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Modeling Soil Loss to Determine Water Erosion Risk at Camp Williams National Guard Base, Utah

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MODELING SOIL LOSS TO DETERMINE WATER EROSION RISK AT CAMP WILLIAMS NATIONAL GUARD BASE, UTAH

by

Kevin P. Bartsch

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Watershed Science

UTAH STATE UNIVERSITY
Logan, Utah

1998

ABSTRACT

Modeling Soil Loss to Determine Water Erosion Risk
at Camp Williams National Guard Base, Utah

by

Kevin P. Bartsch, Master of Science
Utah State University, 1998

Major Professor: Dr. Helga Van Miegroet
Watershed Science Unit

Soil erosion was assessed at Camp Williams National Guard Base by creating an erosion risk classification map and comparing the erosion impact of disturbance regimes on different hillslopes. Soil erosion does not appear to be a problem for most of Camp Williams.

The Revised Universal Soil Loss Equation was applied using GIS to create a soil erosion risk map for the entire Camp Williams facility. The map indicated where problem areas occurred and showed relative erosion risk, but its lack of quantitative accuracy should be noted. Areas of concern included landscapes with little or no protective vegetation such as roads, abandoned agricultural fields, and sensitive riparian areas where gullies tend to form and expand.

The Water Erosion Prediction Project model was used to evaluate the erosion impacts of various disturbances on five study hillslopes. The model did not appear to function well on the Camp Williams study hillslopes because the distribution of infiltration rates could not be satisfactorily represented. However, hydraulic conductivity measurements collected for this task were useful in providing insight into some of the physical processes of erosion. The hydraulic conductivity measurements showed some of the impacts of military activities, grazing, and wildfire on soil properties.

Erosion bridges were also used on the five study hillslopes in an attempt to measure soil loss and deposition. However, the bridges lacked the capability of measuring the low rates of erosion during the time period set for this experiment. The bridges showed potential for measuring erosion in rills, gullies, highly disturbed areas, or in longer duration experiments.

(122 pages)

DEDICATION

I would like to dedicate this thesis and my work at Utah State University to my late grandparents. My accomplishments are a tribute to them for their contribution to my personality, disposition, and intellect, all of which are the essence of my ability to earn a graduate degree. My grandfather, Gustave Bartsch, passed to me a mathematical inclination and the ability to analyze. My grandmother, Lillian (Laporte) Bartsch, taught me my social and communication skills. My grandmother, Marie (Dostie) Racine, gave me my exceptional organizational skills and articulate nature. And from my grandfather, Armand Racine, I inherited the character to pull it altogether.

I also dedicate this thesis to my father, Albert J. Bartsch, who died shortly before I finished my master's degree.

ACKNOWLEDGMENTS

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Kevin P. Bartsch

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CHAPTER I

INTRODUCTION

Justification for Research

Camp Williams is an Army National Guard training facility located in northern Utah. An ongoing effort to address ecological concerns at Camp Williams has spawned research to determine effects of military activities on the environment. Research is required to ascertain: (1) what areas are sensitive to military and other activities allowed on the base; (2) which activities degrade the landscape; and (3) what actions can be taken to lessen the effects of degrading activities.

The project discussed in this thesis addressed soil erosion at Camp Williams. The objective was to characterize water erosion at Camp Williams with the use of soil erosion models and physical measurements of soil erosion. The research was aimed at determining which areas are most sensitive to erosion and assessing the influence of base activities on soil erosion. The scope of this project was limited to the erosion processes that are mediated by water.

Ultimately, this research provides Camp Williams and the National Guard with comprehensive tools to make informed environmental management decisions. Military activities and natural rangeland habitats are not unique to Camp Williams. The research from this project provides innovative approaches for studying soil erosion in other areas with similar conditions. One contribution from this research is a method for applying soil erosion models to large areas. Another is an increased understanding of how military activities impact rangeland areas and affect soil erosion.

Objective and Approach

The objective of this project was to assess the water erosion sensitivity at Camp Williams. This objective was accomplished through the following tasks: (1) creation of a Geographic Information System (GIS) coverage of soil erosion risk for the entire facility based on the Revised Universal Soil Loss Equation (RUSLE); (2) application of the Water Erosion Prediction Project (WEPP) model to five study hillslopes to compare the effects of different disturbance regimes; and (3) physical measurement of soil erosion on the five study hillslopes using erosion bridges.

The first task of creating an erosion risk map for the entire facility was done in GIS with the application of the RUSLE (Renard et al., 1996). The RUSLE and grid GIS are very compatible due to the simplicity of the soil loss equation and the ability to create compatible grid coverages within GIS. These grid coverages were simply multiplied together to determine annual soil loss. However, the objective was not to predict soil loss but rather assess the relative soil erosion risk. Erosion risk was broken down into classes based on soil loss estimates as determined by the RUSLE. This part of the project indicated areas on the base that are the most sensitive to disruptive activities that increase soil erosion potential.

The second task of comparing disturbance regimes was accomplished with the WEPP model. The complexity and data-intensive nature of WEPP limits its use to only a few well defined hillslopes. Five study hillslopes were chosen based on disturbance by military activities, grazing, and fire. They were divided into two sets with similar characteristics for vegetation cover type, aspect, and slope. One set of three hillslopes included a military-impacted hillslope, a grazing-impacted hillslope, and a less-impacted hillslope. The other set consisted of a burn hillslope (resulting from a wildfire in the summer of 1995) and an unburned hillslope. Data for hydraulic conductivity, soil texture, bulk density, plant species, standing biomass, and coverage details were collected for the WEPP application input parameters. A WEPP simulation of one to several years was used to determine the degree in which disturbances would increase the soil's susceptibility to water erosion.

The third task of physically measuring erosion at the five study hillslopes was attempted with an erosion bridge (Gleason, 1957; Hornung, 1990). The erosion bridge was used to determine soil loss or deposition by measuring the change in depth from a fixed reference point. An estimate of soil movement can be ascertained by placing bridges at various locations on the hillslope profile.

Soil Erosion Primer

Natural geologic erosion processes include water erosion in the form of rain drop impact, sheet wash, channel erosion, and soil creep -- the freeze thaw action that moves rock fragments down hill. In arid areas where very little vegetation and soil moisture are available, wind erosion contributes to the natural erosion process. Camp Williams does not have an arid climate and there is no apparent evidence of wind erosion there. Geologic erosion occurs slowly everywhere under natural conditions and is an important element to the geomorphology of the landscape. When an area becomes disrupted, such as removal of the vegetal cover, soil erosion may increase to unacceptable levels. This is a problem in semiarid rangelands where precipitation is not high enough to quickly regenerate a protective vegetation cover (Weltz et al., 1987). Erosion tends to be higher at sites that are disturbed by elements that remove the sensitive vegetation such as agriculture, fire, roads, livestock grazing, and perhaps, military activities.

Implications of Soil Erosion at Camp Williams

Soil erosion is frequently associated with severe disturbance, mass wasting, and tons of topsoil flowing down river. This is not the case at Camp Williams or for most semiarid environments. There is little and only seasonal water flowing off the base, and therefore the mechanism for soil to leave Camp

Williams is not available. Soil erosion at Camp Williams occurs in the form of downhill movement of material. In many cases detached soil is deposited only a few meters away from the source. This phenomenon is not a problem on most hillslopes, but may be in riparian areas at the base of hillslopes. The addition of large amounts of silt and sand to riparian systems can be detrimental to riparian vegetation and degrades water quality. Another problem posed by soil erosion at Camp Williams is the formation of gullies. One particular gully, Tickville Gulch, maintains very steep and hazardous walls. Such gullies tend to expand, become deeper, and branch out, creating new hazards to National Guard personnel.

CHAPTER II

LITERATURE REVIEW

Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965; 1978) is an empirical model that predicts the amount of annual soil loss for a specified set of conditions. The USLE was compiled from thousands of plot-years of data and is designed to compute rill and interrill (sheet) erosion on hillslopes under agricultural conditions. It does not predict deposition or sediment yields from gully and stream channel erosion. The equation is:

$$A = R * K * L * S * C * P$$

where: A is the annual soil loss; R is the rainfall and runoff factor; K is the soil erodibility factor; L is the slope length factor; S is the slope steepness factor; C is the cover and management factor; and P is the support practice factor (Wischmeier and Smith, 1978).

Problems with Applying the USLE to Rangelands

The USLE's limitations are apparent when applied to semiarid rangelands like Camp Williams. Over the years, the USLE has received criticism for its lack of accuracy in predicting annual soil losses (e.g., Trieste and Gifford, 1980). It is designed for agricultural field units and tends to estimate high when applied to other scenarios (Hart, 1984). The empirical data that support the equation are from mesic, agricultural landscapes which have three fundamental differences from semiarid rangelands. First, the slopes of agricultural landscapes are relatively low (1% to 18%) (Wischmeier and Smith, 1978), whereas the slopes of semiarid, western rangelands are steeper (exceeding 25%) and more complex. Second, rangeland vegetation is not spatially and taxonomically homogeneous like cropping systems. Although undisturbed rangeland vegetation is relatively stable, frequently there are interspaces of sparse vegetation. Finally, the precipitation that occurs in western rangelands in the form of intense summer rainfall events is different from the more frequent, less intense storms of the mesic east where the equation was developed. Several authors discuss these issues and recommend further research in rangeland conditions (Foster, 1981a; Foster, 1981b; Gebhardt, 1981; McCool, 1981; Weltz et al., 1987). Despite the criticism and shortcomings, the USLE is still frequently used for determining water erosion potential and functions acceptably when its limitations are recognized and reconciled (Wischmeier, 1976; Foster et al., 1981; Renard and Foster, 1985).

Modified Soil Loss Equation

The Modified Soil Loss Equation (MSLE) (Warrington et al., 1980) was developed in an attempt to be applicable to forest environments. It is modeled after the USLE (Wischmeier and Smith, 1965) and uses most of the same factors. The cover and management (C) and support practice (P) factors are replaced with a vegetation management (VM) factor. Like the USLE, the MSLE estimates the amount of soil loss from sheet erosion and cannot quantify gully erosion or predict deposition. Additionally, the MSLE provides estimates for VM factors on disturbed sites such as bare soil conditions and chemically treated soils (Warrington et al., 1980).

Revised Universal Soil Loss Equation

The RUSLE (Renard et al., 1996) replaces the previous release of the USLE (Wischmeier and Smith, 1978) but retains the same factors. Since the 1978 release of the USLE, many enhancements, improvements, and modifications were developed for the individual factors and are incorporated into the revised version. Developers continue to work to improve methods for factor calculation (Weltz et al., 1987; Desmet and Govers, 1996; Liu et al., 1994; Nearing, 1997).

The Water Erosion Prediction Project

The WEPP is the latest technology in water erosion prediction. It promises new and more advanced modeling over the RUSLE and is intended to be the standard model for water erosion prediction (Laflen et al., 1991b; J.

Dobrowolski, personal communication, 1997). It is a physical, process-based model using fundamentals of infiltration theory, hydrology, soil physics, plant science, and erosion mechanics. The WEPP has capabilities for estimating spatial and temporal distributions of soil movement (Nearing et al., 1990; Laflen et al., 1991b; Baffaut et al., 1996). It computes by storm, accounts for deposition, and addresses channel erosion (Laflen et al., 1991a; Laflen et al., 1991b).

The WEPP is presented in two versions--hillslope and watershed. The hillslope version is designed to estimate sheet and rill erosion on a hillslope profile. It predicts soil detachment, deposition, and distribution on a complex slope before reaching the channel. The watershed version estimates erosion for watershed units compiled from two or more hillslopes and predicts interrill/rill erosion, sediment deposition, and transport/deposition in channels (Laflen et al., 1991b; Flanagan and Nearing, 1995).

The WEPP represents the area where sheet and rill erosion occur as overland flow elements (OFEs). The OFEs are homogeneous units of hillslope from the top of slope to the channel or to the next OFE. Vegetation, soil, and management characteristics are used to define the boundaries between the elements (Laflen et al., 1994).

The Components of WEPP

The WEPP is composed of process-based components: climate, winter processes, infiltration, water balance, surface runoff, hydraulics of overland flow, irrigation, soil, plant growth, residue decomposition, grazing, and erosion. Each component consists of one to several equations that model the physical processes of soil erosion. The WEPP integrates these equations to adjust variables and account for the physical interactions between the components (Laflen et al., 1991b; Chaves and Nearing, 1991; Laflen et al., 1994).

The climate component consists of rainfall parameters, wind velocity, wind direction, temperature, and solar radiation (Laflen et al., 1991b; Flanagan and Nearing, 1995). Rainfall consists of four input variables that control the hydrology portion of the model: rainfall amount, rainfall duration, normalized peak rainfall intensity, and normalized time to peak intensity (Nearing et al., 1990; Tiscareno-Lopez et al., 1993). The data are entered as an input file of measured values or generated by the weather model CLIGEN, which is incorporated into the WEPP. The CLIGEN weather generator stochastically creates daily weather patterns based on antecedent conditions and skewed normal distribution curves. Rainfall duration is determined by an exponential distribution of mean monthly values. The statistics are obtained from 1400 weather stations representing most areas in the United States (Baffaut et al., 1996).

The winter processes component considers snow accumulation, freeze and thaw cycles in soils, snowmelt, and snow drifts. Temperature, solar radiation, vapor transfer, and precipitation are factored into this component. Fundamental heat flow theory controls the soil frost subcomponent (Flanagan and Nearing, 1995).

The infiltration component computes movement of water into the soil. It is adjusted for crusting and macroporosity depth by the soil component (Dobrowolski, 1994; Flanagan and Nearing, 1995). Infiltration is based on the Green/Ampt equation (1911) as modified by Chu (1978) for ponding time calculations during unsteady rainfall. The infiltration process is divided into two stages: one in which the ground surface is without standing water and a second stage for a ponded surface in which the infiltration process is independent of rainfall intensity. The stages may alternate during unsteady rainfall (Tiscareno-Lopez et al., 1993; Risse et al., 1994). The infiltration component interacts with the soil component to factor in the raindrop compaction of soils and its effect on infiltration. A breakdown of soil aggregates and the formation of a surface crust occurs when rain impacts exposed mineral soil. A surface-crusted soil has a significantly reduced hydraulic conductivity compared to the original uncrusted soil surface (Dobrowolski, 1994).

The water balance component looks at the movement of water into the root zone, plant transpiration, bare soil evaporation, and drainage. This component uses factors generated by the climate component, infiltration component, and plant growth component (Flanagan and Nearing, 1995). Factors for soil water status are computed on a daily basis to update the water balance (Laflen et al., 1991b).

The surface runoff and hydraulics of overland flow components model surface water storage, concentrated flow in rills, overland flow on interrills, surface roughness, and residue effect on overland flow. Under fixed rainfall conditions, the saturated hydraulic conductivity is the most important factor in determining runoff volumes. The resulting overland flow is routed using the kinematic wave equations (Tiscareno-Lopez et al., 1993).

The irrigation component considers waterflow additions. It can model sprinkler irrigation systems (solid-set, side-roll, and hand-move) or furrow irrigation systems. Four irrigation scheduling options are available: no irrigation, soil moisture depletion scheduling, fixed date scheduling, or a combination of the second and third options (Flanagan and Nearing, 1995).

The soil component considers characteristics and properties of soils on a daily basis. Adjustments are made for bulk density, organic matter content, random roughness, oriented roughness, wetting front suction, critical shear stress, hydraulic conductivity, and erodibility (Laflen et al., 1994). Bulk density reflects the total pore volume of the soil and is used to update several infiltration-related variables, including wetting front suction. Effective hydraulic conductivity, a key parameter in the model due to its effect on infiltration and runoff, is another part of this component. Interrill erodibility is a measure of soil resistance to particle detachment by raindrop impact (Flanagan and Nearing, 1995).

The plant growth component incorporates cover type, plant life cycles, growing season, and soil moisture impacts (Laflen et al., 1991b). Plant growth is simulated for cropland, forest, and rangeland conditions where temporal changes in plant variables influence runoff and erosion processes. The rangeland plant growth model estimates the initiation and growth of aboveground and below-ground biomass for different rangeland plant communities by using a unimodal or a bimodal potential growth curve. Range plant variables for this model include plant type, litter cover, foliar canopy cover, ground surface cover, exposed bare soil, and leaf area index (Flanagan and Nearing, 1995). Rangeland management practices such as herbicide application and burning may also be simulated (Laflen et al., 1994).

The residue decomposition component estimates decomposition of plant materials in contact with the soil surface (Flanagan and Nearing, 1995). Coefficients for estimating litter and residue decomposition were determined for many crops, but little information is available for rangeland plant decomposition rates (Laflen et al., 1994).

The grazing component estimates the impact of livestock on vegetation. The risk of soil erosion heightens when a critical depletion of canopy and groundcover occurs as a result of increased forage consumption. The daily forage consumption is based on the body weight of the grazing animals and the digestibility of the forage (Laflen et al., 1994).

The erosion component models interrill and rill erosion for hillslopes. Different forces are involved in the detachment of soil particles for interrill and rill erosion processes. The source of erosion on interrill areas is particle detachment by raindrop impact and transport by sheet flow (Huang and Bradford, 1993; Laflen et al., 1994). Soil erosion in rills is caused by detachment, transport, and deposition by concentrated water flows. Rill erosion is modeled as a function of the flow's capacity to detach and transport soil and the existing sediment load of the flow (Laflen et al., 1994).

Some Limitations of WEPP

As with any complex model, predictions from hydrologic and erosion models include a great degree of uncertainty (Bekey, 1977; Chaves and Nearing, 1991). The uncertainty originates from three sources--structural, input, and parameter. Structural uncertainty arises from the inaccuracy and incompleteness of the model. Input uncertainty refers to the spatial and temporal inaccuracy associated with measurement errors. Parameter uncertainty refers to the error associated with fixed internal parameters within the model that cannot be adjusted by the user (Chaves and Nearing, 1991).

The model varies in its sensitivity to different factors. The major sources of error in predicting runoff volumes at the watershed outlet originate from errors in estimating rainfall parameters, hydraulic conductivity, and antecedent soil moisture conditions (Tiscareno-Lopez et al., 1994). Other parameters such as canopy height are relatively insignificant to WEPP's prediction of soil erosion (Nearing et al., 1990).

