Effect of slope gradient and plant cover on soil loss on reconstructed high altitude slopes
by Nicole Michelle Kapolka

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Land Rehabilitation
Montana State University

Abstract:
The objectives of this study were to 1) evaluate effect of slope gradient and plant cover on soil loss on high altitude (2590 meters) sites, 2) evaluate effect of coversoil thickness on plant cover, and 3) determine if the Revised Universal Soil Loss Equation (RUSLE) version 1.06 computer model can predict the quantity of soil loss in a high - — altitude steep slope environment.

Four slopes each with a different gradient (25%, 33%, 40%, and 50%) were constructed and each slope was divided into four plots with different coversoil thicknesses (0 cm, 15 cm, 30 cm, and 45 cm). These sixteen plots received an identical seed mixture and fertilizer application.

Soil loss increased with slope gradients up to 40% and then decreased as slope gradient increased to 50%. Afterjust one year mean soil loss from test plots decreased from 16.38 Mg/ha to 1.01 Mg/ha. Soil loss rates the second year approached normal soil loss rates from undisturbed lands. Plots without coversoil had the lowest soil loss, but it would not be possible to meet current reclamation regulations without using coversoil during reclamation. Plots with coversoil, regardless of soil thickness, had more plant growth than plots without coversoil. There was a significant correlation during the first and second years ($r = 0.65$ and 0.70, respectively) between coversoil thickness and plant production. Increased plant production on plots with thicker coversoil, however, did not reduce soil loss.

Data indicated that slope as steep as 50% can be constructed without adversely increasing soil loss. At least 15 cm of coversoil should be applied on reconstructed slopes.

The RUSLE computer model underestimated soil loss by 15 +/- 17 Mg/ha during the first year following slope construction. During the second year, predicted soil loss was, on average, 0.4 +/- 0.6 Mg/ha lower than measured soil loss rates. Results from this study indicated that RUSLE v. 1.06 is an effective long-term planning tool to use on steep slopes at high altitudes.

EFFECT OF SLOPE GRADIENT AND PLANT COVER ON SOIL LOSS ON RECONSTRUCTED HIGH ALTITUDE SLOPES

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Nicole Michelle Kapolka

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APPROVAL

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Nicole Michelle Kapolka

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date November 17, 1999

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ABSTRACT

The objectives of this study were to 1) evaluate effect of slope gradient and plant cover on soil loss on high altitude (2590 meters) sites, 2) evaluate effect of coversoil thickness on plant cover, and 3) determine if the Revised Universal Soil Loss Equation (RUSLE) version 1.06 computer model can predict the quantity of soil loss in a high altitude steep slope environment.

Four slopes each with a different gradient (25%, 33%, 40%, and 50%) were constructed and each slope was divided into four plots with different coversoil thicknesses (0 cm, 15 cm, 30 cm, and 45 cm). These sixteen plots received an identical seed mixture and fertilizer application.

Soil loss increased with slope gradients up to 40% and then decreased as slope gradient increased to 50%. After just one year mean soil loss from test plots decreased from 16.38 Mg/ha to 1.01 Mg/ha. Soil loss rates the second year approached normal soil loss rates from undisturbed lands. Plots without coversoil had the lowest soil loss, but it would not be possible to meet current reclamation regulations without using coversoil during reclamation. Plots with coversoil, regardless of soil thickness, had more plant growth than plots without coversoil. There was a significant correlation during the first and second years (r = 0.65 and 0.70, respectively) between coversoil thickness and plant production. Increased plant production on plots with thicker coversoil, however, did not reduce soil loss.

Data indicated that slope as steep as 50% can be constructed without adversely increasing soil loss. At least 15 cm of coversoil should be applied on reconstructed slopes.

The RUSLE computer model underestimated soil loss by 15 +/- 17 Mg/ha during the first year following slope construction. During the second year, predicted soil loss was, on average, 0.4 +/- 0.6 Mg/ha lower than measured soil loss rates. Results from this study indicated that RUSLE v. 1.06 is an effective long-term planning tool to use on steep slopes at high altitudes.

INTRODUCTION

Soil loss from reconstructed steep slopes associated with mining is a potential source of down gradient watershed degradation. One of the primary challenges when reclaiming these slopes is to control soil loss. As demonstrated in the Universal Soil Loss Equation (USLE), as slope gradient increases soil loss also increases; however, increased plant cover can decrease sediment loss. To reconstruct slopes in an environmentally sound and cost effective manner, mining companies want to maximize slope gradient, have adequate coversoil to support vegetation, and minimize soil erosion rates.

As ore is mined from an open pit, overburden is removed and then stockpiled adjacent to the pit. This stockpiled overburden is then graded to conform with adjacent slopes. Before stockpiling the topography of these adjacent areas can vary from very steep slopes (67%) to more gentle slopes (20%) and therefore the gradient of the constructed slopes may fall within this range. The maximum slope gradient that will successfully support vegetation while minimizing soil erosion needs to be determined to develop reclamation procedures for companies that disturb the landscape.

The Treasure Mine, a talc mine, is located within the Stone Creek watershed in southwest Montana, which consists of approximately 17,000 acres of Bureau of Land Management (BLM), State, and private lands. Primary activities within the watershed include talc mining, livestock grazing, timber harvest, and recreation. The cumulative effects of these activities have degraded the watershed by increasing sediment and wastewater pollution, decreasing vegetation along stream banks, and altering physical characteristics of the stream. BLM and the Montana Department of Fish, Wildlife, and Parks studied Stone Creek watershed. They found that Stone Creek is habitat for pure westslope cutthroat trout. In June 1997 this species was petitioned to be listed as threatened under the Endangered Species Act. These two agencies and United States Fish and Wildlife Service, Montana Department of Natural Resources and Conservation, Ruby Valley Conservation District, Barretts Minerals, Inc., Luzenac America, Inc., Malesich Ranches, and Madison County formed a committee to develop strategies for rehabilitating the Stone Creek watershed (Whittingham, 1997). As part of this rehabilitation effort the Treasure Mine is attempting to minimize soil loss from reconstructed slopes, thereby minimizing the quantity of sediment entering Stone Creek.

Research was conducted at the Treasure Mine to address these objectives:

* evaluate effect of slope gradient and plant cover on soil loss,
* evaluate effect of coversoil thickness of plant cover, and
* determine if the Revised Universal Soil Loss Equation (RUSLE) version 1.06 can predict soil loss in a high altitude steep slope environment.

LITERATURE REVIEW

Soil erosion is an inevitable, natural process that is responsible for the development of many geologic formations. Normal erosion rates average about 0.2 – 0.5 Mg/ha (Mg/ha = 2.24 tons/acre) annually (Brady & Weil,1996). Erosion that exceeds the normal rate is termed accelerated erosion and is usually caused by human activities. Accelerated erosion has been studied in the United States since the eighteenth century but it was not until the early 1930s that scientists and resource managers gained support from the United States government to help control erosion. Many scientists have since studied the processes of soil erosion and have determined how to minimize soil erosion.

Universal Soil Loss Equation

Wischmeier and Smith published the Universal Soil Loss Equation (USLE) in 1965 (Wischmeier & Smith, 1965). USLE is the most widely used method of soil loss prediction in the United States. The six variables in USLE are useful in describing the major factors that control soil erosion:

$$A = RKLSCP$$

where A is the predicted soil loss per unit area and time, R is the rainfall and runoff erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness or gradient factor, C is the cover and management factor, and P is the erosion-control practice factor (Brady & Weil, 1996; Satterlund & Adams, 1992). The USLE has revised since 1965, but these variables are still used.

Rainfall and Runoff Factor (R)

The rainfall and runoff factor, also called the rainfall erosion index (EI), accounts for the energy responsible for erosion. It takes into consideration the intensity and seasonal distribution of precipitation, as well as the total amount of precipitation. The intensity of precipitation events may affect erosion losses more than the actual amount of precipitation. Low intensity precipitation events may cause very little soil erosion even if total annual precipitation is very high. Likewise, a few high-intensity storms can result in severe soil erosion losses, even if total annual precipitation is low. Soil erosion losses are often dominated by a few severe high-intensity storms (Larson et al, 1997; McCool, 1987; Peterson et al., 1995). For example Larson et al. (1997) reported that: two years from a total of 24 years accounted for 59% of total soil erosion on natural runoff plots in Kingdom City, MO; three precipitation events of 357 events accounted for 25% of soil erosion on an 83 acre cultivated watershed in Treynor, IA; and similar results were reported from an erosion observation site in Oregon.

The probability and intensity of severe storms varies geographically. Single, large storms account for an increased percentage of the annual EI as one moves north from the Gulf Coast to the Canadian border (Larson et al., 1997). Erosion in the semi-arid western United States is governed largely short-duration, high-intensity rainstorms (Peterson et al., 1995).

Soil Erodibility Factor (K)

The ULSE estimates soil erodibility using the following variables: soil permeability, soil structure, soil texture, and percent organic matter. Soil permeability and structure are most important (Brady & Weil, 1996). As permeability or infiltration rates increase, erodibility decreases. Soils with larger aggregates and better structure (i.e. blocky or platy rather than massive) are less likely to erode. Soils with a high silt and fine sand percentage are more likely to erode than clayey or sandy soils. Clayey soils are resistant to detachment and sandy soils generally have high infiltration rates thereby decreasing erodibility. Silty soils are easily detached and tend to crust, leading to high soil erosion rates (Galetovic, 1998). Erodibility decreases as soil organic matter content increases (Satterlund & Adams, 1992). Organic matter binds soil particles, increasing aggregation and decreasing soil detachment. Organic matter also increases infiltration which decreases runoff and soil loss (Galetovic, 1998).

Coarse fragment percentage reduces soil erodibility by decreasing potential area of erosion, increasing soil roughness, and increasing infiltration rates (Ashby et al., 1984; Sidle & Brown, 1993). Coarse fragment percentage is inversely related to soil erosion (Ashby et al., 1984; McIssac, 1987; Rawitz & Shirley, 1984; Sidle & Brown, 1993; Simanton et al., 1984).

Slope Length Factor (L)

As slope length increases, soil erosion increases because runoff, the transport mechanism for erosion, has more opportunity to concentrate on longer slopes (Brady &

Weil, 1996). Runoff amounts and velocities increase with increasing slope length, which increases soil erosion (Satterlund & Adams, 1992).

In ULSE the length and gradient of a slope are referred to as the length-slope (LS) factor; however, the effect of slope gradient is more important than the effect of slope length on soil erosion (Branson et al., 1981). Soil loss increases more with slope steepness than it does with slope length.

Slope Gradient Factor (S)

USLE assumes a direct, positive relationship between slope gradient and soil erosion. Sediment yields tend to increase roughly linearly with slope gradient on natural runoff plots and disturbed plots (Hahn, 1985; Hartley and Schuman, 1984; Liu et al., 1994; McIssac, 1987; Schroeder, 1987). Two reasons may explain why soil erosion increases as slope gradient increases. The ease with which soil particles are detached appears to increase with slope gradient. Rainsplash, which provides most of the energy for detachment of soil particles, is more active on steeper slopes thereby increasing soil detachment and the subsequent transport of this sediment (Mathier et al., 1989). The influence of gravity increases with gradient and may cause aggregates to break loose more easily, making them more susceptible to be transported with runoff (Grosh, 1994).

Rill erosion also increases on steeper slopes (Hahn, 1985; Hartley & Schuman, 1984; McCool, 1987). Rills are small channels, less than six inches deep that are formed by runoff and have the potential to transport a high volume of soil in a short period of time. Once a slope exceeds a critical steepness, rill erosion begins and causes soil erosion to increase rapidly with slope gradient (McCool et al., 1987). Their data indicate that rills usually formed on slopes with gradients steeper than 30%. Hahn (1985) showed a linear relationship between length of rills and slope gradient and stated that it was likely that soil loss and rill formation are related to and are dependent on slope steepness.

The effect of slope gradient can vary and depends on other soil properties. There is an unique slope steepness from which a maximum quantity of erosion will occur and this steepness varies with soil properties such as aggregate stability, soil texture, bulk density, coarse fragment percentage, and antecedent moisture (Bradford and Foster, 1996). Soil properties and the effect of slope gradient are not independent of each other (Singer & Blackard, 1982).

Generally, soil erosion increases as slope gradient increases (Hahn, 1985; Hartley & Schuman, 1984; Liu et al., 1994; McCool, 1987; McIssac, 1987; Schroeder, 1987). There is evidence, however, that suggests that as slope gradients become very steep (i.e. >40%), soil erosion losses may level off or may possibly decrease (Bradford and Foster, 1996). On very steep slopes, direct raindrop impact on a given area of soil surface is reduced, thereby reducing the likelihood of detachment of soil particles (Bradford and Foster, 1996; Singer & Blackard, 1982). Singer & Blackard (1982) showed that soil loss increased rapidly with slope gradient, but when slope gradients increased to 35 – 40%, soil loss then became nearly constant.

The effect of slope gradient on runoff is not clear. Literature on this relationship is ambiguous. While some studies have observed a positive relationship between slope gradient and runoff, other studies have observed no clear relationship, or an inverse relationship between steep gradients and runoff volumes (Govers, 1991).

Several studies examining the relationship between slope angle and runoff found no clear relationship between the two (Grosh, 1994; McCool et al., 1987; Yair and Klein, 1973). Grosh (1994) subjected six slopes with gradients ranging from 5% to 85% to 20 minutes of rainfall with an intensity of 92 mm/hr. Grosh found no significant differences between runoff rates on slopes from 5% to 85% and concluded that runoff is not affected by slope gradient. McCool et al. (1987) found no significant differences in the amount of runoff on slopes greater than 8%. Mathier et al. (1989) found a much stronger correlation between runoff and sediment yield than between runoff and slope gradient. Their data suggest that slope gradient is less important than other factors with respect to runoff.

Few studies have found a positive relationship between slope gradient and runoff. Several studies, however, have found an inverse relationship between slope gradient and runoff rates. As slope gradients become very steep, infiltration rates increase and runoff rates decrease. Scientists think that infiltration rates increase on steep slopes because crust development does not occur. Crusting is hampered by increased erosion rates (Govers, 1991; Poesen, 1984). Poesen (1984) showed that runoff decreased with increased slope gradient. Runoff on a 15% slope was higher than on a 30% slope. Poesen and Govers agree that soil loss increases with slope gradient; however they do not believe the relationship between runoff and slope gradient is as direct.

The conflicting results regarding slope gradient and runoff suggest that other factors may be more important to runoff generation. For example, Schmittner and Giresse (1994) concluded that runoff is influenced more by vegetation cover than by slope gradient.

The effect of slope gradient on soil erosion has been studied for over 50 years (Krusekopf, 1943). Many early studies focused on erosion from agricultural lands and therefore did not study steep slopes. Few studies have examined the erosion processes on slopes greater than 20% (Grosh, 1994). Review of the literature supports this observation and shows that discrepancies exist regarding the effect of slope gradient on sediment loss and runoff rates. More information regarding the relationship between slope gradient and erosion on steep slopes is needed.

Cover Management Factor (C)

Plant cover is the factor over which land managers have the most control. It is also considered to be the most important factor affecting soil erosion. Regardless of the duration or intensity of rainfall, or the steepness or length of slope, soil losses are lowest when the ground is covered with vegetation. The effects of other factors are modified by the presence and density of vegetation and vegetative residue (Krusekopf, 1943).

As vegetation increases, soil erosion decreases (Hartley & Schuman, 1984; Kirkby, 1980; Toy, 1989). The presence of vegetation minimizes soil erosion through the following processes:

a) vegetation intercepts precipitation and reduces the energy of the raindrops thereby decreasing the R value;
b) vegetation increases the infiltration capacity of the soil and thereby decreasing the K value;
c) total runoff is lower due to the results of greater interception, infiltration, and evapotranspiration;

d) vegetation increases the roughness of the soil which reduces the runoff velocity;

e) reduced velocity encourages deposition of soil particles, which are trapped by vegetation; and

f) vegetation increases the structural stability of the soil due to an increase in organic matter with the soil, and reducing the K value (Kirkby, 1980).

Properties of vegetation that determine its effectiveness in minimizing erosion are percent ground cover, plant density, and plant height. Soil erosion decreases with increased plant cover. Researchers have found that there are threshold values for plant cover at which runoff and erosion rates increase rapidly. Erosion rates increase rapidly on soils with less than 70% plant cover (Clark, 1980, Kirkby, 1980). Another threshold for rapid soil erosion occurs when plant cover is less than 30% (Kirkby, 1980). When plant densities are low, plant cover is also low and erosion and runoff rates are related to the proportion of bare ground. Vegetation is more effective in retarding erosion than reducing runoff, since vegetation encourages deposition on of sediment (Kirkby, 1980; Krusekoff, 1943).

Support Practice Factor (P)

Various conservation practices may be used to minimize erosion losses. Conservation practices may include contour tillage, contour furrows, construction of terraces, and gouging (Dollhopf et al., 1985; Munshower, 1994). These practices can be used on disturbed lands, but are most often used on agricultural lands. Therefore, in practice, the P factor, usually only applies when calculating erosion rates on croplands (Satterlund & Adams, 1992).

Soil Erosion on Undisturbed and Disturbed Sites

Soil properties on disturbed sites often differ from soil properties on undisturbed sites. Soils on disturbed sites generally have higher bulk densities, an increased coarse fragments percentage, increased levels of surface sealing, less soil structure, decreased organic matter, and decreased root matter (McIssac, 1987; Schroeder, 1989). These properties decrease infiltration rates and increase runoff rates. In addition, the vegetative cover on disturbed sites is usually less dense and more variable across the disturbed landscape (Schroeder, 1989). These changes in soil properties, except for the increased coarse fragment percentage, can increase erosion rates by increasing the erodibility of the soil. A greater percentage of coarse fragments decreases soil erosion (Ashby et al., 1984; McIssac, 1987; Rawitz & Shirley, 1984; Sidle & Brown, 1993; Simanton et al., 1984). McIssac et al. (1987) reviewed published and unpublished studies of soil erosion on disturbed slopes. Their analysis revealed that erosion rates on steep, disturbed sites were less than expected. They suggested that this may have been attributed to the fact that soil detachment by runoff was limited by the increased quantity of coarse fragments. Disturbed lands generally have greater erosion rates than undisturbed lands (Peterson et al., 1995; Schroeder, 1989; Toy, 1989). Peterson et al. (1995) found that sediment yields from reclaimed slopes were generally 1.5 to 2 times higher from premine slopes having comparable slope lengths and gradients. Runoff for postmine conditions was similar to average runoff from premine slopes. Peterson et al. (1985) believed that increased erosion rates reflected different vegetation types and associated higher cover densities on premine lands.

As time progresses, erosion rates on disturbed lands can become similar to rates on undisturbed lands (Schroeder, 1989; Toy, 1989). Schroeder's study on reclaimed grasslands in North Dakota indicated that when a high percentage of vegetative cover is established, runoff and sediment yields on some reclaimed grasslands are similar to undisturbed grasslands.

Toy (1989) compared erosion rates on newly reclaimed, old reclaimed, and undisturbed slopes. He found that new reclaimed slopes had greater sediment yields than old reclaimed slopes, and old reclaimed slopes had sediment yields similar to undisturbed slopes. His results suggested that it takes about five years for reclaimed slopes to yield the same amount of sediment as undisturbed slopes.

Effect of Coversoil Thickness on Plant Growth

Several studies have investigated the effect of coversoil depth on plant growth on reclaimed land (Barth & Martin, 1982; McGinnies & Nicholas, 1980; Power et al., 1981; Rendente & Hargis, 1985; Redente et al.,1997). Within limits, increased coversoil depths correspond with increased vegetation growth (Barth & Martin, 1982; Power et al., 1981; Redente & Hargis, 1985). Barth and Martin (1982) found nonalkaline, nonsaline spoil material with coversoil depths up to 50 cm increased plant growth. McGinnies and Nicholas (1980) found that above and below-ground growth increased significantly with coversoil depths up to 46 cm. Redente and Hargis (1985) showed that biomass and canopy cover increased significantly with coversoil depths up to 60 cm. Powers et al.

(1981) studied the average annual native grass yield over 3 years as influenced by thickness of coversoil and subsoil over sodic spoils. Their results implied that although coversoil improves production, there is no benefit to applying an excess quantity of coversoil. Excess depth of coversoil may slightly increase soil loss. Gilley (1977) found that increasing coversoil thickness from 25 to 61 cm reduced runoff by 24%, but increased soil loss by 7%. The above studies were all short-term, consisting of less than 5 growing seasons. Few studies have looked at the long-term effects of coversoil thickness on vegetation growth (Redente et al., 1997).

Redente et al. (1997) studied the long-term effects of coversoil thickness on vegetation growth. They used four different coversoil thickness: 15, 30, 45 and 60 centimeters. After 10 years there was not a significant difference in biomass between 15 and 60 cm of coversoil. The 15 and 60 cm treatments had significantly higher biomass yields than the 30 and 45 cm treatments. There were no significant differences in the total canopy cover among the four treatments, but there were differences when canopy cover was evaluated by life form. On shallower coversoil depths, forb cover was greater than on the deeper coversoil depths. The thicker coversoil depths supported a higher percentage of grass cover than on thinner depths. Redente et al. (1997) concluded that the primary reason for this response is that forbs and other less competitive species can thrive on shallower coversoil depths, which have less grass production and therefore less competition. While results from this study support the hypothesis that growth increases with increased coversoil depth it also suggests that shallow coversoil depths can support productive plant communities. Redente et al. suggested that 15 cm of coversoil over nontoxic spoil is sufficient for the establishment and continued productivity of rangeland vegetation.

Effect of Coversoil Quality on Soil Erosion

Coversoil enhances plant growth and also increases infiltration. Coversoils have better physical (i.e. infiltration rate, cation exchange capacity) and chemical (i.e. pH, mineral concentrations, electrical conductivity) properties than the soils they overlie. Coversoils generally have increased organic matter, organisms, and nutrients than spoil material (Munshower, 1994). Due to the presence of these characteristics, areas with coversoil generally have greater plant growth and less soil erosion than areas without coversoil.

Revised Universal Soil Loss Equation (RUSLE): Version 1.06

The Revised Universal Soil Loss Equation (RUSLE) Version 1.06 on Mined Lands, Construction Sites, and Reclaimed Lands is a computer model developed by the Office of Surface Mining and Reclamation in Denver, Colorado (Galetovic, 1998). RUSLE v. 1.06 retains the same factors as the Universal Soil Loss Equation. Unlike the USLE, which was developed for use in calculating agricultural erosion rates, this particular version of RUSLE was developed to calculate soil erosion on disturbed lands. This model was designed to estimate the long-term soil erosion rates based on site-specific environmental conditions and was not designed to determine the amount of erosion from a single precipitation event.

METHODOLOGY

Site Description

The Treasure Mine is a open-pit talc mine operated by Barretts Minerals Inc. (BMI). The mine is about 15 miles east northeast of Dillon, Montana in the Ruby Mountain Range in southwestern Montana (Figure 1). The mine has an elevation of approximately 2590 meters. Average annual precipitation, based on 20 years of record, is 26.0 cm (Western Regional Climate Center, 1999). The mine has a snowpack for about half of the year.

