over the plot. The edges of the spray pattern were moved by the wind, and a mist was felt down wind from the simulation. The wind screens were used on some simulations, but if the wind was strong enough to require their use, it was usually strong enough to limit their effectiveness.

Each simulation began by starting the pump and generator. The valve on the simulator was then slowly opened allowing water through the simulator and out the nozzles. The plots remained covered while all the air in the lines was purged. Once the air was blown out of the lines, the valve was opened until the pressure gauge mounted above on the simulator head read a constant 41.4 kPa (6 psi).

When the pressure was constant, and there was no more air blowing out the nozzles, the tarp was pulled off the plots and the nozzle arms were started rotating. A stopwatch was started at the same time the sprayer arms were started. This represented the beginning of the rainfall event. One person was responsible for observing the plots, maintaining water pressure at 41.4 kPa (6 psi), watching the time of the simulation, and filling out the notebook. Two other people were responsible for removing the tarp, and timing and taking water and sediment samples from both plot A and plot B.

The plots were observed for ponding, overland flow, and any problems or comments. The two people that removed the tarp moved to the tubs at the end of the PVC pipe. They watched for the initiation of water and sediment flow out the end of the pipe. When flow water and sediment reached the end of the pipe, the amount of time since the beginning of the rainfall event was recorded for each plot.

Stopwatches were also started with the beginning of water and sediment flow from the PVC pipe for each plot. These stopwatches recorded the duration of runoff from each plot and were used to time sediment grab samples used to calculate the sediment yield. This procedure normalized the water and sediment flow for later use in calculating a plot of sediment yield versus the time of the runoff for each plot, or the sedigraph for each plot.

Water and sediment samples were taken from both plot A and plot B for ten second durations at 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 240 s, and 300 s if runoff lasted that long. After the simulator ran for five minutes and sixty revolutions, the water was shut off. The sprayer arms were stopped with the nozzles off of the plots to prevent any excess water draining out of the simulator and onto the plots.

All the water and sediment from the plots that was not actually taken as a sample, was collected in the tub below the PVC pipe. When a simulation was finished, the water and sediment in the tub was thoroughly mixed by swirling the sample and a sub-sample was taken. This sub-sample was labelled the final sample from this plot and was assumed to represent the average water and sediment mixture for all the sediment collected in the tub. The total water volume in each tub was also measured and recorded.

The edge of the plot below the pans was checked after the simulation for any piping or seepage under the pans. The sheet metal tins were left in place to allow the placement of the elevation table for measuring surface roughness and percentage cover. The simulator was then moved to the next site.

Approximately twenty-four hours after the simulation was run, the plots were dry enough to remeasure the surface roughness with the elevation table. The elevation table was carefully placed in the same position inside the tins, raised all the way up and the high corner lowered until the table was level across the top and across the bottom. The elevation of the pins was remeasured. The elevations and cover measured may be evaluated in the future to determine where erosion and deposition occurred around the cover present in the plot.

The sheet metal tins around the plots were removed, after the second elevation readings. The ground cover within each simulation plot was measured using a point frame with 10 pins. Fifty randomly selected points were measured. A pin was lowered until it intercepted vegetation, litter. rock, or bare ground. Each interception was considered one data point, fifty per plot. Individual plant species cover was measured by counting interceptions of the pins, with the stem parts of the plants, at ground level. Litter, rock cover, and bare ground were also measured by recording the contact of the pins at ground level. Percentage ground cover was then calculated for each plot.

LAB ANALYSIS

The water and sediment samples were brought to the lab for analysis. The bundles of sample bottles for each simulation were taped together in the field to prevent losing any samples. In the lab, the samples were organized by site and plot. Small .568 l (pint) jars were used to evaporate the water from each sample to give the weight of sediment in the sample. An empty jar was weighed and the weight recorded. The volume of water in the sample bottle was measured, recorded, and poured into the jar. The graduated cylinder used to measure the volume of water and the sample bottle were rinsed of any sediment and the rinse water poured into the jar.

The jars with water and sediment samples were placed in an oven heated to 104 C. All the water was evaporated from the samples in 24 h. The jars were allowed to cool for 10 min, then they were reweighed. The weight of the jars was subtracted from the final weight to give the weight of the sediment for each sample.

The sample data sheets contained the volume of water and the weight of sediment for each sample. The volumes of water and masses of sediment at each collection time were added to the volume of water and the mass of sediment collected in the tub. This was a direct measurement of the volume of water from each plot.

The mass of sediment was calculated by assuming the sub-sample from the swirled collection tub had the same mass of sediment per volume of water as the remainder of the water in the collection tub. By multiplying the mass of the sub-sample times the total volume of water in the collection tub, then dividing this product by the volume of water in the sub-sample the mass of sediment in the collection tub was measured indirectly. The mass of sediment in the collection tub was added to the mass of sediment collected at each collection time to provide an indirect estimate of the mass of sediment from each plot.

The volume of water and mass of sediment at each collection time with the volume of water and mass of sediment from each sub-sample and the volume of water in the collection tub provided information to estimate the sediment yield and the sedigraph for each plot. A BASIC program was written for this task (See Appendix A).

Inputs into the program were the amount of sediment and volume of water at each sample time and for each plot. The final sub-sample and the total final volume were also input for each plot.

The total volume of runoff for each plot was calculated by adding the volume of water and sediment at each sample time to the final volume of water collected in the tub. If the runoff collected in the tub was larger than 500 ml, a sub-sample was taken. An estimate of the sediment contained in the tub was made by assuming the sub-sample had the same concentration of sediment as the runoff collected in the tub.

The sediment yield was calculated two different ways. First, the weight of sediment for plot A and plot B was averaged and divided by the area of one plot (1.2 $m^2$). Then, this value was used to calculate the average sediment yield in $mt \cdot ha^{-1}$ and $t \cdot ac^{-1}$. This calculation accounted for the rotating action of the simulator that accelerated sediment from plot A and decelerated sediment from plot B. The second method that sediment yield was calculated was for each plot individually. The weight of sediment for plot A was divided by the area of one plot (1.2 $m^2$) and this value used to find the sediment yield from plot A in $mt \cdot ha^{-1}$ and $t \cdot ac^{-1}$. The weight of sediment for plot B was divided by the area of one plot and this value used to calculate the sediment yield from plot B.

The sedigraph was also calculated for each site. The sediment was collected for ten second intervals at 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 240 s, and 300 s for each plot. These values were added together for plot A and plot B to get the total sediment collected in the samples, excluding the final grab samples, or the percentage of sediment collected in the sample bottles. If there was runoff from both plots, the weight of sediment from plot A at 30 s was divided by the percentage of sediment collected in the bottles from plot A. The weight of sediment from plot B at 30 seconds was divided by the percentage of sediment collected in the bottles from plot B. The values from plot A and plot B were then averaged together. The average was divided by 10 to convert the 10 second sample to a single 1 second sample assumed to occur half way through the collection (for the 30 second sample, the sedigraph point would be at 35 seconds). This value was then multiplied by the sediment yield calculated earlier to give a value of sediment yield in $mt \cdot ha^{-1}$ and $t \cdot ac^{-1}$ at 35 s. This was done for each 10 s collection time. If there was no runoff from either plot, the program indicated insufficient data.

The program then printed out all of the input values. The values for the sediment yield in $mt \cdot ha^{-1}$ and $t \cdot ac^{-1}$ were printed for the average of both plots and each plot independently.

One of the purposes of this project was to find the relationship between total ground cover and sediment yield. The values of sediment yield for the plots was plotted versus the ground cover to get a graph of the relationship. The average value of sediment yield for the two plots in each site was first plotted versus ground cover. However, this presented problems because the percentage of ground cover for plot A was sometimes different from the value of ground cover for plot B, as these plots were not identical.

The values of sediment yield calculated for each plot could be plotted with the percentage cover measured for each plot, but the rotating action of the sprayer arms would not be taken into account. To determine the dependence of the sediment yield versus ground cover on the action of the simulator, the data for each plot was analyzed with a Paired T-Test. The results of the Paired T-Test showed that sediment yield and ground cover were independent of the rotating action of the sprayer arms. Therefore, the sediment yield for each plot could be plotted with its own cover value.

The soil from each site was subjected to a sieve analysis and hydrometer test to determine the grain size characteristics for each soil (ASTM D-442-63). The soils were not the same at the four research sites. Sites were selected based on having soils with similar distributions of particle grain sizes. Soils were chosen with high amounts of silt and very fine sand (sand with a diameter between 0.002 and 0.1 mm) (Barfield et al., 1987) because of the erodibility of these soils (Goldman et al., 1986).

# CHAPTER IV

## RESULTS AND DISCUSSION

The primary goal of this research was to establish a relationship between total ground cover and sediment yield for a "most damaging storm". This relationship was derived by keeping all variables (slope, plot size, storm intensity, and storm duration) in each simulation constant, and measuring the sediment yield for plots with different amounts of ground cover. Ground cover was defined as any plant, litter, or rock on the soil surface of the plots.

### SOIL TEXTURE

Ideally, soil type would also be held constant. Undisturbed rangeland sites with the same highly erodible soil and a range of cover from 0 to 100% were not found. To minimize the effect of having different soils, simulations were run on soils with similar particle sizes. Soil samples from each plot were classified by grain size, with the average soil consisting of 79% sand, 17% silt, and 4% clay. The percentage of clay was approximately the same (less than 7%) with an average value of 4% in all plots. Only two of the plots at the Rawlins research area with 100% cover had slightly different percentages of silt and sand (See Appendix D). Some variability existed in the amount of silt and very fine sand of the soils, typically the texture of highly erodible soils.

SURFACE ROUGHNESS

Surface roughness of a plot is related to the effectiveness of ground cover to control sediment yield (Renard, 1989). It is difficult to maintain a level surface while varying the percentage of ground cover on natural rangeland. The surface roughness was not a decision variable in this research. However, the value of roughness associated with the selected cover was measured.

Surface roughness reflects the undulations of the soil surface and the ground cover on the soil surface. To evaluate surface roughness, RUSLE uses the standard deviation of the soil surface from a level plane (Renard et. al, 1987). On a tilled field, an average value for surface roughness is easy to estimate, and is reasonably uniform. Rangeland presents a problem because roughness may vary greatly in a small distance.

The elevation table was used before and after each simulation to measure the surface roughness of each plot. Improving the analysis of surface roughness and its relation to sediment yield was beyond the scope of this research, but roughness information was needed to evaluate RUSLE. The standard deviation of each plot, before simulation, was used as the surface roughness in the RUSLE equation to estimate soil loss from each plot.

When surface roughness of the plots was plotted against sediment yield, sediment yield appeared to level off at 0.1 mt•ha$^{-1}$ when the surface roughness reached 18 mm (Figure 5). There was a very weak correlation between surface roughness and sediment yield with a correlation coefficient of 0.28 (Devore, 1982)(Appendix E). Since surface roughness was not a decision variable, the measured roughness values were not over a specific range. Roughness values were not random, because they were associated with the chosen cover values. There were no data points below 10 mm and only 9 above 25 mm. The narrow range of surface roughness data points (10 to 25 mm) was not sufficient for a realistic evaluation of surface roughness. There was a trend towards lower sediment yield as roughness increased, but more study over a wide range of roughness values is needed.

When ground cover was plotted against the surface roughness, there was no obvious relationship (Figure 6). The correlation coefficient for these data were 0.45 (Appendix E). This indicated a weak correlation between ground cover and surface roughness (Devore, 1982). Surface roughness and sediment yield however, appeared to be related (Figure 5). But how much sediment yield is dependent on surface roughness or ground cover separately is difficult to discern and beyond the scope of this research.

Figure 5 shows that a small amount of surface roughness affects sediment yield, but there is no indication of how

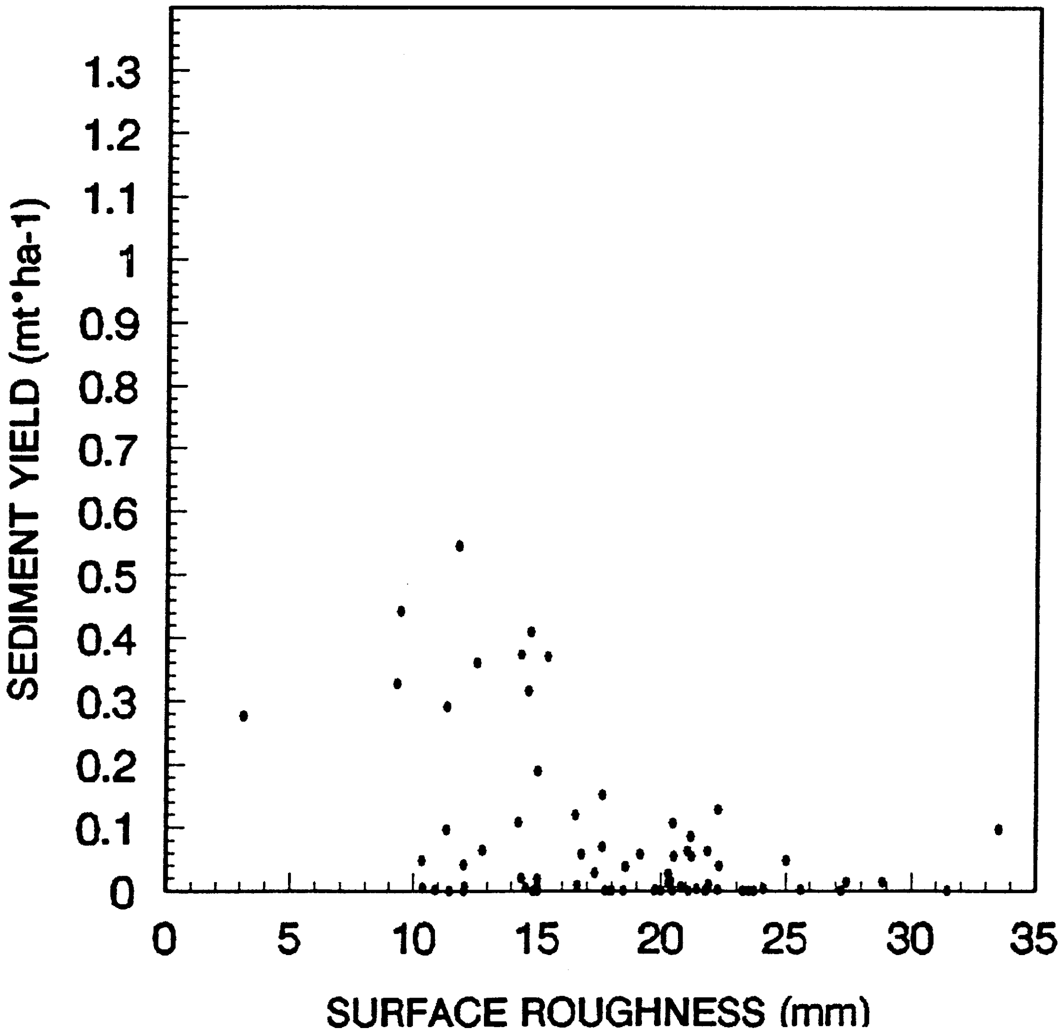


Figure 5. Standard Deviation of Surface Roughness vs. Sediment Yield.

spatial variability of surface roughness relates to sediment yield. Spatial variability may play an important role in surface roughness when surface roughness is below 18 mm. If the surface roughness occurs predominately along one side of the plot, the depressions may join to form a channel, or rill. This interconnection may allow considerable erosion from the plot. If the roughness occurs predominately on the

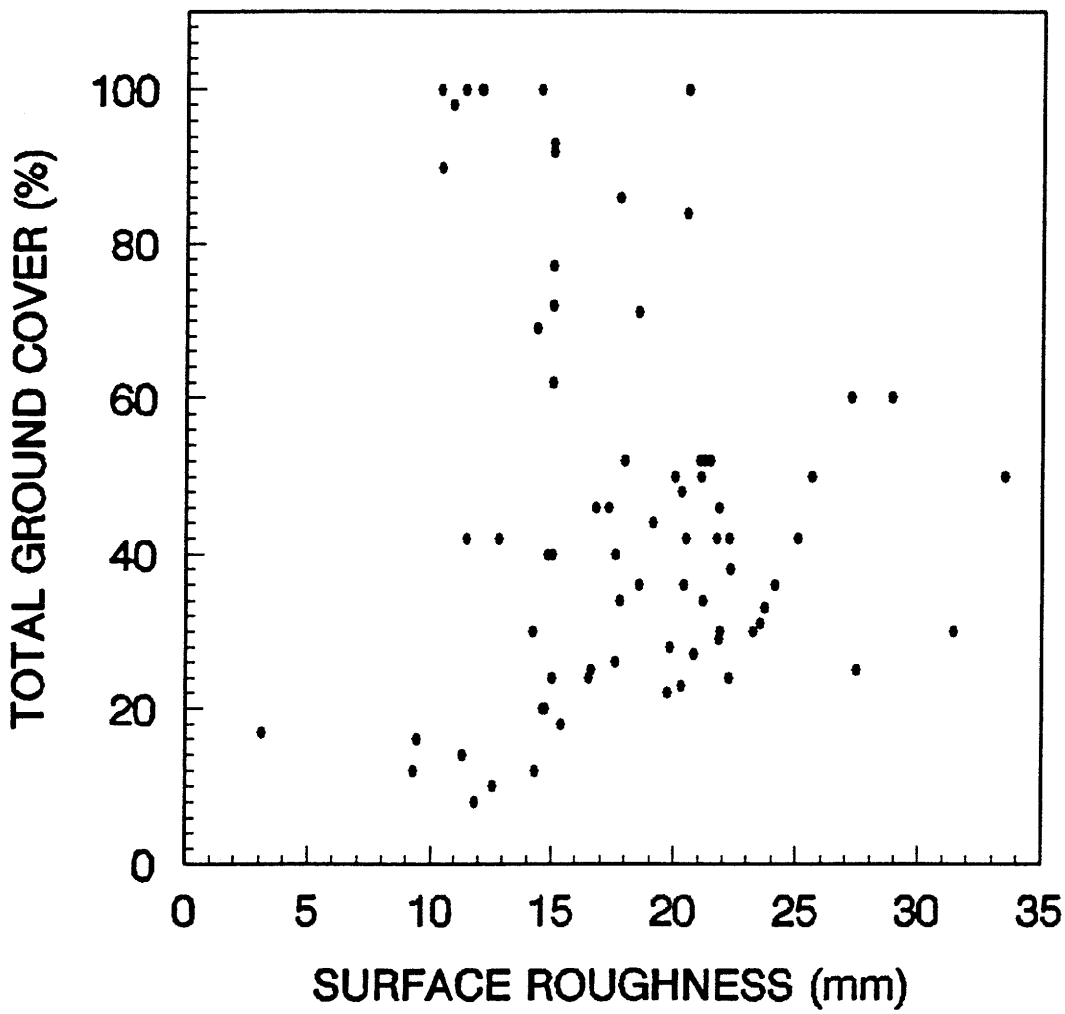


Figure 6. Standard Deviation of Surface Roughness vs. Percent Ground Cover.

top half of the plot, more erosion may occur on the bottom half of the plot. Conversely, if roughness occurs predominately on the bottom half of the plot, the soil surface at the bottom of the plot may act to trap sediment from the top of the plot. The size of the plot might have an effect of spatial variability and its importance to sediment yield. If the plots are large enough, the runoff will find a path downslope. There was no literature found on the role of spatial variability of cover or surface roughness as it might affect sediment yield.