Whenever modeling a natural system, some assumptions that simplify nature are necessary and acceptable (Bekey, 1977). The WEPP model is not an exception. The sediment deposition routines are based on assumptions of uniform flow velocity, no lateral sediment inflow, discrete particle settling, and uniform sediment concentration at the entry of a rill segment. All of these assumptions are incorrect under typical field conditions (Storm et al., 1994).

The WEPP algorithms are based on field measurements of total sediment yield. It is possible that many different patterns of erosion on a hillslope profile can produce the same total amount of sediment. The total estimate of soil erosion may be accurate, but all the processes involved may not be represented (Huang et al., 1996).

Another potential discrepancy between models and field reality is the resolution of scale. The infiltration algorithms tend to overpredict runoff during small events and underpredict runoff during large events. The accuracy of predictions from WEPP is better at larger temporal scales (Risse et al., 1994; Zhang et al., 1996).

CHAPTER III

EROSION RISK ANALYSIS BASED ON THE REVISED UNIVERSAL SOIL LOSS EQUATION

Introduction

The first task was to create an erosion risk map for Camp Williams. Erosion risk was based on annual soil loss estimates from the application of the RUSLE (Renard et al., 1996). Grid-based GIS was used by creating RUSLE-factor coverages and simply multiplying them together to determine an annual soil loss estimate. The soil loss estimates were then grouped into erosion risk classes. This part of the project indicates the areas most sensitive to soil erosion at Camp Williams.

The erosion risk map was developed for the entire area of Camp Williams plus a 600-m buffer around the base boundary. Similar undertakings have been accomplished in GIS by Warren et al. (1989) for woodlands in Texas; Mellerowicz et al. (1994) for agricultural lands in New Brunswick, Canada; and Jones et al. (1996) for a shrub-steppe ecosystem in Washington.

Methodology

Study Site

Camp Williams National Guard Base straddles Salt Lake and Utah Counties (Fig. 1). It is composed of 11,500 ha of semiarid rangeland and forest

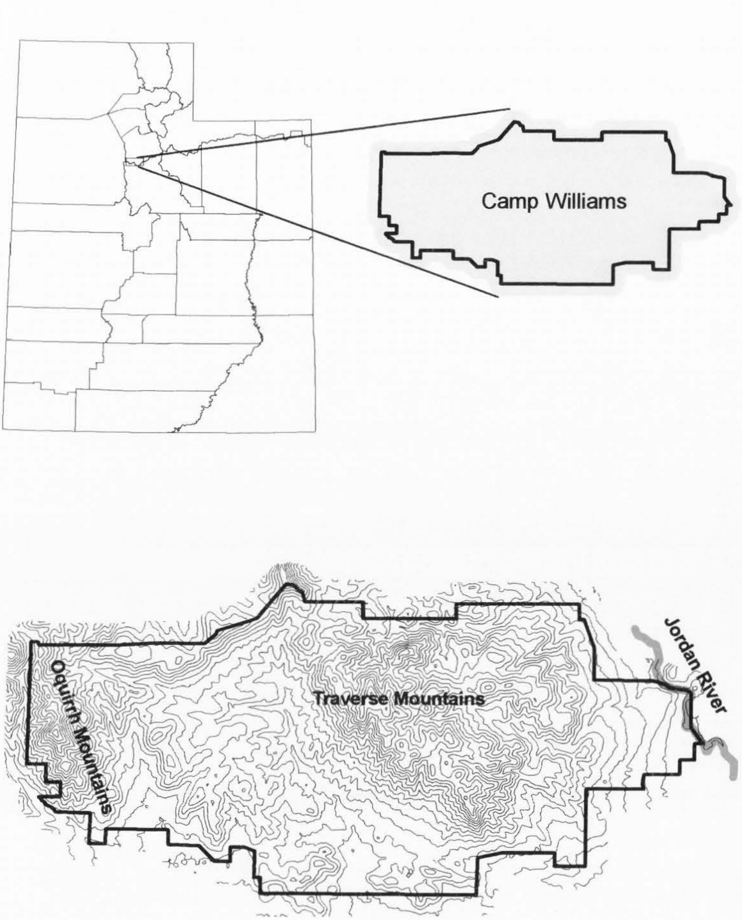


Fig. 1. Location of W. G. Camp Williams National Guard Training Facility, Utah.

with elevations ranging between 1,360 and 2,220 m above sea level. The facility, located on the southern portion of the Traverse Mountains, is bounded by the Jordan River to the east and the Oquirrh Mountains to the west. The average annual precipitation ranges from 380 mm to 550 mm and the mean annual temperature is approximately 13°C (Ashcroft et al., 1992).

Much of the landscape at Camp Williams exhibits varied topography with steep hillslopes. Many escarpments have slopes in the range of 40% to 50% with some rock outcrops exceeding 100%. However, based on a GIS analysis, less than 1% of the slopes at Camp Williams exceed 60%.

The Camp Williams geology consist of quartzite, limestone, sandstone, granite, andesite, and conglomerate. The geomorphology is strongly influenced by the pluvial Lake Bonneville cycle. The lower elevations consist of dissected lake bottom sediments, alluvial fans, deltas, and lake terraces associated with the Bonneville shoreline. Above the shoreline and into the mountainous areas, the landscape consists of pediments and hillslopes underlain by bedrock. The soils above the Bonneville shoreline are derived from residuum and colluvium (Swenson et al., 1972; Woodward et al., 1974; Trickler and Hall, 1984).

Camp Williams soils are composed of seven associations representing three soil orders--Mollisols, Aridisols, and Inceptisols. The Bingham-Parleys association is made up of nearly level to moderately sloping soils on intermediate and high lake terraces near the Jordan River. The Donnardo-Borvant-Juab association consist of shallow and very deep, gently sloping to steep soils on alluvial fans and lake terraces near the southern boundary of the base. The Butterfield-Horrocks association is dominantly moderately deep and deep, stony soils derived from andesite rocks on the low mountains of the northern portion of the base. The Harkers-Wallsburg-Lucky Star-Gappmayer association consists of deep to shallow soils derived from mixed sedimentary rocks on the highest elevations of the Traverse Mountains. The Wallsburg-Agassiz-Rock outcrop association is shallow, steep and very steep soils and rock outcrops on the lower hillsides of the Traverse Mountains. The Amtoft-Rock outcrop-Reywat association is shallow, sloping to very steep soils and rock outcrops on hillsides, ridges, and mountainsides in the central portion of the base. The Lundy-Hamtah-Rock outcrop association are shallow and very deep, steep and very steep soils and rock outcrops on the hillsides of the Oquirrh Mountains (Swenson et al., 1972; Woodward et al., 1974; Trickler and Hall, 1984).

These soils are well drained or somewhat excessively drained with textures ranging from silty clay to sandy loam. However, most soils are silt loam and clay loam with a substantial surface rock fragment content of gravel, cobble, and/or stone. Most of the soils are slightly to very strongly calcareous and some have calcic horizons and other calcareous features (Swenson et al., 1972; Woodward et al., 1974; Trickler and Hall, 1984).

There are four perennial springs within the bounds of Camp Williams but most stream channels are ephemeral. Riparian vegetation is supported near the

Jordan River and in some drainages near the perennial springs (Shultz and Hysell, 1996).

Camp Williams supports a variety of plant communities. Four basic vegetation cover types found at the facility include: oakbrush and mixed brush, sagebrush including sagebrush and grass mix, mixed grass and herbs including recently abandoned agricultural fields and bare ground, and juniper (Shultz and Hysell, 1996).

The base is used primarily for military training, which involves heavy vehicle traffic, road construction practice, combat simulations, and artillery practice. Artillery practice is limited to a dedicated impact zone of approximately 2400 ha and the other military activities are concentrated in another 600 ha in the southern part of the base. These military activities occur throughout the year but are more prevalent during the summer. There is an extensive road network on the base ranging from well maintained gravel surfaces to infrequently used four-wheel-drive roads and fire breaks. Additionally, much of the base is open to sheep and cattle grazing. The livestock density is about 1300 animal unit months over 4000 ha (Utah National Guard, 1998) and its greatest impacts are in the riparian areas.

Approach

Each RUSLE factor was represented in GIS by a grid coverage created from spatial and nonspatial data (Fig. 2). The rainfall and runoff factor (R) began with a regional value and was enhanced by a model based on elevation. The soil erodibility factor (K) was based on estimated K values from the Natural Resources Conservation Service (NRCS) which were applied to the corresponding soil mapping units digitized from the soil surveys of the area. Algorithms for the slope length (L) and slope steepness (S) factors were applied to the digital elevation model for the study area. The cover and management factor (C) was calculated with a series of equations applied to the 11 vegetation and landuse classes identified on Camp Williams. The support practice factor (P) for this project was based on the measured reduction in hydraulic conductivity caused by grazing and military activities. A vegetation management factor (VM) was created by multiplying the C and P coverages and then overlaying the result with the roads coverage. The terminology for the P factor and VM factor was borrowed from the USLE (Wischmeier and Smith, 1978) and the MSLE (Warrington et al., 1980), but the factors were calculated in unique ways for this project. The annual soil loss estimates (A_1 and A_2) were obtained from multiplying the factors and were then broken down into classes to produce soil erosion sensitivity maps. One map represents an erosion risk classification by multiplying R, K, L, S, and C factors. Another map represents the current landuse-influenced erosion risk classification by multiplying R, K, L, S, and VM factors.

The spatial data used for this model originated from an extensive GIS database for Camp Williams including coverages for vegetation types, roads,

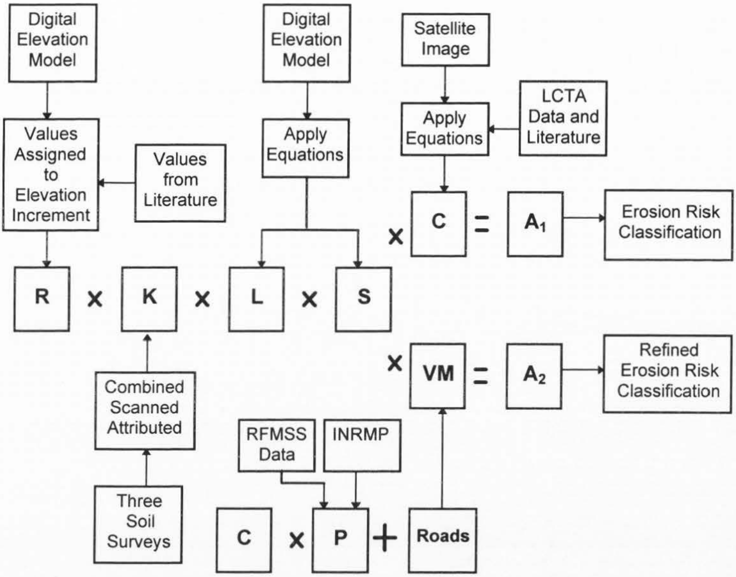


Fig. 2. A GIS procedure for creating coverages for each RUSLE factor.

and a Digital Elevation Model (DEM). A soil coverage was digitized from existing NRCS soil surveys. Approximately 70% of the study area is represented with third-order soil surveys while the other 30% is from a second-order survey. Other data for vegetation and soil were obtained from several Land Condition Trend Analysis (LCTA) plots. Delineation of military and grazing impacts came from the Range Facilities Management Support System (RFMSS) and the Integrated Natural Resources Management Plan (INRMP) (Utah National Guard, 1998). Parameters for the P factor calculations were based on field measurements of hydraulic conductivity. Other data regarding underground biomass and random roughness in rangeland and forest ecosystems were obtained from the literature (Tiedemann, 1986; Tiedemann et al., 1987; Arnold et al., 1995; Renard et al., 1996).

A 600-m area was extended around the actual base boundary, which provided a buffer for each of the factors to lessen the edge effect and the error associated with the edge of a coverage. This was of particular concern for the slope factors where the base boundary may not correspond with the top of the hillslope. On the final erosion risk classification maps, the base boundary is distinctly shown to indicate the actual area of concern.

Rainfall and Runoff Factor

The rainfall and runoff factor (R) represents the eroding energy in units of MJ mm ha^{-1} h^{-1} y^{-1}. The minimum and maximum values were obtained from an isoerodent map of the western United States by Calvin et al. (1978). When converted to metric units the values range from 240 to 440 MJ mm ha^{-1} h^{-1} y^{-1} for the Camp Williams area. There is a distinct, positive relationship between elevation and rainfall. Therefore, the R factor was interpolated with an elevation regression model similar to models by Peck and Brown (1962) and Duffy and Al-Hassan (1988). Elevation was broken down into six equal increments with the lowest R value of 240 MJ mm ha^{-1} h^{-1} y^{-1} assigned to the lowest elevation increment and the highest R value of 440 MJ mm ha^{-1} h^{-1} y^{-1} assigned to the highest elevation increment. A simple linear regression was used to assign appropriate R values to the intermediate elevation increments (Table 1).

The R factor coverage is basically an alternative representation of elevation because of the approach to assign the R values (Fig. 3). The lowest R values are associated with the low lying area near the Jordan River while the highest R values are associated with the higher elevations of the Oquirrh Mountains and the Traverse Mountains.

Soil Erodibility Factor

The soil erodibility factor (K) is the soil's resistance to erosion by water in units of t ha h ha^{-1} MJ^{-1} mm^{-1}. A composite map, identifying soil mapping units from the three existing Soil Conservation Service soil surveys (Swenson et al., 1972; Woodward et al., 1974; Trickler and Hall, 1984), was traced onto mylar and then scanned. The scanned file was converted into a GIS coverage using

Table 1. Elevation increments and R factor values for Camp Williams.

Elevation increment	R factor value †
m	MJ mm ha^{-1} h^{-1} y^{-1}
1364 - 1506	240
1507 - 1648	280
1649 - 1791	320
1792 - 1933	360
1934 - 2075	400
2076 - 2218	440

† R = Elevation * 0.281 - 163

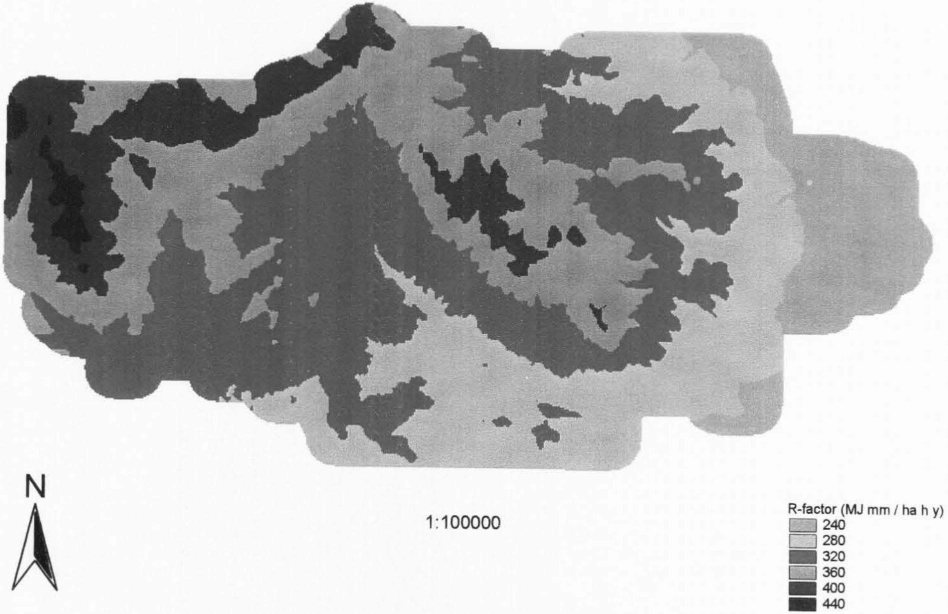


Fig. 3. The rainfall and runoff (R) factor coverage.

township corners to rectify the coverage. Finally, the K factor values were assigned to the corresponding mapping units (Appendix A).

Most K factor values are based on estimates from the NRCS (M. Domeier, personal communication, 1997). The NRCS derived these values by estimation and association with similar mapping units with well established K factor values. The majority of these estimates were based on soil texture. A few mapping units had additional data for structure, organic matter, and permeability, which were used to make better approximations. Six mapping units, including disturbed areas such as gravel pits and alluvial surfaces, did not have K factor values from the NRCS and were estimated based on soil properties and their associated landscapes.

The K factor values for Camp Williams ranged from 0 for standing water to 0.065 t ha h ha^{-1} MJ^{-1} mm^{-1} for the most sensitive soils (Fig. 4). These values cover the full range of global soil erodibility values (Renard et al., 1996) and are typical for the state of Utah.

The highest K factor values correspond to the silty, low rock fragment lacustrine soils at low elevations and on gentle slopes (Fig. 5). The lowest K factor values are associated with the high rock fragment soils at higher elevations on steeper slopes. Soils with a greater volume of rock fragments are better protected against raindrop impact which dislodges soil particles on interrill areas. This is further illustrated with higher K factor values in drainages where the slope is gentler than the adjacent hillslopes. Because texture, volume of

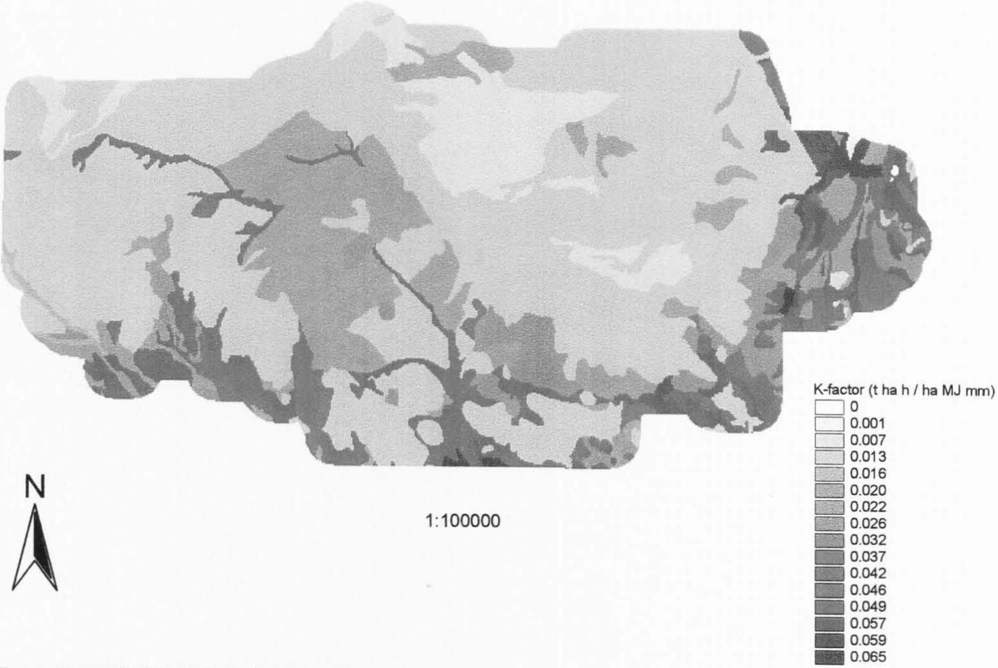


Fig. 4. The soil erodibility (K) factor coverage.