Experimental Design

The experimental design consisted of four slopes, each with a different slope gradient: 25%, 33%, 40%, and 50%. Each slope was divided into four plots, each with a different coversoil depth: 0 centimeters, 15 centimeters, 30 centimeters, and 45 centimeters of coversoil. There were sixteen plots in total (Figure 2). Each plot was 3.0 meters wide and 30.5 meters long and was bounded laterally by an earthen berm to prevent sediment and runoff from flowing onto an adjacent plot. Plots were bounded by a drainage ditch at the top of the slope to prevent runoff and sediment from upslope from entering the plots. Troughs were installed at the base of each plot to collect runoff and sediment.

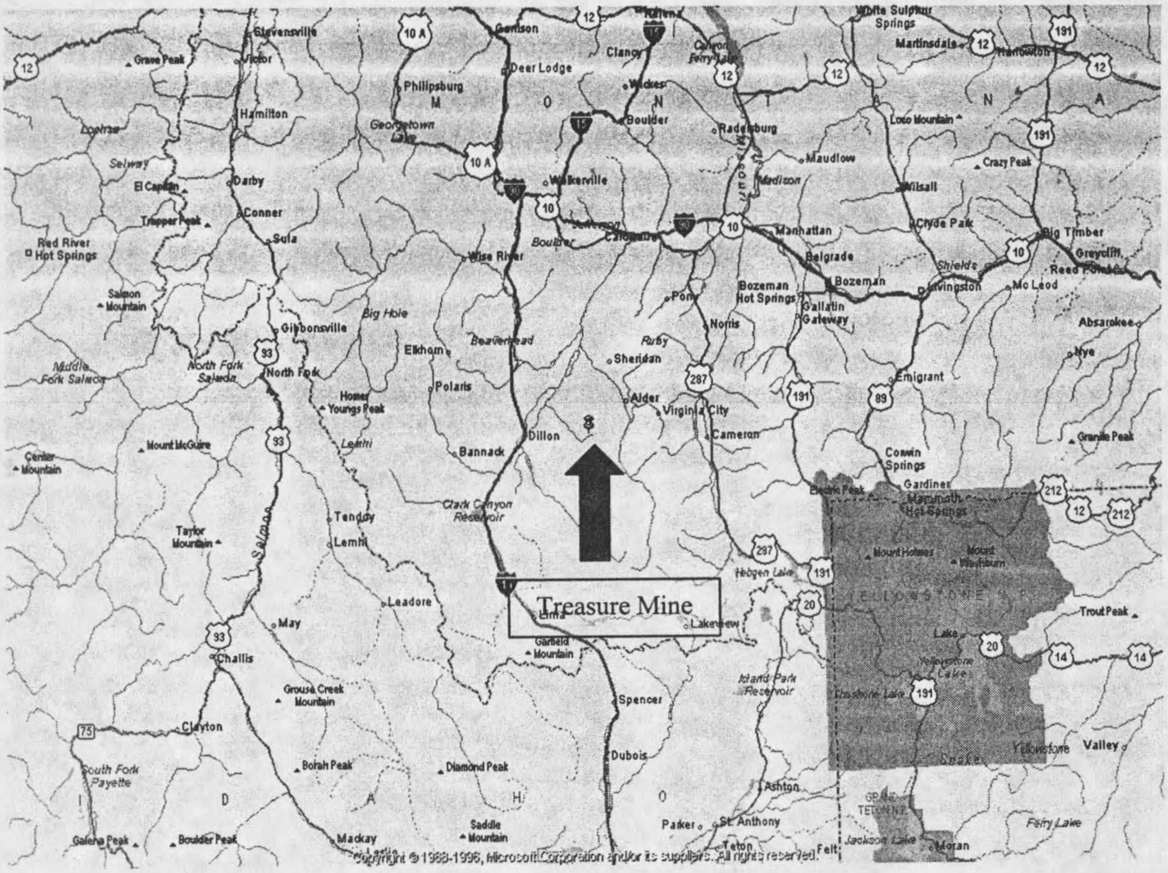


Figure 1. Location of study site in southwest Montana.

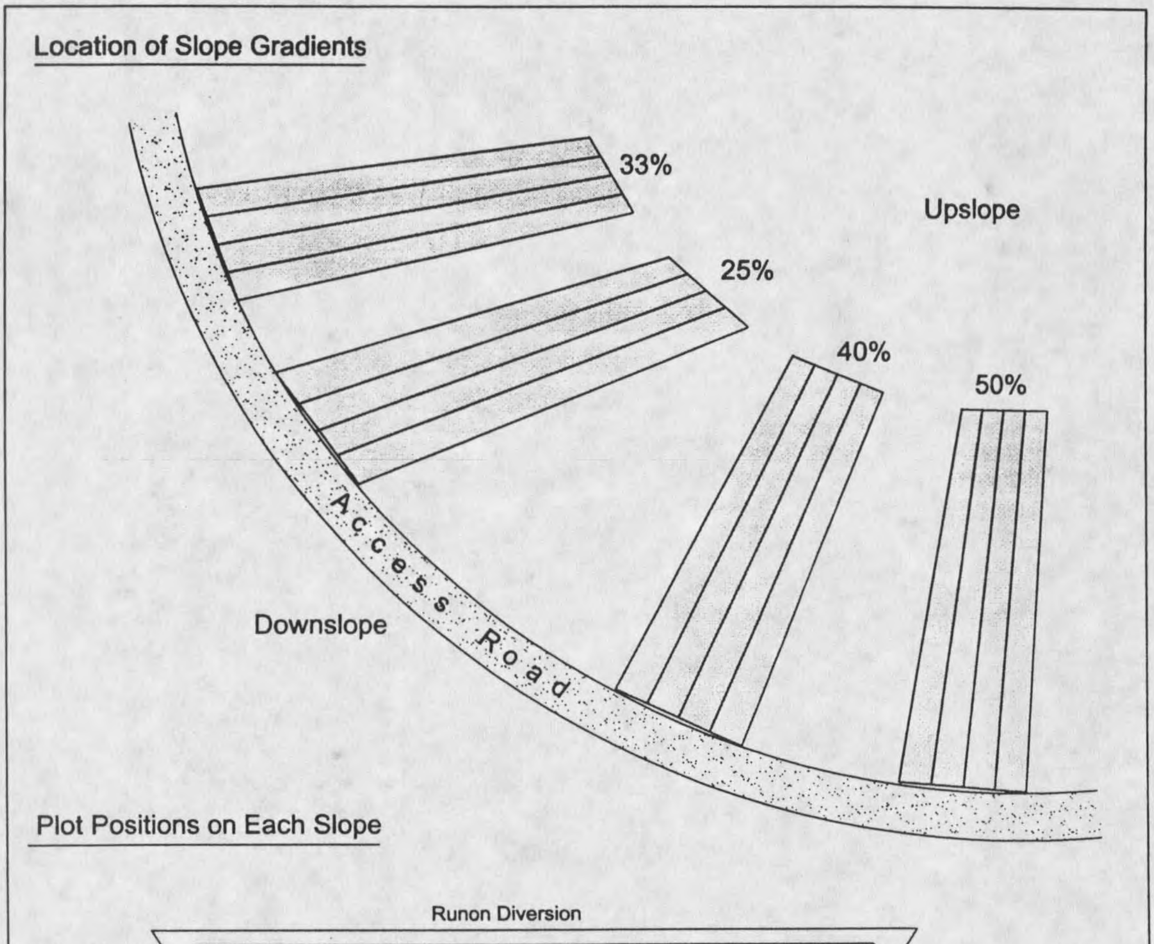


Figure 2. Experimental design of test plots at Treasure Mine, MT

Trough Dimensions and Design

Collection troughs were constructed of steel and were half cylinder in shape. Troughs were 3.0 meters in length, 1.2 meters in diameter and 0.6 meters in depth. These troughs were designed to collect approximately 25% of the runoff from a 24 hour-100 year precipitation event, assuming no infiltration. Troughs were installed underneath the ground surface so that there was a smooth transition between the slope and the lip of the trough. During the first two months of data collection the transition between the plot and the trough eroded causing infrequent loss of runoff and sediment from collecting in the trough. These small erosion pockets were repaired by filling them with soil located downslope of the trough. Repairs were infrequent and minor and the amount of sediment lost to these pockets was considered negligible.

Seed Mix and Seeding Procedures

Plots were seeded in November 1997 by BMI. The seed was broadcast seeded by hand and was raked into the surface. Seed mix and application rates are presented in Table 1. An annual species, *Triticum aestivum*, was seeded with the perennial seed mix. Annual species are often used as cover crops because they grow quickly and provide short-term protection against erosion before perennial vegetation is established.

In May 1998 0.6 kg/ha PLS of *Chrysothamnus nauseosus* was broadcast seeded on to the ground surface. These seeds were not raked into the surface so as not to disturb emerging seedlings. *C. nauseosus* was not planted in November because the seed was

Table 1. Seed mix and application rate on test plots.

Species	Common name	Plant type	Pure live seed (PLS) kg/ha
Agropyron dasystachum	Thickspike wheatgrass	grass	7.8
Agropyron spicatum	Bluebunch wheatgrass	grass	9.8
Agropyron tracycaulum	Slender wheatgrass	grass	7.8
Festuca ovina	Sheep fescue	grass	2.0
Poa compressa	Canada bluegrass	grass	2.0
Achillea millefolium	Western yarrow	forb	0.6
Medicago sativa	Alfalfa	legume	2.0
Onobrychis viciaefolia	Sainfoin	legume	5.9
*Chrysothamnus nauseosus**	Rubber rabbitbrush	shrub	0.6
Triticum aestivum	Winter wheat	annual	39
*Hordeum vulgare**	Barley	annual	153
Total			230.5

* These species were seeded after the initial seeding

not available. These seeds were planted in the spring after the winter snowpack had melted. In late May 1998, very few seedlings had emerged. It was hypothesized that the cover crop of *Triticum aestivum* had not survived through the winter. To ensure coverage on the slopes, 153 kg/ha PLS of *Hordeum vulgare* was broadcast seeded onto the site in early June 1998.

Data Collection

Subsoil and Coversoil Physiochemical Analysis

Composite samples of the subsoil and coversoil were collected and analyzed for physiochemical characteristics. Composite soil samples were oven dried at 41 C and were then disaggregated with a mortar and pestle. Soil that passed through a two millimeter sieve was used for all analyses. Soil particles greater than two millimeters were classified as coarse fragments. Physical properties evaluated included soil texture and coarse fragment percentage by weight and volume. Chemical properties evaluated included pH, electrical conductivity (EC), sodium adsorption ratio (SAR), and percent organic matter. Analytical procedures used are reported in Table 2.

Table 2. Soil physiochemical analytical methods.

Variable	Analytical Technique
Textural class	Day 1965. Hydrometer method.
Coarse fragment percentage	Sieved 2mm fraction, measured weight and volume
pH EC SAR	Rhoades 1982. Water saturated paste extract
Organic matter percentage	Nelson and Sommers 1982. Walkley Black method

Precipitation and Evaporation Measurements

A precipitation recording gage was installed adjacent to the 50% slope. The rain gage was capable of measuring one millimeter increments of precipitation. A solar powered datalogger recorded precipitation data on an hourly basis. Hourly measurements gave an indication of the intensity of various precipitation events. Precipitation data are in Appendix B (Tables 24-34).

To measure evaporation at the site a Class I evaporation pan was installed adjacent to the precipitation gage. A 200 liter capacity stilling well was connected to the evaporation pan by a hose and a constant water level in the evaporation pan was maintained using a float and check valve. The volume of water evaporated each hour was recorded using a Stevens recorder located in the stilling well, and used to calculate evaporation (cm). Evaporation data are in Appendix B, Table 35.

Runoff Collection Methods

Runoff that accumulated in collection troughs was measured and collected every two weeks from late spring through the summer. The depth of water in the troughs was measured to the nearest millimeter. After water depth was measured, submersible pumps powered by a gasoline generator were used to remove the water from the troughs. Runoff data are located in Appendix C (Tables 38 and 39)

Runoff volumes were determined using the water depth in the trough. To calculate the volume of water in the troughs the following integral was used:

$$\int (a + (60-x^2)^{1/2})\, dx$$

where the upper limit was $(60-a^2)^{1/2}$ and the lower limit was $-(60-a^2)^{1/2}$,and a was equal to the depth of the water (cm) and x was equal to the lower and upper limits. This value was then multiplied by the length of the trough to obtain total water volume (liters).

Precipitation falling into the trough and evaporation of water from the trough were accounted for using data collected from the precipitation gage and the evaporation pan (Appendix B, Tables 26-35). Total maximum amount of runoff was calculated using the following equation:

$$\text{Total maximum runoff (l)} = l_{\text{(intial water in trough)}} - l_{\text{(ppt)}} + l_{\text{(evap)}}$$

Sediment Collection Methods

Sediment that accumulated in collection troughs was measured every two weeks in the late spring and summer months. Small shovels were used to remove the sediment from the troughs. Masses of sediment less than 22 kilograms from each trough were transported to Montana State University, oven dried at 41C, and weighed. If there was greater than 22 kilograms of sediment in the trough, the total volume of sediment was measured and the mass of dry soil was determined using known mass values for a given volume of saturated sediment. Sediment yields are located in Appendix C (Tables 36 and 37).

Rill Classification Methods

Every two weeks during late spring and summer the test plots were inspected for rill erosion. Rills were described quantitatively using the Erosion Condition Classification System Montana Revised Method (Clark, 1980). Rill classification was characterized by depth and frequency of rills (Table 3). The qualitative ranking is not part of the Montana Revised Method but was provided by the author to give the reader a

Table 3. Soil erosion condition classification for rills.

Qualitative Ranking	Description	BLM Rank	Adjusted Rank
Stable	Rills, if present, are less than 0.5 in deep, and generally at infrequent intervals over 10 ft.	0 or 3	0 or 1
Slight	Rills are mostly 0.5 to 1 in. deep, and generally at infrequent intervals over 10 ft.	6	2
Moderate	Rills are mostly 1 to 1.5 in deep, and generally at 10 ft intervals.	9	3
Critical	Rills are mostly 1.5 to 3 in deep, and at intervals of 5 to 10 ft.	12	4
Severe	Rills are mostly 3 to 6 in deep, and at intervals of less than 5 ft.	14	5

qualitative idea regarding of rill severity. Rill classification data for test plots are in Appendix C, Tables 40 and 41.

Plant Measurements

During this study plant growth characteristics were measured three times. Seedling density was measured in early July 1998. During the summers of 1998 and 1999 canopy cover, basal cover, and production were measured during the peak of the growing season. All three variables were analyzed by growth form (i.e. annual or perennial grasses, forbs). Vegetative data are in Appendix D (Tables 42 – 62).

Transect locations were permanently staked on all plots. These transects were along the diagonal, running from the upper left-hand corner to the lower right hand corner of each plot. Ten quadrants were sampled on each test plot to measure seedling density, plant cover, and production. A stake was placed in the ground to indicate the location of these ten quadrants on each plot. During 1998 plots were measured every five meters along the transect beginning at the five meter point. During 1999 plots were measured every five meters beginning at the seven meter point along the transect.

Seedling density was determined using a 20 x 20 centimeter frame ten times on all plots. The number of seedlings within each frame was counted and recorded.

Canopy and basal cover were measured using a 20 x 50 centimeter Daubenmire frame. Cover was estimated according to growth form. These cover values were totaled to determine total plant canopy and basal cover. Rock fragments, litter, and bare ground were also measured in terms of cover. All cover measurements were classified using a scale of 0 –10 where 0 = no cover, 1 = 1 – 10% cover, 3 = 11-20% and so forth.

Production was measured using a 20 x 20 centimeter frame on the same quadrants used to measure cover. Vegetation within the frame was clipped two centimeters above the ground, sorted by growth form, and placed into large paper bags. These samples were oven-dried at 21°C to a constant weight . Vegetation was weighed and production for each lifeform was calculated on a kg/ha basis.

Statistical Analysis

Correlation analysis and canonical correlation (CANCOR) were used to analyze data. Correlations were considered significant ($p = 0.1$) if r values were great enough based upon the degrees of freedom in the data set (Little and Hills, 1978). Four data sets did not have normal distributions and were transformed. To normalize rock cover data for 1998 and 1999, and canopy cover data for 1999, reciprocal values were calculated. To normalize production data for 1998, natural log values were calculated. Correlation analysis and canonical correlation statistical tables are in Appendix E (Tables 63-70).

RUSLE v. 1.06 Computer Model Analysis

RUSLE version 1.06 is a Windows operated DOS computer model (Galetovic, 1998). Various input variables were required for each factor in the RUSLE model (Table 4). Using mathematical equations RUSLE estimated an average annual soil loss rate. Input values were either from field data, from Renard et al. (1987), or from the United States Department of Agriculture Natural Resource Conservation Service State Agronomist (Fasching, 1999).

Table 4. Input Variables for RUSLE v. 1.06.

RUSLE Factor	Input Variable	Data Source
R – Rainfall/Runoff Erosivity	City climate database*	Renard et al.
		Field
	Initial R value	Renard et al.
K – Soil Erodibility	Rock cover %	Field
	Number of years to consolidate	Renard et al.
	Hydrologic group	Renard et al.
	Surface texture (% clay, % silt)	Field
	Organic matter %	Field
	Soil permeability class	Renard et al.
	Coarse fragment %	Field
LS – Slope Length & Gradient	Number of hill segments	Field
	General land use	Field
	Slope gradient	Field
	Slope length	Field
C – Cover Management	Effective root mass	Fasching
	Canopy cover %	Field
	Fall height of precipitation	Field
	Roughness of field condition	Fasching
	Ground cover %	Field
	Rock cover %	Field

*City climate database included the following values: an EI curve value, 10 year EI value, a R value, number of freeze-free days per year, site elevation, mean monthly temperature, and mean monthly precipitation. All data, except for elevation and monthly precipitation, were obtained from Renard et al. Elevation and monthly precipitation data were collected in the field.

RESULTS AND DISCUSSION

Coversoil and Subsoil Physiochemical Characteristics

The coversoil applied on the plots was a sandy loam (Table 5). Coarse fragment percentages by weight and volume were 43% and 33%, respectively. Coversoil pH (6.6), EC (0.8 mmhos/cm), and SAR (0.1) were all suitable for plant growth. Organic matter percentage was low (0.6%) and may slow development of vegetation on this site.

The subsoil had a sandy loam texture (Table 5). Coarse fragment percentages by weight and volume were 67% and 52%, respectively. Subsoil pH (7.3) , EC (1.2 mmhos/cm), and SAR (0.9) values were all suitable for plant growth. Organic matter percentage (0.1%) was very low and may slow development of vegetation on this site. Individual soil sample measurements used to determine physiochemical characteristics are in Appendix A (Tables 20-23).

Coarse fragment percentages in the coversoil and subsoil were elevated and may not permit optimal plant growth, (Munshower, 1994), but alternatively bay help reduce soil losses. Regardless of the high coarse fragment percentage both the coversoil and subsoil material were both considered suitable for plant growth. It was presumed that nitrogen and phosphorus levels in the coversoil and subsoil were low so the plots were fertilized with 36 kg/ha nitrogen and 36 kg/ha phosphorus in fall 1997 and with an

Table 5. Coversoil and subsoil physiochemical characteristics

Soil Property	Coversoil	Subsoil
Sand percentage+	62.5 +/- 0.0	61.3 +/- 1.8
Silt percentage+	20.0 +/- 0.0	16.3 +/- 1.8
Clay percentage+	17.5 +/- 0.0	22.5 +/- 0.0
Textural class+	sandy loam	sandy loam
Coarse fragment percentage (weight)*	43	67
Coarse fragment percentage (volume)*	33	52
pH#	6.6 +/- 0.04	7.3 +/- 0.08
EC (mmhos/cm)#	0.8 +/- 0.08	1.2 +/- 0.05
SAR*	0.1	0.8
Organic matter percentage*	0.6	0.1

* n=1, 1 standard deviation
+ n=2, 1 standard deviation
# n=3, 1 standard deviation

additional 60 kg/ha nitrogen in early summer 1999. Fertilizer applications were broadcast onto the surface and were not incorporated into the soil.

Soil Loss Results on High Altitude Steep Slopes

Soil loss rates varied on an annual basis and also varied throughout the course of the season. Figure 3 shows how soil losses changed from the first year to the second year of the study. Normal soil loss rates for undisturbed lands are about 0.2 – 0.5 Mg/ha (Mg/ha = 0.45 tons/acre) (Brady and Weil, 1996). Soil erosion rates for the first year (mean = 16.38 Mg/ha, n = 16) were much greater than these normal rates. Soil loss

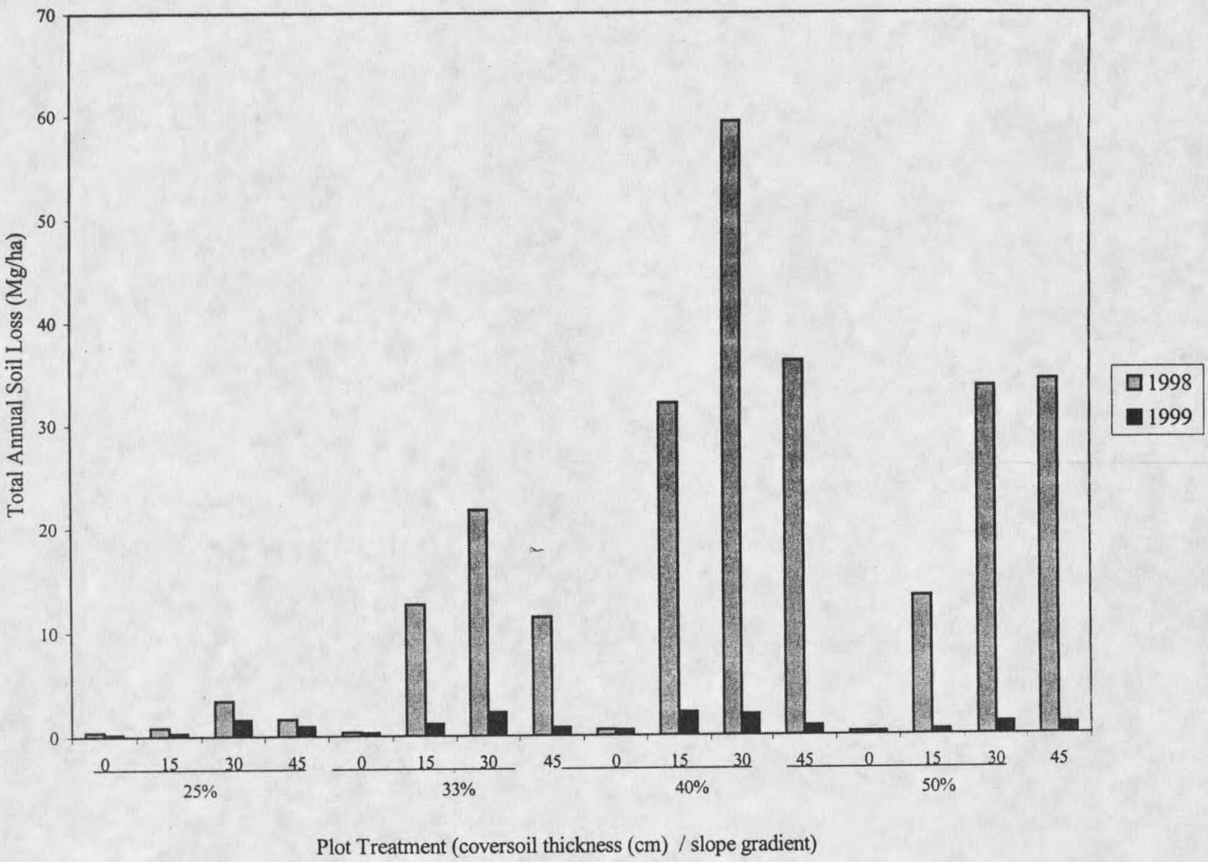


Figure 3. Comparison of total annual soil loss from all test plots in 1998 and 1999.

decreased dramatically during the second year (mean = 1.01 Mg/ha, n = 16). After just one year soil loss rates loss rates on these reconstructed slopes appeared to be in control. This decrease in soil loss may be attributed to increased vegetative cover the second year. Plots had no vegetation for the first two months of data collection the first year. During this time precipitation was high and very high soil loss occurred (Table 6). During the second year vegetative litter increased from 0% to 12% and perennial grasses and forbs continued to develop on all plots providing additional cover and slope stability (Table 7).