GROUND COVER

The relationship between ground cover and sediment yield was evident (Figure 7). The correlation coefficient for the data was 0.71. This moderate correlation (Devore, 1982)(Appendix E) was a better correlation than with surface roughness. The large number of zero values for sediment yield tended to reduce the correlation coefficient. Spatial variability of surface roughness might help explain many of the zero sediment yield values that prevented sediment from leaving the bottom of the plot. Six data points were not used for calculating the correlation coefficient because they were outliers. The values for tilled plots with zero cover were not representative of rangeland conditions, and the very high point at 1.32 $mt{\bullet}ha^{-1}$ was a high outlier. Visual examination of the data shows a well defined upper limit to the curve (Figure 7).

At 30% total ground cover the sediment yield leveled off at about 0.1 $mt{\bullet}ha^{-1}$ (Figure 7). When cover was below 30%, erosion increased dramatically. As cover increased to 70%, erosion declined to negligible values.

Inspection of the plots with 100% cover after a simulation showed little or no water reaching the soil underneath the litter cover. Plant litter was washed from the surface of the grass and collected instead of sediment,

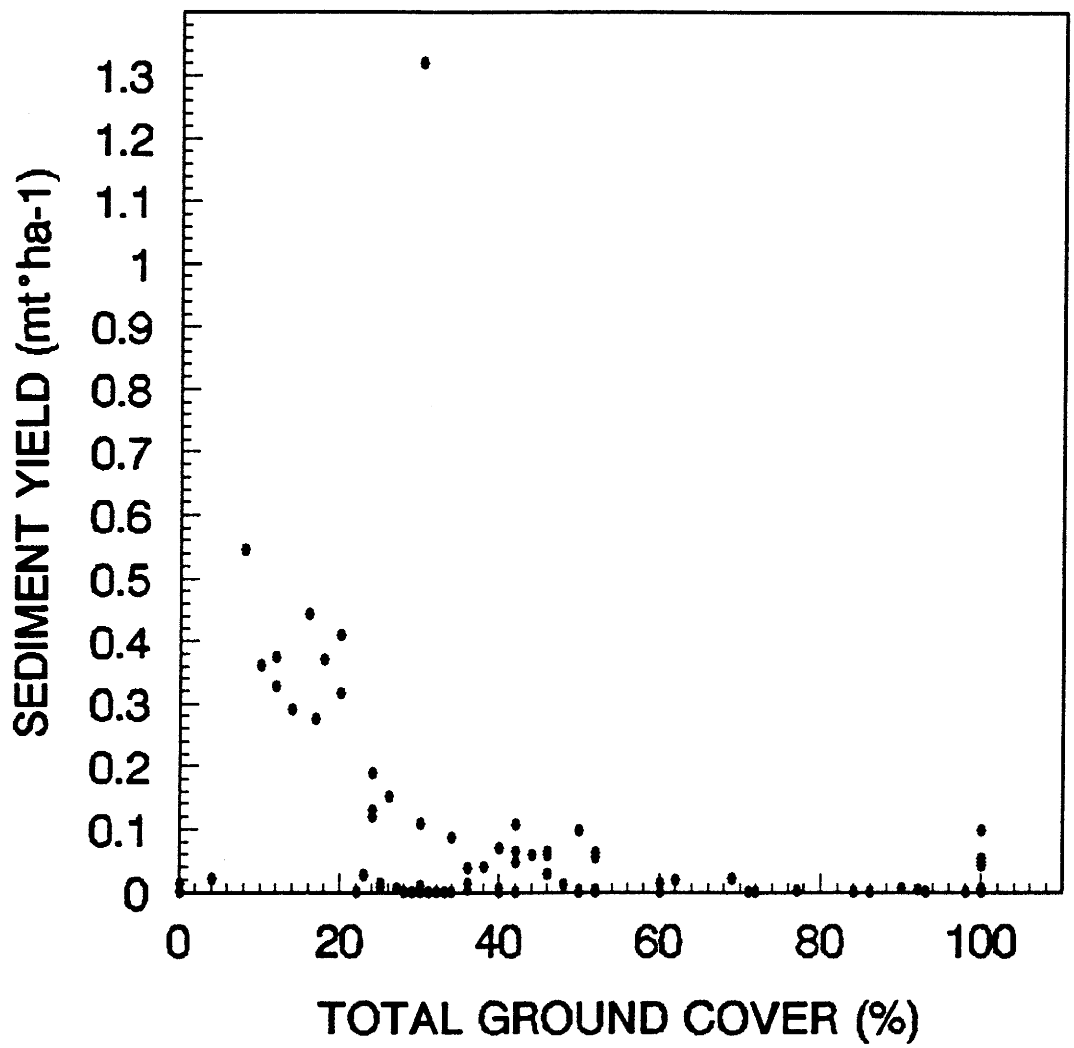


Figure 7. Percent Ground Cover vs. Sediment Yield.

giving false sediment yield values for these plots. Any break in the mat of plants and plant litter appeared to allow infiltration and eliminate erosion until cover decreased to < 70%.

Sediment yield from plots with no cover is low because the plots were disturbed by spading. All the cover was removed, and plots were raked up and down. This allowed very high infiltration over the short duration of the rainfall event.

A multiple regression analysis was performed between standard deviation of surface roughness, total ground cover, sediment yield (See Appendix E). The correlation coefficient was 0.69, indicating a moderate correlation (Devore, 1982), and a slight decrease in correlation compared to the correlation between total ground cover and sediment yield. The relatively large values of the coefficients of the surface cover terms (X1) compared to the values of the standard deviation of surface roughness terms (X2) in the correlation equation may have occurred because total ground cover was the decision variable. Plots were selected based on ground cover. There was no attempt to measure a range of surface roughness in this study.

RUSLE ANALYSIS

Using information on soil, ground cover, storm intensity, and surface roughness, estimates of sediment yield from the plots were calculated using RUSLE with RUSLE's cover factor (See Appendix C). An estimate was also made using the refined cover factor derived by Benkobi (1992) with RRUSLE (Figure 8). Sediment yield measured from the plots was plotted as actual sediment yield, the RRUSLE values were developed using the refined cover equation, and the RUSLE values were developed using Renard's cover equation (Renard, 1987). The curves show that both cover factors substantially underestimated actual sediment yield.

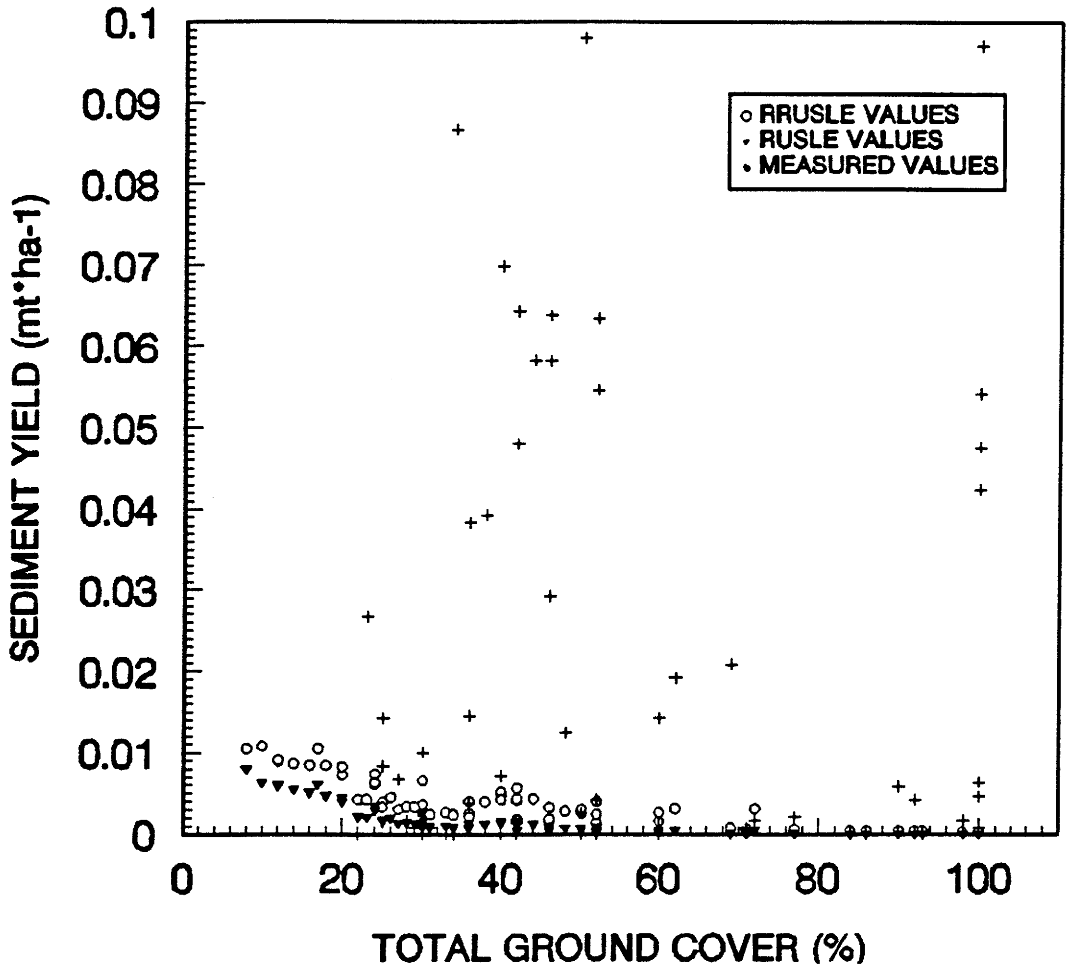


Figure 8. RUSLE and RRUSLE estimates of sediment yield with the measured sediment yield vs. the total ground cover. Measured values for sediment yield over 0.1 mt•ha$^{-1}$ were not graphed.

To represent all three curves in the same figure, increments for sediment yield in Figure 4 were reduced to 0.01 mt•ha$^{-1}$•y$^{-1}$ (from 0.1 mt•ha$^{-1}$•y$^{-1}$ in Figure 3), and measured values greater than 0.1 mt•ha$^{-1}$•y$^{-1}$ were not plotted.

Although RRUSLE estimates sediment yield better than RUSLE, both curves predict very low values for naturally occurring range conditions. RUSLE and RRUSLE predicted values were closer to measured values as cover increased above 70%. RUSLE and RRUSLE both predicted the average annual soil loss from a rangeland for steady state conditions.

FIELD OBSERVATIONS

Typically, soil samples from the rainfall simulation plots have a large percentage (80%) of soil particles between 0.05 mm and 0.50 mm in size. This is also the ideal size range of particles for wind transport (Morgan, 1986). The study areas all had similar summer climatic conditions (steady winds, long periods between rainfall events, and a large percentage of sunlight) (Martner, 1987). Ground cover ranged from 0 to 100% with a large percentage of plots having bare soil surface exposed to sunlight. These conditions are ideal for deposition of wind blown sediment.

Wind action transports fine, dry sediment (< 0.1mm)(Renard, 1987) depositing it when the wind velocity decreases below the critical transport velocity (Morgan, 1986). Surface roughness increases the drag on the wind, forcing the wind to lose velocity near the ground surface. When cover is uniform in height, the wind moves with less friction over the surface (Morgan, 1987). When cover drops below 70%, surface roughness increases, and fine sediment is deposited by the wind. Wind deposited fine sediment increases the percentage of fine sediment on the soil surface.

As the total cover reaches 70%, the effects of wind erosion, water erosion (raindrop impact), and other surface disturbances become minimal (Morgan, 1986). At values less than 70% cover, surface sediment deposited by the wind, or loosened by raindrop impact, animals, and man collects on the surface. The "most damaging storm" of 25.4 $mm \cdot hr^{-1}$ with a 15 minute duration (Huffsmith, 1988), may flush the disturbed, loose sediment off of the surface.

The sedigraph has an initial rise as the loose sediment passes through it. The size of the initial rise in the sedigraph depends on the amount of loose soil on the surface pavement. The time since the last rainfall event also affects the volume of soil on the surface pavement. As the rainfall event continues, more soil particles must be disturbed by raindrop impact, or water flowing over the soil surface for erosion to continue. The production of sediment available for transport reaches a relatively constant rate, or steady state condition, substantially lower than the initial disturbed, loose soil rate.

Using the rainfall simulator to simulate the "most damaging storm" presumably measures the loose surface sediment collected from each plot, not the steady state soil erosion production. The frequency of the "most damaging storm" (2 years) and the relatively large amount of disturbed, loose sediment, compared with steady state sediment production, is a more realistic indication of soil loss from a rangeland site and sediment available for contaminating water supplies.

This hypothesis is based on field observations, characteristics of wind deposited sediment, circumstances for wind deposited sediment, and characteristics of sedigraphs from rainfall simulators. Other factors may also contribute to accumulation of loose sediment on the soil surface. However, a similar situation involving wind blown sediment was observed in experiments involving irrigation furrow erosion (Hinton, 1986).

This research was not directed at the problem of loose sediment accumulating on the soil surface, rather, field observations led to formulation of this hypothesis. If loose sediment is collected on the soil surface pavement between storms, then flushed into the water system during a "most damaging storm" there are important consequences:

1. Changes in management practices may be needed to minimize loose sediment caused by wind deposition or other sources available for transport. Changes in management practices may also involve trapping sediment above the stream by planting grass in swales or other runoff channels to reduce sediment reaching the stream.

2. The computer programs currently used estimate erosion under steady state conditions. This hypothesis suggests that the majority of sediment transported to the stream occurs before a steady state condition is established. Therefore, computer programs would significantly underestimate the sediment yield from upland rangelands. This may explain the large differences in Figure 8 between RUSLE's and RRUSLE's predictions of sediment yield and the actual values collected from the simulation research.

# CHAPTER V

## CONCLUSIONS AND RECOMMENDATIONS

A rainfall simulator was used to evaluate soil erosion from undisturbed upland range sites. Data was gathered on surface roughness, total ground cover, and sediment yield. These data provided better insight into the importance of total ground cover in limiting soil erosion from semi-arid rangeland.

By plotting ground cover versus sediment yield, a relationship became clear (Figure 7). At 30% cover, the sediment yield declined to 0.1 $mt \cdot ha^{-1}$. This value is for the "most damaging storm" and represented a high initial erosion rate while the range surface pavement is washed clean of disturbed, loose sediment. Once the loose sediment is removed from the surface of the soil, a lower steady-state level of erosion was achieved. This steady state level results from longer duration storms, that continue to dislodge soil particles. These storms are less common in the West (Huffsmith, 1988).

The maximum allowable annual soil loss from thin, highly erodible soils is 2.2 $mt \cdot ha^{-1} \cdot y^{-1}$ (Table 1). This indicates that 22 "most damaging storms" each year might be tolerated if cover was maintained at a minimum of 30%. When cover declined to < 30%, the sediment yield increased dramatically. This value for cover is slightly lower than the value of 40% cover found by Shaxson (1981). The increase in sediment yield, when cover was < 30%, indicated there was more sediment available to be transported, because more disturbed soil was on the surface pavement, and more soil surface was exposed to raindrop impact. The higher sediment yield means fewer storms were needed to reach the soil loss tolerance level.

Sediment yield was effectively zero at 70% cover. This agrees with other research which indicated 70% cover eliminated soil erosion (Copeland, 1965). While high cover minimizes erosion, maintaining 70% cover (or greater) is impossible in many areas of the semi-arid West. Upland range sites often can be maintained with cover of 30%. Areas with cover below 30% should be protected from grazing and other uses if the uses result in deterioration of cover. If the range cannot support more than 30% cover, other methods of improving the rangeland might be tried. When grazing livestock is involved, changing the grazing pattern, time of grazing, or size of the herd will often allow the range to be maintained at 30% cover. In areas where more intensive management is needed for erosion control, the potential for using agronomic and mechanical soil conservation practices in conjunction with management practices should be evaluated (Morgan, 1986).

It is important to understand that 30% cover must be maintained everywhere within the range area. By averaging low cover on a ridge with higher cover in an adjacent draw, an average cover value of 30% may be achieved, but more erosion will occur on the ridge and sediment may be deposited in the draw.

Figure 7 provides an easy method to evaluate rangelands that requires no special soil tests or other information to evaluate the erosion potential of an upland range site. By walking over a range site, a rancher or range scientist can often estimate the percentage ground cover. Decisions can be made concerning sediment yield and sediment control measures based on this curve. Since the curve was determined using soils susceptible to erosion, it can be used conservatively as a curve for most soils.

RECOMMENDATIONS FOR FURTHER STUDY

The results of this project indicate further research might include:

1. The role of surface roughness in soil erosion on upland range sites should to be defined. A method of separating the effects of surface cover and surface roughness by maintaining a constant cover while varying surface roughness would provide insight into the importance of surface roughness independently of surface cover.