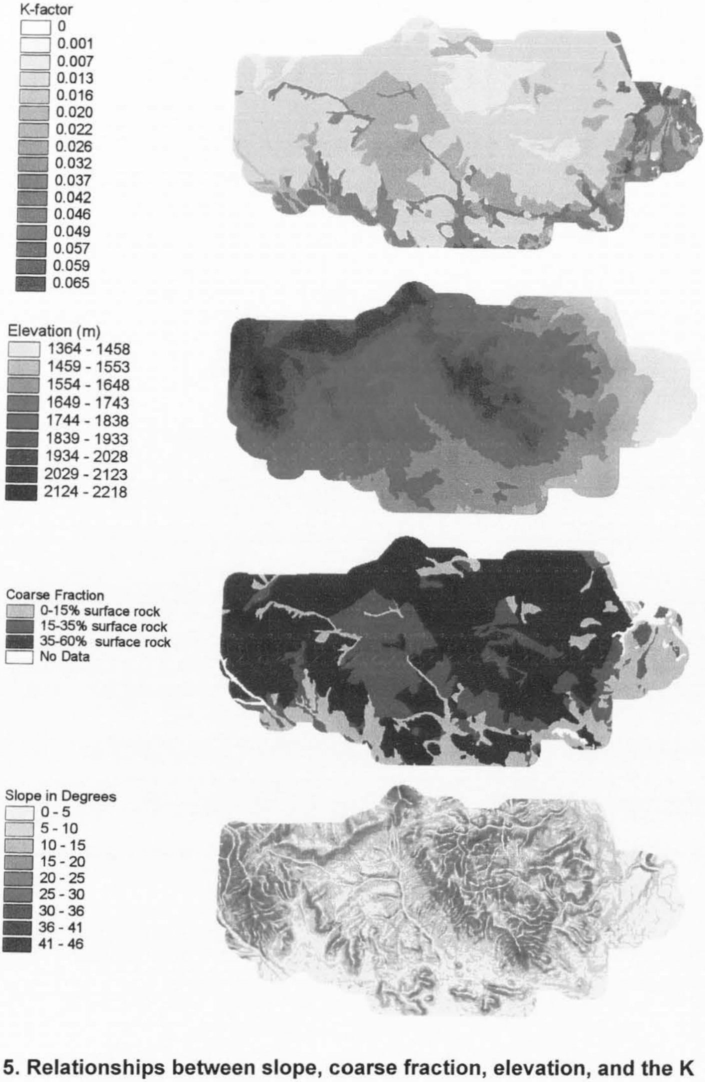


Fig. 5. Relationships between slope, coarse fraction, elevation, and the K factor.

rock fragments, and slope are all related to elevation, there is an apparent relationship between elevation and the K factor.

Slope Length Factor

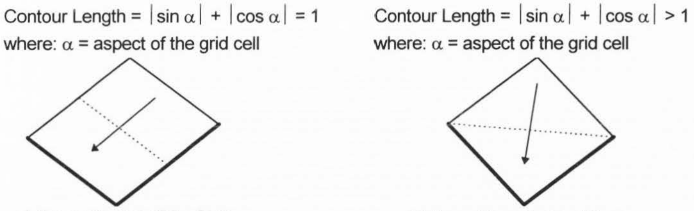
The slope length factor (L) is a unitless representation of the topography of the study area. In its simplest form, it is the ratio of the horizontal slope length to the unit-plot slope length (22.13 m) raised to a slope-dependent exponent. The slope component of the slope length factor significantly influences the factor's value. Complex slopes are broken down into segments (Foster and Wischmeier, 1974). The process of breaking down slopes into segments and evaluating them is somewhat tedious and subjective. The division of topography into discrete hillslope segments on a large-scale contour map is not compatible with GIS applications. Therefore, procedures and algorithms were adapted to calculate the slope length factor within GIS (Appendix B). The algorithms utilized simple mathematical functions, GIS utilities, and a DEM to determine a value. An Arc Macro Language (AML) program was used to apply the equations to the DEM (Appendix C).

The first equation, from Renard et al. (1996), uses the number of grid cells flowing into the cell of evaluation (observation cell) and uses the cell length as a multiplier to determine the total hillslope length of the segment (Appendix B). This cell-based computer method for calculating slope length was derived from Foster and Wischmeier's (1974) original segment equation. The use of the cell-based algorithm is more objective than the traditional map evaluation method, which requires a subjective definition of where the hillslope begins and ends.

The cell-based method accounts for the divergence and convergence of flows and attempts to take into account the complexity of natural landscapes. However, the concept of diverging and converging flows may not be very compatible with the (R)USLE because empirical data that support the model are based on relatively simple hillslopes. The slope length algorithm tends to reflect channels and preferential flow hydrology extending the model beyond its empirical limitations.

The second equation, from Desmet and Govers (1996), also uses the number of grid cells flowing into the observation cell (Appendix B). It is similar to the Renard et al. (1996) equation but also considers the aspect at which the flow is entering the cell and therefore adjusts the factor based on a greater contour length. For this equation, an area of the total number of cells is considered and then divided by the contour length of the observation cell to convert area into a hillslope length. The contour length is a function of the aspect of the observation cell (Fig. 6).

The Desmet and Govers (1996) equation was chosen for the Camp Williams analysis (Fig. 7) and a limitation of 10 cells flowing into the observation cell was set to match the empirical 300-m hillslope length limit of the RUSLE. The L factor values range from 0.97 to 11.11 with a mean of 3.18 and a standard deviation of 2.03. These numbers indicate that the slope length values are



a) Aspect is one of the four cardinal directions

b) Aspect is not one of the four cardinal directions

Fig. 6. Illustration of different contour lengths based on aspect of the grid cell.

skewed with more than half of the values falling below the mean. A fundamental problem with this coverage was the scale in which it was evaluated (30-m grid). The function used to determine the number of cells flowing into the observation cell was barely adequate for this application at this scale. Hydrologic principles need to be considered on a much smaller scale; hence a finer resolution DEM would improve the slope length coverage. Such a DEM would reduce hillslopes into smaller units, which would be more appropriate for the empirical data of the RUSLE.

Slope Steepness Factor

The slope steepness factor (S) is a unitless representation of slope. For this analysis, it was determined using an equation by Nearing (1997) (Appendix B). This equation also used the DEM to calculate a value and was incorporated

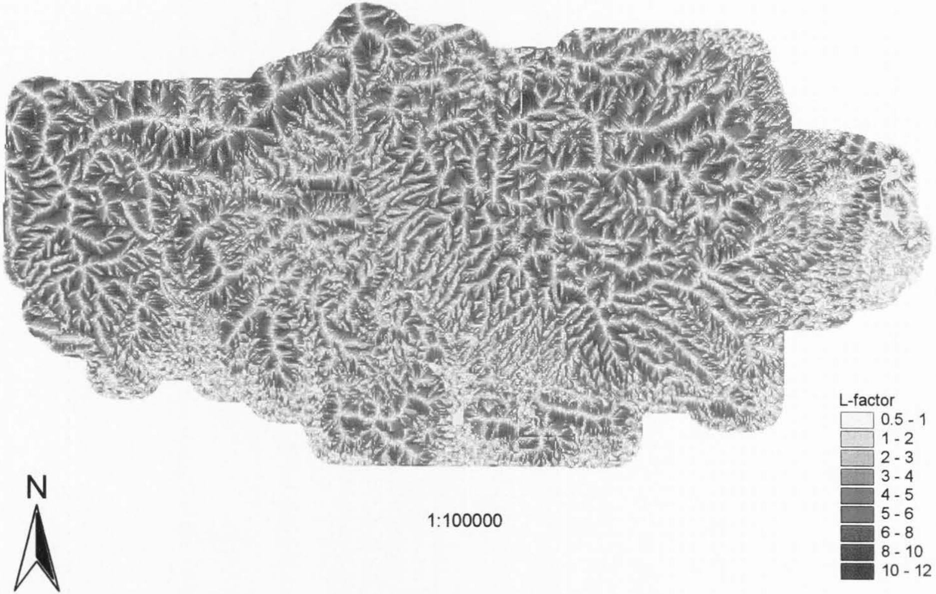


Fig. 7. The slope length (L) factor coverage.

into the AML (Appendix C) so that both slope factor coverages were computed in a single operation.

The standard slope steepness factor equation (McCool et al., 1987; Renard et al., 1996) for the RUSLE is based on data from slopes between 0.1% to 18%. This factor must be extrapolated when applied to slopes greater than 18% and tends to underpredict the slope steepness factor value for slopes greater than 22% (Nearing, 1997). Liu et al. (1994) observed slopes up to 55% and developed an empirical equation to accommodate the steeper slopes but this equation fits poorly on slopes below 20% (Fig. 8). Nearing (1997) interpreted the two equations to algebraically create a universal equation that fits slopes between 0 and 55%. The graph below (Fig. 8) illustrates the difference between the three equations (Appendix B) over the range of slope gradients at

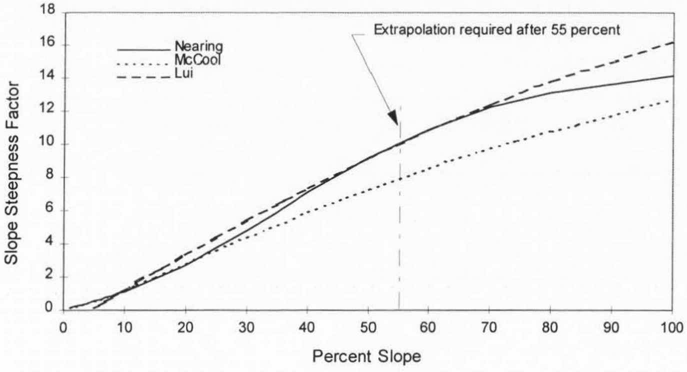


Fig. 8. Comparison of slope steepness factor models by McCool et al., 1987; Liu et al., 1994; and Nearing, 1997.

Camp Williams. Note that slopes greater than 55% were extrapolated beyond the equation's empirical data but only a small proportion (less than 1%) of slopes needed to be extrapolated.

The resulting S factor values range from 0.05 to 13.50 with a mean of 2.72 and a standard deviation of 2.28 (Fig. 9). The S factor is directly related to slope and has lower values on ridge tops and drainages while the highest values are located on the steepest hillslopes and rock outcrops.

Cover and Management Factor

The cover and management factor (C) is a unitless representation of the vegetation characteristics of the study area. The C factor was applied to the 11 vegetation cover type classes identified on Camp Williams (Van Niel, 1995; Shultz and Hysell, 1996). The GIS coverage (Fig. 10) for these vegetation cover types was created from satellite imagery on a 30-m grid scale (Van Niel, 1995). The cover types include: oakbrush, juniper, mixed oakbrush and sagebrush (includes oakbrush with open interspaces), sagebrush (greater than 70% sagebrush coverage), mixed sagebrush and grass, mixed grass and herbs, riparian areas, disturbed ground (annual grass and weeds with substantial bare ground), vegetated agriculture (primarily wheat fields), standing water, and developed areas.

The RUSLE provides a set of detailed equations for determining C factor values that consist of subfactors for previous landuse, canopy cover, surface

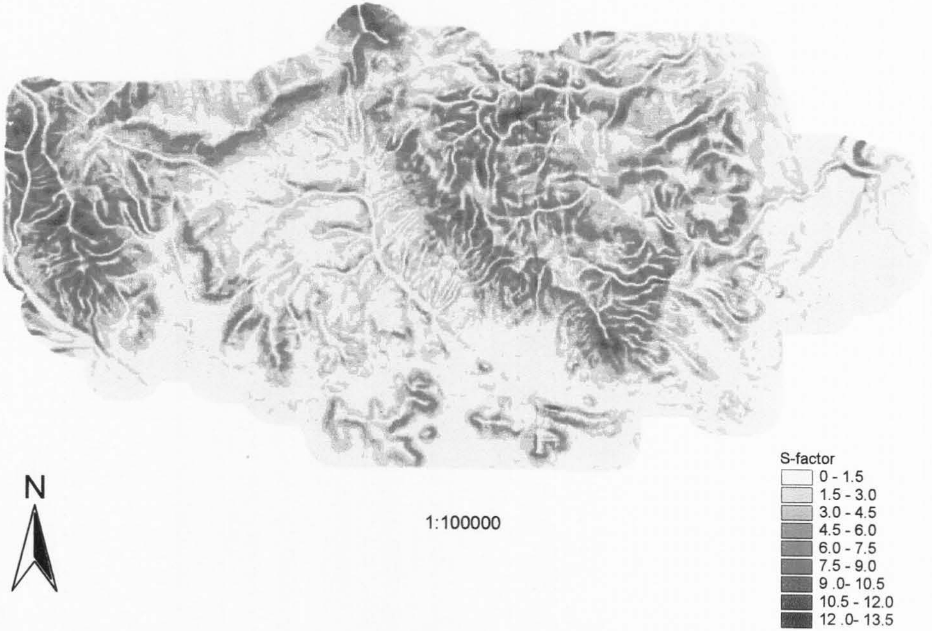


Fig. 9. The slope steepness (S) factor coverage.

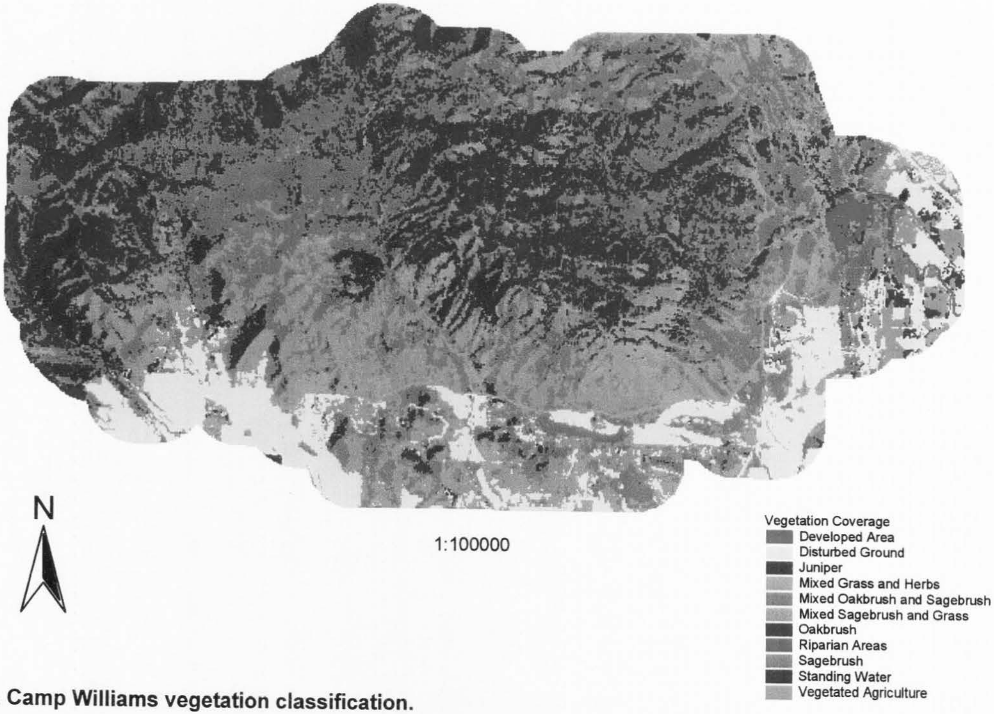


Fig. 10. Camp Williams vegetation classification.

cover, surface roughness, and soil moisture (Appendix D) (Weltz et al., 1987; Renard et al., 1996). Soil moisture is not used for natural rangeland conditions because it is only needed for time varying analysis on agricultural systems (Renard et al., 1996). In agricultural systems, a crop's entire life cycle occurs in a single year. This requires an analysis of the plant life stage with the soil moisture regime in increments of time. In natural systems, such as rangelands, vegetation provides relatively consistent coverage throughout the year and soil moisture is factored out.

The C value subfactors are a function of disturbance, underground biomass, canopy cover, canopy height, surface cover, and surface roughness. The variables for the calculation of these subfactors came from several sources (Appendix E). Underground biomass and surface roughness were obtained from the literature (Tiedemann, 1986; Tiedemann et al., 1987; Arnold et al., 1995; Renard et al., 1996) and the canopy and surface cover variables were obtained from the LCTA database. The C factor values (Table 2) were calculated for each cover type and assigned appropriately to the GIS coverage (Fig. 11). The values range over three orders of magnitudes from 0.004 to 0.328. These values were heavily influenced by underground biomass, which is characteristically high under oakbrush and low under juniper, agriculture, and disturbed ground.

Table 2. The C factor values for different landuse-vegetation cover types at Camp Williams.

Cover type	C factor value
Standing Water	0.000
Developed Area	0.000
Oakbrush	0.004
Riparian Area	0.005
Mixed Oakbrush and Sagebrush	0.006
Sagebrush	0.006
Mixed Sagebrush and Grass	0.080
Mixed Grass and Herbs	0.086
Juniper	0.106
Vegetated Agriculture (wheat)	0.192
Disturbed Ground	0.328
Roads[†]	1.300

† Note that roads are used in the VM coverage only.

Support Practice Factor

The support practice factor (P) is a unitless representation of agricultural practices and is not used with rangelands. The terminology of the P factor was used in this analysis to represent a current landuse influence. With the hydraulic conductivity data from field measurements at Camp Williams, P factor values were derived for military and cattle grazing impacts. The field measurements provided specific values in the reduction of hydraulic conductivity for both grazing and military activities (Table 3) that were translated into P factor values for those activities (Table 4).

