ACCURACY ASSESSMENT OF WEPP-BASED EROSION MODELS ON THREE SMALL, HARVESTED AND BURNED FOREST WATERSHEDS

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Forest Resources

in the

College of Graduate Studies

University of Idaho

by

Susan Ashley Covert

December, 2003

Major Professor: Timothy Link, Ph.D.

ABSTRACT

This study assesses the accuracy of GeoWEPP model (Geospatial Water Erosion Prediction Project) and a modified version of WEPP for forest soils. Three small watersheds (2-9 ha) in the Interior Northwest were monitored for several years following timber harvest and prescribed fires. Observed site factors of climate variables, percent ground cover and soil erodibility values, along with digital slope data were used to drive the models. The GeoWEPP and WEPP model predictions of runoff and sediment yield were compared to observed yearly totals from each watershed. Monthly totals were also compared the results of the modified version of WEPP. The yearly results showed that GeoWEPP under-predicts runoff and sediment and the results were not acceptable at a 90 percent confidence interval. The same data was tested with the modified version of WEPP containing modified algorithms for deep percolation and subsurface lateral flow intended to better represent forest hydrology. This modified version of the WEPP model showed improvements to yearly predictions of runoff and sediment over the GeoWEPP model and generated acceptable results of runoff and sediment. Monthly values of runoff and sediment yield generated by the modified WEPP generated acceptable results compared to the observed monthly values. The GeoWEPP model has the potential to model erosion with the incorporation of digital elevation data, but lacks the ability to accurately represent forest hydrology. The incorporation of a WEPP algorithms that represent forest soils more realistically would improve the results of GeoWEPP predictions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

Undisturbed forests are a major source of clean water necessary to sustain ecosystem health. High infiltration rates and low levels of overland flow result from the vegetation and litter that protect the soil against the forces of erosion (Baker 1990; Croke et al. 1999; Elliot and Ward 1995). Although forest managers attempt to minimize impacts of their activities, the removal of vegetation and the alteration of soil properties due to logging, road building and prescribed fire may significantly impact forest erosion and water quality (Lindeburgh 1990; Lousier 1990; Rice 1999; Tiedemann et al. 1979).

Watershed simulation modeling is increasingly important to natural resource managers faced with balancing production demands with water quality. Watershed modeling is useful for understanding the effects of potential management decisions before they are applied to the landscape, and to avoid unnecessary erosion as a consequence of poor management. Process-based models can be tailored and applied to individual locations, making them extremely versatile tools. However, a poorly designed model can lead to bad decisions and unwanted outcomes, making it imperative to validate the predictive ability and limitation of a new model before it is widely used as a management tool (Westervelt 2000).

Forest Disturbance and Erosion

Soil erosion in an undisturbed forest is typically very low (less than 1 Mg ha^{-1} $year^{-1}$), though disturbances can significantly increase erosion depending on the slope, soil type, vegetation, climate and the extent of a disturbance (Elliot et al. 1999b).

Timber harvest operations influence soil erosion through the construction and use of roads, skid trails and log landings and the removal of vegetation (Lousier 1990). Extensive use of heavy equipment can lead to severe soil compaction and high erosion rates depending on the soil type (Croke et al. 2001; Elliot et al. 1999b; Lousier 1990). Compaction decreases porosity, causing reduced hydraulic conductivity, and infiltration capacity (Croke et al. 2001; Elliot et al. 1999b). When rainfall exceeds the infiltration rate, overland flow occurs (Baker 1990). Bare soil exposed after logging or prescribed fire has an increased risk of both rill and interrill (or sheet) erosion due to raindrop impact and increased overland flow that occurs in the absence of ground cover (vegetation and litter) that normally protects the soil (Benkobi 1993; Robichaud 1996).

Prescribed fire is a management tool commonly used following timber harvest operations to reduce accumulated debris and the associated fire hazard, facilitate planting and natural regeneration, reduce shrub competition, improve wildlife forage or to eliminate disease and insects. Achieving these objectives depends on the intensity and severity of the fire, which is controlled by fuel moisture levels and weather factors at the time of burning (Lindeburgh 1990; Wade and Lunsford 1989; Wells et al. 1979). Fire severity is a measure of the effect that fire has on the ecosystem and is quantified by the relative magnitudes of fire impacts on vegetation, organic matter, and soil (Debano et al. 1998). Low to moderately severe burns have little impact on soil structure and erodibility, and remove vegetation without damaging the soil productivity and causing increased erosion. However, high severity burns can result in long term damage to soil productivity and increased erodibility depending on environmental conditions, such as air temperature and the duff moisture content at the time of burning (DeBano et al. 1998; Lindeburgh

1990; Wells et al. 1979). Water repellent soils resulting from severe burns can temporarily cause a 10-40 percent reduction in hydraulic conductivity, further increasing erosion (Robichaud, 2000).