Table 6. Mean* soil loss and precipitation for two-week periods in 1998.

Date	Sediment yield (Mg/ha)	Total precipitation (cm)	Max daily precipitation (cm)	Max hourly precipitation (cm)
6/5/98	0.04	9.7	4.9	1.3
6/23/99	4.18	8.6	1.3	0.4
7/9/98	7.67	1.8	0.7	0.3
7/21/98	4.45	1.4	1.4	0.5
8/4/98+	2.12	2.2	N/A	N/A
8/12/98	0.05	0.2	0.2	0.2
8/28/98	1.92	0.9	0.3	0.2
9/13/98	0.03	0.9	0.4	0.3
9/26/98	0.02	0.8	0.3	0.3

* n = 16

+ Data were collected using a rain gage, not the data recorder

Table 7. Mean* plant cover at peak of growing seasons.

Year	Canopy cover	Basal cover	Vegetative litter	Bare ground	Rock cover
1998	43%	31%	0%	33%	52%
1999	27%	23%	12%	38%	49%

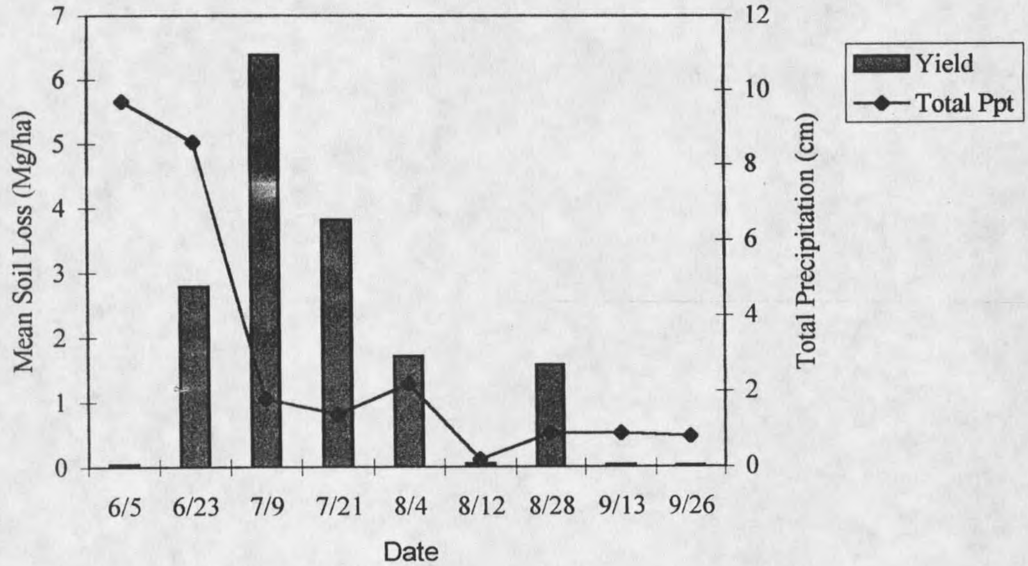
* n = 160

Annual precipitation may also have affected soil loss rates. In 1998 precipitation was about average but precipitation was below average (-6.46 cm) in 1999 (Appendix B, Tables 24 and 25). Greater total precipitation may have had an effect on soil loss in 1998; however, it was more likely that the intensity of the precipitation events had a greater effect on soil loss. Soil loss is dominated by high-intensity storms (Larson, 1997; McCool, 1984; Peterson et al., 1995). Both years had seven storms when greater than 2.5 cm of precipitation fell in an hour, but in 1998 several of these storms occurred while the soil was bare of vegetation. High intensity storms that occurred while soil was bare may have been responsible for the high soil loss rates in 1998.

Figure 4 shows how soil losses fluctuated in 1998 and 1999. The seasonal soil loss trend was similar both seasons. In 1998 snow did not melt completely off of the plots until mid-May and the ground remained frozen for some time after the snow melted. Soil loss rates may have been low since the ground was frozen. Little, if any, soil erosion occurs on frozen ground. In early summer, erosion rates were high. These high soil loss rates may be attributed to the absence of vegetation. Seedlings did not emerge until late June 1998. Recall these plots were constructed and seeded in fall 1997. Initial soil loss rates after the ground thawed may have been high as the coversoil on the plots settled and stabilized. In late July and August soil losses decreased as vegetation established. All soil loss data correspond with this explanation, except data collected from August 12 to August 28, 1998. During this two week period soil loss rates were high. This increase cannot be attributed to total precipitation or storm intensity during this time period (Table 6).

In 1999 soil losses in the beginning of the season were relatively low even though precipitation was high (Figure 3), supporting the presumption that the soil was still frozen so soil erosion did not occur. Snow did not melt completely off of the slopes until mid-

1998



1999

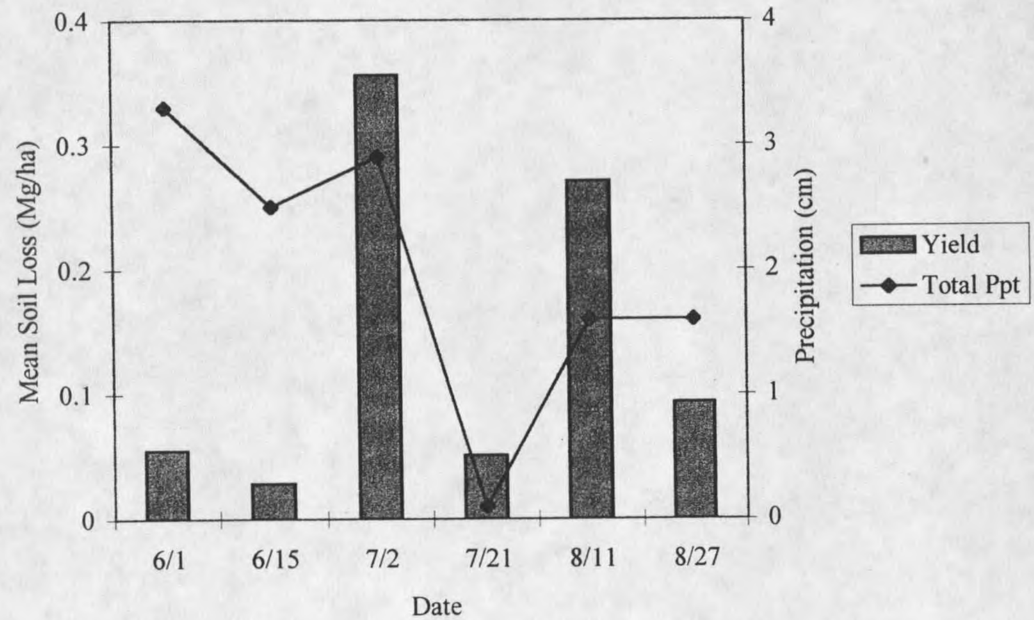


Figure 4. Effect of mean precipitation on total soil loss for two-week periods in 1998 and 1999.

Table 8. Mean* soil loss and precipitation for two-week periods in 1999.

Date	Soil loss (Mg/ha)	Total precipitation (cm)	Max daily precipitation (cm)	Max hourly precipitation (cm)
6/1/99	0.06	3.3	1.5	0.5
6/15/99	0.03	2.5	1.1	0.5
7/2/99	0.36	2.9	0.9	0.5
7/21/99	0.01	0.1	0.1	0.1
8/11/99	0.27	1.6	1.5	0.4
8/28/98	0.03	1.6	0.8	0.5

* n = 16

June. Soon after the snow melted, amounts of soil loss corresponded with amounts of precipitation (Table 8).

Effect of Slope Gradient on Soil Loss

As slope gradient increased from 25% to 40% soil loss also increased; however as slope gradient increased to 50% soil loss decreased (Table 9). Both years the 40% slope had the highest soil erosion rate and the 50% slope had less soil loss than the 40% slope (Figure 5). Differences between slope gradients were more pronounced the first year than the second year. For the first year total soil loss ranged from approximately 0.31 Mg/ha to 59.35 Mg/ha and for the second year soil loss ranged from approximately 0.30 Mg/ha to 2.24 Mg/ha (Mg/ha = 0.45 tons/acre). Sediment yield data are in Appendix C, Tables 36 and 37.

Research indicates that soil loss increases as slope gradient increases (Hahn, 1985; Hartley & Schuman, 1984; Liu et al., 1994; McCool, 1987; McIssac, 1987;

Table 9. Effect of slope gradient on mean* annual soil loss (Mg/ha).

	Slope Gradient			
Year	25%	33%	40%	50%
1998	1.58	11.54	32.02	20.39
1999	0.77	1.12	1.41	0.73

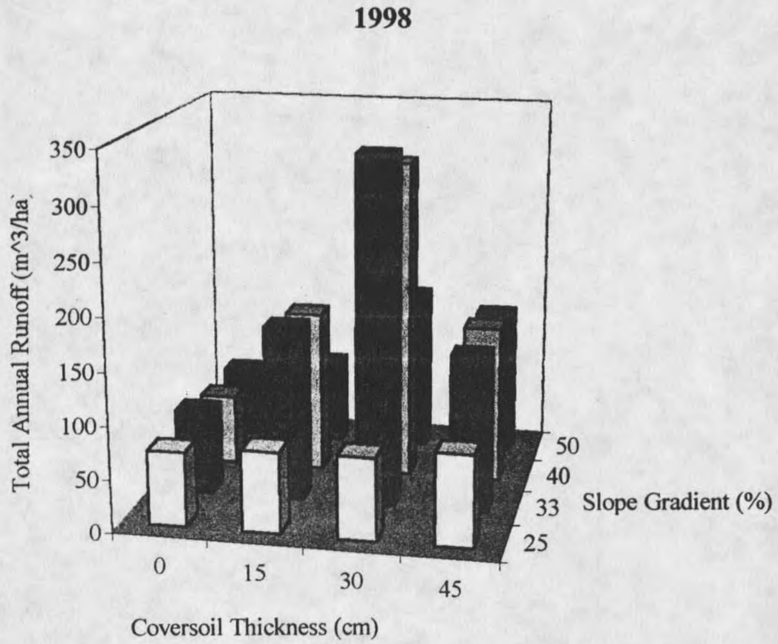
* n = 4

Schroeder, 1987). Several studies, however, has found that soil loss levels off or decreases as slope gradients become very steep (i.e. >40%) (Bradford and Foster, 1996; Singer and Blackard, 1982). Rainsplash provides the energy for detaching soil particles that are then transported downslope. As slope gradient increases rainsplash becomes more active increasing soil loss (Mathier et al., 1989), but as slope gradients become very steep (approximately 35 – 40%) there is less direct rainsplash impact on the surface, thereby reducing detachment of soil particles and decreasing soil loss (Bradford and Foster, 1996; Singer and Blackard, 1982).

Effect of Coversoil Thickness on Soil Loss

Soil loss rates were lowest on plots without coversoil (Table 10). On plots with coversoil, soil loss on the majority of the slopes was greatest on the plots with 30 cm of coversoil. This occurred on all slopes except for the 50% slope in 1998 (Figure 5).

Plots with no coversoil had very little erosion due to the high rock cover (86%). As rock cover increased, soil loss decreased due to increased soil roughness, increased infiltration, and decreased potential area of erosion (Ashby et al., 1984; Sidle and Brown, 1993). The relationship between soil loss and coversoil thickness on plots with coversoil was not linear and is difficult to explain. There is no scientific literature regarding



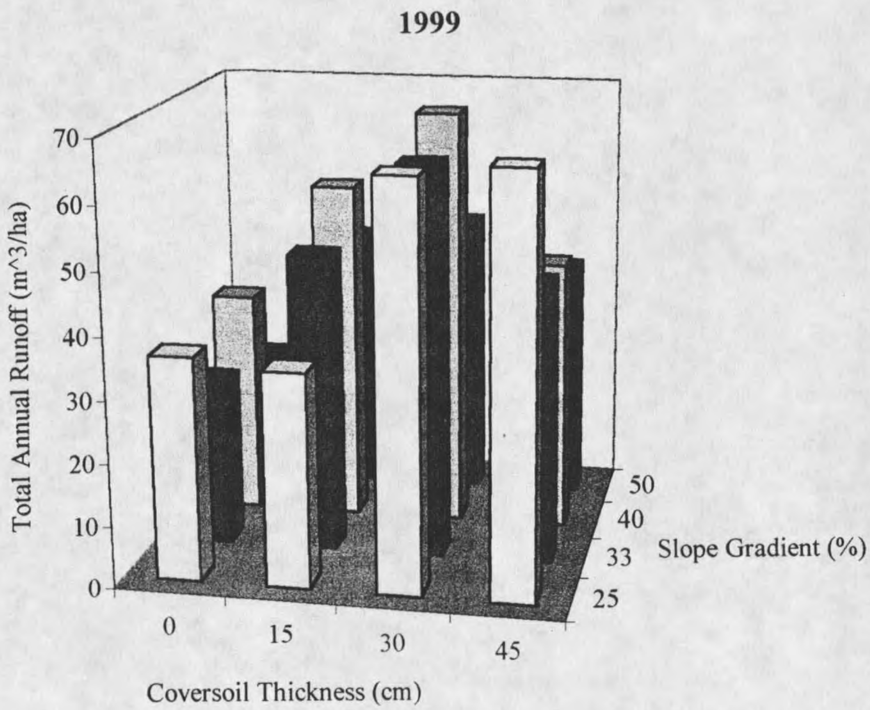


Figure 9. Effect of slope gradient and coversoil thickness on total annual runoff in 1998 and 1999.

Table 10. Effect of coversoil thickness on mean* annual soil loss (Mg/ha).

	Coversoil Thickness (cm)			
Year	0	15	30	45
1998	0.41	14.71	29.53	20.87
1999	0.33	1.06	1.74	0.90

* n = 4

coversoil thickness and soil erosion that offers an explanation for why plots with 30 cm of coversoil had greater rates of soil loss than plots with 15 and 45 cm of coversoil.

Effect of Rills on Soil Loss

Rills are small channels, less than six inches deep that are formed by runoff and have the potential to transport a high volume of soil in a short period of time. Rills on the test plots were classified using the Erosion Condition Classification System Montana Revised Method (Table 3) (Clark, 1980). Mean annual rill severity data are located in Table 11. These mean values were calculated from rill data located in Appendix C, Tables 40 and 41.

Rill severity increased with slope gradients up to 40%. Rills were more severe on the 40% slope than the 50% slope, reflecting the fact that the 40% slope yielded the greatest soil loss. Other researchers have found that rill erosion increased with increased slope gradient (Hahn, 1985; Hartley and Schuman, 1984; McCool, 1987). Rills did not form on the plots without coversoil due to high rock cover (86%). On plots with coversoil rill severity was least on plots with 15 cm of coversoil and was greatest on plots

Table 11. Effect of slope gradient and coversoil thickness on mean rill severity in 1998 and 1999.

Slope Gradient	Coversoil thickness 0 cm	15 cm	30 cm	45cm	mean
		1998			
25%	1.0	1.7	2.1	1.4	1.6
33%	1.0	1.7	2.3	1.8	1.7
40%	1.0	3.3	3.4	3.4	2.8
50%	1.0	3.0	3.4	3.6	2.8
mean	1.0	2.4	2.8	2.6	
			1999		
25%	1.0	1.2	1.8	1.2	1.3
33%	1.0	2.0	2.7	1.8	1.9
40%	1.0	4.0	4.3	3.8	3.3
50%	1.0	2.7	4.0	3.8	2.9
mean	1.0	2.5	3.2	2.7	

with 30 cm of coversoil. These plots with 30 cm of coversoil also had the highest soil loss rates. In general, average rill severity increased slightly during the second year; however, it should be noted that these values are averages and during the first season the rill severity was low early in the season as rills formed.

Soil loss was correlated significantly with the depth and frequency of rills in 1998 (r = 0.88) and in 1999 (r = 0.65) at this site (Figure 6). The stronger correlation in 1998 makes sense since the rill severity rating was cumulative. In 1998 large quantities of soil

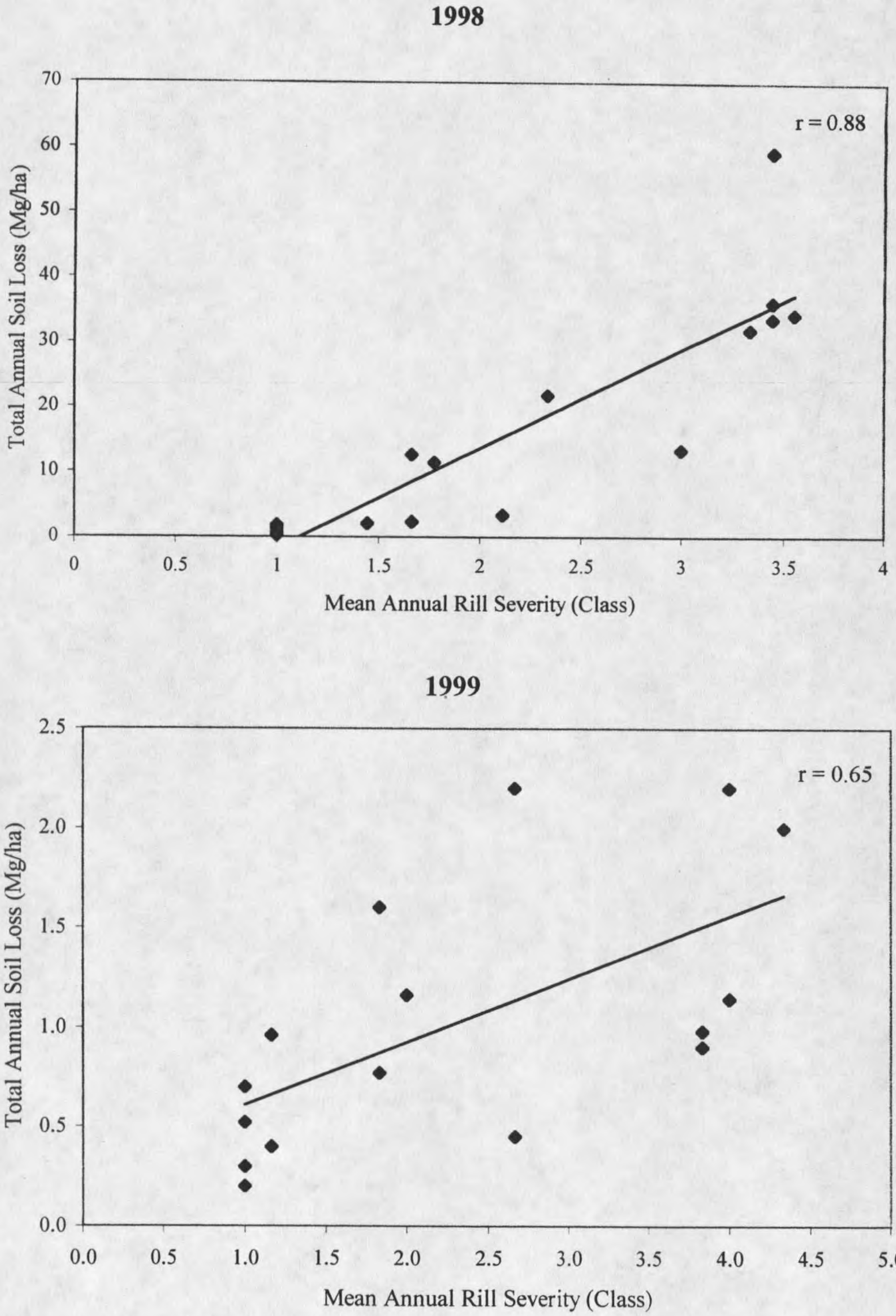


Figure 6. Total annual soil loss for each test plot as a function of mean annual rill severity for each test plot in 1998 and 1999.

were eroded as the rills formed, but in 1999 the rills acted mainly as conduits for sediment transport.

Visual observations in the field also indicated that rills contributed to soil loss. When sediment was collected from the troughs it was observed that sediment was concentrated directly below rills present on these plots. Data in this study suggest that soil loss and rill formation are related to one another and depend on slope gradient.

Effect of Precipitation on Soil Loss

To determine the effect of precipitation on soil erosion, the quantity of soil loss from all plots during each two-week period was averaged and then compared to precipitation amounts during the same two-week period.

During 1998 soil erosion was not significantly correlated with total precipitation ($r = -0.03$), maximum daily precipitation ($r = -0.20$), or maximum hourly precipitation ($r = -0.19$). Although these correlations were not significant, Figure 7 suggests that soil losses decreased with increased precipitation indicating that factors other than precipitation must control soil losses on reconstructed slopes during the first year. The lack of vegetation during the first two months of the season in 1998 probably had the greatest effect on soil loss.