A reduction in hydraulic conductivity translates into a higher K factor value, which includes a component for permeability. When the average K factor value for Camp Williams was considered and the apparent undisturbed hydraulic conductivity was associated with this value, a simple algebraic manipulation was

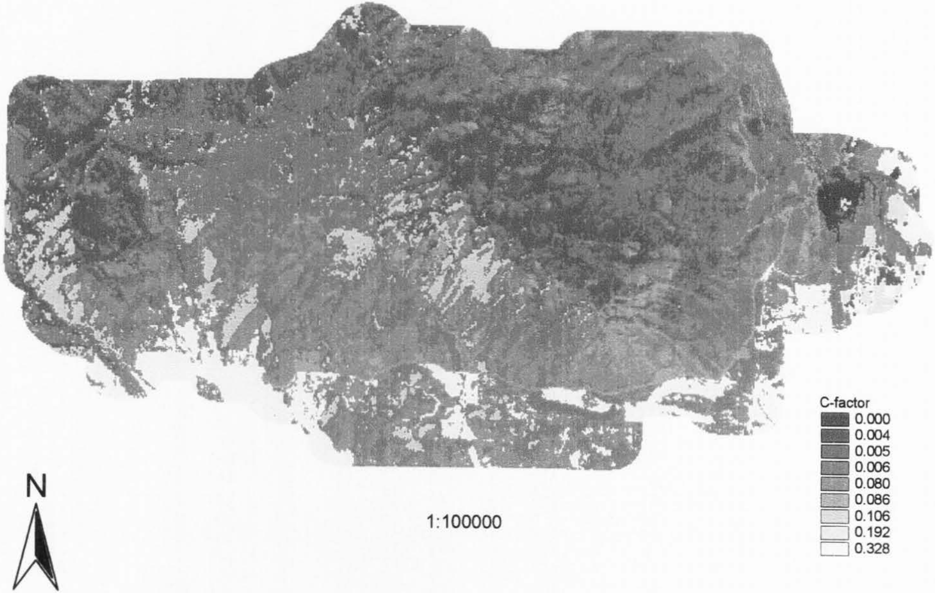


Fig. 11. The cover and management (C) factor coverage.

Table 3. Hydraulic conductivities for various disturbances at Camp Williams

Disturbance	Hydraulic conductivity
	mm hr^{-1}
Military impacted (heavy foot traffic)	26.4
Grazing impacted	49.2
Apparent undisturbed rate	72.5

Table 4. The P factor values for Camp Williams.

Landuse	Usage	P factor values
	person-day	
No landuse influence	0	1.00
Cattle Grazing	NA	1.08
Light military activity	1 to 50	1.02
Moderate military activity	50 to 400	1.07
Heavy military activity	> 400	1.16

done to calculate the percent increase in the K factor value due to reduction in hydraulic conductivity. The calculations revealed that there is an 8% increase in K factor values due to cattle grazing and up to a 16% increase due to military activities. The K factor coverage was left unchanged and a P factor value was used to apply the impact of the grazing and military activities.

Hydraulic conductivity measurements were collected for only one military-impacted hillslope. This hillslope was considered to be heavily impacted based on person-day usage and yielded the maximum P factor value for this study. The P factor values for moderate and light military impacts were estimates based on this maximum value.

The P factor coverage was delineated into areas for each type of landuse influence (Fig. 12). The area of cattle grazing influence was based on several factors: (1) selection of Tickville, Oak Springs, and Rose Canyon drainage basins as the areas designated for cattle grazing in the INRMP (Utah National Guard, 1998); (2) areas within 1.6 km from water as the assumed distance cattle will travel from water; and (3) areas within 6.5 km from the cattle drop-off point (near intersection of Tickville and Watts Roads) as the assumed distance that cattle will randomly travel when ample forage is available (Curtis, 1983).

Camp Williams is delineated into 86 training areas each composed of 100 ha. Military activities are recorded for each training area in the RFMSS database. The 1995 RFMSS data was used to delineate military impact for the P factor coverage. The distribution of person-days recorded for each training area was broken into three groups. These groups were assigned labels of light, moderate, and heavy military activities along with the corresponding P factor values (Table 4). Type of military activities, duration of activities, and time of year in which they occurred all have a significant impact on soil erosion. No effort was made to distinguish between different types, duration, or timing. For example, 100 people on the pistol range for 30 minutes was equated with 100 people riding in heavy vehicles for several hours. More detailed records are available but a more extensive P factor analysis is beyond the scope of this project.

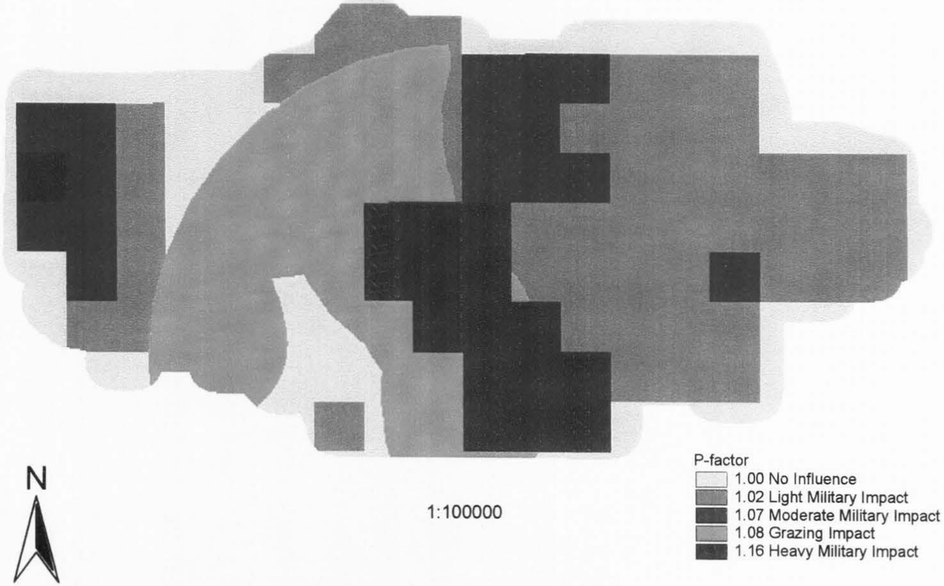


Fig. 12. The support practice (P) factor coverage.

Vegetation Management Factor

The vegetation management factor (VM) is a unitless factor used to represent the vegetation component and an estimate of landuse influence on soil erosion risk. The VM factor terminology was borrowed from the MSLE (Warrington et al., 1980) but was derived in a unique way. In this analysis, the VM factor consists of three components: the C factor, the P factor, and a road overlay.

The C and P coverages were multiplied to create a landuse-influenced coverage. This coverage is a representation of C factor values with associated impacts of the P factor. Next, the roads were overlain because they represent a complete lack of vegetation and a very high VM factor value. No vegetation has a VM factor value of 1.00, which represents freshly tilled soil. The roads were assigned a VM factor value of 1.30 (Warrington et al., 1980) due to much lower infiltration rates and lack of surface relief. Multiplying the C and P factors first and then overlaying the roads prevents the roads from being influenced by the P factor.

Results and Discussion

Erosion Risk Classification

The annual soil loss estimates (A_1 and A_2) in t ha^{-1} y^{-1} were computed by multiplying the contributing factors. Application of the RUSLE to an area as large as Camp Williams and to rangelands in general violates some of the conventions of the model. Error is incorporated into soil loss estimates by extending the RUSLE beyond its empirical data. Some of these errors originate from: intense summer storms, estimation of K factor values, reflection of flow hydrology in the L factor calculation, slopes exceeding 55%, vegetation interspaces, C factor values based on biomass values from the literature for sites outside of Camp Williams, and crude estimates of the P factor values. Due to these issues, an actual soil loss prediction was not the objective of this analysis and the soil loss values were assumed to be overestimates.

An erosion risk map was created by grouping soil loss estimates into classes which were labeled with a simplified level of soil loss sensitivity (Table 5). Four classes were created based on increments of calculated soil loss. The class with the lowest soil loss increment was labeled "Low Risk," the class with the highest was labeled "High Risk," and the other two classes are simply a gradient between the two extremes. These classes were determined by overlaying the A_1 coverage onto a digital ortho photo of Camp Williams and fitting the data to some known problem areas. The first class (Low Risk) was defined by setting the soil loss increment (0 to 9.0 t ha^{-1} y^{-1}) high enough to

Table 5. Classes for soil erosion risk.

Class	Annual soil loss range
	t ha^{-1} y^{-1}
Low Risk	0 - 9.0
Low Intermediate Risk	9.0 - 18.0
High Intermediate Risk	18.0 - 27.0
High Risk	27.0 +

eliminate digressive intermediate risk areas. The "Low Risk" increment of 9.0 t ha^{-1} y^{-1} was used to set the soil loss increment of the other three classes. This procedure calibrated the model for unknown problem areas.

The first erosion risk map, Erosion Risk Classification (A_1), was created by multiplying the factors of R, K, L, S, and C (Fig. 13). This coverage represents Camp Williams in its current state without the influence of grazing, military activities or roads. However, agriculture and very disturbed landscapes were implicitly represented through the C factor coverage.

The second map, Refined Erosion Risk Classification (A_2), is an erosion risk map showing the influences of current landuse (Fig. 14). It was created by multiplying the factors of R, K, L, S, and VM. This map incorporated the influences of roads, grazing, and military activities that were embodied in the VM factor.

The vast majority of area at Camp Williams was classified as non-sensitive to soil erosion under natural conditions. The areas designated most sensitive were attributed to the lack of vegetation associated with roads and agriculture. A noticeable portion of the most sensitive areas actually fall outside the bounds of the facility and are associated with agricultural activities in the buffer area.

A regression analysis was performed on each of the factors to determine their correlation with the final coverages. This was done by calculating the

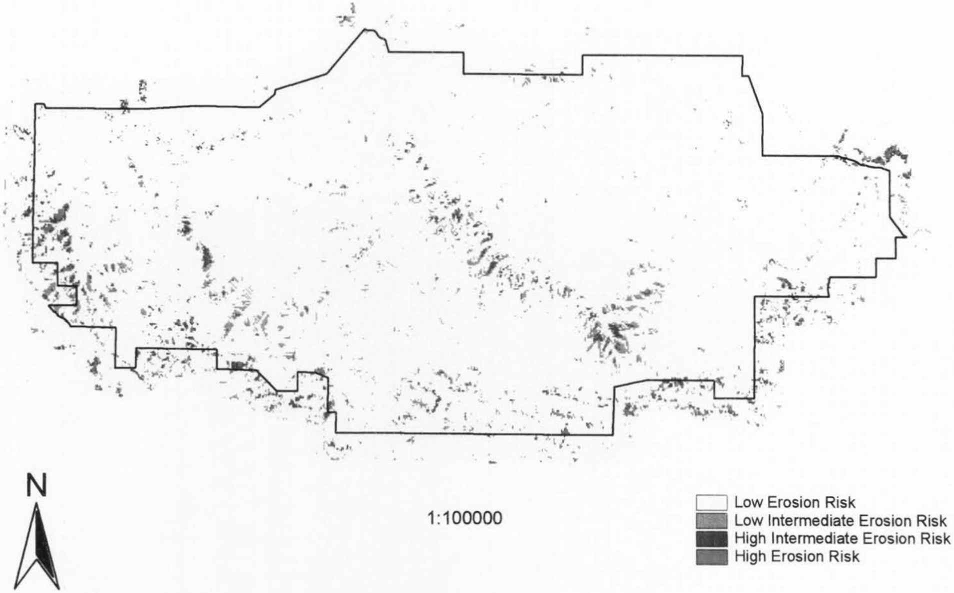


Fig. 13. Erosion risk classification map (A_1).

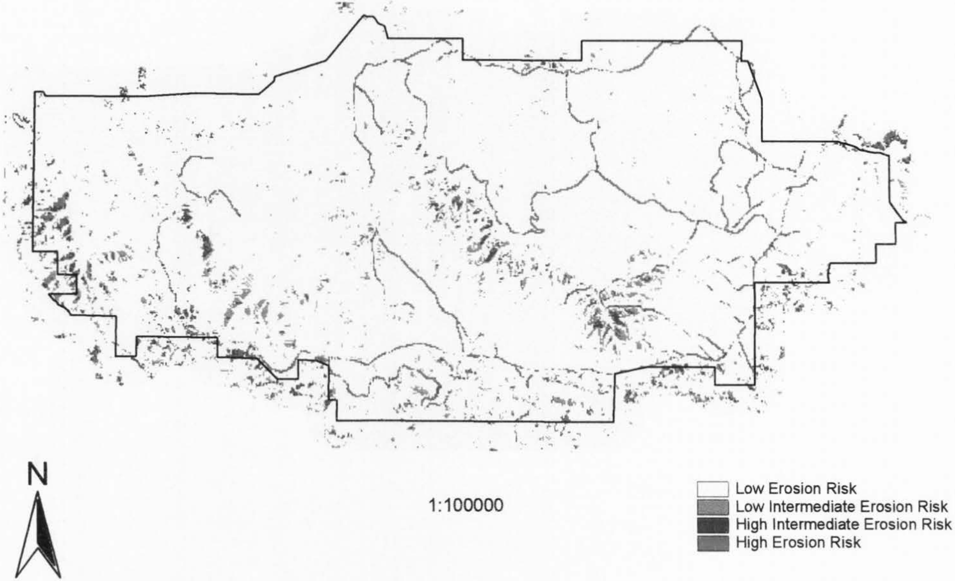


Fig. 14. Refined erosion risk classification map (A_2).

correlation coefficient (r) between each factor coverage (R, K, L, S, C, and VM) and the annual soil loss coverages (A_1 and A_2) on a grid cell by grid cell basis (Table 6). The results showed that neither A_1 or A_2 were strongly correlated with the R factor. This suggests that refining the R factor coverage will have little effect on erosion estimates. The K, L, and S factors were all about equal contributors to variations in soil loss (3% to 5%) in the erosion risk classification (A_1), while the C factor appeared to exert the greatest influence of explained variation on A_1 (over 22%). In the second analysis of the refined erosion risk classification (A_2), the gap between the VM factor influence (38%) and the other factors (less than 3%) was even greater. The C and VM factors had the greatest influence on the final outcome, and refinement of these factors would be the best effort to improve soil loss estimates. The K, L, and S factors also significantly affected soil loss estimates but to a much lesser extent.

Table 6. Summary of analysis between factors and soil loss estimates.

Coverages compared	R	R^2	t	P	n
A_1 and R	-0.031	0.001	-11.79	< 0.0005	144,405
A_1 and K	0.182	0.033	70.34	< 0.0005	144,405
A_1 and L	0.224	0.050	87.34	< 0.0005	144,405
A_1 and S	0.189	0.036	73.14	< 0.0005	144,405
A_1 and C	0.474	0.225	204.56	< 0.0005	144,405
A_2 and R	-0.027	0.001	-10.45	< 0.0005	144,405
A_2 and K	0.095	0.009	36.08	< 0.0005	144,405
A_2 and L	0.135	0.018	51.76	< 0.0005	144,405
A_2 and S	0.074	0.005	28.07	< 0.0005	144,405
A_2 and VM	0.617	0.380	297.67	< 0.0005	144,405

Discussion

The RUSLE and GIS were very compatible in determining potential soil loss, but one must always acknowledge that there is a great deal of error inherent with the process of applying the RUSLE to a large tract of rangeland. The error is in the actual prediction of annual soil loss and becomes less important when determining relative erosion risk. The methods used for this analysis illustrate how a minimal amount of data collection can yield some important soil erosion risk predictions for a large area such as a military installation.

Any analysis performed with a model at a coarse scale provides a poor substitute for actual measurements. The application of the RUSLE with GIS is no exception. Ultimately, the model generates a quantitative value that represents a specific soil loss estimate for a particular area. However, because some of the GIS coverages were based on assumptions and estimates that only provide a crude appraisal of the physical character of Camp Williams, they should never be used for a quantitative analysis. The soil loss quantities in and of themselves have little meaning due to the inherent error in the modeling process, but when converted to a qualitative assessment their analysis becomes more meaningful. By categorizing the soil loss estimates into sensitivity classes, the RUSLE/GIS analysis can provide a relative risk for each area. The validation for the risk classification is justified because the assessment is based on the fundamental components of soil erosion -- climate, soils, relief, vegetation, and landuse.

CHAPTER IV

COMPARISON OF DISTURBANCE REGIMES WITH THE WATER EROSION PREDICTION PROJECT

Introduction

Soil erosion tends to be accelerated on disturbed landscapes. Fire, agriculture, grazing, and military activities are examples of disturbance regimes. The objective for this task was to model erosion at several disturbed and less disturbed sites to evaluate the extent to which disturbance affects erosion at Camp Williams. The Water Erosion Prediction Project (WEPP) model was applied to study hillslopes to compare the impacts of different disturbance regimes on soil erosion. Five hillslopes at Camp Williams were established as study sites based on impacts from fire, grazing, and military activities (Fig. 15). The hillslopes were broken down into two groups based on similar slope gradient, aspect, and vegetation cover type. One group consisted of an adjacent burn and unburned hillslope. They both have a sagebrush cover type and are 130 m long. The other group of three hillslopes included a military-impacted, a grazing-impacted, and a less-impacted hillslope. Each slope in this group is dominated by a juniper vegetation cover type and ranges from 100 to 200 m long.

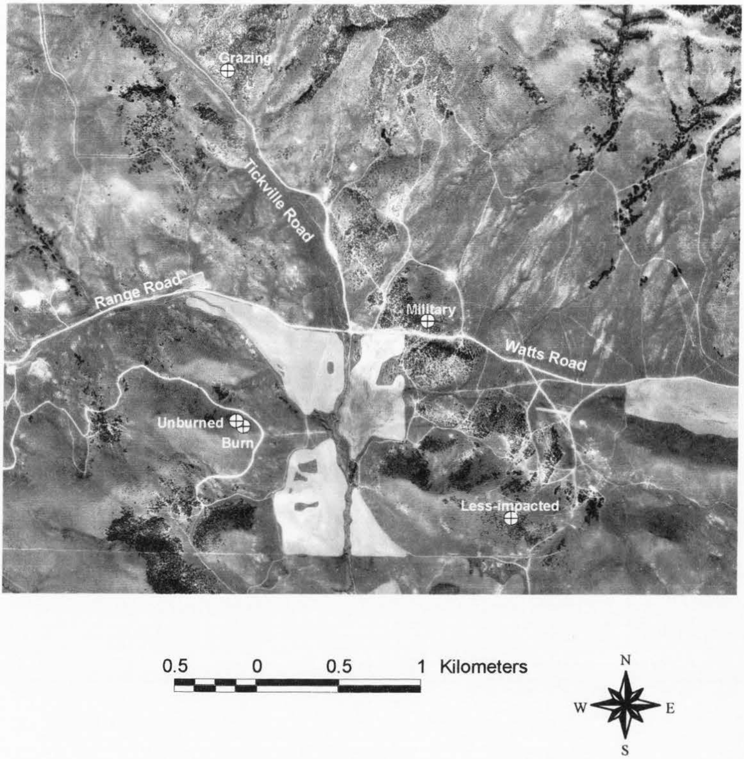


Fig. 15. Location map for study hillslopes.