2. The spatial variability of surface roughness appears important when the standard deviation of the roughness drops below 25 mm. More information on the effect of the location and type of surface roughness on sediment yield for both small plots and overall range sites is essential to understand soil erosion on

upland sites.

3. The surface pavement on rangeland sites lowers infiltration and increases runoff and erosion. Loose sediment collects on the surface from wind erosion and disturbances from livestock and wildlife. The duration between rainfall events should be related to the amount of loose sediment collected on the surface pavement and therefore available for erosion. This relationship needs to be understood.

4. The effects of grazing on rangeland vegetation is well known, but more research is needed on grazing practices which maintain a uniform cover of at least 30% over an entire range. When cover drops below 30%, even in a small area, erosion increases rapidly.

5. RUSLE could be improved to estimate the large amount of sediment which initially comes off of upland range sites before a steady state situation is achieved.

6. Field observations indicate that a large percentage of the sediment entering streams from a most damaging rainfall event existed as loose sediment on the sealed surface pavement before the rainfall event. Sources of this loose sediment, particularly wind blown sediment should be investigated. Understanding the importance of loose sediment on the soil surface pavement may lead to improvements in predicting sediment yield from upland rangelands and to better management of these lands.

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APPENDICES

# Appendix A

---

Computer program.

---

1. Figure 9. Computer program developed in BASIC by Steve Linse and used to calculate sediment yield and sedigraph from rainfall simulation plots.

```
10 REM- THIS PROGRAM CALCULATES THE AVERAGE SEDIMENT ERODED FROM TWO .6M*2M PLOTS
20 REM- UNDER THE RAINFALL SIMULATOR.  IT ALSO COMPUTES AN AVERAGE SEDIGRAPH OF THE
30 REM- TWO PLOTS.
40 REM- ****************************************************************************************
50 REM- THIS SECTION INPUTS DATA FROM PLOT A WITH VOLUMES IN MILLILITERS AND WEIGHTS IN GRAMS.
60 REM- ****************************************************************************************
70 INPUT "WHAT IS THE NAME OF THIS PLOT (SLWOR1)"; FILENAMES
80 INPUT "HOW MUCH WATER FROM PLOT A AT THIRTY SECONDS"; WATHIRTY
90 INPUT "HOW MUCH SEDIMENT FROM PLOT A AT THIRTY SECONDS"; SATHIRTY
100 INPUT "HOW MUCH WATER FROM PLOT A AT ONE MINUTE"; WAONE
110 INPUT "HOW MUCH SEDIMENT FROM PLOT A AT ONE MINUTE"; SAONE
120 INPUT "HOW MUCH WATER FROM PLOT A AT ONE MINUTE THIRTY SECONDS"; WAONETHIRTY
130 INPUT "HOW MUCH SEDIMENT FROM PLOT A AT ONE MINUTE THIRTY SECONDS"; SAONETHIRTY
140 INPUT "HOW MUCH WATER FROM PLOT A AT TWO MINUTES"; WATWO
150 INPUT "HOW MUCH SEDIMENT FROM PLOT A AT TWO MINUTES"; SATWO
160 INPUT "HOW MUCH WATER FROM PLOT A AT TWO MINUTES THIRTY SECONDS"; WATWOTHIRTY
170 INPUT "HOW MUCH SEDIMENT FROM PLOT A AT TWO MINUTES THIRTY SECONDS"; SATWOTHIRTY
180 INPUT "HOW MUCH WATER FROM PLOT A AT THREE MINUTES"; WATHREE
190 INPUT "HOW MUCH SEDIMENT FROM PLOT A AT THREE MINUTES"; SATHREE
200 INPUT "HOW MUCH WATER FROM PLOT A AT FOUR MINUTES"; WAFOUR
210 INPUT "HOW MUCH SEDIMENT FROM PLOT A AT FOUR MINUTES"; SAFOUR
220 INPUT "HOW MUCH WATER FROM PLOT A AT FIVE MINUTES"; WAFIVE
230 INPUT "HOW MUCH SEDIMENT FROM PLOT A AT FIVE MINUTES"; SAFIVE
240 INPUT "HOW MUCH WAS THE FINAL WATER SAMPLE FROM PLOT A"; WAFINAL
250 INPUT "HOW MUCH WAS THE FINAL SEDIMENT SAMPLE FROM PLOT A"; SAFINAL
260 INPUT "HOW MUCH WAS THE TOTAL FINAL WATER SAMPLE FROM PLOT A"; WATFINAL
270 REM- ****************************************************************************************
280 REM- THIS SECTION INPUTS DATA FROM PLOT B WITH VOLUMES IN MILLILITERS AND WEIGHTS IN GRAMS.
290 REM- ****************************************************************************************
300 INPUT "HOW MUCH WATER FROM PLOT B AT THIRTY SECONDS"; WBTHIRTY
310 INPUT "HOW MUCH SEDIMENT FROM PLOT B AT THIRTY SECONDS"; SBTHIRTY
320 INPUT "HOW MUCH WATER FROM PLOT B AT ONE MINUTE"; WBONE
330 INPUT "HOW MUCH SEDIMENT FROM PLOT B AT ONE MINUTE"; SBONE
340 INPUT "HOW MUCH WATER FROM PLOT B AT ONE MINUTE THIRTY SECONDS"; WBONETHIRTY
350 INPUT "HOW MUCH SEDIMENT FROM PLOT B AT ONE MINUTE THIRTY SECONDS"; SBONETHIRTY
360 INPUT "HOW MUCH WATER FROM PLOT B AT TWO MINUTES"; WBTWO
370 INPUT "HOW MUCH SEDIMENT FROM PLOT B AT TWO MINUTES"; SBTWO
380 INPUT "HOW MUCH WATER FROM PLOT B AT TWO MINUTES THIRTY SECONDS"; WBTWOTHIRTY
390 INPUT "HOW MUCH SEDIMENT FROM PLOT B AT TWO MINUTES THIRTY SECONDS"; SBTWOTHIRTY
400 INPUT "HOW MUCH WATER FROM PLOT B AT THREE MINUTES"; WBTHREE
410 INPUT "HOW MUCH SEDIMENT FROM PLOT B AT THREE MINUTES"; SBTHREE
420 INPUT "HOW MUCH WATER FROM PLOT B AT FOUR MINUTES"; WBFOUR
430 INPUT "HOW MUCH SEDIMENT FROM PLOT B AT FOUR MINUTES"; SBFOUR
440 INPUT "HOW MUCH WATER FROM PLOT B AT FIVE MINUTES"; WBFIVE
450 INPUT "HOW MUCH SEDIMENT FROM PLOT B AT FIVE MINUTES"; SBFIVE
460 INPUT "HOW MUCH WAS THE FINAL WATER SAMPLE FROM PLOT B"; WBFINAL
470 INPUT "HOW MUCH WAS THE FINAL SEDIMENT SAMPLE FROM PLOT B"; SBFINAL
480 INPUT "HOW MUCH WAS THE TOTAL FINAL WATER SAMPLE FROM PLOT B"; WBTFINAL
490 REM- ****************************************************************************************
500 REM- THIS SECTION FINDS THE TOTAL VOLUME OF WATER COLLECTED FROM PLOTS A AND B.
510 REM- ****************************************************************************************
520 VOLUMEA = WATHIRTY + WAONE + WAONETHIRTY + WATWO + WATWOTHIRTY + WATHREE + WAFOUR + WAFIVE +
        WAFINAL + WATFINAL
530 VOLUMEB = WBTHIRTY + WBONE + WBONETHIRTY + WBTWO + WBTWOTHIRTY + WBTHREE + WBFOUR + WBFIVE +
        WBFINAL + WBTFINAL
540 REM- ****************************************************************************************
550 REM- THIS SECTION CALCULATES THE WEIGHT OF SEDIMENT COLLECTED IN THE FINAL SAMPLE FOR PLOTS A AND
        B.
560 REM- ****************************************************************************************
570 IF WAFINAL = 0 THEN 610 ELSE 580
580 FINALA = WATFINAL * (SAFINAL / WAFINAL) + SAFINAL
590 IF WBFINAL = 0 THEN 610
600 FINALB = WBTFINAL * (SBFINAL / WBFINAL) + SBFINAL
610 WEIGHTA = SATHIRTY + SAONE + SAONETHIRTY + SATWO + SATWOTHIRTY + SATHREE + SAFOUR + SAFIVE + FINALA
```

Figure 9
Basic Program to calculate sediment yield and sedigraphs.

```
620 WEIGHTB = SBTHIRTY + SBONE + SBONETHIRTY + SBTWO + SBTWOTHIRTY + SBTHREE + SBFOUR + SBFIVE
     + FINALB
630 REM- ******************************************************************************************
640 REM- THIS SECTION CALCULATES THE EROSION FOR PLOTS A AND B INDIVIDUALLY.
650 REM- ******************************************************************************************
660 IF WEIGHTA = 0 THEN 680 ELSE
670 YIELDMA = (WEIGHTA / 1.2) * .01
680 IF WEIGHTB = 0 THEN 720 ELSE
690 YIELDMB = (WEIGHTB / 1.2) * .01
700 YIELDA = YIELDMA * .4461
710 YIELDB = YIELDMB * .4461
720 REM- ******************************************************************************************
730 REM- THE AREA OF EACH PLOT IS 1.2 M^2 (AREA=1.2M^2).
740 REM- THIS SECTION CALCULATES THE AVERAGE EROSION FOR PLOTS A AND B
750 REM- IN METRIC TONS PER HECTARE, AND TONS PER ACRE.
760 REM- ******************************************************************************************
770 YIELDM = (((WEIGHTA + WEIGHTB) / 2) / 1.2) * .01
780 YIELD = YIELDM * .4461
790 REM- ******************************************************************************************
800 REM- THIS SECTION PRINTS THE INPUTS.
810 REM- ******************************************************************************************
820 LPRINT "THIS IS THE EROSION FOR PLOT "; FILENAME$
830 LPRINT "***************************************************************************************"
840 LPRINT "INPUT"
850 LPRINT "                PLOT A                                  PLOT B"
860 LPRINT "VOLUME WATER     WEIGHT SEDIMENT            VOLUME WATER    WEIGHT SEDIMENT"
870 LPRINT USING "####.#                ##.##                  ####.#          ##.##"; WATHIRTY;
      SATHIRTY; WBTHIRTY; SBTHIRTY
880 LPRINT USING "####.#                ##.##                  ####.#          ##.##"; WAONE; SAONE;
     WBONE; SBONE
890 LPRINT USING "####.#                ##.##                  ####.#          ##.##"; WAONETHIRTY;
     SAONETHIRTY; WBONETHIRTY; SBONETHIRTY
900 LPRINT USING "####.#                ##.##                  ####.#          ##.##"; WATWO; SATWO;
     WBTWO; SBTWO
910 LPRINT USING "####.#                ##.##                  ####.#          ##.##"; WATWOTHIRTY;
     SATWOTHIRTY; WBTWOTHIRTY; SBTWOTHIRTY
920 LPRINT USING "####.#                ##.##                  ####.#          ##.##"; WATHREE;
     SATHREE; WBTHREE; SBTHREE
930 LPRINT USING "####.#                ##.##                  ####.#          ##.##"; WAFOUR;
     SAFOUR; WBFOUR; SBFOUR
940 LPRINT USING "####.#                ##.##                  ####.#          ##.##"; WAFIVE;
     SAFIVE; WBFIVE; SBFIVE
950 LPRINT USING "####.#                ##.##                  ####.#          ##.##"; WAFINAL;
     SAFINAL; WBFINAL; SBFINAL
960 LPRINT "THE FINAL VOLUME OF WATER IN A = "; WATFINAL
970 LPRINT "THE FINAL VOLUME OF WATER IN B = "; WBTFINAL
980 REM- ******************************************************************************************
990 REM- THIS SECTION PRINTS THE EROSION IN MTONS PER HECTARE AND TONS PER ACRE.
1000 REM- ******************************************************************************************
1010 LPRINT "***************************************************************************************"
1020 LPRINT "OUTPUT"
1030 LPRINT USING "THE YIELD OF PLOT A IN METRIC TONS PER HECTARE IS =#.########
     #"; YIELDMA
1040 LPRINT USING "THE YIELD OF PLOT A IN TONS PER ACRE IS =#.#########"; YIELDA
1050 LPRINT USING "THE YIELD OF PLOT B IN METRIC TONS PER HECTARE IS =#.#########"; YIELDMB
1060 LPRINT USING "THE YIELD OF PLOT B IN TONS PER ACRE IS =#.#########"; YIELDB
1070 LPRINT USING "THE AVERAGE YIELD OF A AND B IN METRIC TONS PER HECTARE IS =#.#########"; YIELDM
1080 LPRINT USING "THE AVERAGE YIELD OF A AND B IN TONS PER ACRE IS=#.#########"; YIELD
1090 REM- ******************************************************************************************
1100 REM- THIS SECTION CALCULATES THE AVERAGE SEDIGRAPH FOR THE PLOT.
1110 REM- ******************************************************************************************
1120 PERCENTA = SATHIRTY + SAONE + SAONETHIRTY + SATWO + SATWOTHIRTY + SATHREE + SAFOUR + SAFIVE
1130 PERCENTB = SBTHIRTY + SBONE + SBONETHIRTY + SBTWO + SBTWOTHIRTY + SBTHREE + SBFOUR + SBFIVE
1140 IF PERCENTA = 0 THEN 1860
1150 REM-******************************************************************************************
1160 REM-THIS SECTION CALCULATES THE SEDIGRAPH FROM PLOT A.
1170 REM-******************************************************************************************
```

Figure 9 -cont-

```
1180 THIRTYMA = ((SATHIRTY / PERCENTA) / 10) * YIELDMA
1190 THIRTYA = ((SATHIRTY / PERCENTA) / 10) * YIELDA
1200 ONEMA = ((SAONE / PERCENTA) / 10) * YIELDMA
1210 ONEA = ((SAONE / PERCENTA) / 10) * YIELDA
1220 ONETHIRTYMA = ((SAONETHIRTY / PERCENTA) / 10) * YIELDMA
1230 ONETHIRTYA = ((SAONETHIRTY / PERCENTA) / 10) * YIELDA
1240 TWOMA = ((SATWO / PERCENTA) / 10) * YIELDMA
1250 TWOA = ((SATWO / PERCENTA) / 10) * YIELDA
1260 TWOTHIRTYMA = ((SATWOTHIRTY / PERCENTA) / 10) * YIELDMA
1270 TWOTHIRTYA = ((SATWOTHIRTY / PERCENTA) / 10) * YIELDA
1280 THREEMA = ((SATHREE / PERCENTA) / 10) * YIELDMA
1290 THREEA = ((SATHREE / PERCENTA) / 10) * YIELDA
1300 FOURMA = ((SAFOUR / PERCENTA) / 10) * YIELDMA
1310 FOURA = ((SAFOUR / PERCENTA) / 10) * YIELDA
1320 FIVEMA = ((SAFIVE / PERCENTA) / 10) * YIELDMA
1330 FIVEA = ((SAFIVE / PERCENTA) / 10) * YIELDA
1340 GOTO 1570
1350 IF PERCENTB = 0 THEN 1880
1360 REM-******************************************************************************************
1370 REM-THIS SECTION CALCULATES THE SEDIGRAPH FROM PLOT B
1380 REM-******************************************************************************************
1390 THIRTYMB = ((SBTHIRTY / PERCENTB) / 10) * YIELDMB
1400 THIRTYB = ((SBTHIRTY / PERCENTB) / 10) * YIELDB
1410 ONEMB = ((SBONE / PERCENTB) / 10) * YIELDMB
1420 ONEB = ((SBONE / PERCENTB) / 10) * YIELDB
1430 ONETHIRTYMB = ((SBONETHIRTY / PERCENTB) / 10) * YIELDMB
1440 ONETHIRTYB = ((SBONETHIRTY / PERCENTB) / 10) * YIELDB
1450 TWOMB = ((SBTWO / PERCENTB) / 10) * YIELDMB
1460 TWOB = ((SBTWO / PERCENTB) / 10) * YIELDB
1470 TWOTHIRTYMB = ((SBTWOTHIRTY / PERCENTB) / 10) * YIELDMB
1480 TWOTHIRTYB = ((SBTWOTHIRTY / PERCENTB) / 10) * YIELDB
1490 THREEMB = ((SBTHREE / PERCENTB) / 10) * YIELDMB
1500 THREEB = ((SBTHREE / PERCENTA) / 10) * YIELDB
1510 FOURMB = ((SBFOUR / PERCENTB) / 10) * YIELDMB
1520 FOURB = ((SBFOUR / PERCENTB) / 10) * YIELDB
1530 FIVEMB = ((SBFIVE / PERCENTB) / 10) * YIELDMB
1540 FIVEB = ((SBFIVE / PERCENTB) / 10) * YIELDB
1550 GOTO 1720
1560 REM- ****************************************************************************************
1570 REM- THIS SECTION PRINTS OUT THE SEDIGRAPH FROM PLOT A.
1580 REM- ****************************************************************************************
1590 LPRINT "THE SEDIGRAPH FROM PLOT A."
1600 LPRINT " TIME            SEDIMENT                        SEDIMENT"
1610 LPRINT "SECONDS       TONNES/HECTARE                      TONS/ACRE"
1620 LPRINT USING " 0:35          ###.#########                  ###.#########"; THIRTYMA; THIRTYA
1630 LPRINT USING " 1:05          ###.#########                  ###.#########"; ONEMA; ONEA
1640 LPRINT USING " 1:35          ###.#########                  ###.#########"; ONETHIRTYMA; ONETHIRTYA
1650 LPRINT USING " 2:05          ###.#########                  ###.#########"; TWOMA; TWOA
1660 LPRINT USING " 2:35          ###.#########                  ###.#########"; TWOTHIRTYMA; TWOTHIRTYA
1670 LPRINT USING " 3:05          ###.#########                  ###.#########"; THREEMA; THREEA
1680 LPRINT USING " 4:05          ###.#########                  ###.#########"; FOURMA; FOURA
1690 LPRINT USING " 5:05          ###.#########                  ###.#########"; FIVEMA; FIVEA
1700 GOTO 1350
1710 REM- ****************************************************************************************
1720 REM- THIS SECTION PRINTS OUT THE SEDIGRAPH FROM PLOT B.
1730 REM- ****************************************************************************************
1740 LPRINT "THE SEDIGRAPH FROM PLOT B."
1750 LPRINT " TIME            SEDIMENT                        SEDIMENT"
1760 LPRINT "SECONDS       TONNES/HECTARE                      TONS/ACRE"
1770 LPRINT USING " 0:35          ###.#########                  ###.#########"; THIRTYMB; THIRTYB
1780 LPRINT USING " 1:05          ###.#########                  ###.#########"; ONEMB; ONEB
1790 LPRINT USING " 1:35          ###.#########                  ###.#########"; ONETHIRTYMB; ONETHIRTYB
1800 LPRINT USING " 2:05          ###.#########                  ###.#########"; TWOMB; TWOB
```

Figure 9 -cont-

```
1810 LPRINT USING " 2:35          ###.#########              ###.#########"; TWOTHIRTYMB;
       TWOTHIRTYB
1820 LPRINT USING " 3:05          ###.#########              ###.#########"; THREEMB; THREEB
1830 LPRINT USING " 4:05          ###.#########              ###.#########"; FOURMB; FOURB
1840 LPRINT USING " 5:05          ###.#########              ###.#########"; FIVEMB; FIVEB
1850 END
1860 LPRINT "THERE IS NOT ENOUGH INFORMATION TO PROVIDE AN ACCURATE SEDIGRAPH FROM PLOT A!"
1870 GOTO 1350
1880 LPRINT "THERE IS NOT ENOUGH INFORMATION TO PROVIDE AN ACCURATE SEDIGRAPH  FROM PLOT B!"
1890 GOTO 1850
```

# Appendix B

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The median drop diameter versus pressure.