During 1999 soil loss was not correlated significantly with total precipitation ($r = 0.26$), maximum daily precipitation ($r = 0.22$), or maximum hourly precipitation ($r = 0.46$) (Figure 8). Although these correlations were poor they suggested that soil loss increased with increased precipitation. The correlation between soil loss and maximum

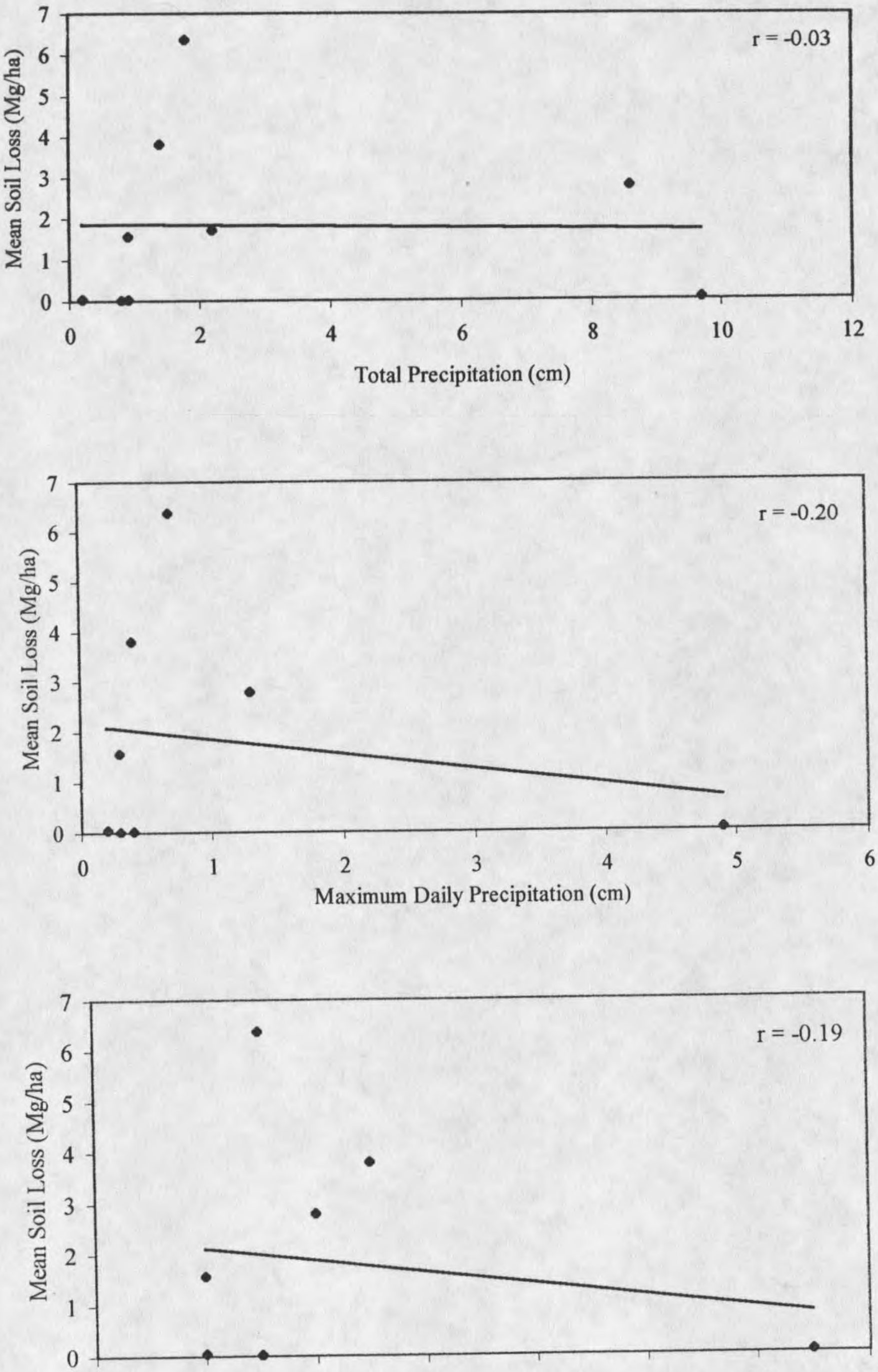


Figure 7. Correlations between total precipitation, maximum daily precipitation, maximum hourly precipitation, and mean soil loss off all test plots for two-week periods in 1998.

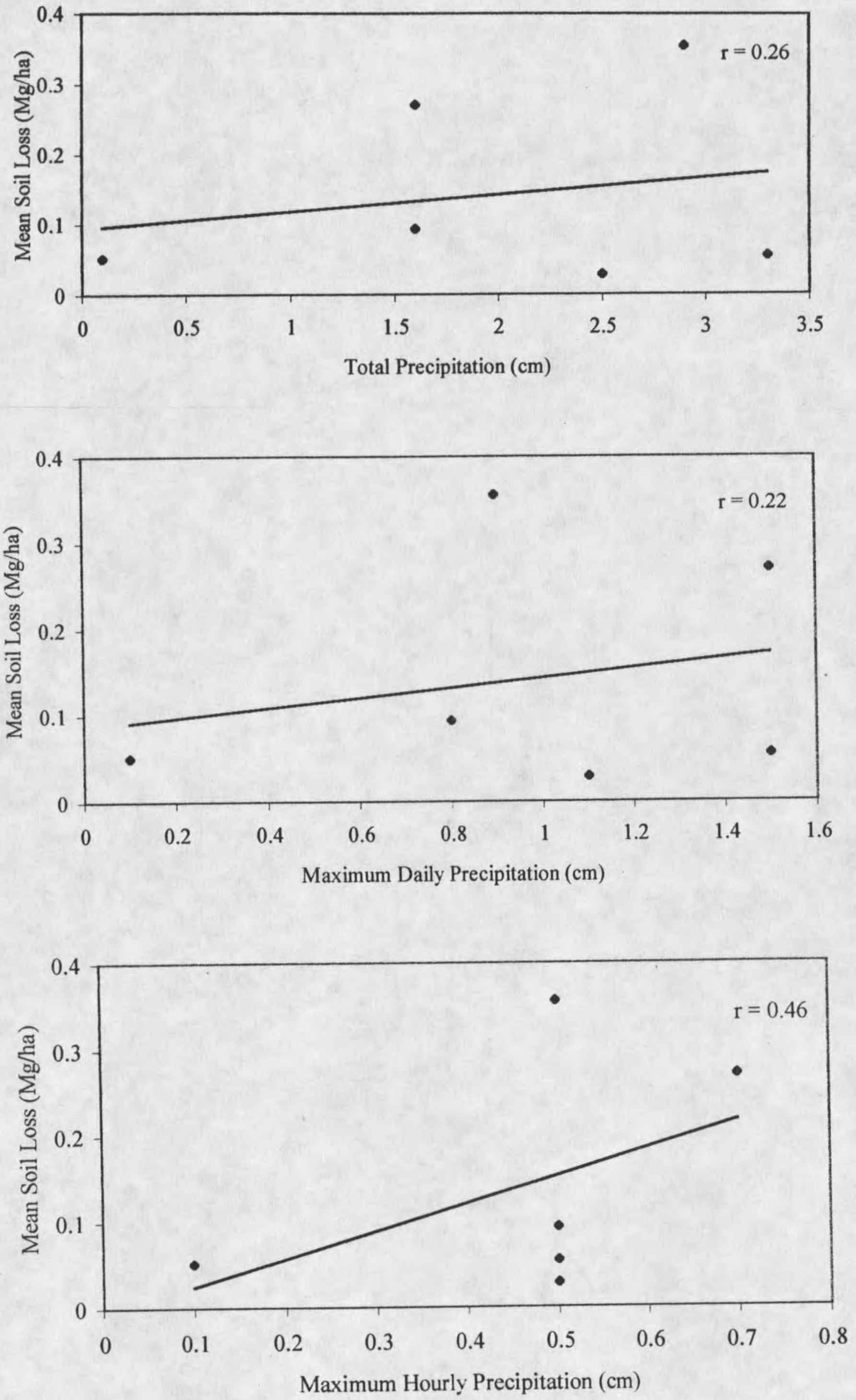


Figure 8. Correlations between total precipitation, maximum daily precipitation, maximum hourly precipitation, and mean soil loss off all test plots for two-week periods in 1999.

hourly precipitation was not significant, but it was stronger than the other correlations indicating that intensity of precipitation had more of an effect on soil losses than total precipitation. Intensity of precipitation rather than total precipitation often has a greater effect on soil losses (Larson, 1997; McCool, 1984; Peterson et al., 1995).

Precipitation had a greater effect on soil loss in the second year than in the first year (Figure 4). In 1999 soil loss corresponded more with precipitation than in 1998. Figure 4 also shows that during both years soil loss rates corresponded with precipitation more from July onward. In the spring soil erosion rates were very low even though precipitation was very high. Although precipitation was high early in the season, erosion was probably low because the ground was still frozen.

Effect of Rock Cover on Soil Loss

Plots without coversoil had a mean of 86% rock cover whereas plots with coversoil had a mean of 39% rock cover (Table 12). Mean rock cover on test plots was calculated from measured data (Appendix D, Tables 49 and 59). Plots with high rock cover had less soil loss and less severe rills (Table 11). There was a significant negative correlation between soil loss and rock cover during the first ($r = -0.66$) and the second ($r = -0.61$) year. Plots without coversoil had very little soil loss (Figure 5).

The inverse relationship between soil loss and rock cover is well documented in the scientific literature (Ashby et al., 1984; McIssac, 1987; Rawitz and Shirley, 1984; Sidle and Brown, 1993; Simanton et al., 1984). High rock content increased infiltration rates and surface roughness decreasing runoff and soil loss. In addition, the higher the

Table 12. Effect of slope gradient and coversoil thickness on mean* rock cover (%).

	Coversoil thickness			
Slope Gradient	0 cm	15 cm	30 cm	45cm
25%	90	41	44	45
33%	89	43	40	42
40%	82	38	35	33
50%	85	46	37	26

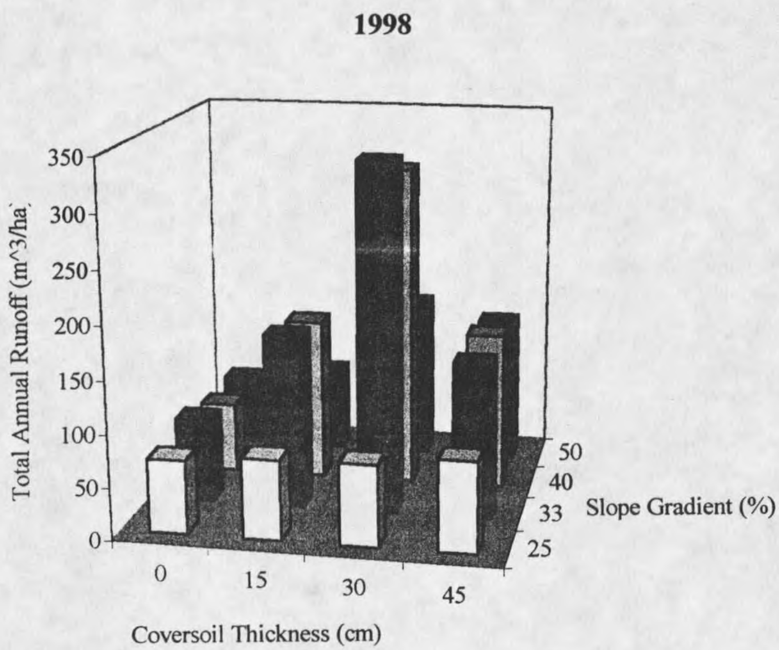
* n = 20

rock content, the less soil available for soil loss (Ashby et al., 1984; Sidle and Brown, 1993). On soils with high rock contents as soil material eroded, rock cover increased as the coarse fragments were exposed. This armoring of the soil can further help to reduce soil erosion (Box and Meyer, 1984). Although general principles of soil reconstruction recommend that coarse fragment percentage by volume be less than 20%, on high elevation steep slopes it is appropriate to exceed this criterion to reduce soil loss rates.

Runoff Results on High Altitude Steep Slopes

Effect of Slope Gradient on Runoff

There was no discernible relationship between runoff and slope gradient (Table 13 and Figure 9). Runoff was not correlated with slope gradient in 1998 ($r = 0.15$) or 1999 ($r = -0.28$). There was, however, a significant correlation between runoff and soil loss. Correlation values between runoff and soil loss were similar in 1998 ($r = 0.78$) and 1999 ($r = 0.81$) (Figure 10).



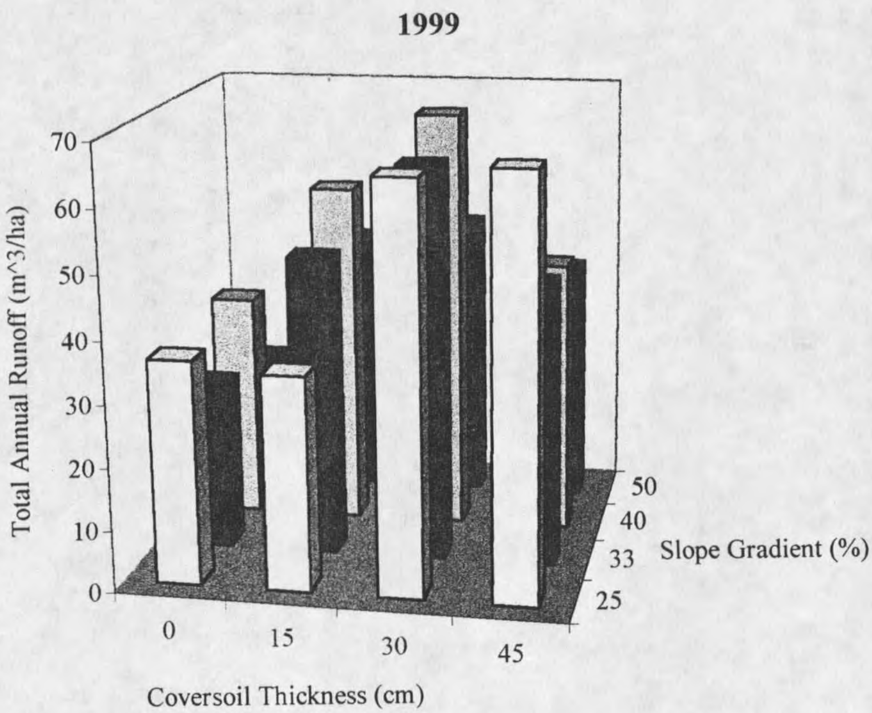
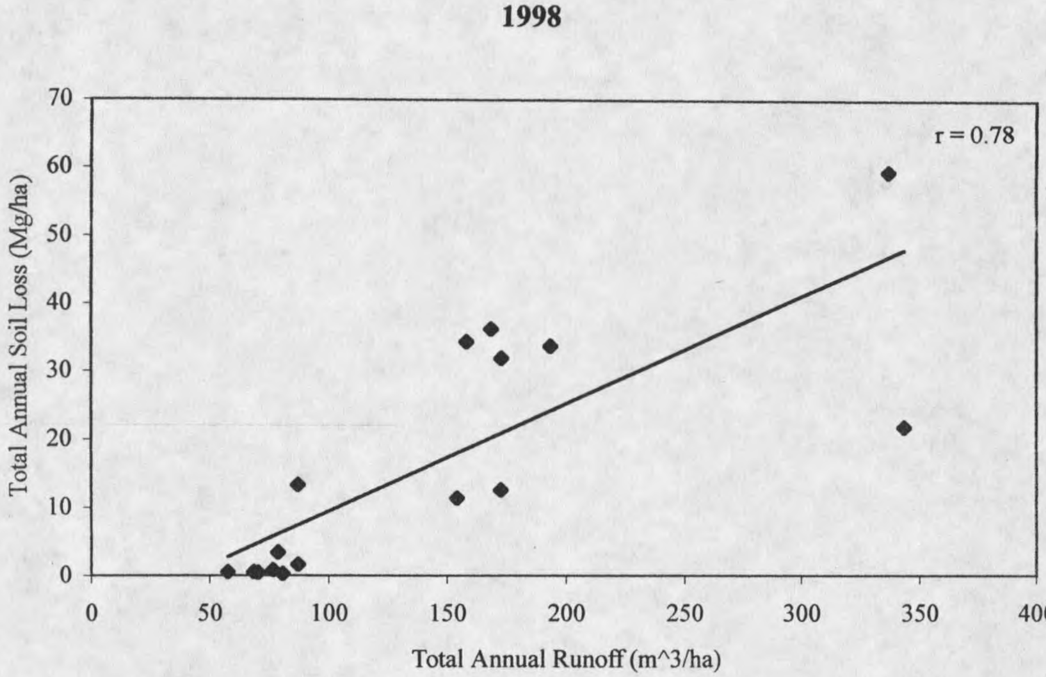


Figure 9. Effect of slope gradient and coversoil thickness on total annual runoff in 1998 and 1999.



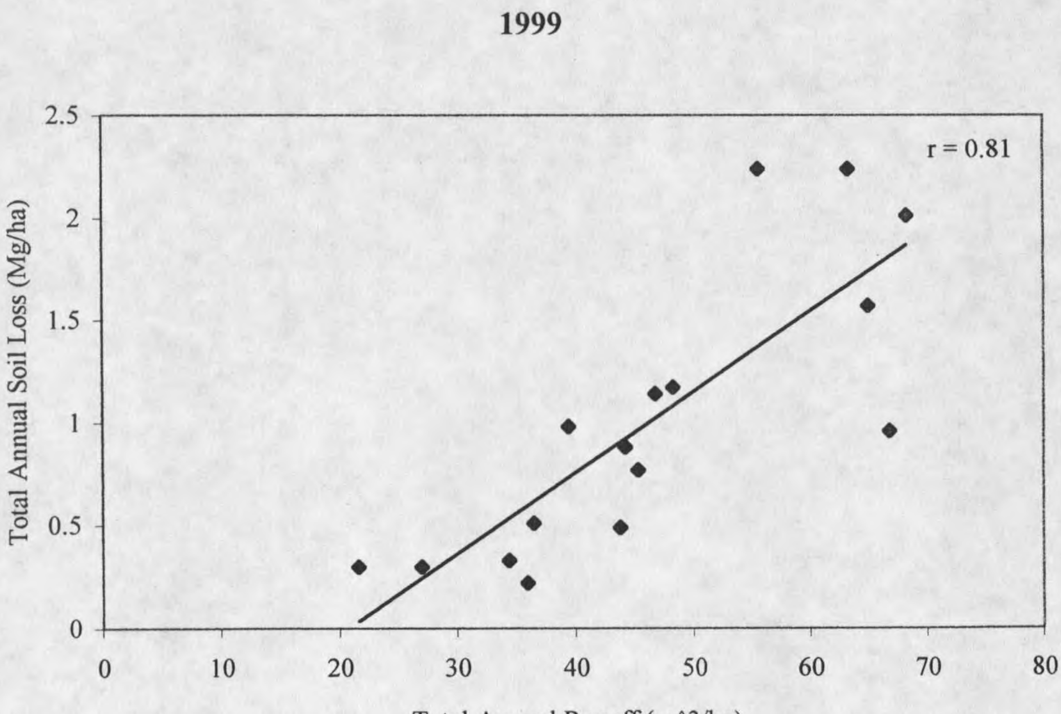


Table 10. Correlation between total annual soil loss and runoff on each test plot in 1998 and 1999.

Table 13. Effect of slope gradient on mean annual runoff (m^3/ha).

	Slope Gradient			
Year	25%	33%	40%	50%
1998	79	188	186	122
1999	51	46	51	38

Several other studies have found no significant differences in runoff rates as slope gradient increased (Grosh, 1994; McCool, 1987, Yair and Klein, 1973). Their results indicated that factors other than slope gradient had a greater effect on runoff. Schmittner and Giresse (1994) though that vegetative has more of an effect than slope gradient on runoff. Mathier et al. (1989) found that the relationship between runoff and soil loss was much stronger than the relationship between runoff and slope gradient. Results from this study support their data.

Effect of Coversoil Thickness on Runoff

Runoff occurs when the precipitation rate exceeds the infiltration rate of a soil. Differing coversoil thicknesses may have an effect on vegetation that, in turn, may have an effect on infiltration rates. Increased vegetation increases infiltration rates and decreases runoff rates (Hartley and Schuman, 1984; Kirkby, 1980; Toy 1989). Rock cover also increases infiltration rates and decreases runoff rates (Ashby et al., 1984; Sidle and Brown, 1993).

Plots without coversoil had more rock cover (86%), less vegetation, and lower runoff rates (Figure 9 and Table 14). On plots with coversoil, runoff rates varied with coversoil thickness. Plots with 30 cm of coversoil had the highest runoff rates. These

Table 14. Effect of coversoil thickness on mean annual runoff (m^3/ha).

	Coversoil thickness			
Year	0 cm	15 cm	30 cm	45cm
1998	71.8	127.6	233.4	142.2
1999	30.3	45.5	60.9	49.0

plots also had the highest soil loss rates (Table 10), indicating that there was a strong relationship between runoff and soil loss (Figure 10).

Results from this study demonstrated that increased rock content decreased runoff rates. In 1999 the correlation between these two variables was significant ($r = -0.55$); however there was not a significant correlation in 1998 ($r = 0.40$). Results and observations from this study do not offer an explanation as to what factors influenced runoff generation on plots with coversoil.

Effect of Time on Runoff

Total runoff was lower the second year than the first year (Table 14). In part, decreased runoff could have been attributed to precipitation. In 1999 precipitation was further below average than in 1998 (Appendix B, Tables 24 and 25). Vegetation probably had an effect on runoff generation. During 1999 vegetative litter and perennial plants were present on the plots all season, in contrast to the first year when the ground was virtually devoid of vegetative matter about two months. Runoff was greater on these bare plots in 1998. In 1999 the presence of vegetation decreased runoff by increasing infiltration, interception, and evapotranspiration (Kirkby, 1980).

Plant Growth Results on High Altitude Steep Slopes

Effect of Coversoil Thickness on Plant Growth Characteristics

In general, plant canopy cover, basal cover, and production increased with increased coversoil thickness (Table 15). During the first year there was a significant correlation between canopy cover (r = 0.58), basal cover (r = 0.48), and coversoil thickness. During the second year correlations between canopy cover (r = 0.49) and basal cover (r = 0.36) were not as strong, and only the correlation between canopy cover and coversoil thickness was significant. The relationship between production and coversoil thickness was stronger than the relationship between plant cover and coversoil thickness. Production and coversoil thickness were significantly correlated in 1998 (r = 0.65) and in 1999 (r = 0.70). Figures 11, 12, and 13 depict the respective relationships between plant canopy cover, basal cover, production, and coversoil thickness.

Total vegetative canopy cover, basal cover, and production values decreased from 1998 to 1999, however, perennial grass cover, forb cover, and production all increased after the first year. Decreases in total vegetative canopy and production were due to the absence of annual grasses during the second year (Figure 14).

Results from this study indicated that vegetation increased with increased coversoil depths and support studies in the literature regarding plant growth and coversoil thicknesses (Barth and Martin, 1982; McGinnies and Nicholas, 1980; Power et al., 1981; Redente and Hargis, 1985).

Table 15. Effect of coversoil thickness on mean* plant growth characteristics.

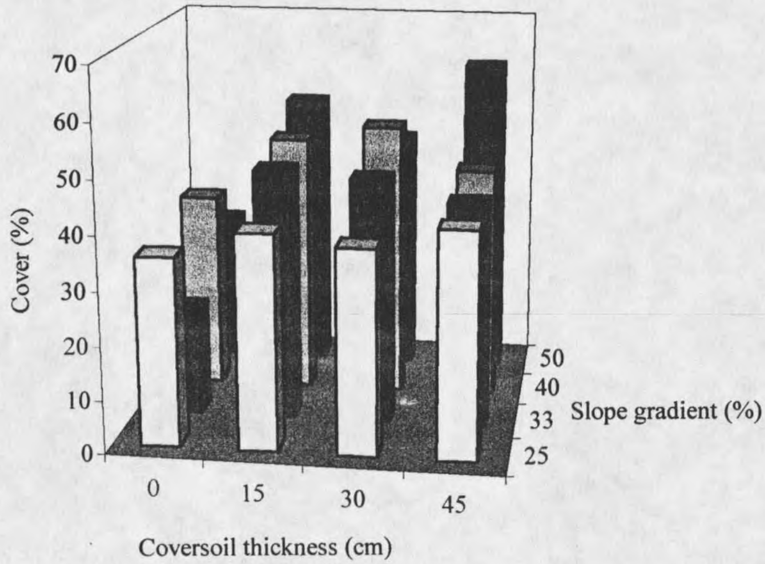
	Coversoil thickness			
Characteristic	0 cm	15 cm	30 cm	45cm
		1998		
Canopy cover (%)	30.0	47.3	45.5	47.3
Basal cover (%)	24.0	34.0	31.5	33.0
Production (kg/ha)	597	1795	1522	2858
		1999		
Canopy cover (%)	23.3	26.3	27.8	30.8
Basal cover (%)	21.8	22.0	22.8	24.8
Production (kg/ha)	775	1233	1369	1613

* n = 160

Effect of Slope Gradient on Plant Growth Characteristics

There were no significant correlations between plant growth characteristics and slope gradient during the first year of this study (Table 16). During the second year there were significant correlations between both vegetative canopy cover (r = 0.69), basal cover (r = 0.75), and slope gradient, but there was no correlation between production and slope gradient (r = 0.08). Figures 11, 12, and 13 illustrate the relationships between vegetative canopy cover, basal cover, production, and slope gradient, respectively.