Description of the Study Hillslopes

The burn hillslope is located south of Range Road and west of Tickville Gulch. It has a northeast aspect and an elevation of 1650 m midslope. It was burned by a wildfire in the summer of 1995 changing it from a thick sagebrush community to a grass-dominated community. Cheatgrass (*Bromus tectorum* L.), alyssum (*Alyssum* spp.), wheatgrass (*Elymus* spp.), and rabbitbrush (*Chrysothamnus* spp.) are dominant. Sunflower (*Helianthus* spp.) is also common to this area. There is a noticeable wildlife impact with deer trails scarring the hillslope.

The unburned hillslope is adjacent to the burn hillslope and is the same in every way except vegetation cover. The deer trails are present but not as extensive. Big sagebrush (*Artemisia tridentata* Nutt.) has a 40% coverage and is accompanied by broom snakeweed (*Gutierrezia sarothrae* Pursh), bitterbrush (*Purshia tridentata* D.C.), and Indian ricegrass (*Oryzopsis* spp.).

The military impacted hillslope is located on a Region Five hill adjacent to Watts Road. It has a south aspect and an elevation of 1620 m midslope. The hill is frequently used by National Guard Personnel. Large groups of foot soldiers traverse the hillslope, discharge small weapons, and ignite smoke bombs during combat simulations. The hillslope is littered with debris from these activities. Wildlife and cattle roam here but their presence is minimal due to the lack of forage and near constant human activity. Juniper (*Juniperus* *osteosperma* (Torr.) Little) is the primary vegetation type with a 40% coverage and large interspaces. The interspaces are dominated by cheatgrass and alyssum. Big sagebrush, broom snakeweed, and Indian ricegrass can also be found sparsely distributed in this area.

The grazing hillslope is adjacent to Tickville Road approximately 2 km north of the intersection of Watts Road. It is on the east side of the road with a west aspect and an elevation of 1640 m midslope. This hillslope is more impacted by cattle grazing than the other hillslopes. It is scarred with several cow trails that cover at least 10% of the area but there is little evidence of military activity. The plant community is juniper-sagebrush with 10% juniper and 20% big sagebrush. Other associated species include: bitterbrush, cheatgrass, broom snakeweed, rabbitbrush and Indian ricegrass.

The less-impacted hillslope is located approximately 1 km south of Watts Road and 1 km east of Tickville Road. It is adjacent to the southern boundary of the base. It has a south aspect and an elevation of 1620 m midslope. This hillslope provides a basis to compare the military and grazing hillslopes. However, there is a slight impact of military activities, wildlife, and hunters trespassing over the southern boundary of the base. The plant community is juniper-sagebrush with 20% juniper and 10% big sagebrush. Other associated species include cheatgrass and Indian ricegrass.

Approach

The WEPP application requires four input files: climate, slope, soil, and management. The climate file was created by the CLIGEN weather generator for a particular region by using statistics from the most appropriate weather station. The slope file required field measurements to create a detailed description of the hillslope. Each hillslope was broken down into segments of steepness and entered into the application as percent slope and horizontal distances for each segment. The other two input files are the soil file and the management file, which contain soils and vegetation data. The parameters for these files were measured, estimated, or provided by WEPP from its database of default values.

The WEPP requires many parameters for the input files and to model a hillslope. It has the ability to generate estimated variables, but estimating all the variables invites error. Due to the large number of WEPP variables, measurement of a select few, significant parameters is the most practical approach to using the application. Slope, soils, and vegetation characteristics were the target parameters for measurement in this study and chosen from the most significant factors listed by Flanagan and Nearing (1995). In mid September 1997, at least three samples or measurements for the target parameters were collected from each hillslope at midslope. Other input variables were obtained from soil and vegetation data collected at the LCTA plots in previous years. The LCTA plots were matched with the study hillslopes by soil and vegetation characteristics. All data was entered into the WEPP application through the four input files.

The Climate Input File

The climate input file for the WEPP was created with CLIGEN, which uses a database of weather statistics from about 1400 stations nationwide. Preparation of a specific climate file is critical to the effective application of WEPP. The fundamental process that WEPP uses to predict erosion is rainfall exceeding infiltration. Therefore, any error associated with rainfall amounts and intensities is directly conveyed to the erosion estimate.

The five study hillslopes are at elevations between 1600 and 1650 m. Unfortunately, none of the Utah weather stations in the CLIGEN database were adequate for that elevation at Camp Williams. However, the Bingham Canyon weather station is only 25 km away at the same elevation as the study hillslopes. It provides the best available representation of climate for the study area but is not included in the CLIGEN database. Therefore, based on information from Flanagan and Nearing (1995) and W. Elliot (personal communication, 1998), a procedure to convert raw weather data into CLIGEN statistics was developed and used (Appendix F).

The resulting statistics for the Bingham Canyon weather station are summarized in Table 7. Each statistic is calculated on a per month basis. The

Table 7. Summary of Bingham Canyon weather statistics.

	J	F	M	A	M	J	J	A	S	O	N	D
MEANP	0.17	0.17	0.18	0.22	0.23	0.24	0.21	0.20	0.24	0.23	0.20	0.18
SDEVP	0.20	0.20	0.17	0.25	0.26	0.29	0.32	0.24	0.32	0.23	0.21	0.22
SQEWP	2.83	2.69	1.61	2.52	2.05	1.97	3.00	2.52	2.37	1.71	1.76	3.59
P(W/W)	0.56	0.50	0.53	0.57	0.60	0.55	0.46	0.47	0.41	0.52	0.55	0.57
P(W/D)	0.24	0.26	0.31	0.24	0.17	0.13	0.13	0.14	0.14	0.14	0.20	0.25
TMAXAV	35.00	38.50	44.70	53.80	64.90	73.90	82.90	80.80	72.20	59.80	44.90	36.50
TMINAV	20.30	22.80	26.90	34.20	44.00	51.60	61.20	59.10	51.20	40.80	30.00	22.10
SDTMAX	8.14	8.69	9.11	9.33	9.47	8.78	4.85	5.60	8.72	9.45	9.24	7.49
SDTMIN	12.15	11.06	7.53	6.25	6.93	6.51	5.06	5.99	6.72	6.04	6.98	8.66

MEANP is the mean precipitation (in) for wet days (days precipitation occurred). The SDEVP is the standard deviation of precipitation for wet days. The SQEWP is the skewness of precipitation for wet days. The P(W/W) is the probability of a wet day following a given wet day. The P(W/D) is the probability of a wet day following a given dry day. The TMAXAV is the monthly average maximum temperature (°F). The TMINAV is the monthly average minimum temperature (°F). The SDTMAX is the standard deviation of the maximum temperature. The SDTMIN is the standard deviation of the minimum temperature.

The Slope Input File

Slope profiles for all five study hillslopes were measured with a 100-m tape measure and clinometer. The overall slopes for the burn and unburned hillslopes are about 45%, while the slopes for the other three hillslopes range from 32% to 40%. Flags were placed at points of distinct slope changes as determined by visual inspection. The overland distance between the flags was determined with the tape measure and the slope angle was measured with the clinometer. These segment measurements were converted to a WEPP format of percent slope and horizontal distance. An arbitrary width of 50 m was assigned to each hillslope because WEPP treats hillslopes as a homogeneous profile within a user specified width.

The Soils Input File

The soils input file requires values for interrill erodibility (ki), rill erodibility (kr), critical shear stress (shcrit), hydraulic conductivity (avke), texture (sand, clay), percent coarse fraction (rfg), organic matter content (orgmat), and cation exchange capacity (cec). The parameter values used for the five hillslopes are summarized in Appendix G, Table 16. Hydraulic conductivity, texture, percent coarse fraction, and cation exchange capacity were directly measured *in situ* or in the laboratory from the top 10 cm of soil collected at midslope of each hill. The soil organic matter content was computed from the soil organic carbon measurements (Van Miegroet, unpublished data) associated with LCTA plots by multiplying them with a conversion factor (1.724). The study hillslopes and LCTA plots were matched using soil and vegetation characteristics. The other three parameters were empirically derived from bulk density and texture as per Flanagan and Nearing (1995).

Gravimetric moisture content was determined by collecting the soil with a 2.5-cm diameter tube sampler to a depth of 10 cm. About 10 g of mixed soil from each sample was weighed, oven-dried at 105°C for at least 24 h, and weighed again.

Bulk density was determined by the excavation method (Blake and Hartge, 1986). A small amount of soil (about 250 ml) was excavated and collected with rock fragments included. The excavation hole was filled with clean sand from a graduated cylinder to determine the sample volume. Coarse fragments were removed from the soil with a 2-mm sieve, weighed, and converted to volume by multiplying by 2.65 g cm^{-3}. The fine fraction was oven-dried at 105°C for at least 24 h and weighed.

Textural analysis was performed with the Bouyoucos hydrometer method (Gee and Bauder, 1986). A 2.5-cm diameter tube sampler was used to collect a 10-cm deep soil sample for this analysis.

Hydraulic conductivity was determined by the dripper method (Shani et al., 1987; Dobrowolski, 1994). This procedure was performed midslope on each hill until there were at least three valid measurements per hillslope. Placement of the apparatus was based on: location for optimal apparatus performance, lack of surface cracks, and minimal slope. The soil surface was prepared by removing the litter layer.

A Marriot tower and dripper apparatus, constructed with button drippers, were used to establish five constant flow rates ranging from 5 ml min^{-1} to 60 ml min^{-1}. Starting with the slowest water delivery rate, each rate was applied to the soil surface until the saturated area delineated by straight pins remained constant for at least 3 min. The next drip rate was applied to the same area. The drip rate and two diameters from the resulting ellipse of saturated soil were recorded for each rate. For each measurement location, the inverse of the average of the two saturated radii and the flux (drip rate / saturated area) were graphed for the five drip rates (see example, Fig. 16). A linear regression was calculated and linear data with an $R^2 > 0.60$ were retained as a valid measurement. If one rate was a visual outlier in the regression analysis, it was discarded and only the other four rates were included in the regression. Finally, the effective saturated hydraulic conductivity was determined from the y-intercept of the regression line. The effective saturated hydraulic conductivity for each hillslope was determined by taking the average of the valid measurements. The hydraulic conductivity values obtained from the less-impacted hillslope are not truly representative of the maximum hydraulic conductivity of a totally undisturbed site because of the influence of wildlife, military, and trespasser impacts. Therefore, the average of the five highest values from the grazing and military slopes was used to obtain the apparent maximum hydraulic conductivity (Table 8).

The Management Input File

Vegetation parameters were entered into the WEPP application via the management input file. The management input file has three subcomponents

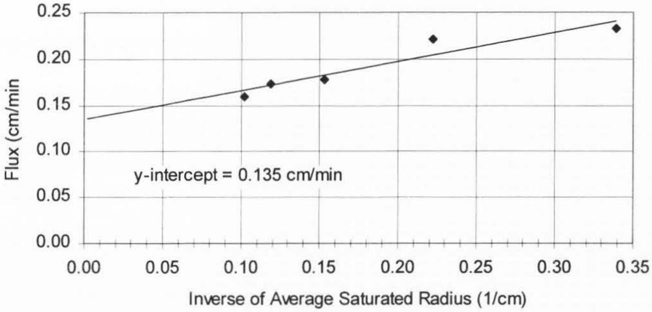


Fig. 16. Example of a hydraulic conductivity regression analysis (grazing hillslope, trial 3).

Table 8. Effective saturated hydraulic conductivity values.

Hillslope	Mean	Standard deviation	n
	mm hr^{-1}		
Burn	19.8	6.0	3
Unburned	49.8	9.6	3
Grazing	49.2	24.0	7
Military	26.4	28.8	6
Less-impacted	34.8	8.4	3
Apparent Maximum	72.5	15.1	5

that were used: initial conditions, grazing, and plants (Appendix G). Herbicide application and prescribed burning were not used.

Variables (Appendix G, Table 17) measured for initial conditions were initial residue mass and surface cover. Three randomly selected areas of 1 m^2 were delineated on each hillslope from which litter (rmogt) and standing biomass (rmagt) were collected separately, oven-dried (95°C for 24 h), and weighed

(Bonham, 1989). Three 10-m transects per hillslope were used to determine intersecting surface cover variables of the relative canopy/interspace areas and the fractions of bare soil, litter, rock, basal, and cryptogamic surface covers (resi, roki, basi, cryi, resr, rokr, basr, cryr, cancov). The remaining parameters (frdp, pptg, rrough, snodpy, thdp) were obtained from the literature (Ashcroft et al., 1992; Flanagan and Nearing, 1995).

Grazing variables (Appendix G, Table 18) included the area of cattle grazing (area), number of cattle (animal, bodywt), access to forage (access), digestibility (digmax, digmin), and grazing cycles (suppmt, jgraz, gday, gend). Most information was obtained from the Natural Resource Management Plan for Camp Williams (Utah National Guard, 1998) except for the digestibility parameters, which were obtained from Flanagan and Nearing (1995).

The plant variables (Appendix G, Table 19) were either measured or obtained from the literature (Tiedemann, 1986; Ashcroft et al., 1992; Flanagan and Nearing, 1995; or M. Caldwell, personal communication, 1998). The measured variables for this study were population and dimensional parameters. They were chosen on the basis of their sensitivity to the WEPP application as per Flanagan and Nearing (1995). Each plant was differentiated as a grass, shrub, or tree. The average number of plants was counted along a 100-m by 2-cm transect (gpop, spop, tpop). Then three typical plants in each category of grass, shrub, and tree were measured for plant variables of canopy diameter (gdiam, sdiam, tdiam) and canopy height (ghgt, shgt, thgt).

Results and Discussion

One-, three-, and ten-year WEPP simulations for each of the five study hillslopes were run. No ponding occurred in 11 of the simulations and less than 0.05 mm of ponding occurred in the other four. None of the simulations produced erosion. This occurred because hydraulic conductivity was sufficiently high to accommodate rainfall thus preventing overland flow.

The major components that control the amount of overland flow in WEPP are the amount of rainfall and the infiltration rate. Rainfall was well represented by the Bingham Canyon weather data but hydraulic conductivity may not have been as well represented. The WEPP application requires a single hydraulic conductivity value to represent a large area. Overland flow, and hence erosion, may not be accurately simulated on these study hillslopes due to a poor representation of the overall infiltration capacity of the hillslope, which is directly related to hydraulic conductivity. Meanwhile, other characteristics, such as canopy cover, fine-tune erosion estimates at a lower order of magnitude.

The hydraulic conductivity used for this analysis was based on three to seven point measurements taken *in situ* midslope on each hill via the dripper method. The average of these three or more point samples (about 20 cm diameter each) was used to represent an entire hillslope of 1.0 to 1.5 ha. By averaging a range of hydraulic conductivities, any measure of the spatial heterogeneity of the hillslope was effectively eliminated. Cow trails (very low infiltration rate), which represent 10% of the area on the grazing hillslope, were inadequately represented when averaged with the higher rates from the rest of the hillslope. Noticeable variability in the hydraulic conductivity measurements was observed on the grazing and military hillslopes despite the selection of sampling points that were absent of soil cracks. Additionally, the projection of these small samples onto a large area misrepresents surface cracks, rills, and canopy that may concentrate rainfall. These shortcomings in the overall infiltration estimates make it reasonable to assume that overland flow was not accurately simulated on these hillslopes.

Additional, more extreme simulations were required to use WEPP to compare the study hillslopes. Two rare event climate files were inputted into the WEPP application and applied to each hillslope for a total of 10 more simulations (Table 9). Defining a hundred-year storm is difficult because Bingham Canyon has only 40 years of climate data. Therefore, a hundred-year CLIGEN simulation and a large single storm (25.4 mm, 30 min duration, 1.5 min to maximum intensity) were used.

Table 9. Soil loss estimates from WEPP simulations.

Hillslope	100 y simulation	Large single storm
	------------- kg m^{-2}	----------------
Burn	0.023	0.202
Unburned	0.000	0.000
Grazing	0.000	0.000
Military	0.005	0.019
Less-impacted	0.001	0.000

The rare storm simulations indicated some erosion on the burn and military hillslopes. The WEPP-predicted soil loss on the burn hillslope was substantial and probably due to less vegetation and a lower hydraulic conductivity than the other hillslopes. However, the small differences in the erosion predictions between the military, grazing, and less-impacted hillslopes are not meaningful enough to compare the impacts of disturbance on erosion potential. The level at which WEPP adjusted soil loss values (0.001 kg m^{-2}) is very fine compared to the error associated with the hydraulic conductivity representation.

The evaluation of the measured hydraulic conductivities of the different disturbance regimes is more meaningful than the rare event simulations (Fig. 17). The burned and unburned hillslopes had significantly different hydraulic conductivity values which showed the impact of fire. The grazing hillslope shows

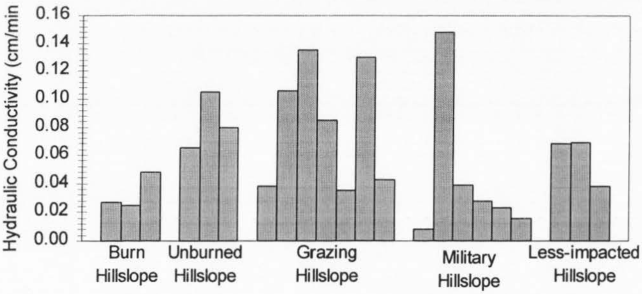


Fig. 17. Measured hydraulic conductivities on study hillslopes with each bar representing one point sample.

a group of lower rates likely representing areas heavily traversed by cattle, while the higher rates represent less traveled areas. The military hillslope exhibited lower hydraulic conductivities compared to the grazing and less-impacted hillslopes except for the single outlier. This outlier was probably the result of a measurement taken near the canopy in a location not easily traveled by foot. In summary, the variation in hydraulic conductivities on the five study hillslopes appears to be a function of the different disturbance regimes. The measured hydraulic conductivity values illustrated that different disturbances are reflected in physical soil properties that ultimately influence erodibility.