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1. Figure 10. The manufacturer's (Spraying Systems Incorporated) plot of median drop diameter versus pressure for the 9570 flat nozzle used by the University of Wyoming Rainfall Simulator.

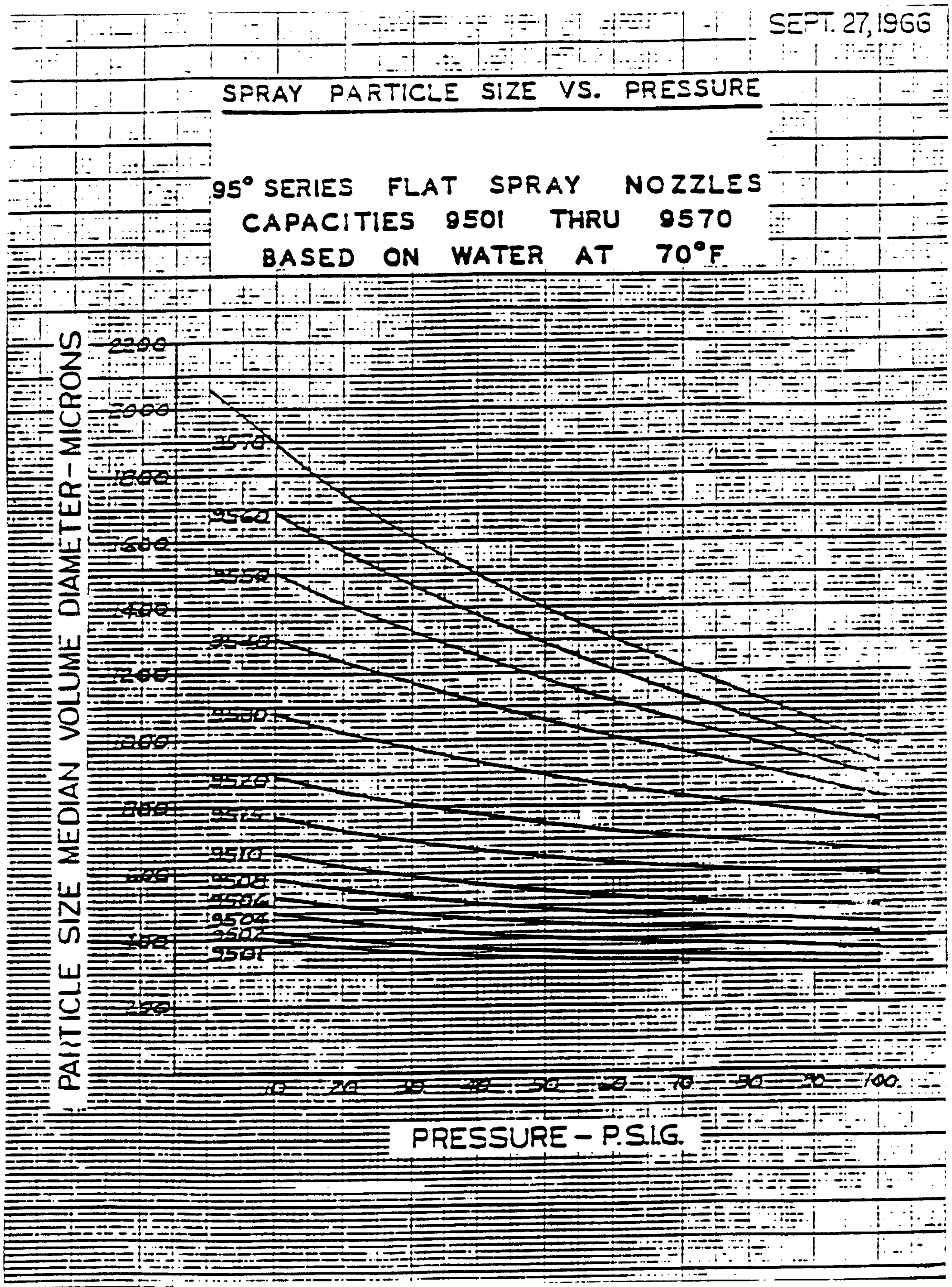


Figure 10. The manufacturers's (Spraying Systems Incorporated) plot of median drop diameter versus pressure for the 9570 flat nozzle used by the University of Wyoming Rainfall Simulator.

# Appendix C

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Data sheets identifying the plots, the plots study area, the total cover, the surface roughness, the measured soil loss, and the sand, silt, clay makeup of the soil.

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1. Table 2. A list of study plots including total cover, the standard deviation of surface roughness, measured soil loss, soil particle size, and plot study area.
2. Table 3. RUSLE and RRUSLE variables and input data for plots on the Fifteen Mile Creek Drainage.
3. Table 4. RUSLE and RRUSLE variables and input data for plots on the Fifteen Mile Creek Drainage.
4. Table 5. RUSLE and RRUSLE variables and input data for plots on the Fifteen Mile Creek Drainage.
5. Table 6. RUSLE and RRUSLE variables and input data for plots on the Fifteen Mile Creek Drainage.
6. Table 7. RUSLE and RRUSLE variables and input data for plots on the Ten Mile Creek Drainage.
7. Table 8. RUSLE and RRUSLE variables and input data for plots on the Ten Mile Creek Drainage.
8. Table 9. RUSLE and RRUSLE variables and input data for plots on the Beaver Creek and Little Jack Creek Drainages.

Table 2. A list of study plots including total cover, the standard deviation of surface roughness, measured soil loss, soil particle size, and plot study area.

| PLOT | TOTAL COVER (prop.) | STANDARD DEVIATION of SURFACE ROUGHNESS (mm) | MEASURED SOIL LOSS (t/ha) | SOIL Sand % | SOIL Silt % | SOIL Clay % | PLOT STUDY AREA |
|---|---|---|---|---|---|---|---|
| WOR1A | 0.26 | 13.2 | 0.1521 | 88 | 10 | 2 | Ten Mile Creek (Worland) |
| WOR1B | 0.30 | 18.2 | 0.0100 | 88 | 10 | 2 | Ten Mile Creek (Worland) |
| WOR2A | 0.25 | 12.1 | 0.0142 | 88 | 10 | 2 | Ten Mile Creek (Worland) |
| WOR2B | 0.22 | 12.1 | 0.0000 | 88 | 10 | 2 | Ten Mile Creek (Worland) |
| WOR3A | 0.23 | 9.1 | 0.0267 | 88 | 10 | 2 | Ten Mile Creek (Worland) |
| WOR3B | 0.29 | 10.1 | 0.0008 | 88 | 10 | 2 | Ten Mile Creek (Worland) |
| WOR4A | 0.34 | 8.6 | 0.0000 | 88 | 10 | 2 | Ten Mile Creek (Worland) |
| WOR4B | 0.42 | 10.6 | 0.0000 | 88 | 10 | 2 | Ten Mile Creek (Worland) |
| WOR5A | 0.33 | 10.2 | 0.0000 | 88 | 10 | 2 | Ten Mile Creek (Worland) |
| WOR5B | 0.36 | 15.0 | 0.0036 | 88 | 10 | 2 | Ten Mile Creek (Worland) |
| WOR6A | 0.26 | 5.6 | 0.0017 | 89 | 9 | 2 | Ten Mile Creek (Worland) |
| WOR6B | 0.34 | 6.9 | 0.0667 | 89 | 9 | 2 | Ten Mile Creek (Worland) |
| WOR7A | 0.27 | 7.7 | 0.0067 | 77 | 20 | 3 | Ten Mile Creek (Worland) |
| WOR7B | 0.25 | 11.1 | 0.0063 | 77 | 20 | 3 | Ten Mile Creek (Worland) |
| WOR8A | 0.36 | 17.6 | 0.0369 | 78 | 19 | 3 | Ten Mile Creek (Worland) |
| WOR8B | 0.31 | 9.7 | 0.0008 | 78 | 19 | 3 | Ten Mile Creek (Worland) |
| WOR9A | 0.32 | 12.0 | 0.0000 | 91 | 8 | 1 | Ten Mile Creek (Worland) |
| WOR9B | 0.30 | 16.2 | 0.0008 | 91 | 8 | 1 | Ten Mile Creek (Worland) |
| SLWOR1A | 0.46 | 6.3 | 0.0637 | 89 | 8 | 3 | Ten Mile Creek (Worland) |
| SLWOR1B | 0.42 | 7.7 | 0.0479 | 89 | 8 | 3 | Ten Mile Creek (Worland) |
| SRWOR1A | 0.62 | 11.2 | 0.0633 | 94 | 6 | 1 | Ten Mile Creek (Worland) |
| SRWOR1B | 0.62 | 5.4 | 0.0546 | 94 | 6 | 1 | Ten Mile Creek (Worland) |
| SL1WOR1A | 0.46 | 6.5 | 0.0292 | 79 | 18 | 3 | Ten Mile Creek (Worland) |
| SL1WOR1B | 0.42 | 7.4 | 0.0013 | 79 | 18 | 3 | Ten Mile Creek (Worland) |
| SLWOR2A | 0.72 | 18 | 0.0017 | 90 | 8 | 2 | Fifteen Mile Creek (Worland) |
| SLWOR2B | 0.62 | 10 | 0.0192 | 90 | 8 | 2 | Fifteen Mile Creek (Worland) |
| SLWOR3A | 0.12 | 8.2 | 0.3279 | 67 | 26 | 7 | Fifteen Mile Creek (Worland) |
| SLWOR3B | 0.16 | 16.2 | 0.4430 | 67 | 26 | 7 | Fifteen Mile Creek (Worland) |
| SRWOR3A | 0.17 | 1.5 | 0.2706 | 76 | 20 | 4 | Fifteen Mile Creek (Worland) |
| SRWOR3B | 0.14 | 5.3 | 0.2807 | 76 | 20 | 4 | Fifteen Mile Creek (Worland) |
| SLWOR4A | 0.48 | 5.4 | 0.0124 | 70 | 26 | 4 | Fifteen Mile Creek (Worland) |
| SLWOR4B | 0.58 | 4.6 | 0.0000 | 70 | 26 | 4 | Fifteen Mile Creek (Worland) |
| SRWOR4A | 0.46 | 6.9 | 0.0681 | 70 | 26 | 4 | Fifteen Mile Creek (Worland) |
| SRWOR4B | 0.62 | 5.8 | 0.0042 | 70 | 26 | 4 | Fifteen Mile Creek (Worland) |
| SLWOR6A | 0.36 | 5.4 | 0.0145 | 83 | 14 | 3 | Fifteen Mile Creek (Worland) |
| SLWOR6B | 0.38 | 6.6 | 0.0392 | 83 | 14 | 3 | Fifteen Mile Creek (Worland) |
| SRWOR6A | 0.42 | 4.9 | 0.1666 | 91 | 5 | 4 | Fifteen Mile Creek (Worland) |
| SRWOR6B | 0.30 | 16.7 | 0.1084 | 91 | 5 | 4 | Fifteen Mile Creek (Worland) |
| SLWOR9A | 0.60 | 6 | 0.0026 | 78 | 18 | 4 | Fifteen Mile Creek (Worland) |
| SLWOR9B | 0.62 | 6.4 | 0.0000 | 78 | 18 | 4 | Fifteen Mile Creek (Worland) |
| SRWOR9A | 0.60 | 11 | 0.0142 | 81 | 16 | 3 | Fifteen Mile Creek (Worland) |
| SRWOR9B | 0.40 | 3.6 | 0.0071 | 78 | 16 | 3 | Fifteen Mile Creek (Worland) |
| SLWOR10A | 0.80 | 3.8 | 0.0000 | 83 | 15 | 2 | Fifteen Mile Creek (Worland) |
| SLWOR10B | 0.50 | 6.7 | 0.0000 | 83 | 15 | 2 | Fifteen Mile Creek (Worland) |
| SRWOR10A | 0.40 | 7.2 | 0.0000 | 83 | 15 | 2 | Fifteen Mile Creek (Worland) |
| SRWOR10B | 0.42 | 7.5 | 0.0000 | 83 | 15 | 2 | Fifteen Mile Creek (Worland) |
| SLWOR11A | 0.24 | 6.2 | 0.1205 | 75 | 18 | 7 | Fifteen Mile Creek (Worland) |
| SLWOR11B | 0.08 | 5.6 | 0.5466 | 75 | 18 | 7 | Fifteen Mile Creek (Worland) |
| SRWOR11A | 0.30 | 6.6 | 1.3200 | 75 | 18 | 7 | Fifteen Mile Creek (Worland) |
| SRWOR11B | 0.24 | 7.4 | 0.1293 | 75 | 18 | 7 | Fifteen Mile Creek (Worland) |
| S1WOR11A | 0.40 | 6 | 0.0698 | 75 | 18 | 7 | Fifteen Mile Creek (Worland) |
| S1WOR11B | 0.42 | 6.6 | 0.0642 | 75 | 18 | 7 | Fifteen Mile Creek (Worland) |
| S2WOR11A | 0.44 | 5.9 | 0.0582 | 75 | 18 | 7 | Fifteen Mile Creek (Worland) |
| S2WOR11B | 0.50 | 27.1 | 0.0980 | 75 | 18 | 7 | Fifteen Mile Creek (Worland) |
| SRWOR12A | 0.20 | 3.8 | 0.4105 | 88 | 10 | 2 | Fifteen Mile Creek (Worland) |
| SRWOR12B | 0.18 | 6.3 | 0.3704 | 88 | 10 | 2 | Fifteen Mile Creek (Worland) |
| SR1WOR12A | 0.04 | 3 | 0.0208 | 80 | 15 | 5 | Fifteen Mile Creek (Worland) |
| SR1WOR12B | 0.00 | 3 | 0.0000 | 80 | 15 | 5 | Fifteen Mile Creek (Worland) |
| ESWOR2A | 0.10 | 3.3 | 0.3608 | 85 | 13 | 2 | Fifteen Mile Creek (Worland) |
| ESWOR2B | 0.12 | 6.1 | 0.3738 | 85 | 13 | 2 | Fifteen Mile Creek (Worland) |
| ESWOR3A | 0.20 | 9.5 | 0.3162 | 74 | 19 | 7 | Fifteen Mile Creek (Worland) |
| ESWOR3B | 0.24 | 7.6 | 0.1896 | 74 | 19 | 7 | Fifteen Mile Creek (Worland) |
| ESWOR4A | 0.00 | 0 | 0.0137 | 78 | 16 | 6 | Fifteen Mile Creek (Worland) |
| ESWOR4B | 0.00 | 0 | 0.0033 | 78 | 16 | 6 | Fifteen Mile Creek (Worland) |
| SRAW1A | 0.98 | 12.2 | 0.0017 | 62 | 33 | 5 | Beaver Creek (Rawlins) |
| SRAW1B | 1.00 | 8.8 | 0.0008 | 62 | 33 | 5 | Beaver Creek (Rawlins) |
| SRAW2A | 1.00 | 10.1 | 0.0971 | 62 | 33 | 5 | Beaver Creek (Rawlins) |
| SRAW2B | 1.00 | 12.0 | 0.0046 | 62 | 33 | 5 | Beaver Creek (Rawlins) |
| SRAW3A | 1.00 | 24.1 | 0.0063 | 62 | 33 | 5 | Beaver Creek (Rawlins) |
| SRAW3B | 1.00 | 18.4 | 0.0474 | 62 | 33 | 5 | Beaver Creek (Rawlins) |
| SRAW4A | 1.00 | 8.6 | 0.0423 | 60 | 36 | 4 | Beaver Creek (Rawlins) |
| SRAW4B | 1.00 | 18.9 | 0.0640 | 60 | 36 | 4 | Beaver Creek (Rawlins) |
| SRAW5A | 0.86 | 13.6 | 0.0090 | 72 | 24 | 4 | Beaver Creek (Rawlins) |
| SRAW5B | 0.93 | 17.4 | 0.0000 | 72 | 24 | 4 | Beaver Creek (Rawlins) |
| SRAW6A | 0.77 | 13.8 | 0.0021 | 80 | 16 | 4 | Beaver Creek (Rawlins) |
| SRAW6B | 0.92 | 17.4 | 0.0042 | 80 | 16 | 4 | Beaver Creek (Rawlins) |
| SRAW7A | 0.00 | 0.6 | 0.0000 | 80 | 18 | 2 | Little Jack Creek (Rawlins) |
| SRAW7B | 0.00 | 0.8 | 0.0008 | 80 | 18 | 2 | Little Jack Creek (Rawlins) |
| SRAW8A | 0.89 | 26.3 | 0.0208 | 68 | 27 | 5 | Little Jack Creek (Rawlins) |
| SRAW8B | 0.90 | 16.8 | 0.0058 | 68 | 27 | 5 | Little Jack Creek (Rawlins) |
| SRAW9A | 0.71 | 31.9 | 0.0008 | 71 | 23 | 6 | Little Jack Creek (Rawlins) |
| SRAW9B | 0.84 | 36.1 | 0.0000 | 71 | 23 | 6 | Little Jack Creek (Rawlins) |
| | | | AVERAGE= | 79 | 17 | 4 | |
| | | | SD | 8.94 | 7.83 | 1.83 | |

Table 3. RUSLE and RRUSLE variables and input data for plots on the Fifteen Mile Creek Drainage.