Soil, vegetation, topography, and disturbances (natural and human caused) vary both temporally and spatially across watersheds. Prescribed fires and timber harvest operations can produce random spatial patterns of burn severity, soil compaction, vegetation composition and subsequent recovery (Croke et al. 1999; Robichaud and Miller 1999; Ryan 2002). The severity of disturbances and their location relative to one another within a watershed influences the total amount of runoff and sediment that is generated therefore it is important to explicitly account for this spatial variability to accurately simulate natural processes (Croke et al. 1999; Robichaud and Monroe 1997).

Erosion Modeling with WEPP

The Water Erosion Prediction Project (WEPP), first developed in 1989, is a physically-based, numerical process model that was designed to predict erosion on agricultural, forest and range lands based on a simple hillslope profile (Flanagan et al. 1995). WEPP was developed to replace the empirically-based Universal Soil Loss Equation with a user-friendly simulation model that could be readily modified to nearly any type of watershed at any location (Laflen et al. 1997). WEPP was further developed to model whole watersheds by combining hillslopes with channels and impoundment elements (Flanagan et al. 1995). WEPP can currently simulate erosion from both a hillslope version and a watershed version.

In 2000, the USDA Forest Service developed FS WEPP, a suite of internet-based interfaces to the WEPP model specific to forests and forest management such as roads and timber harvest (Elliot et al. 1999a). Currently, ERMiT (Erosion Risk Management Tool), an internet-based probabilistic erosion prediction model is being developed based on WEPP technology to help determine the risk of erosion in forests, rangeland and chaparral after fire (Robichaud and Elliot 2003).

Further development of the WEPP model continues in order to improve the parameterization of forest conditions. Such changes are included in the GeoWEPP model and a version of WEPP specific to forest soils.

GeoWEPP

In 2002 GeoWEPP, a geo-spatial erosion prediction model was developed in collaboration with Purdue University, the Agriculture Research Service, and the USDA National Soil Erosion Research Laboratory (Renschler 2002). GeoWEPP combines the Water Erosion Prediction Project (WEPP) (Flanagan et al. 1995) with TOpography PArameteriZation software (TOPAZ) (Garbrecht and Martz 1997) within the ArcView 3.2 GIS program (ArcView 2000) to model erosion at the hillslope and watershed scale (Figure 1). GeoWEPP was developed to allow WEPP hillslope parameterization to be based on digital data sources such as digital elevation models (DEMs), and the digital outputs to be viewed and analyzed in a GIS environment. The incorporation of other types of digital data such as ortho-photos, soil surveys, land use maps, and precision farming data is currently under development (Renschler 2002).

The major components of GeoWEPP are explained in more detail below.

TOPAZ

GeoWEPP uses TOPAZ to parameterize topographic data from DEMs to create hillslope profiles called sub-catchments for each watershed. TOPAZ delineates a channel network from the DEM based on the steepest downslope path from each raster cell (pixel) from the 8 cells surrounding it (Garbrecht and Martz 1997). Adjustments can be made to the detail of the channel network by changing values of Mean Source Channel Length (MSCL) and Critical Source Area (CSA). The MSCL is the shortest length that any channel is allowed to be. The CSA defines the minimum drainage area below which a permanent channel forms (Garbrecht and Martz 1997). Setting these to low values will increase the density of channels, which is useful when defining small watersheds. From the defined channel network, the user specifies the exact watershed outlet and TOPAZ generates the sub-catchments that make up the watershed. Each sub-catchment represents the direct contributing area for each side of the drainage (Garbrecht and Martz 1997) and has homogeneous slope and aspect (Renschler 2002).

WEPP

After the sub-catchments have been delineated by TOPAZ, GeoWEPP accesses the WEPP model. WEPP requires four input files that describe the slope, soil, climate, and management to simulate hillslope erosion (Flanagan and Livingston 1995). The inputs to these files are described below.