CHAPTER V

PHYSICAL MEASUREMENT OF EROSION WITH EROSION BRIDGES

Introduction

The best way to determine actual soil loss is through sediment yield measurements obtained from running water leaving a given area. However, Camp Williams is not conducive to direct sediment yield measurements because there is little running water. This situation required an alternative approach to estimating soil erosion on a hillslope such as the physical *in situ* measurement of soil loss/deposition. The third objective for this research was to measure soil erosion on the five study hillslopes by means of erosion bridges.

Methodology

The erosion bridge was used to determine soil loss or deposition by measuring the change in soil depth from a fixed reference point (Fig. 18). The portable unit of custom design was constructed of an aluminum rail approximately 1-m long with pipes on both ends to fit on a stationary foundation installed at each field location. When seated on the foundation, a wooden dowel was placed in each of 20 holes in the rail and measured to the nearest millimeter from the rail to the top of the rod. A change in height in subsequent measurements were assumed to be the depth of soil loss or deposition.

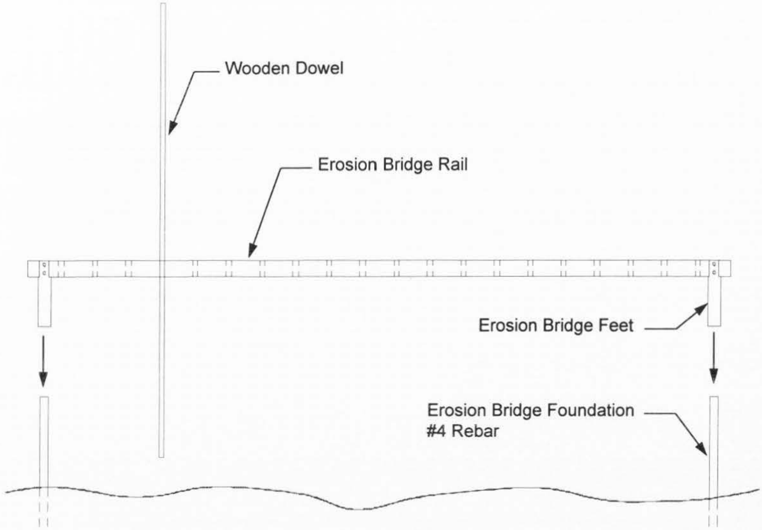


Fig. 18. Illustration of portable erosion bridge.

Two erosion bridge foundations were placed on the burn and unburned hillslopes and three foundations were placed on the grazing, military, and less-impacted hillslopes, for a total of 13 locations. The foundations were placed in such a way to divide each hillslope profile into equal increments. Data were collected with the erosion bridges for approximately 5 weeks during the fall of 1997 (17 September to 21 October) at 3- to 9-day intervals for a total of seven measurements per location.

Initial measurements were considered baseline values and subsequent measurements were converted to a change in soil depth from this initial measurement. The burn and unburned hillslopes were treated as a separate study group from the military, grazing, and less-impacted hillslopes because of different vegetation and relief characteristics.

Due to the erosion bridge design, the individual holes are not independent samples. Measurements for the individual 20 holes were considered as nested samples within each bridge location, and the erosion bridge locations constituted the true replication per hillslope (n = 2 or 3). The nested models treat the individual holes as samples nested within the bridge locations.

Results and Discussion

The results shown in Tables 10 and 11 are means, standard deviations, and ranges of change in soil depth for each hillslopes across time. The time intervals are the number of days since the initial measurement. The numbers in the tables illustrate the magnitude of the values obtained and at first glance suggest more net erosion on the burn and disturbed hillslopes compared to the unburned and less-impacted hillslopes. However, the observed differences are often small compared to measurement precision (0.1 cm). Additionally, more detailed statistics showed no statistically significant differences between the hillslopes.

The first statistical analysis performed on the erosion bridge data was a two-way ANOVA by hillslope and time interval to determine only if there was a

Table 10. Comparison of burned and unburned hillslopes by showing the mean, standard deviation, and range of change in soil depth from first erosion bridge measurement.

Time Interval	Burn †	Unburned †
days	cm	
3	-0.04 ± 0.58 (-1.2, 1.3)	0.26 ± 0.66 (-1.3, 1.9)
8	-0.02 ± 0.42 (-0.7, 0.9)	0.24 ± 0.55 (-1.1, 1.7)
11	-0.12 ± 0.47 (-1.1, 1.2)	0.01 ± 0.69 (-1.8, 2.1)
20	-0.08 ± 0.47 (-1.2, 1.0)	0.13 ± 0.62 (-1.9, 1.9)
27	0.01 ± 0.50 (-0.9, 1.4)	0.11 ± 0.56 (-1.4, 1.7)
32	-0.01 ± 0.50 (-1.0, 1.3)	-0.02 ± 0.52 (-1.7, 1.8)

† Based on two bridges for each hillslope with 20 sample points per bridge (n=40).

Table 11. Comparison of grazing, military, and less-impacted hillslopes by showing the mean, standard deviation, and range of change in soil depth from first erosion bridge measurement.

Time Interval	Grazing †	Military †	Less-impacted †
days		cm	
3	-0.01 ± 0.75 (-3.0, 3.0)	-0.11 ± 0.28 (-1.4, 0.4)	0.08 ± 0.35 (-0.6, 1.8)
8	0.06 ± 0.79 (-2.9, 2.9)	-0.03 ± 0.38 (-1.3, 1.3)	0.15 ± 0.54 (-0.6, 3.5)
11	-0.21 ± 0.81 (-2.9, 2.7)	-0.10 ± 0.25 (-0.8, 0.6)	0.08 ± 0.36 (-0.7, 1.6)
20	-0.09 ± 0.82 (-2.8, 3.3)	-0.13 ± 0.36 (-0.9, 1.3)	-0.17 ± 0.37 (-1.5, 1.4)
27	-0.06 ± 0.78 (-2.8, 3.0)	-0.13 ± 0.50 (-3.0, 1.2)	0.08 ± 0.32 (-0.9, 0.9)
32	-0.08 ± 0.79 (-2.9, 2.7)	-0.23 ± 0.55 (-3.2, 0.9)	0.02 ± 0.42 (-1.0, 1.6)

† Based on three bridges for each hillslope with 20 sample points per bridge (n=60).

significant interaction between hillslope and time interval. In both the comparison between the burn and unburned hillslopes (model one) and between the military, grazing, and less-impacted hillslopes (model two), there was no significant interaction between the effect of hillslopes and time interval (Table 12). This implied that hillslope effects, if existing, were not significantly influenced by the time interval chosen.

Table 12. Two-way ANOVA for hillslope and time interval. Model one is for the comparison of the burn and unburned hillslopes. Model two is for the comparison of grazing, military, and less-impacted hillslopes.

Source	DF	Sum of squares	F value	P > F
Model One (n=480)	11	6	1.88	0.0394
Error	468	142	-	-
Corrected Total	479	148	-	-
Time Interval	5	2	1.22	0.3003
Hillslope	1	3	10.52	0.0013
Hillslope and Time Interval	5	1	0.82	0.5348
Model Two (n=1080)	17	12	2.27	0.0023
Error	1062	335	-	-
Corrected Total	1079	347	-	-
Time Interval	5	4	2.67	0.0208
Hillslope	2	5	7.32	0.0007
Hillslope and Time Interval	10	3	1.06	0.3874

In a subsequent analysis the effect of time interval alone was not further considered because of the short study period and lack of eroding rainfall during that time. This is further illustrated by Figure 19, which showed no consistent pattern or cumulative erosion effect with time, irrespective of location, and/or hillslope.

The next statistical analysis was a nested ANOVA to compare erosion between hillslopes for the sixth (longest) time interval (Table 13). Based on the outcome of the two-way ANOVA, results for the other time intervals were not expected to be different. This analysis failed to reject the null hypothesis that the hillslope treatments are equal. There was no statistically significant difference in soil depth change between either the burned and unburned hillslopes or between the grazing, military, and less-impacted hillslopes.

It is doubtful that these results would be meaningful even if statistically significant differences were found. The erosion bridge measured a relatively fine phenomenon with a relatively coarse tool. The magnitude of observed differences (Tables 10 and 11) was often small compared to the measurement error. The erosion bridge lacks the capability of measuring erosion at the low rates occurring on the study hillslopes over a short time period (Fig. 20).

In addition to lack of precision, this methodology had several problems that make it difficult to equate soil depth values with the actual amounts of soil

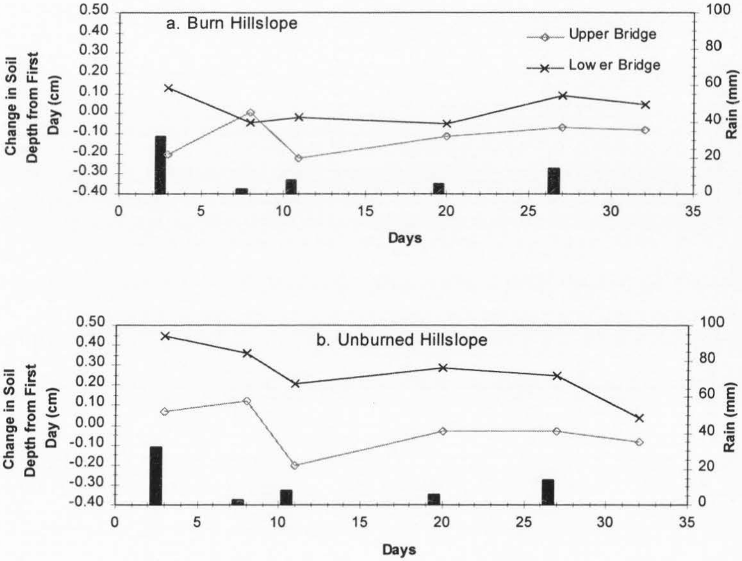


Fig 19. Cumulative mean change in soil depth with time for each bridge location (n = 20). Rainfall events are shown by the bars on the x-axis.

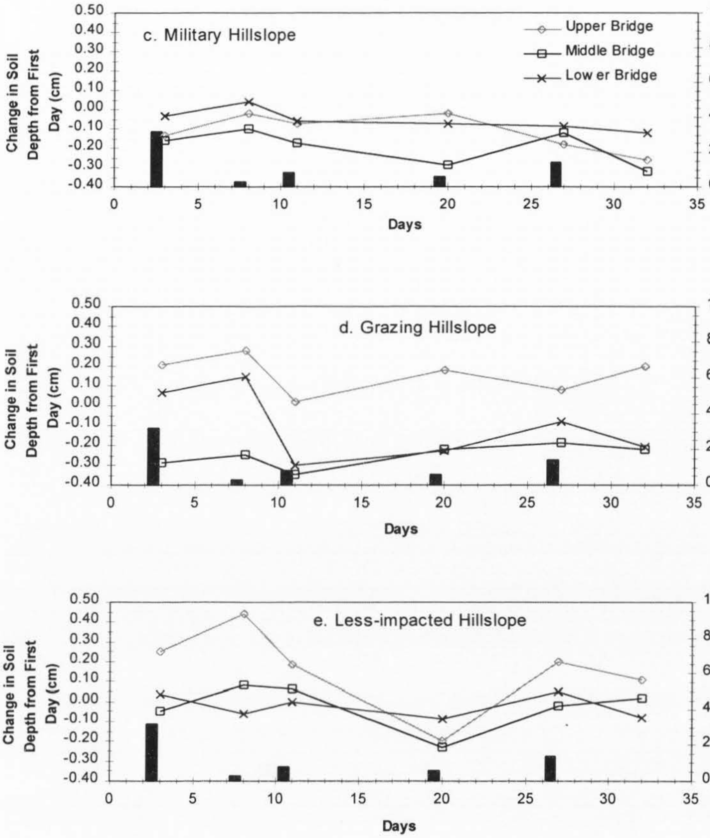


Fig 19. continued.

Table 13. Nested ANOVA for hillslope and location during the sixth time interval. Model one is for the comparison of the burn and unburned hillslopes. Model two is for the comparison of grazing, military, and less-impacted hillslopes.

Source	DF	Sum of squares	F value	P > F	Mean squares	Variance component	Percent of total
Model One (n=80)	79	20	-	-	0.26	0.264	100.0
Hillslope	1	0	0.001	0.9787	0.00	-0.003	0.0
Location	2	0	0.524	0.5943	0.14	-0.006	0.0
Error	76	20	-	-	0.26	0.264	100.0
Model Two (n=180)	179	67	-	-	0.38	0.378	100.0
Hillslope	2	2	1.894	0.2303	0.94	0.007	1.9
Location	6	3	1.367	0.2305	0.50	0.007	1.8
Error	171	62	-	-	0.36	0.365	96.3

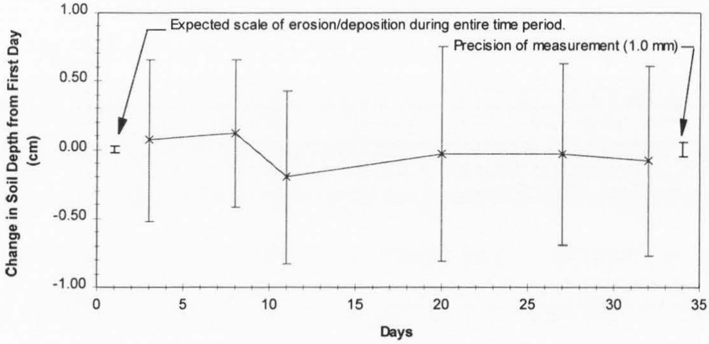


Fig. 20. Graph comparing the variability of the mean erosion bridge measurements to the expected scale of erosion/deposition for the entire time period. The measurements are for the unburned, up-slope bridge with standard deviation for the 20 holes indicated by the error bars.

loss and deposition. First, the space between the wooden dowel and the wall of the hole in the bridge allowed the dowel to hit the surface of the ground in various locations. This made replication of measurements implausible. The problem was amplified with some poorly oriented foundations that were not perpendicular to the ground.

Another problem was the movement of stones in or out of sample locations due to soil creep. This provided very good evidence for the occurrence of soil creep at Camp Williams but added variability to the measurements. Yet another problem was the swelling of high clay content soils during wet conditions. These problems resulted in measurements that were highly variable, seldom reproducible, and unreasonable estimates of soil movement that were not supported by visual evidence.

In this study, the erosion bridge analysis did not prove to be useful in evaluating soil erosion on the study hillslopes over a short period of time. The instrument and approach may be more suitable for measuring erosion in rills, gullies, and extremely degraded sites, or during long-term studies.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Soil erosion was assessed at Camp Williams National Guard Base by creating an erosion risk classification map and comparing the erosion impact of disturbance regimes on different hillslopes. Soil erosion does not appear to be a problem for most of Camp Williams. Areas of concern include landscapes with little or no protective vegetation such as roads, abandoned agricultural fields, and sensitive riparian areas where gullies tend to form and expand.

The use of GIS and the RUSLE was an excellent strategy for evaluating soil erosion risk for Camp Williams. The erosion risk maps indicated where the erosion potential is greatest and which problem areas need to be addressed. The analysis that created the map required minimal field data collection and yielded results that can be used to make informed management decisions. Other researchers have used these technologies together (Warren et al., 1989; Mellerowicz et al., 1994; Jones et al., 1996) but unlike these prior efforts, this work integrated objective slope length calculations and the landuse impacts of military and grazing activities into the risk analysis.

The RUSLE/GIS analysis methodology presented in this thesis can be applied in other areas, but its coarse scale and lack of quantitative accuracy should be noted. Additionally, an adequate GIS database with coverages for vegetation, soils, and roads is prerequisite for a soil erosion risk analysis at other installations.

Future research should be directed towards improving GIS coverages for the RUSLE factors. Up-to-date vegetation coverages, better digital elevation models, and a more detailed soil survey will provide improved results in the erosion risk analysis and should be implemented when available.

Additional work can be directed towards refining factors and coverages, particularly the C factor coverage. Some steps can be taken to improve the data set for creating RUSLE factor coverages at Camp Williams as well as other military bases. Additional LCTA protocols to collect soil and geomorphologic data every 5 or 10 years would provide excellent resources for erosion risk analysis. For example, a qualitative evaluation of soil erosion (e.g. "no erosion," "excessive erosion," etc.) requires minimal training and time but can be used to ground truth a GIS analysis. A larger commitment of time and effort can yield valuable data by measuring some of the variables for the C subfactors at representative plots. The number of years since the last disturbance, type of disturbance, and surface roughness can all be evaluated or measured as part of a standard LCTA protocol.

The VM factor can also be enhanced with a more sophisticated road coverage and by improving the P factor coverage. Warrington et al. (1980) provides several VM factor estimates for roads under different conditions of slope, chemical treatment, and mechanical manipulation (VM = 0.7 to 1.3). The

VM factor values can be assigned to a road coverage classified in terms of erosion potential. Better P factor values can be obtained by equating particular activities with degree of erosion impact. This can be done by studying the impacts of sheep grazing, prescribed burning, fire suppression, and a host of military activities. Part of this effort should be directed towards maintaining accurate RFMSS data with details about specific activities. Using these data in combination with vehicle usage records could provide a more detailed P factor coverage.

Application of the WEPP model to hillslopes and the erosion bridge experiment did not prove to be useful in evaluating soil erosion at Camp Williams. Some of the detailed data collected for these tasks were nevertheless useful in providing insight to some of the physical processes of erosion.

The WEPP model did not appear to function well on the Camp Williams study hillslopes because of the distribution of infiltration rates that could not be satisfactorily represented. The hydraulic conductivity value is a critical factor in a WEPP simulation. In order for overland flow, and hence erosion, to occur, rainfall must exceed infiltration. Therefore, the amount of overland flow in WEPP is directly related to hydraulic conductivity while other characteristics fine-tune erosion estimates at a lower order of magnitude. The WEPP model is more useful for different erosion analysis such as roads (Zalewsky, 1998) where a relatively low and uniform hydraulic conductivity is factored out.

The hydraulic conductivity measurements were meaningful in the comparison of disturbance regimes on the study hillslopes for this project. They reflected some physical characteristics in soil properties as the result of different disturbances.

The erosion bridge experiment failed to yield statistically significant results to compare the erosion impacts of disturbance. The bridges lacked the capability of measuring erosion at the low rates occurring on the study hillslopes during the time period set for this experiment. However, the methodology showed potential for measuring erosion in rills, gullies, highly disturbed areas, or longer duration experiments.