1998



1999

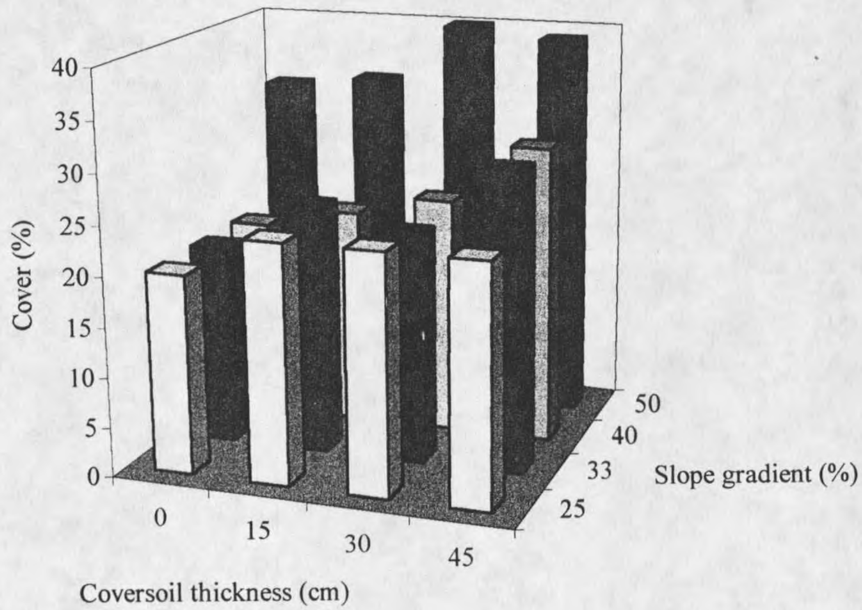
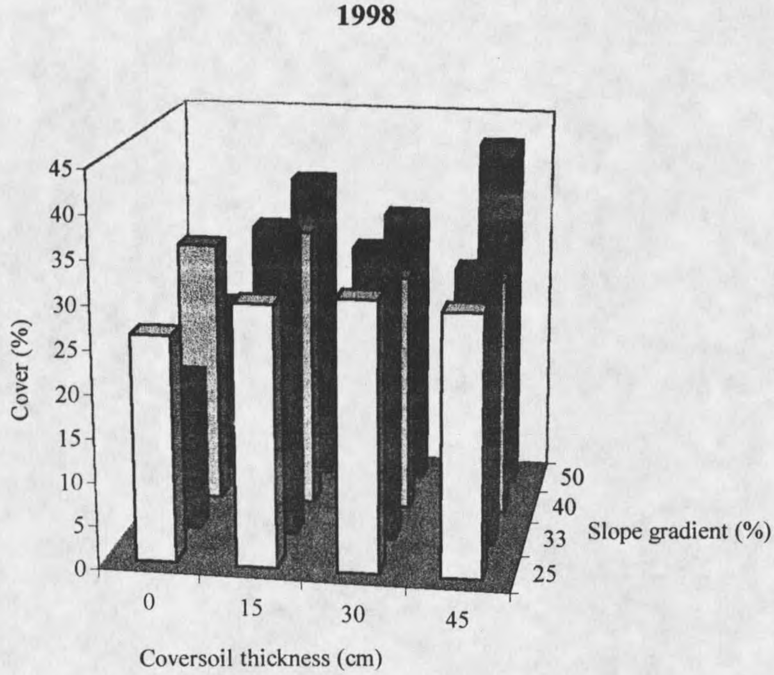


Figure 11. Effect of slope gradient and coversoil thickness on canopy cover in 1998 and 1999.



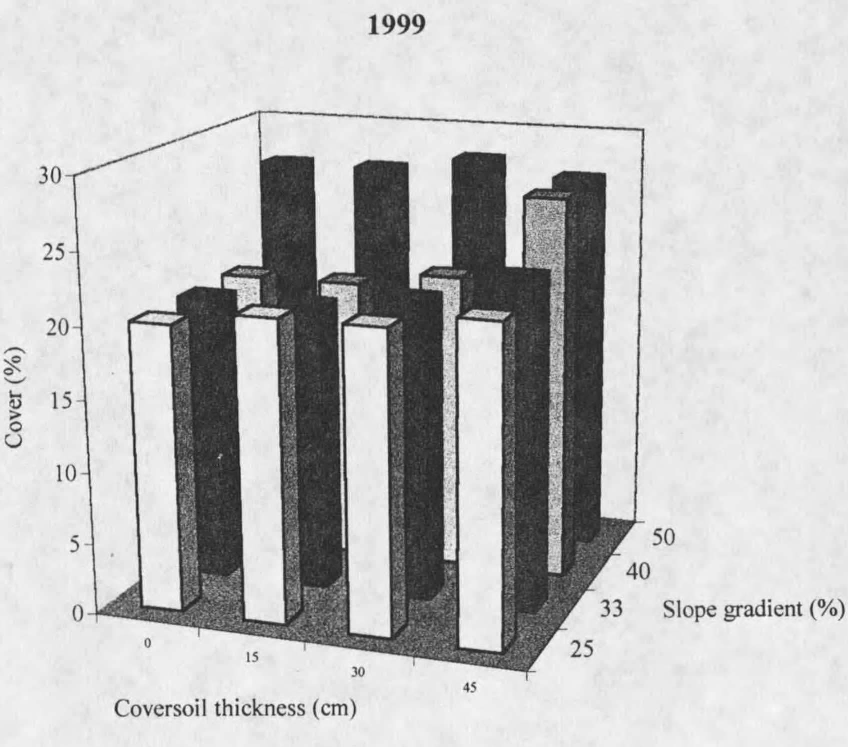


Figure 12. Effect of slope gradient and coversoil thickness on basal cover in 1998 and 1999.

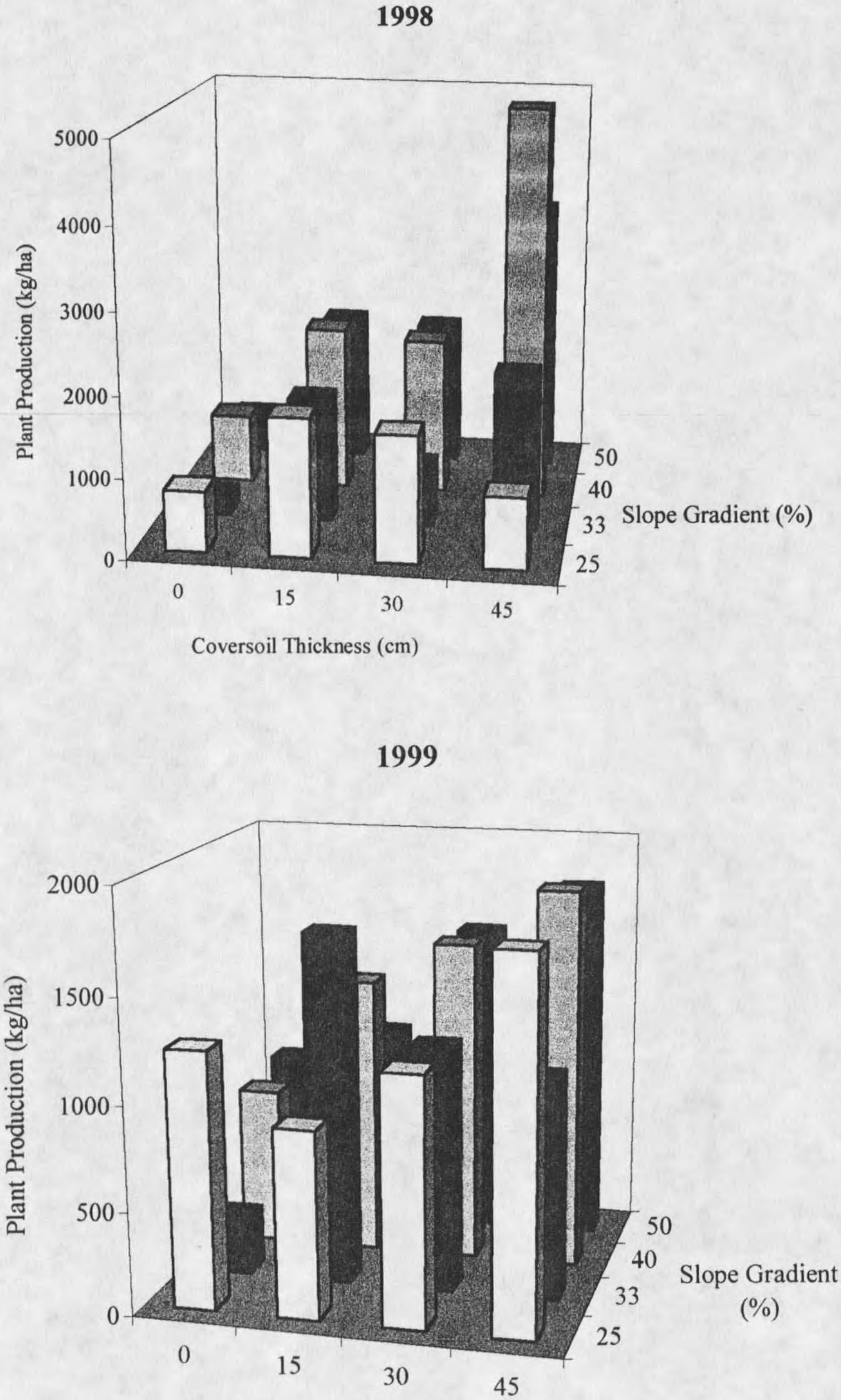
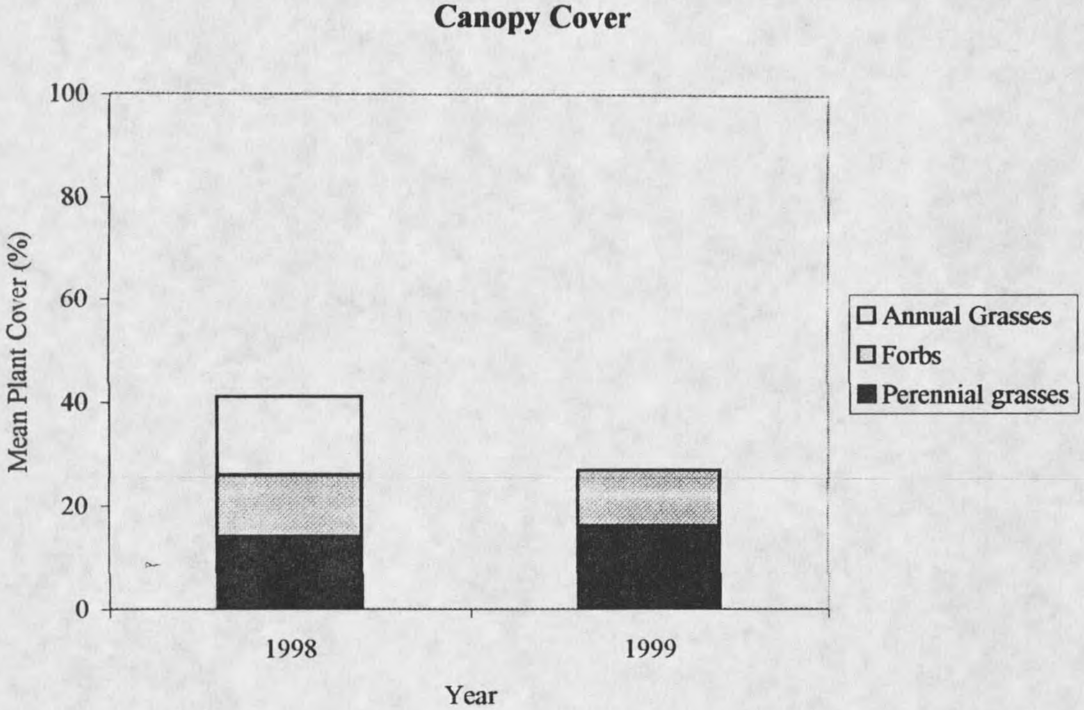


Figure 13. Effect of slope gradient and coversoil thickness on plant production in 1998 and 1999.



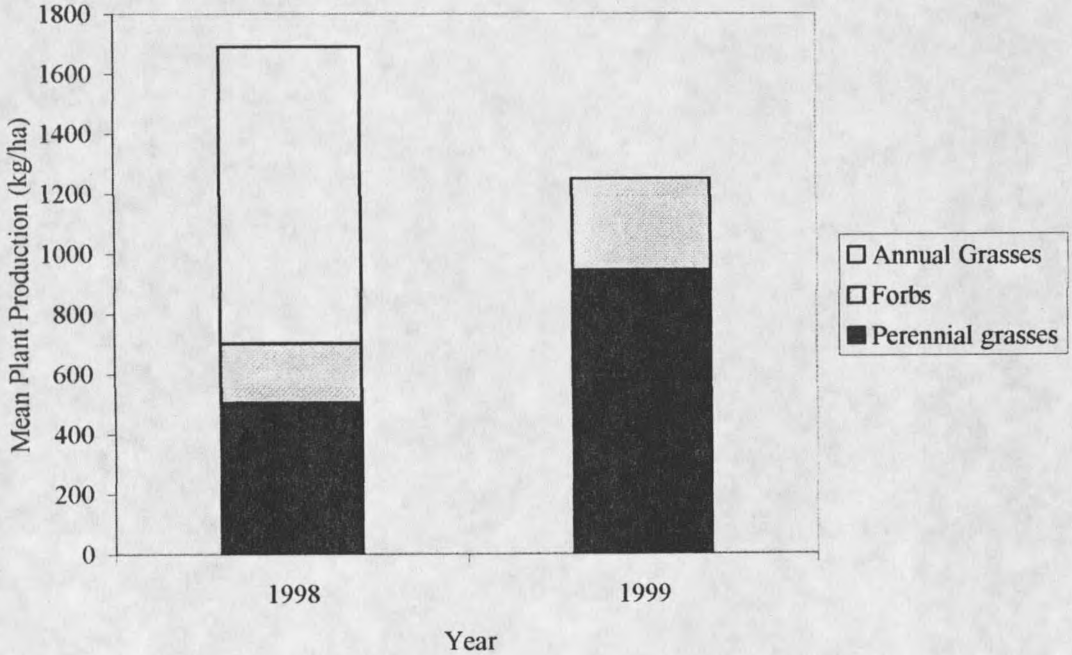


Figure 14. Comparisons between mean annual plant canopy cover and mean annual plant production in 1998 and 1999.

Table 16. Effect of slope gradient on mean* plant growth characteristics.

Characteristic	Slope gradient 25%	33%	40%	50%
		1998		
Canopy cover (%)	38.8	38.8	45.5	47.0
Basal cover (%)	29.3	30.0	30.0	33.3
Production (kg/ha)	1228	1112	2509	1902
		1999		
Canopy cover (%)	23.0	24.5	24.0	36.5
Basal cover (%)	21.0	21.0	22.0	27.3
Production (kg/ha)	1275	1057	1385	1275

* n = 160

Correlations between plant cover and slope gradient in 1999 can be attributed to the increased cover on the 50% slope. Cover values on the remaining three slopes are similar. Production values were not higher on the 50% slope indicating that the vegetative cover data for the 50% slope were erroneous. Cover measurements are more subjective than production measurements and this subjectivity probably accounted for the apparent increased cover on the 50% slope. Production values indicated that slope gradient did not have an effect on plant growth.

Effect of Plant Growth of Soil Loss

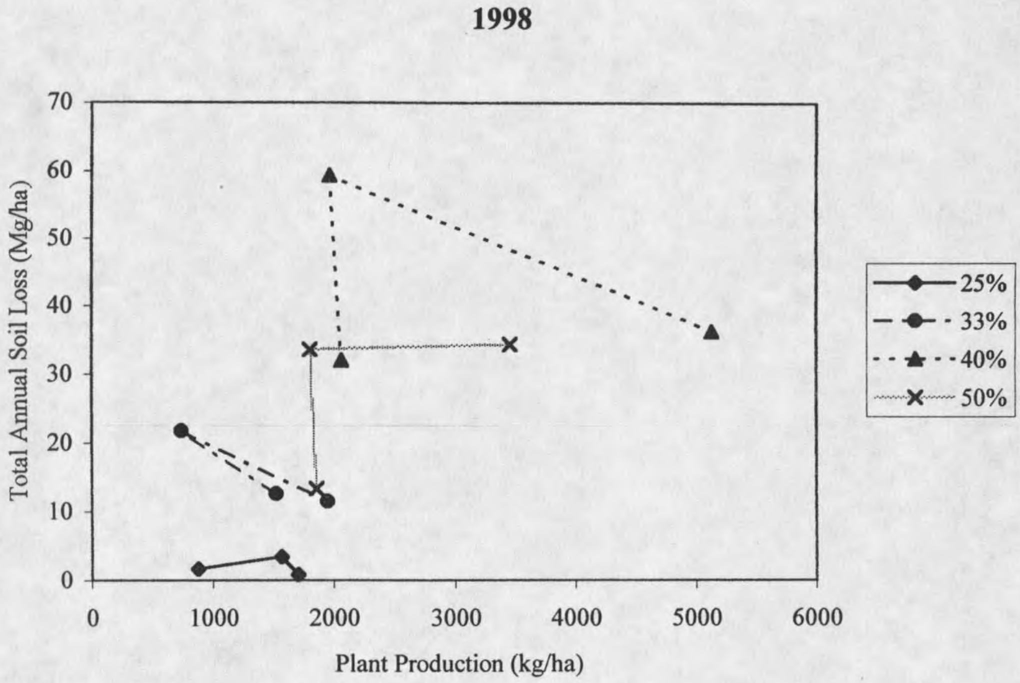
On plots without coversoil, rock cover was very high (86%), and, as a result, both plant growth and soil loss rates were low. On plots with coversoil increased coversoil depths yielded increased plant production, however increased plant production did not result in decreased soil loss rates (Figure 15). Results from 1998 may not have shown a relationship between plant growth and soil loss since most soil loss occurred before the plant community established. An inverse relationship between plant growth and soil loss would have more likely during 1999, but only the 40% slope showed a decrease in soil loss with increasing plant growth.

Soil loss decreases with increases in plant growth (Galetovic, 1998; Hartley & Schuman, 1984; Kirkby, 1980; Toy, 1989). Results from this study indicated that although increased coversoil depths yielded increased plant production, these increases in plant production were not sufficient to minimize soil losses.

Ability of Measured Factors to Predict Soil Loss and Runoff

Canonical correlation analysis is a statistical tool used to examine the relationships between two sets of variables, criterion and predictor variables. In this study, total annual soil loss and total annual runoff rates were considered criterion variables. Predictor variables were slope gradient, coversoil thickness, rill severity, rock cover, and plant growth characteristics. Canonical correlation data are located in Appendix E, Tables 69 and 70.

In canonical correlation analysis canonical variables are derived to maximize the correlations between criterion and predictor variables. Squared multiple correlations



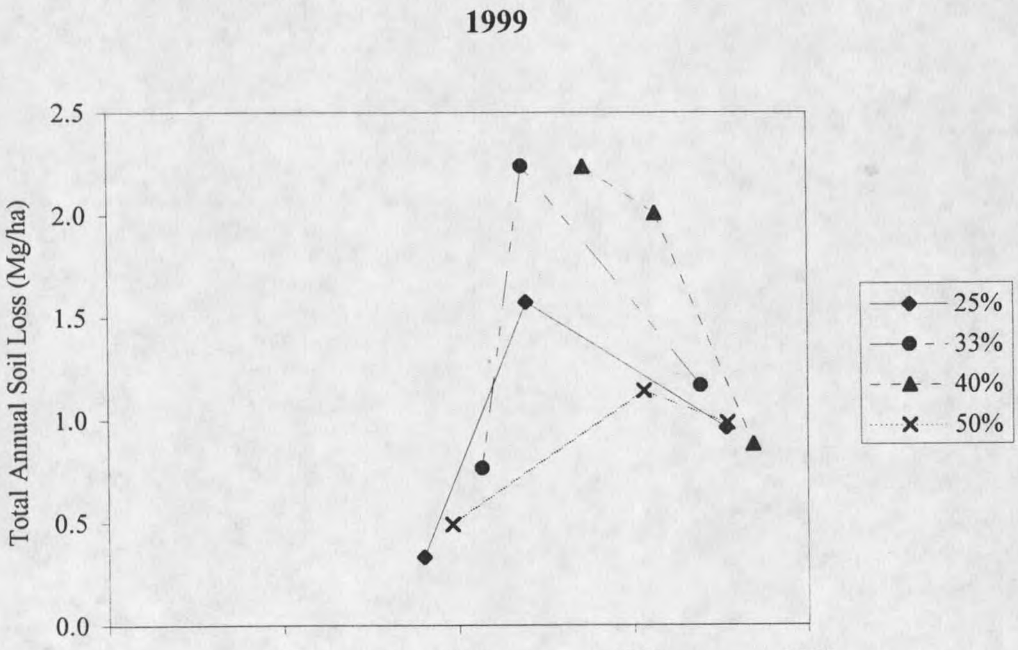


Figure 15. Effect of plant production on total annual soil loss for test plots with coversoil on all slope gradients

between criterion variables and canonical variables of the predictor values provided an interpretation of how well predictor variables can predict criterion variables. In 1998 and 1999 predictor variables had greater predictive power for annual soil loss (0.86, 1998; 0.73, 1999) than for annual runoff (0.30, 1998; 0.57, 1999).

Redundancy analysis provided a redundancy coefficient, which is analogous to a squared multiple correlation coefficient. Redundancy coefficients showed how much variance in the criterion variables was explained by the predictor values. In 1998, 58% of the variance in criterion variables was explained by predictor variables, and in 1999, 65% of the variance in criterion variables was explained by predictor variables.

Ability of RUSLE to Predict Soil Loss at High Elevation Sites

The RUSLE version 1.06 computer model was used to calculate annual soil loss values for both years of this study. On average, predicted values for 1998 underestimated the rate of soil loss by 15 +/- 17 Mg/ha (Table 17). RUSLE underestimated soil loss on 14 of the plots and underestimated soil loss by more than 1 Mg/ha on plots with an average annual rill severity rating of greater than 1.5 (Table 11). In 1998, the correlation between measured soil loss and rill severity was significant ($r = 0.88$) (Figure 6).

RUSLE predicted soil loss rates for 1999 more accurately than for 1998. In 1999, RULSE, on average, underestimated soil loss by 0.4 +/- 0.6 Mg/ha (Table 18). There was still a significant correlation between soil loss and rill severity ($r = 0.65$), however the plots with a high rill severity rating did not have the high soil loss rates observed the first year. Although the RUSLE model accounts for rill and interrill erosion data

Table 17. RUSLE predicted and measured soil loss values (Mg/ha) in 1998 for all test plot treatments.