**ESTIMATED RUSLE FACTOR AND SUBFACTOR VALUES**

| | | |
|---|---|---|
| EI = | 27.4793 | Storm energy factor |
| K = | 0.016183 | Soil erodibility factor |
| L = | 0.28748 | Slope length factor |
| S = | 0.996922 | Slope steepness factor |
| PLU = | 0.311281 | Prior land use subfactor |
| CC = | 0.716848 | Plant canopy subfactor |
| SR = | 0.542563 | Surface roughness subfactor |
| SC = | 0.056135 | Surface cover subfactor |
| RSC = | 0.4008 | Refined surface cover subfactor |

**INPUT RUSLE CONSTANTS**

| | | |
|---|---|---|
| a, soil organic matter (%) | = | 1.4 |
| b, soil stucture index | = | 2 |
| c, profile permeability index | = | 2 |
| VFS, very fine sand plus silt (%) | = | 23 |
| percentage of clay (%) | = | 2 |
| m = (vfs)*(100 - % clay) | = | 2254 |
| lambda, horizont project of slope | = | 6 |
| M, slope length exponent | = | 0.5 |
| Alpha, slope angle (degrees) | = | 5.16 |
| ni, rangeland constant-RUSLE table | : | 0.45 |
| alphai, .......................... | = | 27.3 |
| RS = Bio*ni*alphai/100 | = | 30.71 |

| INPUT VARIABLES FOR RUSLE and RRUSLE TO ESTIMATE SOIL LOSS FROM RANGELAND WATERSHEDS | | | | | | | | | | RUSLE and RRUSLE OUTPUTS AND FIELD MEASUREMENTS OF SOIL LOSS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot No. | Rainfall intensity (mm)/h | Canopy cover (prop.) | Canopy height (m) | Total cover (prop.) | Surface roughness (mm) | Plant biomass (kg/ha) | Organic cover Plant+Litter (prop.) | Rock cover (prop.) | Bare ground (prop.) | RUSLE Estimated soil loss (t/ha) | RRUSLE Estimated soil loss (t/ha) | Actual soil loss (t/ha) |
| SLWOR2A | 97.1 | 0.30 | 0.17 | 0.72 | 10.0 | 250 | 0.72 | 0 | 0.28 | 0.00087 | 0.00618 | 0.0017 |
| SLWOR2B | 97.1 | 0.43 | 0.17 | 0.62 | 10.0 | 180 | 0.62 | 0 | 0.38 | 0.00107 | 0.00623 | 0.0192 |
| SLWOR11A | 97.1 | 0.13 | 0.17 | 0.24 | 6.2 | 320 | 0.24 | 0 | 0.76 | 0.00798 | 0.01696 | 0.1205 |
| SLWOR11B | 97.1 | 0.06 | 0.17 | 0.08 | 5.6 | 90 | 0.08 | 0 | 0.92 | 0.01653 | 0.02166 | 0.5466 |
| SRWOR11A | 97.1 | 0.15 | 0.17 | 0.30 | 6.6 | 170 | 0.30 | 0 | 0.70 | 0.00608 | 0.01538 | 1.3200 |
| SRWOR11B | 97.1 | 0.17 | 0.17 | 0.24 | 7.4 | 290 | 0.24 | 0 | 0.76 | 0.00740 | 0.01573 | 0.1293 |

## Table 4. RUSLE and RRUSLE variables and input data for plots on the Fifteen Mile Creek Drainage.

| ESTIMATED RUSLE FACTOR AND SUBFACTOR VALUES | | |
|---|---|---|
| EI = | 27.4793 | Storm energy factor |
| K = | 0.029309 | Soil erodibility factor |
| L = | 0.090148 | Slope length factor |
| S = | 0.996922 | Slope steepness factor |
| PLU = | 0.311281 | Prior land use subfactor |
| CC = | 0.716848 | Plant canopy subfactor |
| SR = | 0.542563 | Surface roughness subfactor |
| SC = | 0.056135 | Surface cover subfactor |
| RSC = | 0.4006 | Refined surface cover subfactor |

| INPUT RUSLE CONSTANTS | | |
|---|---|---|
| a, soil organic matter (%) | = | 1 |
| b, soil stucture index | = | 2 |
| c, profile permeability index | = | 4 |
| VFS, very fine sand plus silt (%) | = | 29 |
| percentage of clay (%) | = | 3 |
| m = (vfs)*(100 - % clay) | = | 2813 |
| lambda, horizont project of slope | = | 0.59 |
| M, slope length exponent | = | 0.5 |
| Alpha, slope angle (degrees) | = | 5.16 |
| ni, rangeland constant-RUSLE table | = | 0.45 |
| alphal, .......................... | = | 27.3 |
| RS = Bio*ni*alphal/100 | = | 30.71 |

| INPUT VARIABLES FOR RUSLE and RRUSLE TO ESTIMATE SOIL LOSS FROM RANGELAND WATERSHEDS | | | | | | | | | | RUSLE and RRUSLE OUTPUTS AND FIELD MEASUREMENTS OF SOIL LOSS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot No. | Rainfall intensity (mm)/h | Canopy cover (prop.) | Canopy height (m) | Total cover (prop.) | Surface roughness (mm) | Plant biomass (kg/ha) | Organic cover Plant+Litter (prop.) | Rock cover (prop.) | Bare ground (prop.) | RUSLE Estimated soil loss (t/ha) | RRUSLE Estimated soil loss (t/ha) | Actual soil loss (t/ha) |
| SLWOR2A | 97.1 | 0.30 | 0.17 | 0.72 | 10.0 | 250 | 0.72 | 0 | 0.28 | 0.00049 | 0.00351 | 0.0017 |
| SLWOR2B | 97.1 | 0.43 | 0.17 | 0.62 | 10.0 | 180 | 0.62 | 0 | 0.38 | 0.00061 | 0.00354 | 0.0192 |
| SLWOR11A | 97.1 | 0.13 | 0.17 | 0.24 | 6.2 | 320 | 0.24 | 0 | 0.76 | 0.00453 | 0.00963 | 0.1205 |
| SLWOR11B | 97.1 | 0.06 | 0.17 | 0.08 | 5.6 | 90 | 0.08 | 0 | 0.92 | 0.00939 | 0.01230 | 0.5466 |
| SRWOR11A | 97.1 | 0.15 | 0.17 | 0.30 | 6.6 | 170 | 0.30 | 0 | 0.70 | 0.00345 | 0.00874 | 1.3200 |
| SRWOR11B | 97.1 | 0.17 | 0.17 | 0.24 | 7.4 | 290 | 0.24 | 0 | 0.76 | 0.00420 | 0.00893 | 0.1293 |
| S1WOR11A | 97.1 | 0.25 | 0.17 | 0.40 | 6.0 | 360 | 0.40 | 0 | 0.60 | 0.00209 | 0.00701 | 0.0898 |
| S1WOR11B | 97.1 | 0.27 | 0.17 | 0.42 | 6.6 | 380 | 0.42 | 0 | 0.58 | 0.00185 | 0.00656 | 0.0642 |
| S2WOR11A | 97.1 | 0.32 | 0.17 | 0.44 | 5.9 | 200 | 0.44 | 0 | 0.56 | 0.00163 | 0.00609 | 0.0582 |
| S2WOR11B | 97.1 | 0.26 | 0.17 | 0.50 | 27.1 | 210 | 0.50 | 0 | 0.50 | 0.00080 | 0.00349 | 0.0980 |
| SRWOR12A | 97.1 | 0.11 | 0.17 | 0.20 | 3.8 | 110 | 0.20 | 0 | 0.80 | 0.00578 | 0.01092 | 0.4105 |
| SRWOR12B | 97.1 | 0.09 | 0.17 | 0.18 | 6.3 | 120 | 0.18 | 0 | 0.82 | 0.00599 | 0.01066 | 0.3704 |
| SR1WOR12A | 97.1 | 0.00 | 0.00 | 0.04 | 3.0 | 60 | 0.04 | 0 | 0.96 | 0.01250 | 0.01445 | 0.0208 |
| SR1WOR12B | 97.1 | 0.00 | 0.00 | 0.00 | 3.0 | 0 | 0.00 | 0 | 1.00 | 0.01466 | 0.01496 | 0.0000 |

Table 5. RUSLE and RRUSLE variables and input data for plots on the Fifteen Mile Creek Drainage.

**ESTIMATED RUSLE FACTOR AND SUBFACTOR VALUES**

| | | |
|---|---|---|
| EI = | 27.4793 | Storm energy factor |
| K = | 0.029309 | Soil erodibility factor |
| L = | 0.090148 | Slope length factor |
| S = | 0.996922 | Slope steepness factor |
| PLU = | 0.342585 | Prior land use subfactor |
| CC = | 0.867883 | Plant canopy subfactor |
| SR = | 0.466822 | Surface roughness subfactor |
| SC = | 0.618783 | Surface cover subfactor |
| RSC = | 0.9168 | Refined surface cover subfactor |

**INPUT RUSLE CONSTANTS**

| | | |
|---|---|---|
| a, soil organic matter (%) | = | 1 |
| b, soil stucture index | = | 2 |
| c, profile permeability index | = | 4 |
| VFS, very fine sand plus silt (%) | = | 29 |
| percentage of clay (%) | = | 3 |
| m = (vfs)*(100 - % clay) | = | 2813 |
| lambda, horizont project of slope | = | 0.59 |
| M, slope length exponent | = | 0.5 |
| Alpha, slope angle (degrees) | = | 5.16 |
| nl, rangeland constant-RUSLE table | = | 0.45 |
| alphal, .......................... | = | 27.3 |
| RS = Bio*nl*alphal/100 | = | 22.73 |

| INPUT VARIABLES FOR RUSLE and RRUSLE TO ESTIMATE SOIL LOSS FROM RANGELAND WATERSHEDS | | | | | | | | | | RUSLE and RRUSLE OUTPUTS AND FIELD MEASUREMENTS OF SOIL LOSS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot No. | Rainfall intensity (mm)/h | Canopy cover (prop.) | Canopy height (m) | Total cover (prop.) | Surface roughness (mm) | Plant biomass (kg/ha) | Organic cover Plant+Litter (prop.) | Rock cover (prop.) | Bare ground (prop.) | RUSLE Estimated soil loss (t/ha) | RRUSLE Estimated soil loss (t/ha) | Actual soil loss (t/ha) |
| SLWOR3A | 97.1 | 0.14 | 0.17 | 0.12 | 8.2 | 185 | 0.12 | 0 | 0.88 | 0.00622 | 0.00921 | 0.3279 |
| SLWOR3B | 97.1 | 0.15 | 0.17 | 0.16 | 15.2 | 290 | 0.14 | 0 | 0.84 | 0.00437 | 0.00728 | 0.4430 |
| SRWOR3A | 97.1 | 0.10 | 0.17 | 0.17 | 1.6 | 185 | 0.17 | 0 | 0.83 | 0.00632 | 0.01090 | 0.2758 |
| SRWOR3B | 97.1 | 0.11 | 0.17 | 0.14 | 5.3 | 100 | 0.14 | 0 | 0.86 | 0.00639 | 0.01006 | 0.2907 |
| SLWOR4A | 97.1 | 0.38 | 0.17 | 0.48 | 5.4 | 270 | 0.48 | 0 | 0.52 | 0.00100 | 0.00413 | 0.0124 |
| SLWOR4B | 97.1 | 0.23 | 0.17 | 0.50 | 4.6 | 130 | 0.50 | 0 | 0.50 | 0.00091 | 0.00366 | 0.0000 |
| SRWOR4A | 97.1 | 0.31 | 0.17 | 0.46 | 6.9 | 310 | 0.46 | 0 | 0.54 | 0.00108 | 0.00423 | 0.0581 |
| SRWOR4B | 97.1 | 0.38 | 0.17 | 0.52 | 5.8 | 410 | 0.52 | 0 | 0.48 | 0.00078 | 0.00359 | 0.0042 |
| SLWOR8A | 97.1 | 0.35 | 0.17 | 0.36 | 5.4 | 330 | 0.36 | 0 | 0.64 | 0.00198 | 0.00592 | 0.0145 |
| SLWOR8B | 97.1 | 0.31 | 0.17 | 0.38 | 6.6 | 370 | 0.38 | 0 | 0.62 | 0.00187 | 0.00592 | 0.0392 |
| SRWOR8A | 97.1 | 0.27 | 0.17 | 0.42 | 4.9 | 285 | 0.42 | 0 | 0.58 | 0.00175 | 0.00619 | 0.1065 |
| SRWOR8B | 97.1 | 0.11 | 0.17 | 0.30 | 15.7 | 460 | 0.18 | 0 | 0.70 | 0.00257 | 0.00634 | 0.1084 |

Table 6. RUSLE and RRUSLE variables and input data for plots on the Fifteen Mile Creek Drainage.

ESTIMATED RUSLE FACTOR AND SUBFACTOR VALUES

| | | |
|---|---|---|
| EI = | 27.4793 | Storm energy factor |
| K = | 0.02653 | Soil erodibility factor |
| L = | 0.09015 | Slope length factor |
| S = | 0.99692 | Slope steepness factor |
| PLU = | 0.29348 | Prior land use subfactor |
| CC = | 0.88853 | Plant canopy subfactor |
| SR = | 0.67387 | Surface roughness subfactor |
| SC = | 0.13534 | Surface cover subfactor |
| RSC = | 0.59 | Refined surface cover subfactor |

INPUT RUSLE CONSTANTS

| | | |
|---|---|---|
| a, soil organic matter (%) | = | 1 |
| b, soil stucture index | = | 2 |
| c, profile permeability index | = | 4 |
| VFS, very fine sand plus silt (%) | = | 26 |
| percentage of clay (%) | = | 2 |
| m = (Vfs)*(100 - % clay) | = | 2548 |
| lambda, horizont project of slope | = | 0.59 |
| M, slope length exponent | = | 0.5 |
| Alpha, slope angle (degrees) | = | 5.16 |
| ni, rangeland constant-RUSLE table | = | 0.45 |
| alphai, ........................ | = | 27.3 |
| RS = Bio*ni*alphai/100 | = | 35.63 |

| INPUT VARIABLES FOR RUSLE and RRUSLE TO ESTIMATE SOIL LOSS FROM RANGELAND WATERSHEDS | | | | | | | | | | | RUSLE and RRUSLE OUTPUTS AND FIELD MEASUREMENTS OF SOIL LOSS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot No. | Rainfall intensity (mm/h) | Canopy cover (prop.) | Canopy height (m) | Total cover (prop.) | Surface roughness (mm) | Plant biomass (kg/ha) | Organic cover Plant+Litter (prop.) | Rock cover (prop.) | Bare ground (prop.) | RUSLE Estimated soil loss (t/ha) | RRUSLE Estimated soil loss (t/ha) | Actual soil loss (t/ha) |
| SLWOR9A | 97.1 | 0.33 | 0.17 | 0.50 | 5.0 | 290 | 0.50 | 0.00 | 0.50 | 0.00121 | 0.00526 | 0.0025 |
| SLWOR9B | 97.1 | 0.26 | 0.17 | 0.52 | 6.4 | 290 | 0.52 | 0.00 | 0.48 | 0.00118 | 0.00540 | 0.0000 |
| SRWOR9A | 97.1 | 0.26 | 0.17 | 0.60 | 11.0 | 440 | 0.60 | 0.00 | 0.40 | 0.00076 | 0.00422 | 0.0142 |
| SRWOR9B | 97.1 | 0.31 | 0.17 | 0.40 | 3.5 | 310 | 0.40 | 0.00 | 0.60 | 0.00192 | 0.00644 | 0.0071 |
| SLWOR10A | 97.1 | 0.33 | 0.17 | 0.60 | 3.8 | 410 | 0.60 | 0.00 | 0.40 | 0.00053 | 0.00292 | 0.0000 |
| SLWOR10B | 97.1 | 0.31 | 0.17 | 0.50 | 6.7 | 340 | 0.50 | 0.00 | 0.50 | 0.00089 | 0.00386 | 0.0000 |
| SRWOR10A | 97.1 | 0.29 | 0.17 | 0.40 | 7.2 | 270 | 0.40 | 0.00 | 0.60 | 0.00154 | 0.00515 | 0.0000 |
| SRWOR10B | 97.1 | 0.27 | 0.17 | 0.42 | 7.5 | 190 | 0.38 | 0.00 | 0.58 | 0.00137 | 0.00478 | 0.0000 |
| ESWOR2A | 97.1 | 0.12 | 0.17 | 0.10 | 3.3 | 230 | 0.40 | 0.06 | 0.90 | 0.00805 | 0.01374 | 0.3608 |
| ESWOR2B | 97.1 | 0.06 | 0.17 | 0.12 | 6.1 | 200 | 0.32 | 0.00 | 0.88 | 0.00735 | 0.01127 | 0.3738 |
| ESWOR3A | 97.1 | 0.14 | 0.17 | 0.20 | 8.5 | 30 | 0.10 | 0.00 | 0.80 | 0.00461 | 0.00654 | 0.3162 |
| ESWOR3B | 97.1 | 0.22 | 0.17 | 0.24 | 7.6 | 90 | 0.12 | 0.00 | 0.76 | 0.00367 | 0.00762 | 0.1698 |
| ESWOR4A | 97.1 | 0.00 | 0.00 | 0.00 | 0.0 | 0 | 0.00 | 0.00 | 1.00 | 0.01476 | 0.01505 | 0.0137 |
| ESWOR4B | 97.1 | 0.00 | 0.00 | 0.00 | 0.0 | 0 | 0.00 | 0.00 | 1.00 | 0.01476 | 0.01505 | 0.0033 |

Table 7. RUSLE and RRUSLE variables and input data for plots on the Ten Mile Creek Drainage.