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APPENDICES

Appendix A

Soil Mapping Units

and Their Associated K Factor Values

Table 14. Camp Williams soil mapping units and their associated K factor values converted to units of t ha h ha^{-1} MJ^{-1} mm^{-1}.

Code	Mapping Unit	K value
AaF	Agassiz very stony loam, 30 to 70% slopes	0.013
AmE	Atepic Shaly loam, 10 to 40% slopes	0.026
BDG	Bradshaw gravelly sandy loam, 40 to 70% slopes	0.020
BEG	Bradshaw-Agassiz Association, steep	0.013
Bf	Birdow loam	0.049
BFF	Butterfield extremely stony loam, 5 to 50% slopes	0.013
BgA	Bingham loam, 1 to 3% slopes	0.037
BgC	Borvant cobbly loam, 2 to 8 % slopes	0.022
BgD	Borvant cobbly loam, 8 to 25% slopes	0.022
BhA	Bingham gravelly loam, 1 to 3% slopes	0.022
BhB	Bingham gravelly loam, 3 to 6% slopes	0.032
BhD	Borvant-Reywat complex, 8 to 30% slopes	0.022
BkB	Bingham gravelly loam, 1 to 3% slopes	0.020
BkC	Bingham extremely stony loam, 3 to 10% slopes	0.013
BnD	Broadhead loam, 3 to 25% slopes	0.042
Br	Bramwell silty clay loam	0.049
BuE	Butterfield soils, 0 to 25% slopes	0.013
CaB	Calita loam, 2 to 4% slopes	0.042
CaC	Calita loam, 4 to 8% slopes	0.042
CaD	Calita loam, 8 to 15% slopes	0.042
CbF	Calpac-Agassiz complex, 30 to 70% slopes	0.013
CG †	Cumulic Haploxerolls, sloping	0.016
CrD	Cleverly cobbly sandy loam, 6 to 15% slopes	0.020
CsC	Cleverly gravelly fine sandy loam, 3 to 6% slopes	0.020
CsD	Cleverly gravelly fine sandy loam, 6 to 15% slopes	0.020
DaC	Dagor Loam, 2 to 8% slopes	0.037
DbD	Deer Creek cobbly loam, 6 to 25% slopes	0.020
DcD	Deer Creek-Borvant complex, 2 to 25% slopes	0.020
DdC	Donnardo stony loam, 2 to 8% slopes	0.020
DEF	Dry Creek extremely stony loam, stony subsoil variant, 6 to 30% slopes	0.007
DhD	Dry Creek cobbly loam, 4 to 15% slopes	0.026
DkD	Dry Creek-Reebok complex, 4 to 15% slopes	0.026
FcF	Flygare-Parkay rock outcrop complex, 30 to 70% slopes	0.042
GEG	Gappmayer very cobbly loam, 30 to 60% slopes	0.013
GGG	Gappmayer-Wallsburg association, very steep	0.007
HaF	Hamtah loam, 30 to 70% slopes	0.037
HDF	Harkers-Dry Creek association, moderately steep	0.013
HeC	Hillfield silt loam, 2 to 5% slopes	0.065
HfC	Hillfield sandy loam, 2 to 6% slopes	0.026
HfD	Hupp gravelly loam, 8 to 15% slopes	0.020
HHF	Harkers soils, 6 to 40% slopes	0.013
HIC	Hillfield loam, 3 to 6% slopes	0.042
HKF	Henefer-Harkers association, moderately steep	0.020
HmE	Hillfield silt loam, 10 to 20% slopes	0.057
HmF	Hillfield silt loam, 20 to 30% slopes	0.057
HNF	Henefer-Horrocks complex, 5 to 50% slopes	0.013
HOF	Hillfield-Sterling complex, 20 to 35% slopes	0.057
HpF	Hillfield-Welby silt loam, 6 to 35% slopes	0.057
HtF2	Hillfield-Taylorsville complex, 6 to 30% slopes, eroded	0.042

HWF	Horrocks extremely stony loam 5 to 50%	0.013
HXF	Horrocks-Little Pole association, steep	0.007
JbB	Juab loam, 2 to 4% slopes	0.037
JbC	Juab loam, gravelly substratum, 2 to 4% slopes	0.037
JcC	Juab loam, gravelly substratum, 4 to 8% slopes	0.037
JeD	Justesen loam, 4 to 15% slopes	0.042
KaB	Keigley silt loam, dry, 0 to 2% slopes	0.049
KaC	Kearns silt loam, 3 to 6% slopes	0.049
KdB	Kidman very fine sandy loam, 1 to 3% slopes	0.037
KRE2	Kilburn gravelly fine sandy loam, 15 to 30% slopes, eroded	0.020
LdE	Lodar-Rock outcrop complex, 3 to 30% slopes	0.013
LdF	Lodar-Rock outcrop complex, 30 to 70% slopes	0.013
LeD	Layton loamy fine sand, 6 to 15% slopes	0.022
LeF	Lundy-Rock outcrop complex, 30 to 70% slopes	0.013
LfC	Layton fine sandy loam, 1 to 6% slopes	0.026
LmA	Layton fine sandy loam, slowly permeable substratum, 0 to 1% slopes	0.026
MrB	Mountainville, sandy substratum-Doyce complex, 2 to 4% slopes	0.026
MU †	Mixed Alluvial land	0.013
PaB	Parleys loam, 0 to 3% slopes	0.037
PaC	Parleys loam, 3 to 6% slopes	0.037
PbC	Parleys gravelly loam, overwashed, 3 to 6% slopes	0.020
PcB	Parleys silty clay loam, 0 to 3% slopes	0.037
PeA	Parleys silt loam, 0 to 3% slopes	0.057
PeB	Parleys silt loam, 3 to 6% slopes	0.057
PfA	Parleys loam, 0 to 2% slopes	0.049
PfB	Parleys loam, 2 to 4% slopes	0.049
PfC	Parleys loam, 4 to 8% slopes	0.049
PhB	Pleasant Grove gravelly loam, 2 to 6% slopes	0.020
PK †	Pits-Dumps complex	0.046
PoC	Pleasant Vale loam, extended season, 3 to 6% slopes	0.042
PrD	Pleasant Vale gravelly sandy loam, extended season, 1 to 3% slopes	0.020
RaE	Reebok cobbly loam, 15 to 40% slopes	0.026
ReC	Redola gravelly loam, 3 to 6% slopes	0.022
ReE	Reywat-Rock outcrop complex, 10 to 30% slopes	0.013
SgD	Sterling gravelly fine sandy loam, 3 to 6% slopes	0.020
SkF	Sheep Creek very cobbly loam, dry, 30 to 70%	0.013
SNG	Sterling-Terrace escarpments complex, 30 to 70% slopes	0.020
SP †	Stony terrace escarpments	0.059
SsE	Sumine-Reywat-rock complex, 10 to 30% slopes	0.013
SsF	Sumine-Reywat-rock complex, 30 to 60% slopes	0.013
St †	Stony Alluvial land	0.001
TaA	Taylorsville silt loam, 0 to 2% slopes	0.057
TaB	Taylorsville silt loam, 2 to 4% slopes	0.057
TaC	Taylorsville silt loam, 4 to 8% slopes	0.057
TbB	Taylorsville silty clay loam, gravelly substratum, 1 to 3% slopes	0.037
TcC2	Taylorsville silty clay loam, extended season, 3 to 6% slopes, eroded	0.049
TmB	Timpanogos loam, 0 to 3% slopes	0.042
TuB	Timpanogos loam, 3 to 6% slopes	0.037
VsA	Vinyard fine sandy loam, moderately saline, 0 to 2% slopes	0.042
W †	Perrenial Pond	0.000
WAG	Wallsburg very cobbly loam, 30 to 70% slopes	0.007
WbA	Welby silt loam, 0 to 1% slopes	0.057

WbB	Welby silt loam, 1 to 3% slopes	0.057
WbC	Welby silt loam, 3 to 6% slopes	0.057
WcF	Wallsburg-Rock outcrop complex, 25 to 70% slopes	0.013
WdE	Wallsburg-Yeates Hollow complex, 25 to 40% slopes	0.013
WeC	Welby silt loam, extended season, 3 to 6% slopes	0.057
WeD2	Welby silt loam, extended season, 6 to 10% slopes	0.057
WgD	Wasatch loamy coarse sand, 1 to 10% slopes	0.013
WhD	Welby-Hillfield silt loam, 6 to 10% slopes	0.057
WhE	Welby-Hillfield silt loam, 10 to 30 %	0.057
YaD	Yeates Hollow very stony loam, 10 to 25% slopes	0.013
YaE	Yeates Hollow very stony loam, 25 to 40% slopes	0.013

† These mapping units do not have K factor values from the NRCS, therefore they were estimated based on soil properties and characteristics of the associated landscape.

Appendix B

Equations for the RUSLE Slope Factors

1. Slope length (L) as determined from an algorithm by Renard et al. (1996):

$$L_i = \frac{x^m[\,i^{m+1} - (i-1)^{m+1}\,]}{22.13^m}$$

where: L_i = the slope length factor for the cell at ith segment
x = the length of the grid cell (m)
m = the slope length exponent

2. Slope length (L) as determined from an algorithm by Desmet and Govers (1996):

$$L_{ij} = \frac{(A_{ij\text{-}in} + D^2)^{m+1} - A_{ij\text{-}in}^{\;m+1}}{D^{m+2} * x_{ij}^{\;m} * 22.13^m}$$

where: L_{ij} = the slope length factor for the cell at coordinates $x = i$ $y = j$
$A_{ij\text{-}in}$ = the contributing area at the inlet of the grid cell (m^2)
D = the grid cell size (m)
m = the slope length exponent
x_{ij} = the contour length $(|\sin \alpha_{ij}| + |\cos \alpha_{ij}|)$

where: α_{ij} = aspect direction of grid cell

3. The slope length exponent (m) is a function of the ratio of rill and interrill erosion (Weltz et al., 1987). It is determined as follows:

$$m = \beta / (1 + \beta)$$

where: $$\beta = \frac{(\sin \theta / 0.0896)}{(2.96 * \sin^{0.79} \theta + 0.56)}$$

where: θ = the angle of the slope

4. Slope steepness (S) as determined from an equation by McCool et al. (1987):

$$S = 10.8 \sin\theta + 0.03 \quad \text{for slopes} < 9\%$$
$$S = 16.8 \sin\theta - 0.50 \quad \text{for slopes} >= 9\%$$

where: θ = the angle of the slope

5. Slope steepness (S) as determined from an equation by Liu et al. (1994):

$$S = 21.91 \sin\theta - 0.96$$

where: θ = the angle of the slope

6. Slope steepness (S) as determined from an equation by Nearing (1997):

$$S = -1.5 + \frac{17}{1 + \exp(2.3 - 6.1 \sin\theta)}$$

where: θ = the angle of the slope

Appendix C

Slope Factors ARC Macro Language Program

```
/* RUSLE_LS.AML by Kevin Bartsch, Tom Van Niel and Nanette Bergeron, July 1998
/* Utah State University, Logan UT. Inquiries at SLV1V@cc.usu.edu
/* Revision 980811B
/* This AML is designed to calculate the slope length and slope steepness
/* factors for the Universal Soil Loss Equation.  It utilizes a DEM grid coverage and returns
/* a grid coverage for each of the two factors plus a third coverage for the two factors
/* multiplied together with a user inputted maximum value. There are two equations for
/* each factor to choose from. Choose from Desmet or Renard for slope length.  Choose from
/* McCool for slopes 1 to 18% or Nearing for slopes upto 55% for slope steepness.

/*THE AUTHORS MAKE NO CLAIM TO THE ACCURACY OR EFFECTIVENESS OF
/*THIS AML OR THE EQUATIONS WITHIN.... DISTRIBUTE FREELY, USE AT YOUR
/*OWN RISK AND YOU WILL GET AT LEAST WHAT YOU PAID FOR!

/*NOTE: 1)Consider removing the sinks from your DEM with the fill option. See "Creating a
/*depressionless DEM" in the ARC/INFO user documentation. 2)The maximum number of cells
/*for flow accumulation will greatly effect how much channelization occurs. Try values between
/*10 and 25 and consider the reality of your results.

/* REFERENCES:
/*Desmet, P.J. and G. Govers. 1996. A GIS procedure for automatically calculating the USLE
/*LS factor on topographically complex landscape units. J. Soil and Water Cons. 51:427-433.

/*McCool, D.K., L.C. Brown, G.R. Foster, C.K. Mutchler and L.D. Meyer. 1987. Revised
/*slope steepness factor for the Universal Soil Loss Equation. Trans. ASAE 30:1387-1396.

/*Nearing, M.A. 1997. A single continuous function for slope steepness influence on soil loss.
/*Soil Sci. Soc. Am. J. 61:917-919.

/*Renard, K.G., G.R. Foster, G.A. Weesies, DK. McCool and D.C. Yoder. 1996. Predicting
/*soil erosion by water: a guide to conservation planning with revised universal soil loss equation
/*(RUSLE). USDA Agriculture Handbook 703. 384 pp.

/*----------------------------------------------------------------------------------------------------------------------
/* PROGRAM INTIATION
&type Read the header of this AML for information about input variables
&if [show program] ne ARC &then
 &call bailout4
&terminal 9999
grid

/* COMMANDS TO GET USER VARIABLES
&setvar ingrid = [getgrid * -sort 'Select input DEM from this directory']
&setvar gridsize = [response 'Input grid size in meters']
&setvar outsl = [response 'Name of output coverage for slope length']
&setvar outss = [response 'Name of output coverage for slope steepness']
&setvar fill_option =  [getchoice yes no -prompt 'Do you wish to fill the sinks in your DEM?']
&setvar max_value = [response 'Enter the maximum value for the flow accumulation (try 10)']
&setvar interm_files =  [getchoice yes no -prompt 'Do you wish to delete the intermediate files?']
&setvar slope_len = [getchoice Desmet Renard -prompt 'Choose slope length equation.']
&setvar slope_stp = [getchoice McCool Nearing -prompt 'Choose slope steepness equation.']
```

```
/* ERROR TRAPPING STUFF
&if [null %gridsize%] &then
  &call bailout1
&if [null %outsl%] &then
  &call bailout1
&if [null %outss%] &then
  &call bailout1
&if [null %max_value%] &then
  &call bailout1
&if [exist %outsl% -grid] &then
  &call bailout2
&if [exist %outss% -grid] &then
  &call bailout3

/* HOUSE KEEPING STUFF
&type Deleting old intermediate files...
&call delete_files

/* GENERAL CALCULATIONS
&type Calculating the contributing cells...
&if %fill_option% = 'yes' &then
 &call fill
&if %fill_option% = 'no' &then
 &call notfill
DOCELL
if (xxflowacc >= %max_value%)
   xxcells = %max_value%
else
   xxcells = xxflowacc
END

&type Calculating the sine of slope angle...
 xxsin_theta = sin(int(slope (xxingrid, degree)) div deg)

&type Calculating the slope length exponent...
 xxbeta = (xxsin_theta / 0.0896) div (2.96 * pow(xxsin_theta, 0.79) + 0.56)
 xxm = xxbeta / (1 + xxbeta)

&if %slope_len% = 'Desmet' &then
 &call desmet
&if %slope_len% = 'Renard' &then
 &call renard

&if %slope_stp% = 'Nearing' &then
 &call nearing
&if %slope_stp% = 'McCool' &then
 &call mccool
```

```
/*STATS FILE MAKER
&watch stats.wat
&listvar
&type These are stats for slope length; describe %outsl%
&type These are stats for slope steepness; describe %outss%
&watch &off

/* WRAP UP
&if %interm_files% = 'yes' &then
 &call delete_files

&type Program Complete.
q
&return

/*------------------------------------------------------------------------------------------------------------------------
/* ROUTINES FOR FLOW ACCUMULATION AND SINK FILLING
&routine fill
 fill %ingrid% xxfilled
 xxflowacc = flowaccumulation (flowdirection (xxfilled))
 xxingrid = xxfilled
&return

&routine notfill
 xxflowacc = flowaccumulation (flowdirection (%ingrid%))
 xxingrid = %ingrid%
&return

/* ROUTINES FOR SLOPE LENGTH
&routine desmet
 &type Calculating the contributing area...
 xxarea = xxcells * (pow(%gridsize%,2))

 &type Calculating the aspect...
 xxaspect = abs(sin(int(aspect(xxingrid)) div deg)) + abs(cos(int(aspect(xxingrid)) div deg))

 &type Calculating the slope length factor with the Desmet equation...
 %outsl% = (pow((xxarea + pow(%gridsize%,2)),(xxm + 1)) - pow(xxarea,(xxm + 1))) ~
 div (pow(%gridsize%,(xxm + 2)) * pow(xxaspect,xxm) * pow(22.13,xxm))
&return

&routine renard
 &type Calculating the slope length factor with the RUSLE equation...
 %outsl% = (pow(%gridsize%,xxm) * (pow((xxcells + 1),(xxm + 1)) - pow(xxcells,(xxm + 1)))) ~
 div (pow(22.13,xxm))
&return

/*  ROUTINES FOR SLOPE STEEPNESS
&routine nearing
 &type Calculating the slope steepness factor with the Nearing Equation...
 %outss% =  (17 div (1 + exp(2.3 - (6.1 * xxsin_theta)))) - 1.5
&return
```

```
&routine mccool
  &type Calculating the slope steepness factor with the McCool Equation...
  xxslope_perc = int(slope(xxingrid, percentrise))
DOCELL
if (xxslope_perc >= 9)
    %outss% = (xxsin_theta * 16.8) - 0.50
else
    %outss% = (xxsin_theta * 10.8) + 0.03
END
&return

/*ROUTINE TO DELETE INTERMEDIATE FILES
&routine delete_files
&if [exist xxarea -grid] &then
  kill xxarea all
&if [exist xxsin_theta -grid] &then
  kill xxsin_theta all
&if [exist xxbeta -grid] &then
  kill xxbeta all
&if [exist xxm -grid] &then
  kill xxm all
&if [exist xxaspect -grid] &then
  kill xxaspect all
&if [exist xxslope_perc -grid] &then
  kill xxslope_perc all
&if [exist xxcells -grid] &then
  kill xxcells all
&if [exist xxflowacc -grid] &then
  kill xxflowacc all
&if [exist xxfilled -grid] &then
  kill xxfilled all
&if [exist xxingrid -grid] &then
  kill xxingrid all
&return

/* BAILOUT ROUTINES
&routine bailout1
  &type An error has occured. Terminating Program!
&stop
&routine bailout2
  &type Output file for slope length already exist. Terminating Program!
&stop
&routine bailout3
  &type Output file for slope steepness already exist. Terminating Program!
&stop
&routine bailout4
  &type Program must be run from ARC. Terminating !
&stop
```

Appendix D

Equations for the RUSLE Cover and Management Factor

1. Cover and Management (C) as determined from the RUSLE handbook (Renard et al., 1996):

$$C = PLU * CC * SC * SR * SM$$

where:
PLU = the prior landuse subfactor
CC = the canopy cover subfactor
SC = the surface cover subfactor
SR = the surface roughness subfactor
SM = the soil moisture subfactor for time varying analysis which is not applicable to rangelands

2. Prior landuse (PLU) as determined from Weltz et al. (1987):

$$PLU = (1- (Y * 0.55/T)) * \exp (-0.012 * RS)$$

where:
Y = years since disturbance
T = total years in which the disturbance diminishes
RS = underground biomass in top 100 mm of soil (kg ha^{-1} mm^{-1})

3. Canopy cover (CC) as determined from the RUSLE handbook (Renard et al., 1996):

$$CC = 1 - F_c * \exp (-0.1 * H)$$

where:
F_c = fraction of land surface covered by canopy
H = canopy height (ft)

4. Surface cover (SC) as determined from the RUSLE handbook (Renard et al., 1996):

$$SC = \exp [-b * S_p * (0.24/R_u)^{0.08}]$$

where:
b = empirical coefficient
S_p = fraction of land covered by surface cover
R_u = surface roughness (in)

5. Surface roughness (SR) as determined from the RUSLE handbook (Renard et al., 1996):

$$SR = \exp [-0.66 * (R_u - 0.24)]$$

where:
R_u = surface roughness (in)

Appendix E

Variables and Subfactors for the RUSLE Cover and Management Factors

Table 15. Variables and subfactors used to calculate the C factor values.