<u>Slope</u>*:* WEPP requires information about hillslope geometry in order to calculate erosion rates. The slope file includes slope gradient, shape, width and orientation along its length to create a slope profile. GeoWEPP uses the sub-catchment profiles generated by TOPAZ from the user-specified watershed and allows the user to assign a single soil

and management to each sub-catchment. In the standard WEPP model, each slope can be divided into a maximum of ten overland flow elements (OFEs). An OFE is a hillslope section of a desired length that can be assigned individual soil and management parameters in order to create a more realistic representation of the spatial variability within each hillslope (Flanagan and Livingston 1995). Currently, the use of OFEs is not compatible with the digital outputs generated by GeoWEPP and can not be used. Therefore, GeoWEPP users can represent spatial variability between sub-catchments, but not within them.

Climate*:* The WEPP model uses a stochastic weather generation model called CLIGEN, which generates site-specific files with daily values of precipitation, temperature, solar radiation, and wind speed based on historical data from a database of over 2600 climate stations located across the United States (USDA ARS and USFS 2003). The user can request a climate for a specific location and length of time. Customized climate files can be generated by using the Rock:Clime application in FS WEPP (Elliot et al. 2002). Rock:Clime was developed to account for the spatial climate variability in mountain environments (Elliot et al. 1999a). Rock:Clime uses the same weather station database as CLIGEN and includes a number of stations located in remote, mountainous regions. Rock:Clime also allows users to adjust the inputs of monthly average precipitation and temperature values to known values for the site, or access climates from a database generated by PRISM (Parameter-elevation Regressions on Independent Slopes Model) (Elliot and Hall 2000). The PRISM model estimates precipitation and temperature based on orographic effects generated from DEMs with 5-

min lat-long grid spacing (Daly et al. 1994). The final climate file is then added to the WEPP climate database to be used in model simulations.

Soil: Accurate soil property values are essential for erosion prediction. Critical parameters in the soil file are hydraulic conductivity, rill erodibility and interrill erodibility (Laflen et al. 1997). These values can be measured in the field or calculated by the WEPP model based on inputs of soil texture and structure.

Management: The management file dictates the amount of ground cover based on vegetation growth and mortality throughout the simulation period.

For this study the input files were created specifically to each study site based on measured values of soil erodibility parameters, percent ground cover and observed climate.

ArcView

The GeoWEPP program runs as a project in ArcView. The final watershed outputs are generated in ArcView as grid layers of soil loss as a percentage of the tolerable soil loss (TSL) (defined by the user). The grid layer highlights areas that generate soil loss values greater than or less than the TSL. Values greater than the TSL indicate areas where management precautions should be taken. True values of runoff and sediment loss for each pixel are generated in text files that can also be imported to ArcView for viewing. In addition to the grid outputs, GeoWEPP generates text files summarizing average annual rainfall and number of storms, total runoff, soil loss and sediment yield for each sub-catchment and the entire watershed.

WEPP for Forests

Observation of WEPP outputs for forest conditions lead to the development of a modified version of WEPP specific to forest soils. Wu et al. (2000) found that the WEPP model overestimates soil water deep percolation and underestimates subsurface lateral flow in forest conditions resulting in very low outputs of runoff and sediment in forest simulations. Wu et al. (2000) explain three main reasons why WEPP gives these results. The first is that WEPP only allows the user to apply a hydraulic conductivity value to the top layer of soil. The model then estimates the value for the remaining soil layers. This is a reasonable assumption for agricultural soils that are deep and uniform, but forest soils are generally shallow and have a low-permeability bedrock layer. An overestimation of hydraulic conductivity in the deeper soil layers causes an overestimation of deep percolation. Second, WEPP assumes that horizontal and vertical hydraulic conductivities are equal. This may be a reasonable assumption for agricultural soils, but the underlying bedrock and macropores commonly found in forest soils results in a significantly higher horizontal hydraulic conductivity than vertical. WEPP does not account for this, resulting in an underestimation subsurface lateral flow. The third reason is that WEPP estimates and adjusts soil water percolation on a daily basis. If the soil water content is greater than the water content at field capacity, any surplus soil water is removed from the system as deep percolation and not accounted for in overland flow (Wu et al. 2000).

The modified WEPP for forests recognizes a bedrock saturated hydraulic conductivity value (K_{sat}) (entered by the user) in the last line of the soil file as a bedrock layer beneath the observed soil layer. This layer restricts the loss of water to deep percolation, which increases the subsurface lateral flow. The modified WEPP model then adds the values of subsurface lateral flow to the overland flow for the total runoff value. These two changes are not found in the original WEPP model, but represent more realistic forest conditions.