	Coversoil thickness			
Slope Gradient	0 cm	15 cm	30 cm	45cm
		RUSLE Predicted Soil Loss		
25%	0.20	1.23	1.23	1.23
33%	0.27	1.61	1.61	1.61
40%	0.31	1.86	1.86	1.86
50%	0.38	2.24	2.24	2.24
		Measured Soil Loss		
25%	0.40	0.87	3.40	1.64
33%	0.36	12.61	21.75	11.42
40%	0.60	31.99	59.02	36.11
50%	0.31	13.33	33.60	34.67

suggested that RUSLE was not able to account for the extreme quantity of soil loss during the first season as rills formed.

To account for the inaccuracies of prediction in the first year a rill formation factor was determined. Plots were divided into three groups based on the average rill severity rating for each plot: plots with stable to slight rill erosion, plots with slight to moderate rill erosion, and plots with moderate to critical rill erosion (Table 3 and Table 11). Using nonlinear variable estimation (Wraith and Or, 1999), a rill formation factor

Table 18. RUSLE predicted and measured soil losses (Mg/ha) in 1999 for all test plot treatments.

	Coversoil thickness			
Slope Gradient	0 cm	15 cm	30 cm	45cm
		Predicted		
25%	0.11	0.59	0.58	0.56
33%	0.20	0.74	0.74	0.74
40%	0.22	0.90	0.87	0.56
50%	0.25	0.99	0.99	1.01
		Observed		
25%	0.29	1.16	2.24	0.76
33%	0.22	0.34	1.57	0.96
40%	0.52	2.24	2.02	0.87
50%	0.29	0.49	1.14	0.99

was determined for plots with slight to moderate rill severity and for plots with moderate to critical rill severity. The rill formation factor (F) was multiplied by the soil erodibility factor (K) to generate a new soil erodibility factor (K1). This new soil erodibility factor (K1) was then used to generate optimized soil loss values (Table 19). Using the new soil erodibility factor the optimized soil losses were closer to the measured soil losses (Figure 16). On average, the optimized soil losses were 1.4 +/- 8.5 Mg/ha lower than measured soil losses. These rill formation factors were generated from a small sample size and are not necessarily applicable to other sites.

Table 19. Optimized soil loss values (Mg/ha) for 1998 generated by RUSLE using rill formation factors.

Plot Treatment	RUSLE Factor R	K	F	K1	LS	C	P	Optimized Soil Loss
25%, 0 cm	8.0	0.13	1.0	0.13	4.32	0.02	1.0	0.09
25%, 15 cm	8.0	0.15	8.4	1.28	4.32	0.10	1.0	4.58
25%, 30 cm	8.0	0.15	8.4	1.28	4.32	0.10	1.0	4.58
25%, 45 cm	8.0	0.15	8.4	1.28	4.32	0.10	1.0	4.58
33%, 0 cm	8.0	0.13	1.0	0.13	5.72	0.02	1.0	0.12
33%, 15 cm	8.0	0.15	8.4	1.28	5.72	0.10	1.0	6.07
33%, 30 cm	8.0	0.13	8.4	1.28	5.72	0.10	1.0	6.07
33%, 45 cm	8.0	0.15	8.4	1.28	5.72	0.10	1.0	6.07
40%, 0 cm	8.0	0.15	1.0	0.13	6.81	0.02	1.0	0.14
40%, 15 cm	8.0	0.15	16.6	2.52	6.81	0.10	1.0	14.28
40%, 30 cm	8.0	0.15	16.6	2.52	6.81	0.10	1.0	14.28
40%, 45 cm	8.0	0.15	16.6	2.52	6.81	0.10	1.0	14.28
50%, 0 cm	8.0	0.13	1.0	0.13	8.13	0.02	1.0	0.17
50%, 15 cm	8.0	0.15	16.6	2.52	8.13	0.10	1.0	17.07
50%, 30 cm	8.0	0.15	16.6	2.52	8.13	0.10	1.0	17.07
50%, 45 cm	8.0	0.15	16.6	2.52	8.13	0.10	1.0	17.07

There may be other reasons why the RUSLE model predicted soil loss rates so poorly on many of the plots in 1998; however, if the reason for underestimation is due to the formation of rills it would be very useful to incorporate this factor into RUSLE v.

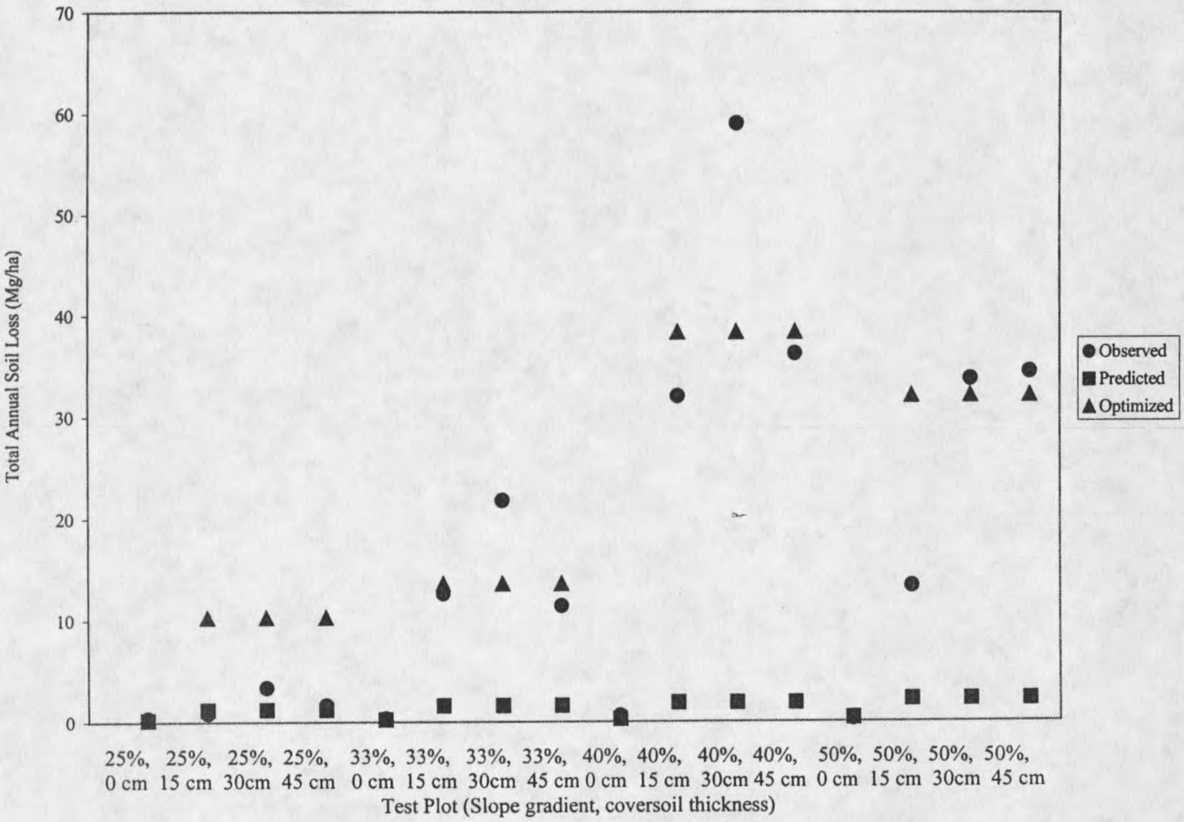


Figure 16. Comparison between measured, predicted, and optimized soil loss rates on test plots in 1998.

1.06. This computer model was designed for mined and reclaimed lands and construction sites. First year rill formation is likely to occur on these newly constructed steep slopes. Hopefully, future research will serve to corroborate the need for a special rill formation factor when using RUSLE v. 1.06 on newly constructed steep slopes.

SUMMARY AND CONCLUSION

A field study at the Barretts Minerals Incorporated (BMI) Treasure Mine, in southwest Montana was designed to evaluate sediment loss from steep reconstructed slopes. These slopes were constructed from overburden that was removed from the pit as the ore was mined. Soil loss from steep reconstructed slopes is a significant concern to mining companies. BMI is attempting to minimize soil loss on reconstructed slopes in an joint effort to rehabilitate Stone Creek. The objectives of this study were to evaluate the effect of slope gradient and plant cover on soil loss, evaluate the effect of coversoil thickness on plant cover, and to determine if the Revised Universal Soil Loss Equation (RUSLE) version 1.06 can predict the quantity of soil loss in a high altitude steep slope environment.

Four slopes, each with a different slope gradient (25%, 33%, 40%, and 50%) were constructed and each slope was divided into four plots, each with a different coversoil thickness (0 cm, 15 cm, 30 cm, and 45 cm). Soil loss and vegetative response were measured and data were analyzed using correlation analysis and canonical correlation.

In 1998, the first plant growth season, mean soil loss off test plots was 16.38 Mg/ha. In 1999 soil loss decreased dramatically and mean soil loss off test plots was 1.01 Mg/ha. After just one year soil loss off reconstructed steep slopes approached erosion rates for undisturbed lands (Brady and Weil, 1996). High soil loss rates during the first year were attributed to the lack of vegetation during the first few months of 1998, therefore it is recommended that slopes are seeded as soon as possible after reconstruction.

As slope gradient increased to 40% soil loss increased; but as slope gradient increased to 50% soil loss decreased. Although soil loss generally increased with slope gradient, soil loss after the second year was less than 2.5 Mg/ha regardless of slope gradient or coversoil thickness. These soil loss rates are considered stable. These data indicated that BMI can reconstruct slopes with gradients as steep as 50% without adversely increasing soil loss.

Soil losses the first year following reclamation were higher for all slope gradients. To protect downgradient water quality during the first year following reclamation, Barretts Minerals should use a support practice (i.e., mulching, constructing sediments basins). Constructing sediment basins at the base of reconstructed slopes would not minimize soil losses during the first year but it would protect water quality by intercepting sediment before it could enter Stone Creek.

Soil loss was least on the plots without coversoil, but this treatment is not recommended. Although the Montana Hard Rock Mining Reclamation Act regulations (1999) does not specifically mandate the use of coversoil, the regulations do state that, "where practicable, soil materials from all disturbed areas must be stockpiled and utilized", and "to the extent reasonable and practicable, the permittee must establish vegetative cover commensurate with the proposed land use specified in the reclamation plan". For reclamation to be considered successful under the current regulatory framework, the use of coversoil would probably be necessary. All plots with coversoil, regardless of thickness, had more plant growth than plots without coversoil. Although increased coversoil thickness yielded increased plant cover and plant production, these increases in plant growth did not have the effect of reducing soil loss. It is recommended that BMI apply at least 15 cm of coversoil to reconstructed slopes. BMI, however, may want to conduct long term monitoring to assess if increased coversoil thicknesses have a greater effect on vegetation and subsequent soil loss as the plant community matures.

RUSLE v. 1.06 underestimated soil loss during the first year by 14.98 +/- 17.35 Mg/ha, but predictions for the second year underestimated soil losses by only 0.38 +/- 0.59 Mg/ha. Although RUSLE is designed to account for rill and interrill erosion, results from this study indicated that it was not able to account for the severe erosion that occurred as rills formed. Based on results of this study RUSLE is an effective tool to use for long term planning on reconstructed high altitude steep slopes.

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APPENDICES

APPENDIX A
SOIL PHYSIOCHEMICAL DATA

Table 20. Coversoil textural analyses.

Sample	Sand (%)	Silt (%)	Clay (%)	Soil Texture
1	62.5	20	17.5	sandy loam
2	62.5	20	17.5	sandy loam

Table 21. Coversoil pH and EC analyses.

Sample	pH	EC (mmhos/cm)
1	6.63	0.94
2	6.56	0.84
3	6.64	0.78

Table 22. Subsoil textural analyses.

Sample	Sand (%)	Silt (%)	Clay (%)	Soil Texture
1	60.0	17.5	22.5	sandy loam
2	62.5	17.5	22.5	sandy loam

Table 23. Subsoil pH and EC chemical analyses.

Sample	pH	EC (mmhos/cm)
1	7.26	1.19
2	7.36	1.18
3	7.42	1.10

APPENDIX B
PRECIPITATION DATA

Table 24. Monthly precipitation (cm) for Dillon, Montana (WMCE) for 1998.

Month	Precipitation	Deviation
January	1.75	+0.30
February	0.74	-0.48
March	2.34	+0.10
April	3.38	-0.07
May	4.37	-1.60
June	7.87	+2.18
July	2.01	-1.27
August	1.68	-1.24
September	2.56	-0.49
October	2.13	+0.10
November	0.74	-0.81
December	3.02	+1.70
Total	32.59	-1.58

Table 25. Monthly precipitation (cm) for Dillon, Montana (WMCE) for the first eight months of 1999.

Month	Precipitation	Deviation
January	1.24	-0.21
February	0.05	-1.17
March	0.18	-2.06
April	3.18	-0.27
May	7.67	+1.7
June	4.42	-1.27
July	0.03	-3.25
August	3.05	+0.13
Total	19.82	-6.46

Table 26. Precipitation (cm) at Treasure Mine – May 1998.

Date	Time	Precipitation
20	100	0.2
21	800	0.1
	900	0.5
	1500	0.1
	1700	0.1
22	1500	0.1
	1700	0.1
	1900	0.1
	2200	0.1
23	1000	0.7
	1100	0.9
	1200	1.3
	1300	1.1
	1400	0.5
	1500	0.5
	1600	0.2
	1900	0.1
	2000	0.1
24	800	0.1
	900	0.1
	1500	0.1
	1600	0.1
25	2100	0.1
26	1600	0.1
30	1600	0.1
	2400	0.1
31	100	0.1
	700	0.1
	800	0.2
	900	0.1
	1400	0.1

Table 27. Precipitation (cm) at Treasure Mine – June 1998.

Date	Time	Precipitation
2	1800	0.2
	1900	0.2
	2100	0.1
	2300	0.1
3	300	0.2
	1100	0.1
	1200	0.1
	1300	0.1
	1400	0.2
	2000	0.2
6	1400	0.3
	1500	0.1
	1600	0.3
7	900	0.1
	1000	0.2
	1100	0.3
	1600	0.2
8	1100	0.1
	1400	0.2
10	1400	0.2
11	500	0.1
	1800	0.2
12	1100-1700	0.9
13	600	0.1
	1400	0.1
	1700	0.1
	2300	0.1
15	600	0.1
	1300	0.2
	1600	0.2
	1700	0.1

Table 27. Precipitation (cm) at Treasure Mine – June 1998. - Continued

Date	Time	Precipitation
16	800	0.1
	900	0.4
	1000	0.1
	1700	0.1
	1800	0.1
	1900	0.1
	2000	0.2
	2300	0.2
17	600	0.1
	700	0.2
	800	0.2
	900	0.2
	1700	0.1
18	1300	0.1
	1600	0.1
	1700	0.4
19	300	0.4
	900	0.1
	1000	0.1
	1200	0.1
	1300	0.1
	1400	0.1
20	900	0.1
	1300	0.1
22	1700	0.1
	1900	0.1
	2000	0.1
23	600	0.1
	700	0.1
	800	0.1
	1500	0.1

Table 27. Precipitation (cm) at Treasure Mine – June 1998. - Continued

Date	Time	Precipitation
25	1200	0.1
	1400	0.3
	1900	0.1
	2200	0.2
26	200	0.1
	1200	0.1
30	2200	0.1

Table 28. Precipitation (cm) at Treasure Mine – July 1998.

Date	Time	Precipitation
3	1600	0.1
4	1300	0.1
	1400	0.3
8	1700	0.2
11	300	0.1
	400	0.1
	500	0.1
	1200	0.5
	1300	0.5
	1800	0.1

Table 29. Precipitation (cm) at Treasure Mine – August 1998.

Date	Time	Precipitation
6	2000	0.2
15	1500	0.2
	1600	0.1
17	900	0.1
	1600	0.1
18	1700	0.1
20	1700	0.1
21	1900	0.1
23	900	0.1

Table 30. Precipitation (cm) at Treasure Mine - September 1998.

Date	Time	Precipitation
7	1800	0.3
8	1500	0.1
11	1100	0.1
12	900	0.1
	1400	0.1
	1500	0.1
	1700	0.1
17	1300	0.3
20	600	0.1
23	1100	0.1
25	1700	0.1
	1800	0.1
26	700	0.1

Table 31. Precipitation (cm) at Treasure Mine – May 1999.

Date	Time	Precipitation
1	400	0.3
	500	0.3
	600	0.3
	700	0.1
	800	0.1
	900	0.1
	1500	0.1
2	1200	0.1
	1600	0.1
	1700	0.3
	1800	0.1
	1900	0.1
	2100	0.2
3	700	0.1
	900	0.1
	1400	0.1
	1600	0.2
	1700	0.1
5	600	0.1
9	200	0.1
	800	0.1
	1300	0.1
	1500	0.1
	1700	0.3
	1800	0.1
	2200	0.2
10	600	0.1
	1500	0.1
	1900	0.1
11	600	0.1
12	1900	0.1

Table 31. Precipitation (cm) at Treasure Mine during May 1999 (cont).

Date	Time	Precipitation
13	900	0.1
	1500	0.1
	1800	0.1
	1900	0.3
	2000	0.4
	2100	0.2
	2200	0.1
14	600	0.2
	1600	0.1
	1700	0.2
15	1700	0.1
	1800	0.1
	2000	0.2
	2100	0.3
	2200	0.1
18	800	0.1
	1100	0.1
20	1600	0.1
29	500	0.1
	600	0.2
	700	0.4
	900	0.4
	1000	0.2
	1400	0.1
30	200	0.1
	300	0.3
	400	0.5
	500	0.3
	1400	0.1
	1900	0.1
	2000	0.2

Table 32. Precipitation (cm) at Treasure Mine – June 1999.

Date	Time	Precipitation
5	600	0.1
	800	0.1
	1400	0.3
	1500	0.2
	1700	0.3
	2100	0.1
6	900	0.2
	1300	0.2
7	200	0.1
8	900	0.1
	1000	0.1
	1100	0.5
	1800	0.2
16	1600	0.4
	1700	0.1
	2100	0.2
	2200	0.1
	2300	0.1
17	1000	0.1
18	1400	0.1
	1700	0.2
	1900	0.1
	2100	0.1
20	1900	0.2
21	1300	0.5
	1400	0.2
	1700	0.2
23	900	0.1
25	1400	0.1

Table 33. Precipitation (cm) at Treasure Mine – July 1999 .

Date	Time	Precipitation
2	1000	0.1

Table 34. Precipitation (cm) at Treasure Mine – August 1999.

Date	Time	Precipitation
6	300	0.1
	500	0.1
	600	0.1
	800	0.1
	1300	0.7
	1400	0.2
	1500	0.1
	1700	0.1
7	1200	0.1
11	800	0.1
	1100	0.5
	1500	0.1
	1800	0.1
12	100	0.1
13	200	0.1
	300	0.1
	400	0.1
14	100	0.1
	1300	0.1
20	700	0.2

Table 35. Evaporation (cm) at Treasure Mine – 1998 and 1999.

Dates	Evaporation
	1998
6/23-7/9	5.7
7/9 – 7/21	5.8
7/21 – 8/4	6.1
8/4 - 8/12	3.2
8/12 – 8/28	5.5
8/28 – 9/13	1.2
9/13 – 9/26	1.9
	1999
6/1 – 6/15	0.0*
6/15 – 7/2	2.2
7/2 – 7/21	6.2
7/21 - 8/11	4.5
8/11 – 8/28	5.1

*evaporation values not available due to snow conditions

APPENDIX C
SEDIMENT YIELD AND RUNOFF DATA

Table 36. Sediment Yields (kg) on test plots – 1998.

	Date								
Plot	6/5	6/23	7/9	7/21	8/4	8/12	8/28	9/13	9/26
25%, 0 cm	1.6	0.49	1.17	0.43	0.39	0.14	0.76	0.07	0.08
25%, 15 cm	0.47	0.83	1.19	1.32	0.83	0.9	2.77	0.38	0.06
25%, 30 cm	0.24	0.68	0.82	0.0*	10.10	1.10	18.0	0.55	0.20
25%, 45 cm	0.40	1.57	0.67	0.0*	2.90	0.98	8.44	0.12	0.14
33%, 0 cm	0.30	0.64	0.73	0.64	0.18	0.09	0.53	0.05	0.07
33%, 15 cm	0.19	8.39	39.74	52.2	7.17	0.24	9.07	0.10	0.14
33%, 30 cm	0.51	50.42	56.98	70.99	8.80	0.40	13.50	0.30	0.28
33%, 45 cm	0.23	9.98	55.12	30.12	4.67	0.19	5.49	0.24	0.15
40%, 0 cm	0.46	0.58	0.58	1.03	0.52	0.10	1.95	0.16	0.17
40%, 15 cm	0.34	6.26	110.2	98.1	49.36	0.54	31.6	0.54	0.29
40%, 30 cm	0.36	229.2	167.2	65.98	42.87	0.17	4.50	0.37	0.24
40%, 45 cm	0.18	92.15	109.1	63.11	39.74	0.51	30.38	0.22	0.18
50%, 0 cm	0.35	0.44	0.56	0.59	0.25	0.13	0.47	0.04	0.04
50%, 15 cm	0.04	0.69	45.98	30.24	23.37	0.36	22.50	0.29	0.11
50%, 30 cm	0.37	9.53	178.5	65.48	30.12	0.77	27.13	0.25	0.14
50%, 45 cm	0.77	2.77	179.6	85.86	32.62	0.82	15.62	0.28	0.17

* Data missing to due erosion at lip of trough.

Table 37. Sediment yield (kg) on test plots - 1999.

	Date						
Plot	5/18	6/1	6/15	7/2	7/21	8/11	8/27
25%, 0 cm	0.47	0.19	0.15	0.75	0.11	0.10	0.26
25%, 15 cm	1.29	0.28	0.13	0.82	0.18	0.14	0.25
25%, 30 cm	1.72	0.5	0.3	6.98	0.83	3.22	1.06
25%, 45 cm	1.41	0.48	0.26	2.86	1.20	1.54	1.18
33%, 0 cm	0.0*	0.35	0.39	0.83	0.29	0.59	0.34
33%, 15 cm	0.0*	0.57	0.27	6.03	0.46	2.60	0.90
33%, 30 cm	0.0*	1.60	0.34	12.65	0.70	4.54	0.96
33%, 45 cm	0.0*	0.71	0.27	3.86	0.36	1.17	0.75
40%, 0 cm	1.50	0.55	0.35	1.18	0.31	0.38	0.43
40%, 15 cm	9.90	0.35	0.30	6.21	0.62	1.76	1.63
40%, 30 cm	2.63	0.44	0.32	5.76	0.83	6.99	1.68
40%, 45 cm	1.08	0.31	0.30	1.15	0.38	3.76	1.20
50%, 0 cm	0.0*	1.10	0.30	0.72	0.15	0.21	0.33
50%, 15 cm	0.80	0.32	0.18	0.99	0.43	0.98	0.87
50%, 30 cm	0.92	0.23	0.15	1.01	0.35	7.00	0.95
50%, 45 cm	0.92	0.21	0.24	1.09	0.38	5.20	1.10

* Data not collected due to snow remaining in troughs.

Table 38. Depth (cm) of runoff in troughs at test plots – 1998.