Cover type	C	Y †	T †	RS	PLU	F_c ‡	H ‡	CC	b §	S_p ‡	R_u §	SC	SR
		---- y ----		kg ha^{-1}		fraction	ft			fraction	in		
Oakbrush	0.004	NA	NA	308 ¶	0.011	0.67	2.65	0.486	0.039	0.71	0.80	0.975	0.691
Riparian	0.005	NA	NA	250 #	0.022	0.95	1.97	0.220	0.039	0.95	0.24	0.964	1.000
Mixed Oakbrush and Sagebrush	0.006	NA	NA	266 ††	0.019	0.61	1.81	0.491	0.039	0.66	0.95	0.977	0.626
Sagebrush	0.006	NA	NA	223 ‡‡	0.031	0.76	1.90	0.371	0.039	0.74	1.10	0.975	0.567
Mixed Sagebrush and Grass	0.080	NA	NA	36 ‡‡	0.292	0.64	1.45	0.446	0.039	0.69	0.95	0.976	0.626
Mixed Grass and Herbs	0.086	NA	NA	12 §§	0.390	0.74	0.98	0.329	0.039	0.82	0.80	0.971	0.691
Juniper	0.106	NA	NA	72 §§	0.190	0.61	8.06	0.728	0.039	0.67	0.60	0.976	0.789
Vegetated Agriculture	0.192	1 ¶¶	10	20 §	0.747	0.55	0.80	0.492	0.060	0.30	1.20	0.984	0.531
Disturbed Ground	0.328	5 ##	10	7 #	0.671	0.20	0.60	0.812	0.039	0.20	1.00	0.993	0.606

Notes:

† Cover types with NA are considered undisturbed areas.
‡ Compiled from LCTA data or estimated for areas with no data available.
§ From Renard et al., 1996
¶ From Tiedemann et al., 1987
# Estimate
†† Weighted average from Tiedemann et al., (1987) for oakbrush and Arnold et al., (1995) for sagebrush.
‡‡ From Arnold et al., 1995
§§ From Tiedemann, 1986
¶¶ Active agricultural fields are disturbed annually by cultivation.
Assumed to be disturbed by cultivation before Camp Williams boundaries were redefined five years ago.

Appendix F

Procedure for Creating a WEPP/CLIGEN Statistics File

This is a procedure for converting raw weather data into CLIGEN statistics for the WEPP application. The SAS program uses an ASCII data file to generate a chart with the values for the first nine parameters in a CLIGEN statistics file. There are additional CLIGEN parameters but most climate data do not contain adequate information for these parameters. Other important parameters not created by this procedure include the maximum half hour rainfall intensity (MX .5 P) and time to peak intensity (Time Pk). They will have an influence on the WEPP outcome. The best way to accommodate these two parameters is by choosing an existing climate station that best matches your site for these characteristics and copying it for your base data.

1. Obtain or produce a climate records file (down load from the internet)
    a. Go to the WEB page to download the data - http://climate.usu.edu
    b. Navigate to the downloadable database page (Climate Data Access)
    c. Pick state or area
    d. Pick the station of interest
    e. Enter the desired years
    f. At this point the data should be seen on the screen

2. Observe the data and consider the formatting. The SAS program is setup for some default formatting. Check for these defaults so you can adjust the SAS program as needed.
    a. Note the weather station code number for reference
    b. Comma delimited (dlm=',')
    c. Fourteen lines of header (firstobs=15)
    d. Nineteen fields, data must match SAS program (input ctry station...)
    e. Be sure the following four fields correspond to the field names (note discrepancies):
        mn$ = month (field 4)
        dtotpcpn = amount of daily precipitation (field 6)
        dmxartmp = daily maximum air temperature (field 12)
        dmnartmp = daily minimum air temperature (field 14)
    f. Save the file (note the file and path name and enter them into the SAS program)

3. Adjust the SAS program as needed and run it. The result should be a chart with a column for each month and nine rows of variables.

4. Copy the CLIGEN state file in which you have your study site. The state files are found in the \wepp\input\climate\cligen directory. Name it with the two letter state code followed by "_old" leaving it in the same directory (e.g. UT is copied to UT_old).

5. Edit the original file in an ASCII editor. Try DOS-Edit because most word processors add unwanted characters to ASCII files and this is detrimental to your objective. Also be careful not to add extra characters or blank spaces.
    a. Choose the weather station that best represents your study area in terms of elevation and regional aspect. Copy the statistics for that station to the top of the file.
    b. Change the name of the station in the newly copied section. Although it will have no effect on what CLIGEN does, the station code number, longitude, latitude, elevation and number of years should be changed to match the new weather station. Be sure that the station number begins at position 42 in the file.
    c. Change the numbers for the first nine parameters in the statistics file based on the values from the SAS chart.

6. Save the file and try it in WEPP.

```
/*SAS procedure for converting climate data to CLIGEN stats*/
/*by: Susan Durham and Kevin Bartsch, October 1998, Rev. A*/

/*Download data from http://climate.usu.edu or prepare your own data file*/
/*The infile command reads comma deliminated ASCII files*/
/*The first 14 lines of the data file are ignored - change as needed*/
/*The number of fields (19) corresponds with the internet database - change as needed*/
/*Change non-data values (in this case -99999) as needed*/
/*Important fields:#4=month;#6=daily precip;#12=daily max temp;#14=daily min temp*/

/* Read data from external ASCII file */
data a;
 infile 'a:\climate.dat' firstobs=15 dlm=',';
 input ctry station year mn$ dy dtotpcpn f1$ dtotsnfl f2$ dsnwdpth
   f3$ dmxartmp f4$ dmnartmp f5$ dobartmp f6$ dwthrinf f7$;
 if dtotpcpn=-99999 then dtotpcpn=.;
 if dmxartmp=-99999 then dmxartmp=.;
 if dmnartmp=-99999 then dmnartmp=.;
run;

/*--------------------------------------*/
/*DO NOT CHANGE ANYTHING BELOW THIS LINE*/
/*--------------------------------------*/

/* Compute statistics for precip omitting dry days */
proc sort data=a;
 by mn;
run;
proc means data=a(where=(dtotpcpn ne 0));
 by mn;
 var dtotpcpn;
 output out=dtotpcpn mean=meanp std=sdevp skewness=sqewp;
run;

/* Compute statistics for temperature */
proc means data=a;
 by mn;
 var dmxartmp dmnartmp;
 output out=temp mean=tmaxav tminav std=sdtmax sdtmin;
run;

/* Compute probabilities of wet and dry days*/
proc sort data=a;
 by year mn dy;
run;
data c;
 set a;
 ppt=dtotpcpn;
 prevppt=lag(dtotpcpn);
 if ppt>0 then do;
  w=1;
  d=0;
```

```
   end;
  else do;
   w=0;
   d=1;
   end;
  if prevppt>0 and ppt>0 then ww=1;
  else ww=0;
  if prevppt=0 and ppt>0 then wd=1;
  else wd=0;
run;
proc sort data=c;
  by mn;
proc means data=c;
  by mn;
  var w ww d wd;
  output out=probs sum=w ww d wd;
run;

/* Merge precip, probabilities and temperature datasets */
data subset;
  merge dtotpcpn probs;
  by mn;
  pww = ww/w;
  pwd = wd/d;
  drop w ww d wd;
run;
data all;
  merge subset temp;
  by mn;
  drop _type_ _freq_;
run;

/* Transpose */
proc transpose data=all out=tran_all;
run;
proc print data=tran_all round;
run;
```

Appendix G

Data for WEPP Soil Input File and Management Input File

Table 16. Variables for soils input file. Sources: NA = not applicable; W = WEPP application; F = Flanagan and Nearing, 1995; M = measured value.

Variable †	Unit	Source	Burn	Unburned	Grazing	Military	Less-imp
ntemp	quantity	NA	1	1	1	1	1
ksflag	NA	NA	1	1	1	1	1
slid	NA	NA	burn	unburn	grazing	military	less_imp
texid	NA	W	loam	clay loam	clay loam	sandy clay loam	clay loam
nsl	quantity	NA	1	1	1	1	1
salb	percent	NA	30	30	30	30	30
sat	$m^3 m^{-3}$	NA	30	30	30	30	30
ki	$kg\ s\ m^{-4}$	F	486787	511617	778111	315413	371158
kr	$s\ m^{-1} *10^{-4}$	F	7.37	2.80	5.16	5.57	2.25
shcrit	$N\ m^{-2}$	F	1.00	0.93	1.84	0.46	0.48
avke	$mm\ h^{-1}$	M	19.8	49.8	49.2	26.4	34.8
solthk	mm	NA	200	200	200	200	200
sand	percent	M	44.4	43.1	31.4	54.3	43.1
clay	percent	M	25.7	32.0	31.0	27.0	29.9
orgmat	percent	M	3.90	3.90	3.22	3.62	6.12
cec	meq/100g	M	20.7	29.5	19.9	22.1	17.7
rfg	percent	M	18.2	16.3	26.8	21.6	16.0

† Variable definitions:

avke	effective hydraulic conductivity
cec	cation exchange capacity
clay	clay content of soil
ki	interrill erodibility
kr	rill erodibility
ksflag	allow internal adjustment of hydraulic conductivity
nsl	number of soil layers
ntemp	number of overland flow elements
orgmat	organic matter content
rfg	coarse fragment content by weight
salb	soil albedo
sand	sand content of soil
sat	initial moisture content
shcrit	baseline critical shear stress
slid	soil identification
solthk	thickness of soil layer
texid	soil texture

Table 17. Variables for the initial conditions section of the management file. Sources: W = WEPP application; A = Ashcroft et al., 1992; M = measured value; F = Flanagan and Nearing, 1995.

Variable †	Unit	Source	Burn	Unburned	Grazing	Military	Less-imp.
frdp	m	W	0	0	0	0	0
pptg	m	A	0.24	0.24	0.24	0.24	0.24
rmagt	kg m^{-2}	M	0.058	0.184	0.489	0.010	0.315
rmogt	kg m^{-2}	M	0.020	0.237	0.307	0.033	0.567
rrough	m	F	0.020	0.028	0.015	0.015	0.015
snodpy	m	A	0.36	0.36	0.36	0.36	0.36
thdp	m	W	0	0	0	0	0
resi	percent	M	8	27	24	22	18
roki	percent	M	18	17	8	14	23
basi	percent	M	13	14	17	3	14
cryi	percent	M	2	10	1	0	0
resr	percent	M	17	6	12	28	19
rokr	percent	M	5	7	17	8	12
basr	percent	M	17	1	6	4	6
cryr	percent	M	0	1	0	0	0
cancov	percent	M	5	40	30	40	30

Table 18. Variables for the grazing section of the management file.

Variable †	Unit	Cycle	Burn	Unburned	Grazing ‡	Military	Less-imp.
area	m^2		NA	NA	41556600	NA	NA
access	percent		NA	NA	50	NA	NA
digmax	percent		NA	NA	55	NA	NA
digmin	percent		NA	NA	50	NA	NA
suppmt	kg d^{-1}		NA	NA	0	NA	NA
jgraz	quantity		NA	NA	2	NA	NA
animal	quantity	1	NA	NA	600	NA	NA
bodywt	kg	1	NA	NA	410	NA	NA
gday	date	1	NA	NA	4/1	NA	NA
gend	date	1	NA	NA	6/30	NA	NA
send	date	1	NA	NA	NA	NA	NA
ssday	date	1	NA	NA	NA	NA	NA
animal	quantity	2	NA	NA	600	NA	NA
bodywt	kg	2	NA	NA	410	NA	NA
gday	date	2	NA	NA	9/15	NA	NA
gend	date	2	NA	NA	10/30	NA	NA
send	date	2	NA	NA	NA	NA	NA
ssday	date	2	NA	NA	NA	NA	NA

‡ Source for these variables are from the Natural Resource Management Plan for Camp Williams National Guard Base, Utah (Utah National Guard, 1998) except *digmax* and *digmin* which are from Flanagan and Nearing (1995).

Table 19. Variables for the plant section of the management file. Sources: W = WEPP application; T = Tiedemann, 1986; C = M. Caldwell, personal communication; A = Ashcroft et al., 1992; M = measured value; F = Flanagan and Nearing, 1995.

Variable †	Unit	Source	Burn	Unburned	Grazing	Military	Less-imp.
aca	NA	W	5.89	2.09	2.69	2.69	2.69
aleaf	NA	W	4.5	12	12	12	12
ar	NA	W	1.3	1.4	1.3	1.3	1.3
bbb	NA	T	0.06	1.76	9.74	9.74	9.74
bugs	kg m^{-2}	W	0.0001	0.0001	0.0001	0.0001	0.0001
cf1	percent	C	75	75	75	75	75
cf2	percent	C	25	25	25	25	25
cn	ratio	T	42	44	50	50	50
cold	kg m^{-2}	W	1	1	1	1	1
ffp	days	A	150	150	150	150	150
gcoeff	fraction	W	0.78	0.43	0.43	0.43	0.43
gdiam	m	M	0.20	0.35	0.14	0.33	0.37
ghgt	m	M	0.20	0.32	0.35	0.40	0.57
gpop	quantity	M	78	97	15	27	47
gtemp	°C	W	5	5	5	5	5
hmax	m	M	0.6	0.6	0.6	0.6	0.6
plive	kg m^{-2}	W	0.10	0.15	0.10	0.10	0.10
pltol	fraction	W	0.25	0.25	0.25	0.25	0.25
pscday	julian day	C	105	120	120	120	120
rgcmin	kg m^{-2}	W	0	0	0	0	0
root10	kg m^{-2}	T	0.12	1.68	1.08	0.72	1.08
rootf	percent	F	66	66	66	66	66
scday	julian day	C	165	195	195	195	195
scoeff	fraction	W	0	0.7	0.7	0.7	0.7
sdiam	m	M	0.16	0.87	1.33	0.23	1.07
shgt	m	M	0.56	0.77	0.91	0.30	0.72
spop	quantity	M	48	32	53	7	22
tcoeff	fraction	W	0	0	0.7	0.7	0.7
tdiam	m	M	0.00	0.00	3.48	3.33	3.50
tempmn	°C	W	-5	-5	-5	-5	-5
thgt	m	M	0.00	0.00	4.50	3.33	3.50
tpop	quantity	M	0	0	6	1	2
wood	percent	W	0	80	80	80	80

† Variable definitions:

aca .... litter decay coefficient
access .... forage available for consumption
aleaf .... leaf area index coefficient
animal .... number of grazing animals
ar .... root decay coefficient
area .... pasture size being grazed
basi .... interrill basal surface cover
basr .... rill basal surface cover
bbb .... a canopy height parameter
bodywt .... average body weight of grazing animal
bugs .... biomass removal by insects

cancov	total foliar (canopy cover)
cf1	fraction of first peak of growing season
cf2	fraction of second peak of growing season
cn	carbon nitrogen ratio of litter
cold	standing biomass where canopy cover is 100%
cryi	interrill cryptogamic surface cover (mosses, lichens, algae...)
cryr	rill cryptogamic surface cover (mosses, lichens, algae...)
digmax	maximum digestibility of forage
digmin	minimum digestibility of forage
ffp	frost free period
frdp	initial frost depth
gcoeff	projected plant area coefficient for grass
gday	date that grazing begins
gdiam	average canopy diameter for grasses
gend	end of grazing period
ghgt	average height for grasses
gpop	average number of grasses along a 100 meter transect
gtemp	minimum temperature to initiate growth
hmax	maximum canopy height
jgraz	number of grazing cycles per year
plive	potential plant productivity
pltol	plant drought tolerance
pptg	annual growing season precipitation
pscday	day of first peak standing crop
resi	interrill litter surface cover
resr	rill litter surface cover
rgcmin	minimum amount of live biomass
roki	interrill rock surface cover
rokr	rill rock surface cover
root10	root biomass in top 10 cm
rootf	root biomass at beginning of year
rmagt	initial residue mass above the ground
rmogt	initial residue mass on the ground
rrough	random roughness
scday	day of second peak standing crop
scoeff	projected plant area coefficient for shrubs
sdiam	average canopy diameter for shrubs
send	ending day of supplemental feeding
shgt	average height of shrubs
snodpy	initial snow depth
spop	average number of shrubs along a 100 meter transect
ssday	starting day of supplemental feeding
suppmt	average amount of supplemental feed per day
tcoeff	projected plant area coefficient for trees
tdiam	average canopy diameter for trees
tempmn	minimum temperature to initiate senescence
thdp	initial depth of thaw
thgt	average height for trees
tpop	average number of trees along a 100 meter transect
wood	initial woody biomass