**ESTIMATED RUSLE FACTOR AND SUBFACTOR VALUES**

| | | | |
|---|---|---|---|
| EI | = | 27.4793 | Storm energy factor |
| K | = | 0.014761 | Soil erodibility factor |
| L | = | 0.090148 | Slope length factor |
| S | = | 0.996922 | Slope steepness factor |
| PLU | = | 0.249527 | Prior land use subfactor |
| CC | = | 0.565834 | Plant canopy subfactor |
| SR | = | 0.785404 | Surface roughness subfactor |
| SC | = | 0.158817 | Surface cover subfactor |
| RSC | = | 0.6244 | Refined surface cover subfactor |

**INPUT RUSLE CONSTANTS**

| | | |
|---|---|---|
| a, soil organic matter (%) | = | 1.1 |
| b, soil stucture index | = | 2 |
| c, profile permeability index | = | 2 |
| VFS, very fine sand plus silt (%) | = | 21 |
| percentage of clay (%) | = | 2 |
| m = (vfs)*(100 - % clay) | = | 2058 |
| lambda, horizont project of slope | = | 0.59 |
| M, slope length exponent | = | 0.5 |
| Alpha, slope angle (degrees) | = | 5.16 |
| nl, rangeland constant-RUSLE table | : | 0.45 |
| alphal, .......................... | = | 27.3 |
| RS = Bio*nl*alphal/100 | = | 49.14 |

| INPUT VARIABLES FOR RUSLE and RRUSLE TO ESTIMATE SOIL LOSS FROM RANGELAND WATERSHEDS | | | | | | | | | | RUSLE and RRUSLE OUTPUTS AND FIELD MEASUREMENTS OF SOIL LOSS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot No. | Rainfall intensity (mm)/h | Canopy cover (prop.) | Canopy height (m) | Total cover (prop.) | Surface roughness (mm) | Plant biomass (kg/ha) | Organic cover Plant+Litter (prop.) | Rock cover (prop.) | Bare ground (prop.) | RUSLE Estimated soil loss (t/ha) | RRUSLE Estimated soil loss (t/ha) | Actual soil loss (t/ha) |
| SLWOR1A | 97.1 | 0.46 | 0.17 | 0.46 | 5.3 | 400 | 0.46 | 0 | 0.54 | 0.00064 | 0.00252 | 0.0637 |
| SLWOR1B | 97.1 | 0.42 | 0.17 | 0.42 | 7.7 | 400 | 0.42 | 0 | 0.58 | 0.00076 | 0.00267 | 0.0479 |
| SRWOR1A | 97.1 | 0.52 | 0.17 | 0.52 | 11.2 | 420 | 0.52 | 0 | 0.48 | 0.00039 | 0.00179 | 0.0633 |
| SRWOR1B | 97.1 | 0.52 | 0.17 | 0.52 | 5.4 | 300 | 0.52 | 0 | 0.48 | 0.00045 | 0.00208 | 0.0545 |
| SL1WOR1A | 97.1 | 0.46 | 0.17 | 0.46 | 6.5 | 380 | 0.46 | 0 | 0.54 | 0.00062 | 0.00244 | 0.0292 |
| SL1WOR1B | 97.1 | 0.42 | 0.17 | 0.42 | 7.4 | 380 | 0.42 | 0 | 0.58 | 0.00076 | 0.00269 | 0.0013 |

Table 8. RUSLE and RRUSLE variables and input data for plots on the Ten Mile Creek Drainage.

**ESTIMATED RUSLE FACTOR AND SUBFACTOR VALUES**

| | | |
|---|---|---|
| EI = | 27.4793 | Storm energy factor |
| K = | 0.017377 | Soil erodibility factor |
| L = | 0.090148 | Slope length factor |
| S = | 0.996022 | Slope steepness factor |
| PLU = | 0.231796 | Prior land use subfactor |
| CC = | 0.950343 | Plant canopy subfactor |
| SR = | 0.671883 | Surface roughness subfactor |
| SC = | 0.353455 | Surface cover subfactor |
| RSC = | 0.7964 | Refined surface cover subfactor |

**INPUT RUSLE CONSTANTS**

| | | |
|---|---|---|
| a, soil organic matter (%) | = | 0.75 |
| b, soil stucture index | = | 2 |
| c, profile permeability index | = | 2 |
| VFS, very fine sand plus silt (%) | = | 23 |
| percentage of clay (%) | = | 2 |
| m = (vfs)*(100 - % clay) | = | 2254 |
| lambda, horizont project of slope | = | 0.59 |
| M, slope length exponent | = | 0.5 |
| Alpha, slope angle (degrees) | = | 5.16 |
| ni, rangeland constant-RUSLE table | = | 0.45 |
| alphai, ......................... | = | 27.3 |
| RS = Bio*ni*alphai/100 | = | 55.28 |

**INPUT VARIABLES FOR RUSLE and RRUSLE TO ESTIMATE SOIL LOSS FROM RANGELAND WATERSHEDS** / **RUSLE and RRUSLE OUTPUTS AND FIELD MEASUREMENTS OF SOIL LOSS**

| Plot No. | Rainfall intensity (mm)/h | Canopy cover (prop.) | Canopy height (m) | Total cover (prop.) | Surface roughness (mm) | Plant biomass (kg/ha) | Organic cover Plant+Litter (prop.) | Rock cover (prop.) | Bare ground (prop.) | RUSLE Estimated soil loss (t/ha) | RRUSLE Estimated soil loss (t/ha) | Actual soil loss (t/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WOR1A | 97.1 | 0.05 | 0.05 | 0.26 | 13.2 | 450 | 0.26 | 0.00 | 0.74 | 0.00225 | 0.00506 | 0.1521 |
| WOR1B | 97 1 | 0.10 | 0.20 | 0.30 | 10.2 | 450 | 0.30 | 0.00 | 0.70 | 0.00197 | 0.00498 | 0.0100 |
| WOR2A | 97.1 | 0.12 | 0.16 | 0.25 | 12.1 | 450 | 0.25 | 0.00 | 0.75 | 0.00224 | 0.00491 | 0.0142 |
| WOR2B | 97.1 | 0.10 | 0.15 | 0.22 | 12.1 | 450 | 0.22 | 0.00 | 0.78 | 0.00258 | 0.00517 | 0.0000 |
| WOR3A | 97.1 | 0.08 | 0.20 | 0.23 | 9.1 | 450 | 0.23 | 0.00 | 0.77 | 0.00274 | 0.00565 | 0.0267 |
| WOR3B | 97.1 | 0.20 | 0.20 | 0.29 | 10.1 | 450 | 0.29 | 0.00 | 0.71 | 0.00184 | 0.00453 | 0.0008 |
| WOR4A | 97.1 | 0.50 | 0.25 | 0.34 | 8.5 | 450 | 0.34 | 0.00 | 0.66 | 0.00105 | 0.00297 | 0.0000 |
| WOR4B | 97.1 | 0.62 | 0.28 | 0.42 | 10.5 | 450 | 0.41 | 0.01 | 0.58 | 0.00058 | 0.00211 | 0.0000 |
| WOR5A | 97.1 | 0.30 | 0.13 | 0.33 | 10.2 | 450 | 0.33 | 0.00 | 0.67 | 0.00138 | 0.00379 | 0.0000 |
| WOR5B | 97.1 | 0.45 | 0.32 | 0.36 | 15.0 | 450 | 0.36 | 0.00 | 0.64 | 0.00090 | 0.00270 | 0.0038 |
| WOR6A | 97.1 | 0.23 | 0.09 | 0.28 | 5.6 | 450 | 0.28 | 0.00 | 0.72 | 0.00206 | 0.00493 | 0.0017 |
| WOR6B | 97.1 | 0.40 | 0.17 | 0.34 | 5.9 | 450 | 0.34 | 0.00 | 0.66 | 0.00129 | 0.00366 | 0.0867 |
| WOR7A | 97.1 | 0.30 | 0.12 | 0.27 | 7.7 | 450 | 0.27 | 0.00 | 0.73 | 0.00186 | 0.00432 | 0.0067 |
| WOR7B | 97.1 | 0.21 | 0.10 | 0.25 | 11.1 | 450 | 0.25 | 0.00 | 0.75 | 0.00207 | 0.00453 | 0.0083 |
| WOR8A | 97.1 | 0.40 | 0.11 | 0.36 | 17.6 | 450 | 0.36 | 0.00 | 0.64 | 0.00087 | 0.00260 | 0.0383 |
| WOR8B | 97.1 | 0.38 | 0.13 | 0.31 | 9.7 | 450 | 0.31 | 0.00 | 0.69 | 0.00135 | 0.00351 | 0.0008 |
| WOR9A | 97 1 | 0.30 | 0.10 | 0.32 | 12.0 | 450 | 0.29 | 0.03 | 0.68 | 0.00136 | 0.00386 | 0.0000 |
| WOR9B | 97.1 | 0.28 | 0.12 | 0.30 | 15.2 | 450 | 0.27 | 0.03 | 0.70 | 0.00140 | 0.00373 | 0.0008 |

Table 9. RUSLE and RRUSLE variables and input data for plots on the Beaver Creek and Little Jack Creek Drainages.

| ESTIMATED RUSLE FACTOR AND SUBFACTOR VALUES | | |
|---|---|---|
| EI = | 27.4793 | Storm energy factor |
| K = | 0.011281 | Soil erodibility factor |
| L = | 0.090148 | Slope length factor |
| S = | 0.996922 | Slope steepness factor |
| PLU = | 0.076723 | Prior land use subfactor |
| CC = | 0.99977 | Plant canopy subfactor |
| SR = | 0.840906 | Surface roughness subfactor |
| SC = | 0.019841 | Surface cover subfactor |
| RSC = | 0.1772 | Refined surface cover subfactor |

| INPUT RUSLE CONSTANTS | | |
|---|---|---|
| a, soil organic matter (%) | = | 9.9 |
| b, soil stucture index | = | 2 |
| c, profile permeability index | = | 4 |
| VFS, very fine sand plus silt (%) | = | 44 |
| percentage of clay (%) | = | 3 |
| m = (vfs)*(100 - % clay) | = | 4268 |
| lambda, horizont project of slope | = | 0.59 |
| M, slope length exponent | = | 0.5 |
| Alpha, slope angle (degrees) | = | 5.16 |
| nl, rangeland constant-RUSLE table | = | 0.45 |
| alphal, ......................... | = | 27.3 |
| RS = Bio*nl*alphal/100 | = | 147.4 |

| INPUT VARIABLES FOR RUSLE and RRUSLE TO ESTIMATE SOIL LOSS FROM RANGELAND WATERSHEDS | | | | | | | | | | RUSLE and RRUSLE OUTPUTS AND FIELD MEASUREMENTS OF SOIL LOSS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot No. | Rainfall intensity (mm)/h | Canopy cover (prop.) | Canopy height (m) | Total cover (prop.) | Surface roughness (mm) | Plant biomass (kg/ha) | Organic cover Plant+Litter (prop.) | Rock cover (prop.) | Bare ground (prop.) | RUSLE Estimated soil loss (t/ha) | RRUSLE Estimated soil loss (t/ha) | Actual soil loss (t/ha) |
| SRAW1A | 97.1 | 0.68 | 23.50 | 0.98 | 12.2 | 1200 | 0.98 | 0 | 0.02 | 0.00004 | 0.00032 | 0.0017 |
| SRAW1B | 97.1 | 0.73 | 23.50 | 1.00 | 8.0 | 1200 | 1.00 | 0 | 0.00 | 0.00004 | 0.00032 | 0.0006 |
| SRAW2A | 97.1 | 0.29 | 23.50 | 1.00 | 10.1 | 1600 | 1.00 | 0 | 0.00 | 0.00003 | 0.00030 | 0.0971 |
| SRAW2B | 97.1 | 0.61 | 23.50 | 1.00 | 12.0 | 2200 | 1.00 | 0 | 0.00 | 0.00003 | 0.00029 | 0.0046 |
| SRAW3A | 97.1 | 0.66 | 23.50 | 1.00 | 24.1 | 1800 | 1.00 | 0 | 0.00 | 0.00002 | 0.00021 | 0.0063 |
| SRAW3B | 97.1 | 0.45 | 23.50 | 1.00 | 18.4 | 1600 | 1.00 | 0 | 0.00 | 0.00003 | 0.00024 | 0.0474 |
| SRAW4A | 97.1 | 0.33 | 23.50 | 1.00 | 8.6 | 1700 | 1.00 | 0 | 0.00 | 0.00004 | 0.00032 | 0.0423 |
| SRAW4B | 97.1 | 0.40 | 23.50 | 1.00 | 10.9 | 2000 | 1.00 | 0 | 0.00 | 0.00003 | 0.00030 | 0.0540 |
| SRAW5A | 97.1 | 0.60 | 23.50 | 0.86 | 13.8 | 900 | 0.86 | 0 | 0.14 | 0.00006 | 0.00048 | 0.0000 |
| SRAW5B | 97.1 | 0.44 | 23.50 | 0.93 | 17.4 | 1100 | 0.93 | 0 | 0.07 | 0.00004 | 0.00035 | 0.0000 |
| SRAW6A | 97.1 | 0.64 | 23.50 | 0.77 | 13.8 | 800 | 0.77 | 0 | 0.23 | 0.00008 | 0.00062 | 0.0021 |
| SRAW6B | 97.1 | 0.55 | 23.50 | 0.92 | 17.4 | 700 | 0.92 | 0 | 0.08 | 0.00004 | 0.00036 | 0.0042 |
| SRAW7A | 97.1 | 0.00 | 0.00 | 0.00 | 0.0 | 0 | 0.00 | 0 | 1.00 | 0.00247 | 0.00252 | 0.0000 |
| SRAW7B | 97.1 | 0.00 | 0.00 | 0.00 | 0.0 | 0 | 0.00 | 0 | 1.00 | 0.00247 | 0.00252 | 0.0000 |
| SRAW8A | 97.1 | 0.58 | 23.50 | 0.69 | 26.3 | 1000 | 0.69 | 0 | 0.31 | 0.00008 | 0.00053 | 0.0208 |
| SRAW8B | 97.1 | 0.47 | 23.50 | 0.90 | 15.8 | 800 | 0.90 | 0 | 0.10 | 0.00004 | 0.00040 | 0.0058 |
| SRAW9A | 97.1 | 0.52 | 23.50 | 0.71 | 31.9 | 1200 | 0.71 | 0 | 0.29 | 0.00006 | 0.00044 | 0.0008 |
| SRAW9B | 97.1 | 0.68 | 23.50 | 0.84 | 35.1 | 1000 | 0.84 | 0 | 0.16 | 0.00003 | 0.00029 | 0.0000 |

# Appendix D

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Representative soil particle size plots from each of the four study areas.

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1. Figure 11. A plot of percent passing (by weight) and grain size for the soil from Plot SRWOR1 north of Worland, Wyoming.
2. Figure 12. A plot of percent passing (by weight) and grain size for the soil from Plot SRWOR9 west of Worland, Wyoming.
3. Figure 13. A plot of percent passing (by weight) and grain size for the soil from Plot SRAW3 in the Stratton Sagebrush Study area south of Rawlins, Wyoming.
4. Figure 14. A plot of percent passing (by weight) and grain size for the soil from Plot SRAW8 south of Rawlins, Wyoming.

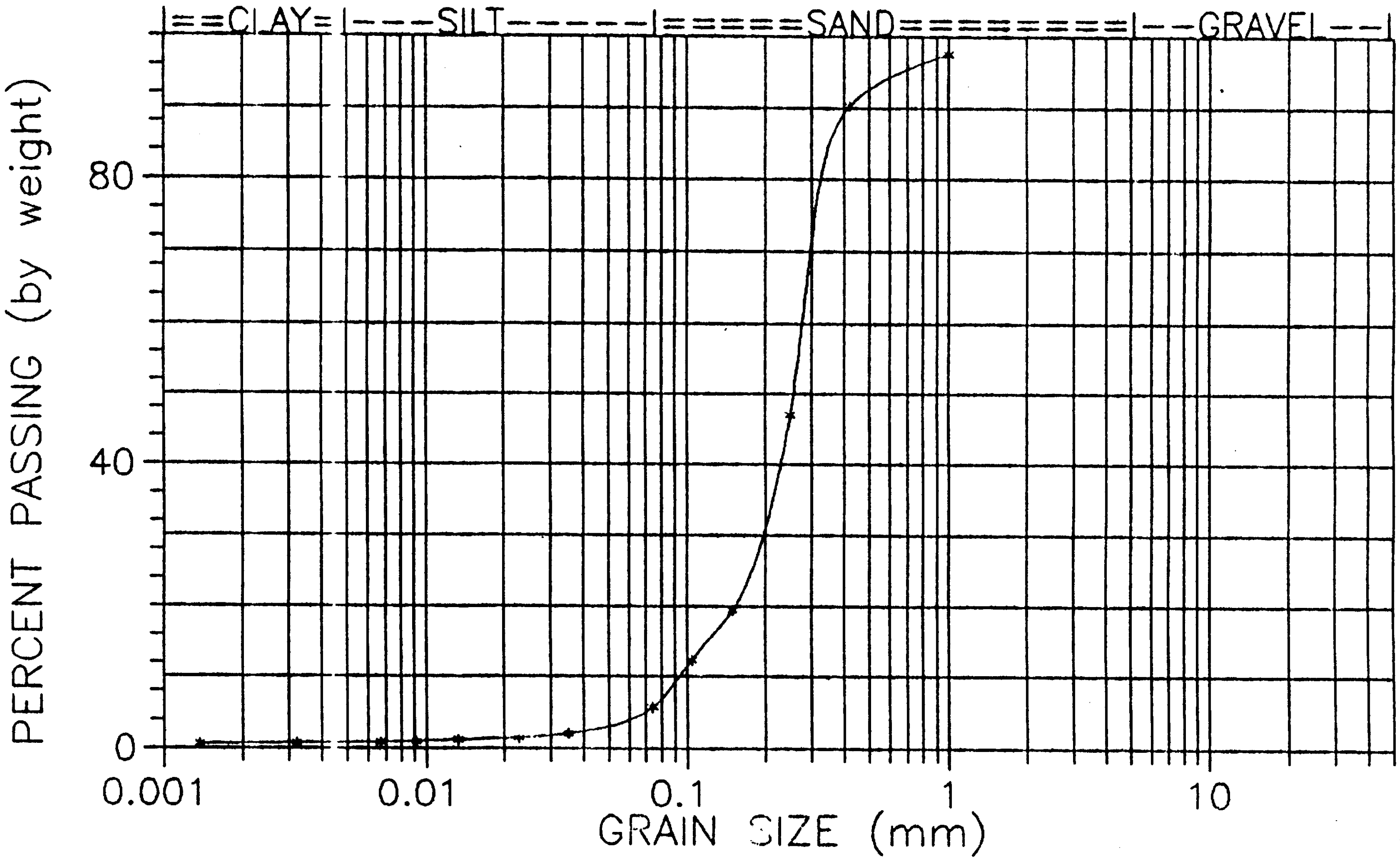



Figure 11. A plot of percent passing (by weight) and grain size for the soil from Plot SRWOR1.