	Date								
Plot	6/5	6/23	7/9	7/21	8/4	8/12	8/28	9/13	9/26
25%, 0 cm	19.1	31.0	0.0	0.0	4.8	0.0	0.0	3.0	2.5
25%, 15 cm	18.9	55.2	1.4	0.0	6.4	0.0	0.0	3.7	3.2
25%, 30 cm	18.73	18.4	22.5	23.7	12.4	0.0	3.6	2.9	2.4
25%, 45 cm	19.7	19.1	0.0	0.0	12.4	0.0	1.0	3.5	2.7
33%, 0 cm	18.3	20.3	0.0	0.0	5.1	0.0	0.0	3.8	3.3
33%, 15 cm	17.6	28.7	10.6	16.4	10.0	0.0	3.0	3.8	2.9
33%, 30 cm	18.7	18.4	22.5	23.7	12.4	0.0	3.6	2.9	2.4
33%, 45 cm	18.1	18.4	10.6	10.5	5.9	0.0	2.7	3.3	3.0
40%, 0 cm	17.8	17.1	0.0	0.0	1.9	0.0	0.0	3.2	3.3
40%, 15 cm	17.6	18.9	12.4	17.9	12.7	0.0	5.6	2.9	2.4
40%, 30 cm	17.8	19.1	23.2	27.6	15.9	0.0	7.1	3.5	2.5
40%, 45 cm	17.6	19.4	13.8	11.0	12.	0.0	7.0	3.1	2.5
50%, 0 cm	17.9	29.1	1.1	0.0	5.7	0.0	0.0	2.9	2.7
50%, 15 cm	17.6	57.8	5.4	6.8	6.5	0.0	2.5	3.3	2.4
50%, 30 cm	18.4	28.9	17.5	15.9	9.2	0.0	2.7	3.7	2.7
50%, 45 cm	17.8	22.2	18.1	20.5	7.5	0.0	2.9	3.5	3.5

Table 39. Depth (cm) of runoff in troughs at test plots – 1999.

Plot	Date						
	5/18	6/1	6/15	7/2	7/21	8/11	8/27
25%, 0 cm	*	11.1	5.4	0.6	0.0	3.2	0.0
25%, 15 cm	*	9.2	5.9	1.0	0.0	3.8	0.0
25%, 30 cm	*	10.2	10.2	5.7	0.0	9.4	0.0
25%, 45 cm	*	10.8	8.9	2.1	0.0	12.7	0.0
33%, 0 cm	*	*	6.2	2.4	0.0	5.7	0.0
33%, 15 cm	*	*	6.5	6.7	0.0	10.8	0.0
33%, 30 cm	*	*	7.9	10.0	0.0	12.7	0.0
33%, 45 cm	*	*	6.0	6.4	0.0	10.2	0.0
40%, 0 cm	*	10.3	22.9	1.0	0.0	4.1	0.0
40%, 15 cm	*	10.5	5.4	2.7	0.0	2.2	0.0
40%, 30 cm	*	9.5	5.1	6.0	0.0	14.6	0.0
40%, 45 cm	*	10.5	5.1	2.0	0.0	7.5	0.0
50%, 0 cm	*	*	5.6	1.6	0.0	4.3	0.0
50%, 15 cm	*	10.2	5.4	2.7	0.0	6.7	0.0
50%, 30 cm	*	10.3	5.7	0.9	0.0	9.0	0.0
50%, 45 cm	*	9.8	4.6	0.6	0.0	7.0	0.0

*troughs were full with snow melt

Table 40. Rill severity (class) on test plots – 1998.

Plot	Date 6/5	6/23	7/9	7/21	8/4	8/12	8/28	9/13	9/26
25%, 0 cm	1	1	1	1	1	1	1	1	1
25%, 15 cm	2	2	2	1	2	2	2	1	1
25%, 30 cm	1	1	2	2	3	3	3	2	2
25%, 45 cm	1	1	2	1	2	2	2	1	1
33%, 0 cm	1	1	1	1	1	1	1	1	1
33%, 15 cm	1	1	1	2	2	2	2	2	2
33%, 30 cm	2	2	2	2	3	3	3	2	2
33%, 45 cm	2	2	1	2	2	2	2	2	1
40%, 0 cm	1	1	1	1	1	1	1	1	1
40%, 15 cm	1	3	2	3	4	4	4	4	5
40%, 30 cm	1	3	3	3	4	4	4	4	5
40%, 45 cm	1	3	3	3	4	4	4	4	5
50%, 0 cm	1	1	1	1	1	1	1	1	1
50%, 15 cm	2	3	3	3	3	3	3	3	4
50%, 30 cm	2	3	3	3	4	4	4	4	4
50%, 45 cm	3	3	3	3	4	4	4	4	4

class: 1: stable 2: slight 3: moderate 4: critical 5: severe

Table 41. Rill severity (class) on test plots – 1999.

	Date						
Plot	5/18	6/1	6/15	7/2	7/21	8/11	8/27
25%, 0 cm	*	1	1	1	1	1	1
25%, 15 cm	*	1	1	1	1	2	1
25%, 30 cm	*	1	1	2	2	3	2
25%, 45 cm	*	1	1	1	1	2	1
33%, 0 cm	*	1	1	1	1	1	1
33%, 15 cm	*	1	2	2	2	2	3
33%, 30 cm	*	1	2	3	3	3	4
33%, 45 cm	*	1	1	2	2	2	3
40%, 0 cm	*	1	1	1	1	1	1
40%, 15 cm	*	4	4	4	4	4	4
40%, 30 cm	*	4	5	5	4	4	4
40%, 45 cm	*	4	4	4	3	4	4
50%, 0 cm	*	1	1	1	1	1	1
50%, 15 cm	*	3	2	2	3	3	3
50%, 30 cm	*	4	4	4	4	4	4
50%, 45 cm	*	4	4	4	3	4	4

*unable to rate rill severity due to snow present on plots

class: 1: stable 2: slight 3: moderate 4: critical 5: severe

APPENDIX D
VEGETATION DATA

Table 42. Seedling density (number of seedlings/400 cm^2) on test plots – 1998.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	28	36	41	21	18	25	48	35	75	39
25%, 15 cm	11	119	500	33	33	50	95	48	25	30
25%, 30 cm	17	45	15	42	46	49	35	51	50	28
25%, 45 cm	21	46	23	32	25	16	45	46	46	22
33%, 0 cm	37	10	64	54	20	43	37	42	13	14
33%, 15 cm	119	49	113	69	80	24	41	80	69	43
33%, 30 cm	98	44	26	70	52	68	61	96	66	43
33%, 45 cm	65	67	89	75	54	58	74	53	88	79
40%, 0 cm	6	22	16	13	18	29	77	58	55	15
40%, 15 cm	22	32	53	19	30	41	16	18	31	27
40%, 30 cm	8	62	28	16	43	20	22	6	43	36
40%, 45 cm	6	13	32	28	71	33	11	8	33	31
50%, 0 cm	16	12	7	22	16	18	5	13	15	14
50%, 15 cm	39	21	18	32	43	91	41	44	39	31
50%, 30 cm	29	25	39	25	100	35	52	52	58	39
50%, 45 cm	79	59	40	114	120	50	38	65	30	28

Table 43. Perennial grass canopy cover at test plots – 1998.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	2	1	2	2	2	2	1	1	1	2
25%, 15 cm	1	1	1	2	1	1	1	2	0	0
25%, 30 cm	1	1	2	1	1	2	1	3	1	2
25%, 45 cm	1	1	2	1	1	1	1	3	3	3
33%, 0 cm	1	1	2	1	0	1	1	2	1	1
33%, 15 cm	2	2	2	4	2	1	4	1	4	2
33%, 30 cm	2	2	1	2	3	3	3	3	2	3
33%, 45 cm	1	2	2	2	2	0	2	1	3	2
40%, 0 cm	1	1	1	1	0	1	2	1	1	1
40%, 15 cm	1	2	2	1	2	2	1	2	1	2
40%, 30 cm	2	2	2	1	2	2	3	2	0	1
40%, 45 cm	0	0	1	1	2	1	1	1	2	3
50%, 0 cm	1	1	1	2	2	2	2	3	2	1
50%, 15 cm	2	2	2	1	1	1	1	1	1	1
50%, 30 cm	1	1	3	1	1	1	1	2	2	1
50%, 45 cm	2	3	1	1	1	1	1	1	1	2

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 44. Forb canopy cover at test plots – 1998.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	1	1	1	1	1	1	1	1	1	1
25%, 15 cm	1	1	1	1	3	1	1	1	2	1
25%, 30 cm	1	1	1	1	1	1	1	1	1	1
25%, 45 cm	1	1	1	2	1	1	1	2	1	1
33%, 0 cm	0	1	0	0	1	0	0	1	1	1
33%, 15 cm	1	1	1	1	1	1	1	1	1	1
33%, 30 cm	1	1	1	1	1	1	1	1	1	1
33%, 45 cm	1	1	1	1	1	1	1	1	1	1
40%, 0 cm	1	1	1	1	1	1	1	1	1	1
40%, 15 cm	3	2	3	2	1	1	1	1	1	2
40%, 30 cm	5	3	1	1	3	2	1	3	1	1
40%, 45 cm	2	1	3	1	4	1	1	1	3	1
50%, 0 cm	1	0	0	1	1	1	1	1	0	1
50%, 15 cm	1	2	1	1	1	1	1	1	1	1
50%, 30 cm	3	1	1	2	1	1	1	1	1	2
50%, 45 cm	2	3	2	1	0	1	1	1	1	4

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 45. Annual grass canopy cover on test plots – 1998.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	0	2	0	2	0	0	2	1	1	1
25%, 15 cm	2	1	4	0	1	2	3	2	1	1
25%, 30 cm	1	1	0	0	2	1	1	1	3	3
25%, 45 cm	1	2	1	0	1	1	3	1	1	2
33%, 0 cm	0	0	1	1	1	0	1	0	0	0
33%, 15 cm	3	1	1	1	1	2	1	1	1	1
33%, 30 cm	1	0	1	1	3	1	1	1	2	1
33%, 45 cm	1	2	1	1	2	2	2	1	1	2
40%, 0 cm	1	1	1	1	1	2	1	3	4	2
40%, 15 cm	1	1	2	3	1	3	2	1	1	1
40%, 30 cm	1	0	2	1	0	2	1	2	3	2
40%, 45 cm	1	3	0	0	0	2	1	2	3	2
50%, 0 cm	0	1	1	0	0	1	0	1	0	0
50%, 15 cm	1	3	1	4	3	8	3	2	4	0
50%, 30 cm	1	0	1	1	4	2	3	3	2	1
50%, 45 cm	1	1	1	6	8	4	4	3	2	1

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 46. Perennial grass basal cover on test plots – 1998.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	1	1	1	1	1	1	1	1	1	1
25%, 15 cm	1	1	1	1	1	1	1	1	0	0
25%, 30 cm	1	1	1	1	1	1	1	2	1	1
25%, 45 cm	1	1	1	1	1	1	1	2	1	1
33%, 0 cm	1	1	1	1	0	1	1	2	1	1
33%, 15 cm	2	1	2	2	1	1	2	1	2	1
33%, 30 cm	1	1	1	1	2	2	1	2	1	2
33%, 45 cm	1	1	1	1	1	0	1	1	2	1
40%, 0 cm	1	1	1	1	0	1	2	1	1	1
40%, 15 cm	1	1	1	1	1	1	1	1	1	1
40%, 30 cm	1	1	1	1	1	1	1	1	0	1
40%, 45 cm	0	0	1	1	1	1	1	1	1	2
50%, 0 cm	1	1	1	1	1	1	1	1	1	1
50%, 15 cm	1	1	1	1	1	1	1	1	1	1
50%, 30 cm	1	1	1	1	1	1	1	1	1	1
50%, 45 cm	1	2	1	1	1	1	1	1	1	1

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 47. Forb basal cover on test plots – 1998.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	1	1	1	1	1	1	1	1	1	1
25%, 15 cm	1	1	1	1	1	1	1	1	1	1
25%, 30 cm	1	1	1	1	1	1	1	1	1	1
25%, 45 cm	1	1	1	1	1	1	1	1	1	1
33%, 0 cm	0	1	0	0	1	0	0	1	1	1
33%, 15 cm	1	1	1	1	1	1	1	1	1	1
33%, 30 cm	1	1	1	1	1	1	1	1	1	1
33%, 45 cm	1	1	1	1	1	1	1	1	1	1
40%, 0 cm	1	1	1	1	1	1	1	1	1	1
40%, 15 cm	2	1	2	1	1	1	1	1	1	2
40%, 30 cm	1	1	1	1	1	1	1	1	1	1
40%, 45 cm	1	1	1	1	1	1	1	1	1	1
50%, 0 cm	1	0	0	1	1	1	1	1	0	1
50%, 15 cm	1	1	1	1	1	1	1	1	1	1
50%, 30 cm	1	1	1	1	1	1	1	1	1	1
50%, 45 cm	1	2	1	1	0	1	1	1	1	2

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 48. Annual grass basal cover on test plots - 1998.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	0	1	0	1	0	0	1	1	1	1
25%, 15 cm	1	1	3	0	1	1	2	1	1	1
25%, 30 cm	1	1	0	0	1	1	1	1	2	2
25%, 45 cm	1	1	1	0	1	1	1	1	1	1
33%, 0 cm	0	0	1	1	1	0	1	0	0	0
33%, 15 cm	2	1	1	1	1	1	1	1	1	1
33%, 30 cm	1	0	1	1	2	1	1	1	1	1
33%, 45 cm	1	2	1	1	1	1	1	1	1	2
40%, 0 cm	1	1	1	1	1	1	1	2	2	1
40%, 15 cm	1	1	1	1	1	1	1	1	1	1
40%, 30 cm	1	0	1	1	0	1	1	1	2	1
40%, 45 cm	1	2	0	0	0	1	1	1	2	1
50%, 0 cm	0	1	1	0	0	1	0	1	0	0
50%, 15 cm	1	2	1	2	2	4	2	1	2	0
50%, 30 cm	1	0	1	1	2	1	3	2	1	1
50%, 45 cm	1	1	1	4	5	2	2	2	1	1

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 49. Rock cover on test plots – 1998.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	9	9	9	8	9	8	9	9	8	8
25%, 15 cm	6	5	5	4	4	5	4	4	4	7
25%, 30 cm	5	5	4	5	3	4	3	6	4	5
25%, 45 cm	4	4	4	5	5	6	4	4	5	5
33%, 0 cm	9	9	9	9	9	9	9	9	9	7
33%, 15 cm	5	4	5	4	5	6	5	6	6	6
33%, 30 cm	5	3	4	3	4	4	4	4	5	6
33%, 45 cm	5	3	4	6	6	5	3	4	3	3
40%, 0 cm	6	8	8	8	9	9	7	7	8	9
40%, 15 cm	3	3	3	5	5	4	3	4	6	4
40%, 30 cm	4	4	3	4	4	4	4	6	4	4
40%, 45 cm	3	3	4	4	3	4	3	4	3	2
50%, 0 cm	10	10	10	10	9	9	10	9	9	9
50%, 15 cm	6	4	4	4	4	6	4	3	6	4
50%, 30 cm	3	4	3	3	5	4	3	3	3	4
50%, 45 cm	3	2	2	2	2	3	3	2	2	1

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 50. Bare ground cover on test plots – 1998.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	1	1	1	2	1	2	2	1	2	2
25%, 15 cm	3	4	3	3	3	3	3	4	4	3
25%, 30 cm	5	4	5	4	4	3	4	3	3	3
25%, 45 cm	5	4	4	4	4	3	4	3	3	3
33%, 0 cm	1	1	1	1	1	1	1	1	2	4
33%, 15 cm	2	5	3	4	4	3	4	4	3	3
33%, 30 cm	3	5	4	5	3	4	3	3	4	3
33%, 45 cm	4	5	5	3	3	4	2	4	4	4
40%, 0 cm	5	2	2	3	1	1	3	3	3	2
40%, 15 cm	4	4	4	4	3	3	5	4	4	4
40%, 30 cm	4	4	5	5	5	4	3	3	3	4
40%, 45 cm	5	4	5	4	5	3	4	3	3	4
50%, 0 cm	1	1	1	1	2	2	1	1	1	1
50%, 15 cm	4	3	3	3	4	2	4	4	2	5
50%, 30 cm	4	3	4	4	3	4	4	4	4	3
50%, 45 cm	5	4	6	4	2	4	5	6	7	8

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 51. Perennial grass production (g) on test plots – 1998.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	0.42	1.15	0.50	0.10	0.25	0.20	0.10	0.25	0.05	0.45
25%, 15 cm	0.30	0.07	0.35	0.45	0.15	0.15	0.10	0.45	0.20	0.40
25%, 30 cm	0.20	0.10	0.25	0.35	0.10	0.10	0.20	0.50	0.30	0.10
25%, 45 cm	0.45	0.10	0.30	0.10	0.10	0.05	0.50	0.20	0.40	0.40
33%, 0 cm	0.07	0.05	0.35	0.10	0.00	0.10	0.05	0.08	0.05	0.15
33%, 15 cm	0.26	0.30	0.20	0.65	0.45	0.25	0.55	0.15	0.42	0.30
33%, 30 cm	0.40	0.15	0.10	0.23	0.30	0.45	0.45	0.30	0.25	0.47
33%, 45 cm	0.50	0.25	0.15	0.25	0.10	0.10	0.20	0.45	0.65	0.50
40%, 0 cm	0.15	0.25	0.10	0.15	0.10	0.25	0.20	0.10	0.15	0.05
40%, 15 cm	0.10	0.50	0.65	0.25	0.16	0.15	0.20	2.10	0.35	0.45
40%, 30 cm	0.28	0.20	0.45	0.35	0.20	0.15	0.75	0.00	1.05	0.15
40%, 45 cm	0.05	0.10	0.40	3.50	0.10	0.090	0.00	0.05	0.75	0.70
50%, 0 cm	0.20	0.39	0.40	0.15	0.20	0.25	0.43	0.05	0.05	0.14
50%, 15 cm	0.15	0.05	0.20	0.10	0.50	0.10	0.25	0.25	0.27	0.15
50%, 30 cm	0.45	0.30	0.70	0.50	0.05	0.05	0.03	0.27	0.15	0.10
50%, 45 cm	0.75	1.00	0.20	0.20	0.05	0.90	0.15	0.20	0.20	0.85

Table 52. Forb production (g) on test plots – 1998.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	0.04	0.05	0.05	0.00	0.15	0.13	0.10	0.02	0.10	0.30
25%, 15 cm	0.11	0.05	0.05	1.10	0.46	0.15	0.00	0.40	0.05	0.35
25%, 30 cm	0.05	0.10	0.25	0.30	0.35	0.05	0.15	0.05	0.00	0.10
25%, 45 cm	0.80	0.25	0.20	0.20	0.10	0.00	0.10	0.10	0.10	0.45
33%, 0 cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
33%, 15 cm	0.02	0.12	0.00	0.00	0.15	0.00	0.00	0.25	0.00	0.10
33%, 30 cm	0.10	0.02	0.02	0.15	0.20	0.00	0.14	0.15	0.10	0.01
33%, 45 cm	0.11	0.05	0.10	0.05	0.05	0.05	0.05	0.15	0.03	0.15
40%, 0 cm	0.00	0.10	0.00	0.00	0.05	0.05	0.00	0.00	0.05	0.00
40%, 15 cm	0.55	0.35	0.34	0.00	0.00	0.00	0.10	0.30	0.20	0.25
40%, 30 cm	1.50	0.50	1.20	0.70	0.45	1.05	0.10	0.70	0.10	0.20
40%, 45 cm	0.00	0.30	0.25	0.23	0.30	0.02	0.41	0.30	0.10	0.00
50%, 0 cm	0.10	0.00	0.05	0.00	0.08	0.00	0.00	0.00	0.00	0.00
50%, 15 cm	0.12	0.35	0.35	0.15	0.0	0.10	0.00	0.10	0.03	0.02
50%, 30 cm	1.25	0.55	0.00	0.20	0.02	0.20	0.15	0.25	0.09	0.20
50%, 45 cm	0.90	0.45	0.95	0.15	0.15	0.05	0.40	0.05	0.20	2.90

Table 53. Annual grass production (g) on test plots –1998..