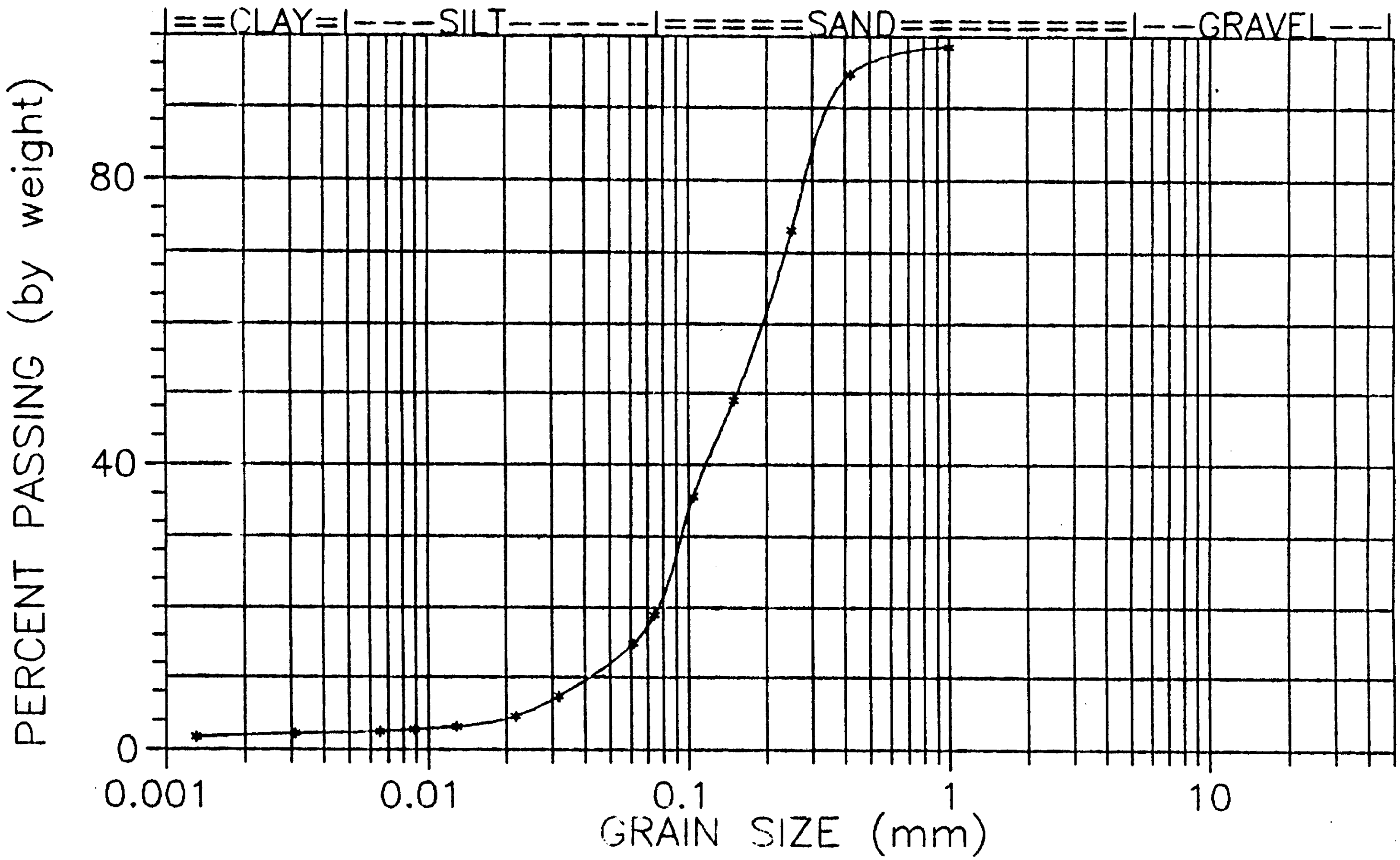



Figure 12. A plot of percent passing (by weight) and grain size for the soil from Plot SRWOR9.

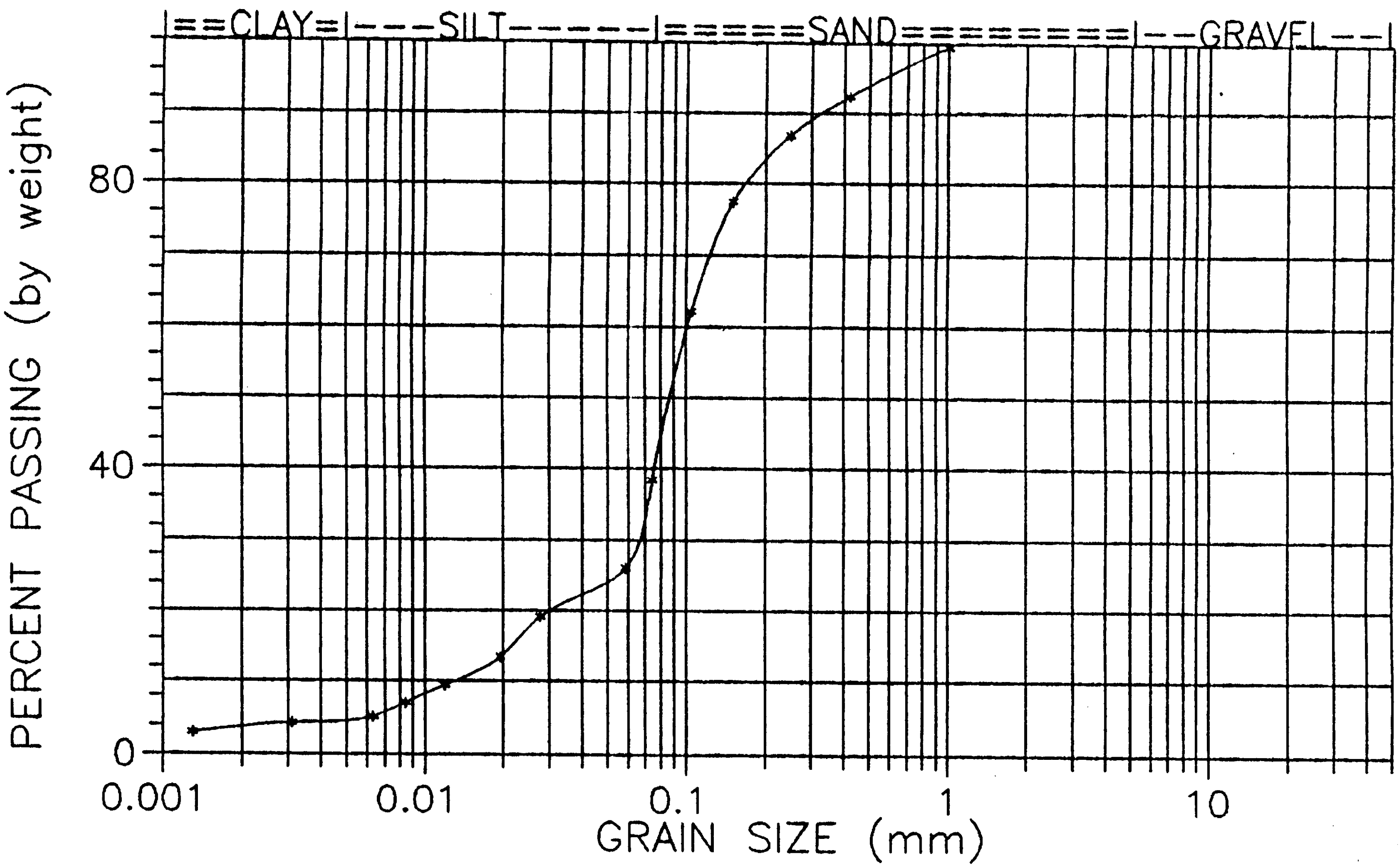
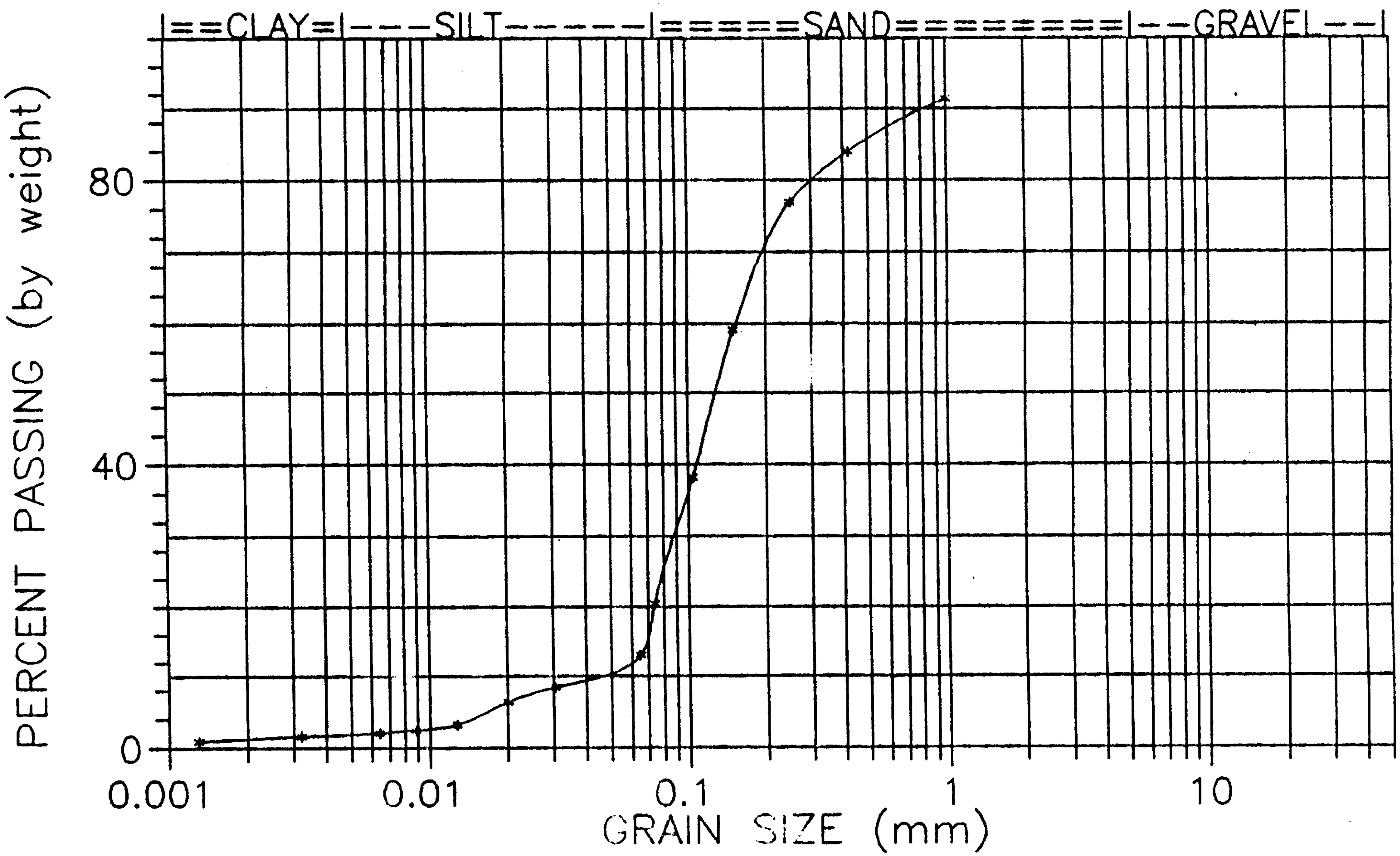



Figure 13. A plot of percent passing (by weight) and grain size for the soil from Plot SRAW3.




Figue 14. A plot of percent passing (by weight) and grain size for the soil from Plot SRAW7.

Appendix E

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Correlation Statistics.

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1. Table 10. Polynomial regression of the standard deviation of surface roughness and sediment yield.
2. Table 11. Polynomial regression of the total ground cover and the standard deviation of surface roughness.
3. Table 12. Polynomial regression of the total ground cover and the sediment yield.
4. Table 13. Multiple regression of ground cover and the standard deviation of surface roughness versus the non-zero values of sediment yield.

Table 10. Polynomial regression of the standard deviation of surface roughness and sediment yield.

| ROUGHNESS (X2) | (X2)^2 | SEDIMENT YIELD (Y) |
|---|---|---|
| 13.17 | 173.46 | 0.1521 |
| 10.23 | 104.85 | 0.0100 |
| 12.07 | 145.68 | 0.0142 |
| 12.06 | 145.44 | 0.0000 |
| 9.09 | 82.63 | 0.0267 |
| 10.14 | 102.82 | 0.0088 |
| 8.52 | 72.59 | 0.0090 |
| 10.54 | 111.09 | 0.0000 |
| 10.20 | 104.04 | 0.0000 |
| 15.00 | 225.00 | 0.0038 |
| 5.53 | 30.81 | 0.0017 |
| 5.9 | 34.93 | 0.0367 |
| 7.72 | 59.60 | 0.0067 |
| 11.06 | 122.32 | 0.0683 |
| 17.60 | 309.76 | 0.0363 |
| 9.72 | 94.48 | 0.0008 |
| 12.00 | 144.00 | 0.0000 |
| 15.[illegible] | 231.04 | 0.0008 |
| 5.29 | 27.98 | 0.0637 |
| 7.57 | 58.83 | 0.0478 |
| 11.16 | 124.55 | 0.0633 |
| 5.36 | 28.73 | 0.0646 |
| 6.[illegible] | 42.77 | 0.0292 |
| [illegible] | 65.20 | 0.0013 |
| 10.[illegible] | 100.00 | 0.0817 |
| 10.00 | 100.00 | 0.0182 |
| 8.20 | 67.24 | 0.3278 |
| 15.20 | 231.04 | 0.4430 |
| 1.50 | 2.25 | 0.2759 |
| 5.30 | 28.09 | 0.2807 |
| 5.40 | 29.16 | 0.0124 |
| 4.[illegible] | 21.16 | 0.0000 |
| 6.90 | 47.61 | 0.0591 |
| 5.80 | 33.64 | 0.0042 |
| 5.40 | 29.16 | 0.0146 |
| 6.60 | 43.56 | 0.0392 |
| 4.90 | 24.01 | 0.1086 |
| 15.[illegible] | 246.49 | 0.1984 |
| 5.[illegible] | 25.00 | 0.0026 |
| 6.[illegible] | 40.96 | 0.0000 |
| 11.00 | 121.00 | 0.0142 |
| 3.50 | 12.25 | 0.0071 |
| 3.[illegible] | 14.44 | 0.0000 |
| 6.7[illegible] | 44.89 | 0.0080 |
| 7.20 | 51.84 | 0.0000 |
| 7.50 | 56.25 | 0.0000 |
| 6.20 | 38.44 | 0.1206 |
| 5.60 | 31.36 | 0.5466 |
| 7.40 | 54.76 | 0.1293 |
| 6.00 | 36.00 | 0.0898 |
| 6.60 | 43.56 | 0.0842 |
| 5.90 | 34.81 | 0.0582 |
| 27.10 | 734.41 | 0.0980 |
| 3.80 | 14.44 | 0.4106 |
| 6.30 | 39.69 | 0.3704 |
| 3.00 | 9.00 | 0.0209 |
| 3.30 | 10.89 | 0.3698 |
| 6.10 | 37.21 | 0.3739 |
| 8.50 | 72.25 | 0.3182 |
| 7.60 | 57.76 | 0.1898 |
| 12.20 | 148.84 | 0.0017 |
| 9.01 | 84.18 | 0.0009 |
| 10.12 | 102.41 | 0.0871 |
| 11.95 | 142.80 | 0.0046 |
| 24.07 | 579.36 | 0.0063 |
| 18.36 | 337.09 | 0.0474 |
| 8.60 | 73.96 | 0.0423 |
| 10.86 | 117.94 | 0.0649 |
| 13.75 | 189.06 | 0.0000 |
| 17.39 | 302.41 | 0.0008 |
| 13.75 | 189.06 | 0.0021 |
| 17.39 | 302.41 | 0.0042 |
| 26.26 | 689.56 | 0.0209 |
| 15.75 | 248.06 | 0.0069 |
| 31.90 | 1017.61 | 0.0009 |
| 35.10 | 1232.01 | 0.0000 |

**Y=-0.015(X1)+ 0.00032(X1)^2+ 0.18**

**R^2=0.079**
**R=0.28**

WHERE: (X2)=STANDARD DEVIATION OF SURFACE ROUGHNESS ,
(Y)=SEDIMENT YIELD.

Regression Output

| | | |
|---|---|---|
| Constant | | 0.179879 |
| Std Err of Y Est | | 0.122336 |
| R Squared | | 0.079009 |
| No. of Observations | | 76 |
| Degrees of Freedom | | 73 |
| | | |
| X Coefficient(s) | -0.01486 | 0.000315 |
| Std Err of Coef. | 0.007482 | 0.000224 |

Table 11. Polynomial regression of total cover and the standard deviation of surface roughness.

| COVER (X1) | (X1)^2 | ROUGHNESS (X2) |
|---|---|---|
| 0.28 | 0.07 | 13.2 |
| 0.30 | 0.09 | 18.2 |
| 0.25 | 0.06 | 12.1 |
| 0.22 | 0.05 | 12.1 |
| 0.23 | 0.05 | 8.1 |
| 0.29 | 0.08 | 10.1 |
| 0.34 | 0.12 | 8.5 |
| 0.42 | 0.18 | 18.5 |
| 0.33 | 0.11 | 18.2 |
| 0.36 | 0.13 | 15.0 |
| 0.28 | 0.08 | 5.8 |
| 0.34 | 0.12 | 5.9 |
| 0.27 | 0.07 | 7.7 |
| 0.25 | 0.06 | 11.1 |
| 0.36 | 0.13 | 17.8 |
| 0.31 | 0.10 | 9.7 |
| 0.32 | 0.10 | 12.0 |
| 0.30 | 0.09 | 16.2 |
| 0.46 | 0.21 | 5.3 |
| 0.42 | 0.18 | 7.7 |
| 0.52 | 0.27 | 11.2 |
| 0.52 | 0.27 | 5.4 |
| 0.46 | 0.21 | 6.5 |
| 0.42 | 0.18 | 7.4 |
| 0.72 | 0.52 | 10 |
| 0.62 | 0.38 | 18 |
| 0.12 | 0.01 | 8.2 |
| 0.16 | 0.03 | 15.2 |
| 0.17 | 0.03 | 1.5 |
| 0.14 | 0.02 | 5.3 |
| 0.48 | 0.23 | 5.4 |
| 0.50 | 0.25 | 4.8 |
| 0.46 | 0.21 | 6.9 |
| 0.52 | 0.27 | 5.8 |
| 0.36 | 0.13 | 5.4 |
| 0.38 | 0.14 | 6.8 |
| 0.42 | 0.18 | 4.9 |
| 0.30 | 0.09 | 16.7 |
| 0.50 | 0.25 | 6 |
| 0.52 | 0.27 | 6.4 |
| 0.60 | 0.36 | 11 |
| 0.40 | 0.16 | 3.5 |
| 0.60 | 0.36 | 3.8 |
| 0.50 | 0.25 | 8.7 |
| 0.43 | 0.18 | 7.2 |
| 0.42 | 0.18 | 7.5 |
| 0.24 | 0.06 | 8.2 |
| 0.08 | 0.01 | 5.8 |
| 0.24 | 0.06 | 7.4 |
| 0.40 | 0.16 | 6 |
| 0.42 | 0.18 | 8.8 |
| 0.44 | 0.19 | 5.9 |
| 0.50 | 0.25 | 27.1 |
| 0.20 | 0.04 | 3.8 |
| 0.18 | 0.03 | 8.3 |
| 0.04 | 0.00 | 3 |
| 0.10 | 0.01 | 3.3 |
| 0.12 | 0.01 | 6.1 |
| 0.20 | 0.04 | 8.5 |
| 0.24 | 0.06 | 7.8 |
| 0.98 | 0.96 | 12.2 |
| 1.00 | 1.00 | 8.8 |
| 1.00 | 1.00 | 10.1 |
| 1.00 | 1.00 | 12.0 |
| 1.00 | 1.00 | 24.1 |
| 1.00 | 1.00 | 18.4 |
| 1.00 | 1.00 | 8.5 |
| 1.00 | 1.00 | 10.9 |
| 0.86 | 0.74 | 13.8 |
| 0.93 | 0.86 | 17.4 |
| 0.77 | 0.59 | 13.8 |
| 0.92 | 0.85 | 17.4 |
| 0.69 | 0.48 | 28.3 |
| 0.90 | 0.81 | 15.9 |
| 0.71 | 0.50 | 31.9 |
| 0.84 | 0.71 | 36.1 |

**Y=11.87(X1)–1.15(X1)^2+4.98**

**R^2=0.20**
**R=0.45**

WHERE: (X1)=TOTAL GROUND COVER ,
(X2)= STANDARD DEVIATION OF SURFACE ROUGHNESS.

Regression Output:

| | | |
|---|---|---|
| Constant | | 4.977103 |
| Std Err of Y Est | | 5.796228 |
| R Squared | | 0.20067 |
| No. of Observations | | 76 |
| Degrees of Freedom | | 73 |
| X Coefficient(s) | 11.87421 | -1.14733 |
| Std Err of Coef. | 10.84092 | 9.3153 |

Table 12. Polynomial regression of the total ground cover and the sediment yield.

| GROUND COVER (X1) | (X1)^2 | SEDIMENT YIELD (Y) |
|---|---|---|
| 0.26 | 0.07 | 0.1521 |
| 0.30 | 0.09 | 0.0100 |
| 0.25 | 0.06 | 0.0142 |
| 0.22 | 0.05 | 0.0000 |
| 0.23 | 0.05 | 0.0267 |
| 0.29 | 0.08 | 0.0008 |
| 0.34 | 0.12 | 0.0000 |
| 0.42 | 0.18 | 0.0000 |
| 0.33 | 0.11 | 0.0000 |
| 0.36 | 0.13 | 0.0038 |
| 0.28 | 0.08 | 0.0017 |
| 0.34 | 0.12 | 0.0867 |
| 0.27 | 0.07 | 0.0067 |
| 0.25 | 0.06 | 0.0083 |
| 0.36 | 0.13 | 0.0383 |
| 0.31 | 0.10 | 0.0008 |
| 0.32 | 0.10 | 0.0000 |
| 0.30 | 0.09 | 0.0008 |
| 0.46 | 0.21 | 0.0637 |
| 0.42 | 0.18 | 0.0479 |
| 0.52 | 0.27 | 0.0633 |
| 0.52 | 0.27 | 0.0545 |
| 0.46 | 0.21 | 0.0292 |
| 0.42 | 0.18 | 0.0013 |
| 0.72 | 0.52 | 0.0017 |
| 0.62 | 0.38 | 0.0192 |
| 0.12 | 0.01 | 0.3279 |
| 0.16 | 0.03 | 0.4430 |
| 0.17 | 0.03 | 0.2758 |
| 0.14 | 0.02 | 0.2907 |
| 0.48 | 0.23 | 0.0124 |
| 0.50 | 0.25 | 0.0000 |
| 0.46 | 0.21 | 0.0581 |
| 0.52 | 0.27 | 0.0042 |
| 0.36 | 0.13 | 0.0145 |
| 0.38 | 0.14 | 0.0392 |
| 0.42 | 0.18 | 0.1065 |
| 0.30 | 0.09 | 0.1084 |
| 0.50 | 0.25 | 0.0025 |
| 0.52 | 0.27 | 0.0000 |
| 0.60 | 0.36 | 0.0142 |
| 0.40 | 0.16 | 0.0071 |
| 0.60 | 0.36 | 0.0000 |
| 0.50 | 0.25 | 0.0000 |
| 0.40 | 0.16 | 0.0000 |
| 0.42 | 0.18 | 0.0000 |
| 0.24 | 0.06 | 0.1205 |
| 0.08 | 0.01 | 0.5466 |
| 0.24 | 0.06 | 0.1293 |
| 0.40 | 0.16 | 0.0698 |
| 0.42 | 0.18 | 0.0642 |
| 0.44 | 0.19 | 0.0582 |
| 0.50 | 0.25 | 0.0980 |
| 0.20 | 0.04 | 0.4105 |
| 0.18 | 0.03 | 0.3704 |
| 0.04 | 0.00 | 0.0208 |
| 0.10 | 0.01 | 0.3608 |
| 0.12 | 0.01 | 0.3738 |
| 0.20 | 0.04 | 0.3162 |
| 0.24 | 0.06 | 0.1898 |
| 0.98 | 0.96 | 0.0017 |
| 1.00 | 1.00 | 0.0008 |
| 1.00 | 1.00 | 0.0971 |
| 1.00 | 1.00 | 0.0046 |
| 1.00 | 1.00 | 0.0063 |
| 1.00 | 1.00 | 0.0474 |
| 1.00 | 1.00 | 0.0423 |
| 1.00 | 1.00 | 0.0540 |
| 0.86 | 0.74 | 0.0000 |
| 0.93 | 0.86 | 0.0000 |
| 0.77 | 0.59 | 0.0021 |
| 0.92 | 0.85 | 0.0042 |
| 0.69 | 0.48 | 0.0208 |
| 0.90 | 0.81 | 0.0058 |
| 0.71 | 0.50 | 0.0008 |
| 0.84 | 0.71 | 0.0000 |

**Y= −1.25(X1)+0.90(X1)^2+0.40**

**R^2=0.51**
**R=0.71**

WHERE: (X1)=TOTAL GROUND COVER.
(Y)= SEDIMENT YIELD.

Regression Output

| | | |
|---|---|---|
| Constant | | 0.39668 |
| Std Err of Y Est | | 0.08946 |
| R Squared | | 0.50748 |
| No. of Observations | | 76 |
| Degrees of Freedom | | 73 |
| X Coefficient(s) | -1.25263 | 0.90343 |
| Std Err of Coef. | 0.16762 | 0.14403 |

Table 13. Multiple regression of ground cover and the standard deviation of surface roughness versus the non-zero values of sediment yield.

$$Y=3.0(X1)-15.33(X1)^{2}+23.7(X1)^{3}-11.3(X1)^{4}-1.1E(-2)(X2)+1.2E(-4)(X2)^{2.5}-9.9E(-5)(X1*(X2^{2.5}))+0.13$$

$$R^2=0.48$$
$$R=0.69$$

WHERE: (X1)=TOTAL GROUND COVER ,
(X2)=STANDARD DEVIATION OF SURFACE ROUGHNESS ,
(Y)=SEDIMENT YIELD.

| | Regression Output: |
|---|---|
| Constant | 0.12641 |
| Std Err of Y Est | 0.10099 |
| R Squared | 0.48165 |
| No. of Observations | 64 |
| Degrees of Freedom | 56 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| X Coefficient(s) | 3.005 | -15.328 | 23.680 | -11.339 | -0.011 | 0.0001 | -9.94E-05 |
| Std Err of Coef. | 0.967 | 3.903 | 5.[illegible]56 | 2.957 | 0.007 | 9E-05 | 9.10E-05 |

# Appendix F

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## Representative Sedigraphs and Hydrographs.

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1. Figure 15. Four sedigraphs representative of the sedigraphs from each study area.
2. Figure 16. Four hydrographs representative of the hydrographs from each study area.

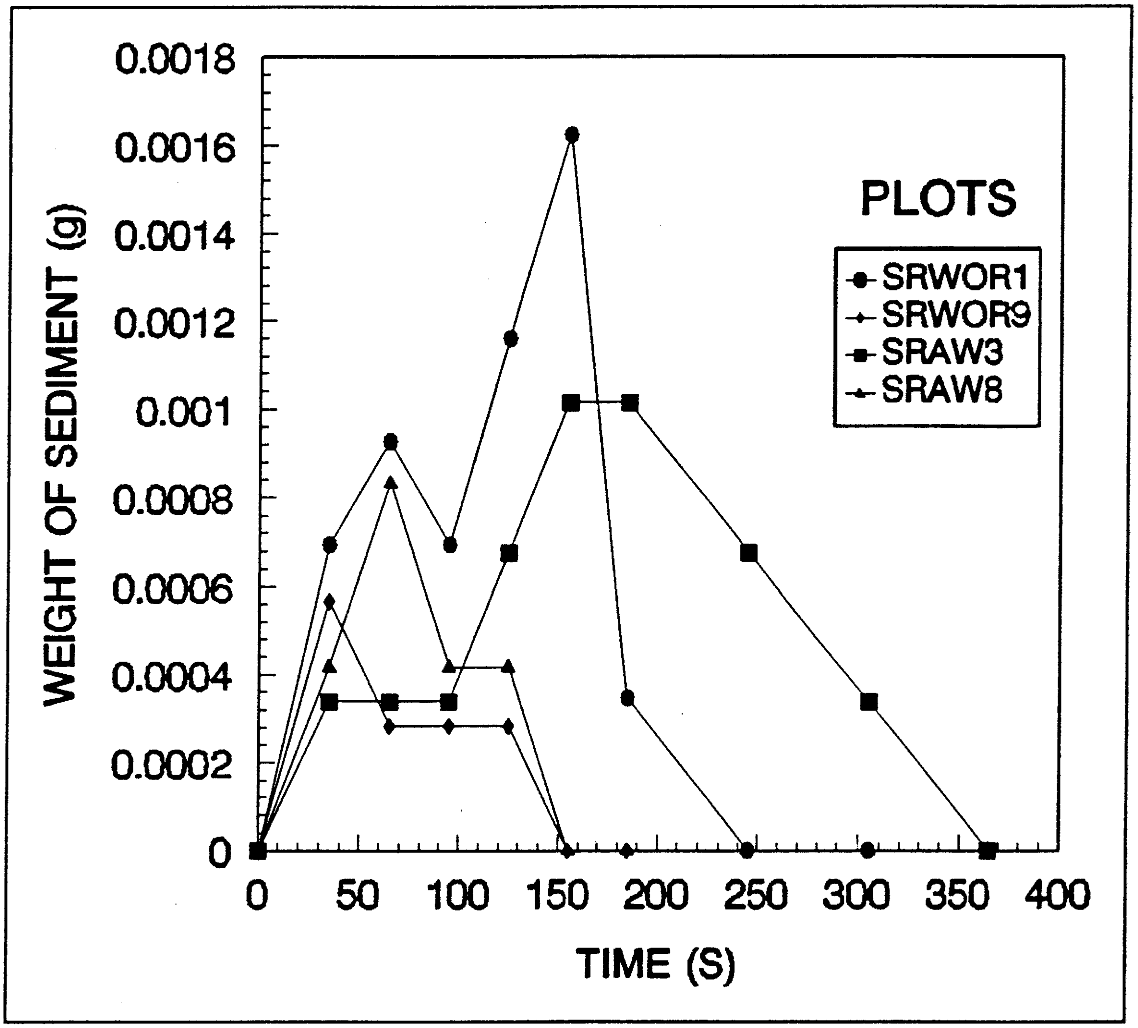


Figure 15. Four sedigraphs representative of the sedigraphs from each study area.

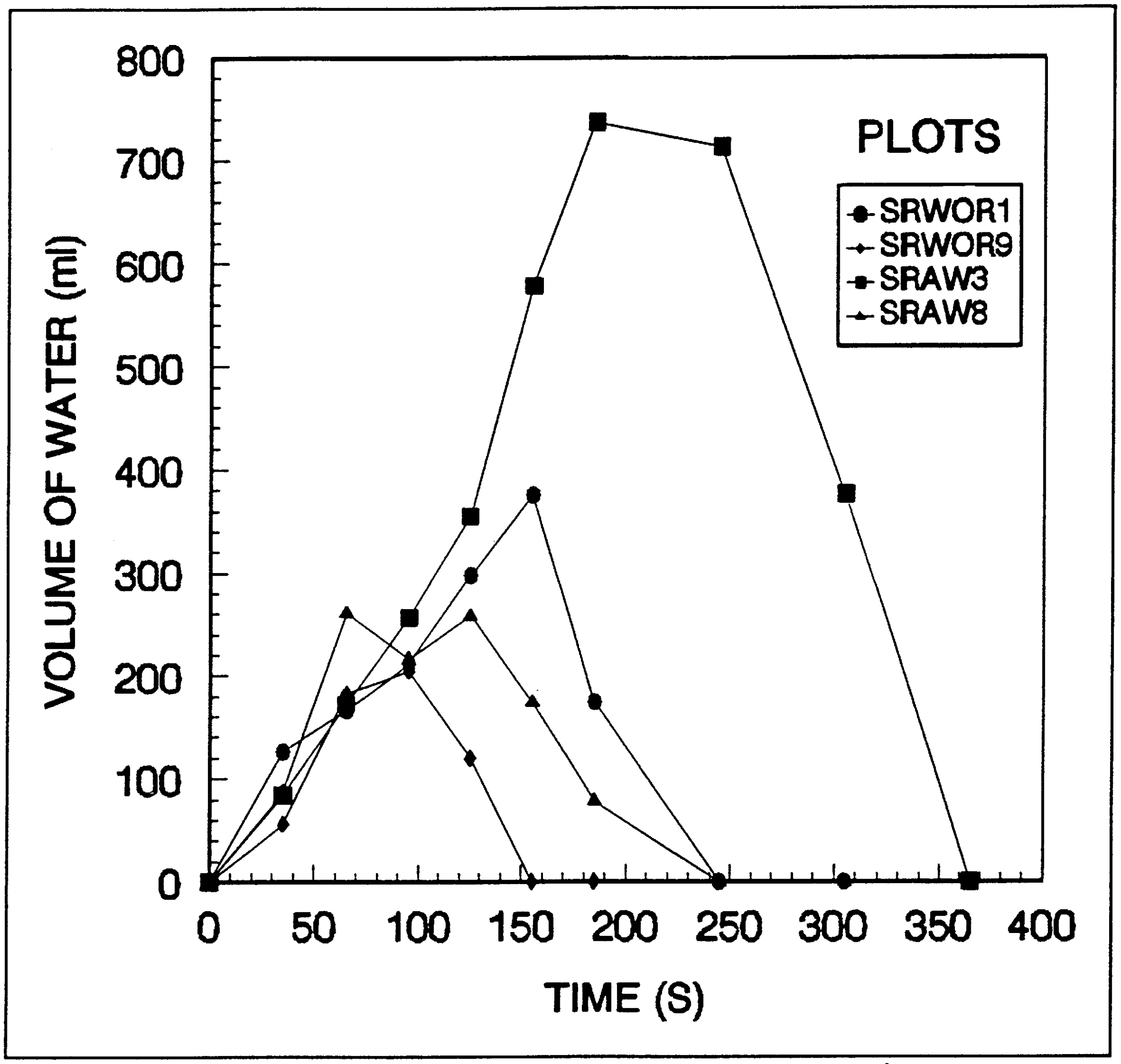


Figure 16. Four hydrographs representative of the hydrographs from each study area.