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	0.00	0.00	0.00	0.65	0.00	0.00	0.95	0.65	0.85	0.00
25%, 15 cm	1.35	0.35	1.65	2.00	0.75	0.30	1.10	0.25	1.70	2.34
25%, 30 cm	0.00	0.70	0.00	0.10	0.10	0.15	0.90	1.10	6.00	3.05
25%, 45 cm	0.00	0.50	0.10	0.00	0.15	0.27	0.75	0.90	1.25	0.0
33%, 0 cm	0.00	0.00	0.50	0.65	0.10	0.00	0.25	0.00	0.00	0.00
33%, 15 cm	0.50	0.30	0.40	0.00	1.10	2.18	2.05	1.91	1.60	1.10
33%, 30 cm	0.00	0.00	0.50	0.00	1.35	0.35	0.00	0.13	0.00	1.40
33%, 45 cm	1.30	1.45	0.00	0.95	3.90	1.60	3.20	0.80	0.70	1.25
40%, 0 cm	0.00	0.38	0.25	0.20	0.95	0.95	0.40	1.70	1.10	0.95
40%, 15 cm	0.25	0.00	2.00	1.30	1.60	3.50	1.05	0.40	2.15	1.45
40%, 30 cm	0.00	0.55	0.50	0.45	0.60	0.00	2.10	1.35	0.80	2.95
40%, 45 cm	3.10	1.90	0.00	0.00	0.25	1.70	1.45	2.20	0.67	0.95
50%, 0 cm	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.45	1.30	0.00
50%, 15 cm	0.75	0.60	0.55	3.20	1.60	3.10	0.46	1.35	1.050	2.67
50%, 30 cm	0.40	0.0	0.00	1.45	3.75	0.60	1.30	1.10	2.40	0.80
50%, 45 cm	1.85	0.25	2.10	5.95	3.75	4.00	1.85	2.05	1.25	0.85

Table 54. Perennial grass canopy cover on test plots – 1999.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	1	1	1	1	1	1	1	1	1	1
25%, 15 cm	1	2	1	1	1	1	2	1	1	3
25%, 30 cm1	2	2	2	1	1	2	1	1	1	1
25%, 45 cm	1	1	1	1	1	2	1	2	2	1
33%, 0 cm	1	1	1	1	1	1	1	1	1	1
33%, 15 cm	2	1	2	2	1	1	2	1	2	1
33%, 30 cm	1	1	2	2	1	1	1	1	1	1
33%, 45 cm	1	2	1	2	0	3	2	2	2	2
40%, 0 cm	1	1	1	1	1	1	1	1	1	1
40%, 15 cm	1	1	1	1	1	2	1	1	1	1
40%, 30 cm	1	1	1	2	1	1	1	1	2	2
40%, 45 cm	1	2	1	1	3	1	3	1	1	4
50%, 0 cm	1	1	2	1	2	1	8	3	1	1
50%, 15 cm	3	4	2	2	1	3	1	3	1	4
50%, 30 cm	2	1	1	4	1	3	2	4	3	4
50%, 45 cm	3	1	1	1	3	3	1	1	3	3

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 55. Forb canopy cover on test plots – 1999.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	1	1	1	1	1	1	1	1	1	1
25%, 15 cm	1	1	1	1	1	1	1	1	1	1
25%, 30 cm	1	1	1	1	1	1	1	1	1	1
25%, 45 cm	1	2	1	1	1	1	1	1	1	1
33%, 0 cm	1	1	1	1	1	1	1	1	1	1
33%, 15 cm	1	1	1	1	1	1	1	1	1	1
33%, 30 cm	1	1	1	1	1	1	1	1	1	1
33%, 45 cm	1	1	1	1	1	1	1	1	1	1
40%, 0 cm	1	1	1	1	1	1	1	1	1	1
40%, 15 cm	1	2	1	1	1	1	1	1	1	1
40%, 30 cm	1	1	1	1	1	1	1	1	1	1
40%, 45 cm	1	1	2	1	1	1	2	1	1	1
50%, 0 cm	1	1	1	1	1	1	3	1	1	1
50%, 15 cm	1	2	1	1	2	2	3	1	1	1
50%, 30 cm	1	2	2	2	2	1	1	1	1	2
50%, 45 cm	2	5	3	2	2	2	1	2	1	1

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 56. Perennial grass basal cover on test plots – 1999.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	1	1	1	1	1	1	1	1	1	1
25%, 15 cm	1	1	1	1	1	1	1	1	1	2
25%, 30 cm	1	1	1	1	1	1	2	1	1	1
25%, 45 cm	1	1	1	1	1	1	1	2	2	1
33%, 0 cm	1	1	1	1	1	1	1	1	1	1
33%, 15 cm	1	1	1	1	1	1	1	1	1	1
33%, 30 cm	1	1	1	2	1	1	1	1	1	1
33%, 45 cm	1	2	1	2	2	1	1	1	1	1
40%, 0 cm	1	1	1	1	1	1	1	1	1	1
40%, 15 cm	1	1	1	1	1	1	1	1	1	1
40%, 30 cm	1	1	1	1	1	1	1	1	2	1
40%, 45 cm	1	1	1	1	2	1	2	1	1	4
50%, 0 cm	1	1	1	1	1	1	5	3	1	1
50%, 15 cm	2	3	1	1	1	2	1	2	1	3
50%, 30 cm	1	1	1	3	1	2	1	2	2	3
50%, 45 cm	2	1	1	1	2	2	1	1	2	2

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 57. Forb basal cover on test plots - 1999.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	1	1	1	1	1	1	1	1	1	1
25%, 15 cm	1	1	1	1	1	1	1	1	1	1
25%, 30 cm	1	1	1	1	1	1	1	1	1	1
25%, 45 cm	1	1	1	1	1	1	1	1	1	1
33%, 0 cm	1	1	1	1	1	1	1	1	1	1
33%, 15 cm	1	1	1	1	1	1	1	1	1	1
33%, 30 cm	1	1	1	1	1	1	1	1	1	1
33%, 45 cm	1	1	1	1	1	1	1	1	1	1
40%, 0 cm	1	1	1	1	1	1	1	1	1	1
40%, 15 cm	1	1	1	1	1	1	1	1	1	1
40%, 30 cm	1	1	1	1	1	1	1	1	1	1
40%, 45 cm	1	1	2	1	1	1	2	1	1	1
50%, 0 cm	1	2	1	1	2	2	1	1	1	1
50%, 15 cm	1	1	1	1	2	1	1	1	1	1
50%, 30 cm	1	1	1	1	2	1	1	1	1	1
50%, 45 cm	2	2	1	1	1	1	1	1	1	1

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 58. Vegetative litter cover on test plots – 1999.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	1	1	1	1	1	1	1	1	1	1
25%, 15 cm	1	1	1	1	1	1	1	1	1	1
25%, 30 cm	1	1	1	1	1	1	1	1	2	1
25%, 45 cm	1	1	2	1	1	1	1	1	1	1
33%, 0 cm	1	1	1	1	1	1	1	1	1	1
33%, 15 cm	1	1	1	1	1	1	1	1	1	1
33%, 30 cm	1	1	1	1	1	1	1	1	1	1
33%, 45 cm	1	1	1	1	1	1	1	1	1	1
40%, 0 cm	1	1	1	1	1	1	1	2	1	1
40%, 15 cm	1	1	1	1	1	3	1	1	2	2
40%, 30 cm	1	1	1	1	1	1	1	1	1	2
40%, 45 cm	1	1	1	1	1	1	1	1	1	2
50%, 0 cm	1	2	1	1	2	2	1	1	1	1
50%, 15 cm	1	1	1	5	2	3	3	1	1	1
50%, 30 cm	1	2	1	1	1	1	1	1	1	2
50%, 45 cm	1	7	2	1	2	1	3	1	1	1

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 59 Rock cover on test plots – 1999.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	9	9	9	9	9	9	10	10	10	10
25%, 15 cm	6	4	3	3	3	3	3	4	3	2
25%, 30 cm	3	4	4	5	7	4	4	5	3	4
25%, 45 cm	4	3	4	7	5	4	5	2	5	5
33%, 0 cm	10	9	9	10	10	10	10	10	10	9
33%, 15 cm	3	4	4	3	3	4	2	3	4	4
33%, 30 cm	4	4	3	2	3	4	4	4	5	5
33%, 45 cm	5	4	5	5	3	5	4	5	3	3
40%, 0 cm	7	8	9	8	10	9	9	8	9	7
40%, 15 cm	4	5	4	4	4	2	5	3	3	2
40%, 30 cm	2	2	4	4	2	1	1	5	4	3
40%, 45 cm	2	3	2	4	3	4	5	5	2	3
50%, 0 cm	9	9	8	8	7	7	4	7	6	9
50%, 15 cm	6	6	4	3	5	3	3	5	6	5
50%, 30 cm	4	3	5	3	3	3	4	5	4	4
50%, 45 cm	3	2	3	3	3	4	4	3	2	3

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 60. Bare ground cover on test plots – 1999.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	2	2	2	2	2	2	1	1	1	1
25%, 15 cm	4	6	6	6	6	6	6	5	6	5
25%, 30 cm	7	5	5	5	3	5	4	4	5	6
25%, 45 cm	5	5	5	3	5	5	5	6	4	5
33%, 0 cm	1	2	2	1	1	1	1	1	1	2
33%, 15 cm	7	6	6	6	6	5	6	6	4	5
33%, 30 cm	4	4	5	5	6	5	5	5	3	3
33%, 45 cm	3	5	4	4	7	4	5	4	5	5
40%, 0 cm	3	2	2	2	1	1	1	2	1	2
40%, 15 cm	5	4	5	6	5	2	5	8	6	7
40%, 30 cm	7	7	6	5	7	7	7	4	5	5
40%, 45 cm	6	4	2	4	2	4	3	3	3	2
50%, 0 cm	1	1	1	2	2	2	1	2	3	1
50%, 15 cm	3	3	3	1	3	2	3	3	3	3
50%, 30 cm	5	4	4	4	4	5	4	3	4	3
50%, 45 cm	2	1	3	4	4	3	2	4	5	5

Cover class 1: 0 – 10% 2: 11-20% 3: 21-30% 4: 31-40% 5: 41-50%
6: 51-60% 7: 61-70% 8: 71-80% 9: 81-90% 10: 91-100%

Table 61. Perennial grass production (g) on test plots – 1999.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	0.97	0.25	0.58	0.44	1.14	0.05	0.77	2.19	0.48	2.12
25%, 15 cm	1.20	0.70	0.49	0.51	0.55	0.74	0.59	0.47	0.55	0.53
25%, 30 cm	1.22	0.83	0.60	0.80	0.71	0.29	0.60	1.47	0.47	0.84
25%, 45 cm	2.24	0.80	0.94	0.49	0.97	1.37	1.22	2.25	1.66	0.70
33%, 0 cm	0.08	0.09	0.28	0.25	0.00	0.30	0.07	0.24	0.39	0.39
33%, 15 cm	2.79	0.62	0.39	2.08	1.49	0.94	1.15	0.10	2.46	0.57
33%, 30 cm	0.73	0.70	0.59	0.87	1.35	0.48	0.85	0.49	0.89	1.37
33%, 45 cm	1.68	0.59	1.06	1.07	0.42	0.74	0.52	0.74	0.82	1.13
40%, 0 cm	0.20	0.11	0.77	0.99	0.41	1.28	0.46	0.45	1.32	0.28
40%, 15 cm	2.31	1.54	1.19	0.62	0.41	1.48	1.19	0.68	054	0.47
40%, 30 cm	1.27	0.57	1.39	0.97	1.34	0.83	2.04	0.55	0.26	1.19
40%, 45 cm	1.27	1.94	0.42	1.14	1.61	1.79	1.19	1.47	1.20	2.84
50%, 0 cm	0.44	0.47	0.47	0.77	0.19	0.78	1.87	1.13	0.95	0.35
50%, 15 cm	0.65	0.92	0.50	1.18	0.55	0.49	0.54	0.54	0.46	1.59
50%, 30 cm	0.69	0.78	1.32	2.48	0.57	1.29	1.83	1.57	0.87	1.28
50%, 45 cm	1.64	0.53	0.95	1.41	1.77	0.71	1.34	1.49	2.81	0.66

Table 62. Forb production (g) on test plots – 1999.

	Frame #									
Plot	1	2	3	4	5	6	7	8	9	10
25%, 0 cm	0.00	0.45	0.17	0.32	0.45	0.32	0.51	0.07	0.33	0.31
25%, 15 cm	0.18	0.09	0.51	0.210	0.44	0.31	0.15	0.44	0.09	0.26
25%, 30 cm	0.14	0.27	0.15	0.16	0.43	0.28	0.91	0.99	0.66	0.13
25%, 45 cm	0.76	0.65	0.69	0.26	0.67	0.36	0.40	0.29	0.37	0.60
33%, 0 cm	0.00	0.14	0.05	0.09	0.00	0.07	0.06	0.08	0.13	0.10
33%, 15 cm	0.13	0.42	0.08	0.33	0.30	0.57	0.19	1.18	0.73	0.43
33%, 30 cm	0.23	0.50	0.21	0.62	0.51	0.35	0.64	0.16	0.25	0.05
33%, 45 cm	0.06	0.34	0.08	0.06	0.11	0.32	0.11	0.58	0.09	0.15
40%, 0 cm	0.08	0.10	0.11	0.16	0.13	0.33	0.25	0.11	0.07	0.08
40%, 15 cm	0.13	0.56	0.35	0.12	0.24	0.36	0.18	0.30	0.48	0.44
40%, 30 cm	0.47	0.32	1.95	0.28	0.34	0.21	0.22	0.36	0.57	0.52
40%, 45 cm	0.21	0.63	0.21	0.35	0.27	0.44	0.27	0.82	0.10	0.28
50%, 0 cm	0.14	0.00	0.13	0.00	0.09	0.11	0.25	0.00	0.00	0.00
50%, 15 cm	0.07	0.23	0.23	0.45	0.24	0.04	0.05	0.18	0.04	0.86
50%, 30 cm	0.53	0.27	0.67	0.19	0.18	0.17	0.33	0.11	0.05	0.13
50%, 45 cm	0.41	0.23	0.18	0.34	0.80	0.34	0.28	0.40	0.62	0.81

APPENDIX E
STATISTICAL DATA ANALYSIS

Table 63. Correlation analysis for soil loss vs. precipitation amounts – 1998.

	Total Precipitation	Maximum Daily Precipitation	Maximum Hourly Precipitation
Correlation Coefficient	-0.03	-0.20	-0.19
P Value	0.942	0.630	0.661
Number of Samples	8	8	8

Table 64. Correlation analysis for soil loss vs. precipitation amounts – 1999.

	Total Precipitation	Maximum Daily Precipitation	Maximum Hourly Precipitation
Correlation Coefficient	0.26	0.22	0.46
P Value	0.626	0.671	0.355
Number of Samples	6	6	6

Table 65. Canonical correlation analysis – 1998

Sediment and Runoff Yields	2
Factors Influencing Yields	7
Observations	16

Means and Standard Deviations

Variable	Mean	Standard Deviation
erosion	16.3798	17.9261
runoff	142.9918	88.7285
gradient	37.0000	9.4938
thick	22.5000	17.3205
product	7.1856	0.7696
canopy	42.5000	9.8725
basal	30.6250	5.8409
rock	0.0221	0.0086
rills	2.1937	1.0069

Correlations Among the Sediment and Runoff Yields

	erosion	runoff
erosion	1.0000	0.7786
runoff	0.7786	1.0000

Correlations Among the Factors Influencing Yields

	gradient	thick	product	canopy	basal	rock	rills
gradient	1.000	0.000	0.244	0.363	0.457	-0.348	0.521
thick	0.000	1.000	0.655	0.585	0.484	-0.789	0.576
product	0.244	0.655	1.000	0.792	0.666	-0.779	0.779
canopy	0.363	0.585	0.792	1.000	0.883	-0.809	0.799
basal	0.247	0.484	0.666	0.883	1.000	-0.718	0.565
rock	-0.348	-0.789	-0.779	-0.809	-0.718	1.000	0.829
rills	0.521	0.576	0.779	0.799	0.565	-0.829	1.000

Table 65. Canonical correlation analysis – 1998 - Continued

Correlations Between the Sediment and Runoff Yields and the Factors Influencing Yields

	gradient	thick	product	canopy	basal	rock	rills
erosion	0.464	0.491	0.615	0.681	0.336	-0.659	0.878
runoff	0.153	0.396	0.282	0.504	0.274	-0.402	0.560

Canonical Correlation Analysis

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	0.964105	0.949041	0.018203	0.929499
2	0.637813	0.498819	0.153162	0.406805

Eigenvalues of Inv(E)*H = CanRsq/(1-CanRsq)

	Eigenvalue	Difference	Proportion	Cumulative
1	13.1842	12.4984	0.9506	0.9506
2	0.6858	0.0494	1.0000	

Test of H0: The canonical correlations in the current row and all that follow are zero

	Likelihood Ratio	Approximate F Value	Num DF	Den DF	Pr > F
1	0.04182071	3.89	14	14	0.0080
2	0.59319479	0.91	6	8	0.5302

Table 65. Canonical correlation analysis – 1998 - Continued

Multivariate Statistics and F Approximations

S=2 M=2 N=2.5

Statistic	Value	F Value	Num DF	Den DF	Pr > F
Wilks' Lambda	0.04182	3.89	4	14	0.0080
Pillai's Trace	1.3363	2.30	14	16	0.0562
Hotelling-Lawley Trace	13.8700	6.51	14	8.36	0.0051
Roy's Greatest Root	13.1842	15.07	7	8	0.0005

NOTE: F Statistic for Roy's Greatest Root is an upper bound.
NOTE: F Statistic for Wilks' Lambda is exact.

Standardized Canonical Coefficients for the Sediment and Runoff Yields

	yield1	yield2
erosion	1.3086	-0.9094
runoff	-0.4482	1.5292

Standardized Canonical Coefficients for the Factors Influencing Yields

	factor1	factor2
gradient	0.1122	-0.5077
thick	-0.1142	0.8268
product	0.1412	-1.5106
canopy	0.8627	0.8936
basal	-0.9269	0.3082
rock	0.2143	-1.1440
rills	0.4845	1.1162

Table 65. Canonical correlation analysis – 1998 - Continued

Canonical Structure

Correlations Between the Sediment and Runoff Yields and Their Canonical Variables

	yield1	yield2
erosion	0.9596	0.2812
runoff	0.5707	0.8212

Correlations Between the Factors Influencing Yields and Their Canonical Variables

	factor1	factor2
gradient	0.5582	-0.2936
thick	0.4820	0.2499
product	0.7040	-0.2014
canopy	0.6905	0.2359
basal	0.3291	0.1764
rock	0.7072	0.0245
rills	0.9307	0.0921

Correlations B/t Sediment & Runoff Ylds & Canonical Var. of Factors Influencing Ylds

	factor1	factor2
erosion	0.9252	0.1794
runoff	0.5502	0.5238

Correlations B/t Factors Influencing Ylds & Canonical Var of Sediment & Runoff Ylds

	yield1	yield2
gradient	0.5381	-0.1873
thick	0.4647	0.1594
product	0.6787	-0.1285
canopy	0.6657	0.1505
basal	0.3173	0.1125
rock	0.6818	0.0156
rills	0.8973	0.0588

Table 65. Canonical correlation analysis – 1998 - Continued

Canonical Redundancy Analysis

Standardized Variance of the Sediment and Runoff Yields Explained by

Canonical Variable Number	Their Own Canonical Variables Proportion	Cumulative Proportion	Canonical R-Square	The Opposite Canonical Variables Proportion	Cumulative Proportion
1	0.6233	0.6233	0.9295	0.5794	0.5794
2	0.3767	1.0000	0.4068	0.1532	0.7326

Standardized Variance of the Factors Influencing Yields Explained by

Canonical Variable Number	Their Own Canonical Variables Proportion	Cumulative Proportion	Canonical R-Square	The Opposite Canonical Variables Proportion	Cumulative Proportion
1	0.4273	0.4273	0.9295	0.3971	0.3971
2	0.0407	0.4680	0.4068	0.0166	0.4137

Squared Multiple Correlations Between the Sediment and Runoff Yields and the First M Canonical Variables of the Factors Influencing Yields

M	1	2
erosion	0.8560	0.8882
runoff	0.3027	0.5770

Squared Multiple Correlations Between the Factors Influencing Yields and the First M Canonical Variables of the Sediment and Runoff Yields

M	1	2
gradient	0.2896	0.3246
thick	0.2159	0.2413
product	0.4606	0.4771
canopy	0.4431	0.4658
basal	0.1007	0.1133
rock	0.4649	0.4652
rills	0.8051	0.8086

Table 66. Canonical correlation analysis – 1999

Sediment and Runoff Yields	2
Factors Influencing Yields	7
Observations	16

Means and Standard Deviations

Variable	Mean	Standard Deviation
erosion	1.0068	0.6867
runoff	46.4050	14.1903
gradient	37.0000	9.4938
thick	22.5000	17.3205
product	1247.7500	438.1931
canopy	0.03891	0.0084
basal	22.8125	3.1668
rock	0.0235	0.0079
rills	2.3312	1.2742

Correlations Among the Sediment and Runoff Yields

	erosion	runoff
erosion	1.0000	0.8125
runoff	0.8125	1.0000

Correlations Among the Factors Influencing Yields

	gradient	thick	product	canopy	basal	rock	rills
gradient	1.000	0.000	0.076	0.686	0.747	-0.136	0.5313
thick	0.000	1.000	0.698	0.493	0.355	-0.696	0.5143
product	0.076	0.698	1.000	0.379	0.267	-0.701	0.609
canopy	0.686	0.493	0.379	1.000	0.923	0.416	-0.462
basal	0.747	0.356	0.267	0.923	1.000	0.192	0.396
rock	-0.136	-0.696	0.701	0.416	0.192	1.000	0.757
rills	0.531	0.514	0.609	0.462	0.396	0.757	1.000

Table 66. Canonical correlation analysis – 1999 - Continued

Correlations Between the Sediment and Runoff Yields and the Factors Influencing Yields

	gradient	thick	product	canopy	basal	rock	rills
erosion	-0.001	0.399	0.442	0.067	-0.223	-0.606	0.646
runoff	-0.285	0.581	0.557	0.100	-0.252	-0.551	0.434

Canonical Correlation Analysis

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	0.8625	0.7890	0.0660	0.7440
2	0.7203	0.6468	0.1242	0.5189

Eigenvalues of Inv(E)*H = CanRsq/(1-CanRsq)

	Eigenvalue	Difference	Proportion	Cumulative
1	2.9067	1.8280	0.7293	0.7293
2	1.0787	0.2707	1.0000	

Test of H0: The canonical correlations in the current row and all that follow are zero

	Likelihood Ratio	Approximate F Value	Num DF	Den DF	Pr > F
1	0.1231	1.85	14	14	0.1310
2	0.4810	1.44	6	8	0.3090

Table 66. Canonical correlation analysis – 1999 - Continued

Multivariate Statistics and F Approximations

S=2 M=2 N=2.5

Statistic	Value	F Value	Num DF	Den DF	Pr > F
Wilks' Lambda	0.1231	1.85	14	14	0.0310
Pillai's Trace	1.2629	1.96	14	16	0.0991
Hotelling-Lawley Trace	3.9853	1.87	14	8.36	0.1824
Roy's Greatest Root	2.9067	3.32	7	8	0.0571

NOTE: F Statistic for Roy's Greatest Root is an upper bound.
NOTE: F Statistic for Wilks' Lambda is exact.

Canonical Correlation Analysis
Standardized Canonical Coefficients for the Sediment and Runoff Yields

	yield1	yield2
erosion	0.8345	-1.4988
runoff	0.1956	1.7043

Standardized Canonical Coefficients for the Factors Influencing Yields

	factor1	factor2
gradient	0.0874	-0.5289
thick	0.4162	0.6249
product	0.0409	0.4631
canopy	-0.4355	0.2681
basal	-1.2103	0.4082
rock	-0.2583	-0.2306
rills	0.9118	-0.5030

Table 66. Canonical correlation analysis – 1999 - Continued

Canonical Structure

Correlations Between the Sediment and Runoff Yields and Their Canonical Variables

	yield1	yield2
erosion	0.9935	-0.1140
runoff	0.8737	0.4865

Correlations Between the Factors Influencing Yields and Their Canonical Variables

	factor1	factor2
gradient	-0.0659	-0.6712
thick	0.5184	0.5418
product	0.5541	0.3982
canopy	0.0873	0.0989
basal	-0.2723	-0.1322
rock	0.7107	0.0430
rills	0.7231	-0.3169

Correlations B/t Sediment & Runoff Ylds & Canonical Var of Factors Influencing Ylds

	factor1	factor2
erosion	0.8569	-0.0821
runoff	0.7536	0.3504

Correlations B/t Factors Influencing Ylds &Canonical Var of Sediment & Runoff Ylds

	yield1	yield2
gradient	-0.0568	-0.4835
thick	0.4472	0.3903
product	0.4780	0.2868
canopy	0.0753	0.0712
basal	-0.2349	-0.0952
rock	0.6131	0.0310
rills	0.6237	-0.2283

Table 66. Canonical correlation analysis – 1999 - Continued

Canonical Redundancy Analysis

Standardized Variance of the Sediment and Runoff Yields Explained by

Canonical Variable Number	Their Own Canonical Variables			The Opposite Canonical Variables	
	Proportion	Cumulative Proportion	Canonical R-Square	Proportion	Cumulative Proportion
1	0.8752	0.8752	0.7440	0.6511	0.6511
2	0.1248	1.0000	0.5189	0.0648	0.7159

Standardized Variance of the Factors Influencing Yields Explained by

Canonical Variable Number	Their Own Canonical Variables			The Opposite Canonical Variables	
	Proportion	Cumulative Proportion	Canonical R-Square	Proportion	Cumulative Proportion
1	0.2414	0.2414	0.7440	0.1796	0.1796
2	0.1474	0.3889	0.5189	0.0765	0.2561

Squared Multiple Correlations Between the Sediment and Runoff Yields and the First M Canonical Variables of the Factors Influencing Yields

M	1	2
erosion	0.7344	0.7411
runoff	0.5679	0.6908

Squared Multiple Correlations Between the Factors Influencing Yields and the First M Canonical Variables of the Sediment and Runoff Yields

M	1	2
gradient	0.0032	0.2370
thick	0.2000	0.3523
product	0.2285	0.3107
canopy	0.0057	0.0107
basal	0.0552	0.0642
rock	0.3758	0.3768
rills	0.3890	0.4412