Model Validation

For any new model, assessment is necessary to ensure the predictive accuracy of the model and to demonstrate to potential users that sound decisions can be made based on the results of that model. The WEPP model has been proven as a good erosion prediction tool in agricultural settings (Povilaitis et al. 1995; Elliot et al. 1991). Elliot et al. (1996) conducted a WEPP accuracy assessment within a harvested forest watershed and found that WEPP predicted only half of the observed runoff and predicted ten times more sediment than was observed. Preliminary validation of Wu et al.'s (2000) modified WEPP for forests showed that outputs of runoff and sediment resulting from the modified algorithms appeared to represent forest hydrologic processes in a more realistic manner than the original WEPP algorithms.

Elliot and Foltz (2001) later validated the FSWEPP interfaces using observed erosion data from previously published forest erosion studies. They found that the FSWEPP interfaces predicted erosion within an acceptable margin of error (90% confidence limits).

Koopman (2002) conducted a GeoWEPP validation study on six small forest watersheds with high severity burns caused by wild and prescribed fires. He found that GeoWEPP over-predicted runoff by 10-50 times the observed values and under-predicted sediment yield by one half of the observed values for watershed delineated by GeoWEPP using 30-m DEMs.

These studies show that further testing of WEPP-based models is necessary to determine the validity of new WEPP versions with different input parameters, and that more work is necessary to accurately simulate forest erosion.

Study Objectives

The purpose of this study is to assess the accuracy of the GeoWEPP outputs of runoff and sediment yield from small (2 - 9 ha) harvested and burned forest watersheds and to verify whether or not reliable forest management decisions can be based upon these outputs. This study also tests the predictions of the WEPP model modified for forests (Wu et al. 2000) using the same input parameters as used in the GeoWEPP validation. This study compares previously unpublished erosion data to the outputs of GeoWEPP simulations using 30-m pixel DEMs and to the outputs of the modified WEPP for forests for each watershed. Researchers at the Rocky Mountain Research Station in Moscow, Idaho collected the field data.

The specific objectives of this study were to 1) asses the accuracy of the GeoWEPP model outputs for three small, harvested and burned forest watersheds with observed runoff and sediment data; 2) identify and discuss GeoWEPP model components that need improvement; and 3) assess the accuracy of the WEPP model that was modified for forests by Wu et al. (2000).

Methods

The following sections describe each study site, how the data were collected and processed, how the models were implemented and the methods used to analyze the accuracy of the predictions.

Study Sites

This study uses runoff and erosion data collected on three small managed watersheds in the Inland Northwest that were burned following timber harvest. The monitoring of each site began within two to three weeks following the burns. The harvest method varied from site to site based on the objectives of the forest manager, and the burns were conducted by USDA Forest Service personnel without the influence of the specific research objectives and were therefore not influenced by researcher bias.

Hermada

The Hermada site is located in the Boise National Forest, southeast of Lowman, Idaho (Figures 2, 3a). The 9-ha site contains slopes from 40 to 60 percent with southeastern and northeastern aspects (approximately 40-135°) with small, intermittent stream channel. The elevation ranges from 1760 to 1880 m. The soils (Typic Cryumbrept) contained 85 percent sand, 13 percent silt and 2 percent clay, formed from weathered granite. The main tree species, ponderosa pine (*Pinus ponderosa)* and Douglas-fir (*Pseudotsuga menziesii*) were harvested in 1992 using a cable-yarding system. The harvest objective was a seed-tree cut, leaving 5-10 trees per hectare.

A prescribed fire was conducted three years later on October 17, 1995. Hand-held drip-torches were used to ignite the top and edges of the unit, followed by a helicopter-mounted drip-torch, which ignited strips starting at the top and proceeding parallel to the contour. About two hours after ignition, a light rain fell, cooling the fire, which then continued to burn very slowly, producing a low intensity burn. A south-facing draw burned hot as the fire funneled up it about one hour after ignition. The north-facing aspect (south side) had a mosaic of burned and unburned areas. On the south-facing aspect (north side) slightly more duff was consumed indicating a low severity burn. The fire produced an overall low severity burn, with 5 percent of the area as high severity and 55 percent low severity, based on burn severity classification described by Phillips and Abercrombie (1987) and Ryan and Noste (1983). The rest of the area was unburned (Robichaud, 2000).

Slate Point

Slate Point is located on the Bitterroot National Forest near Painted Rocks Reservoir, south of Sula, Montana (Figures 2, 4a). The 7-ha site contains slopes from 40 to 63 percent on predominantly north aspects. The channel was not well defined, but was present for 130 m up the slope. The elevation ranges from 1620 to1780 m. The soils (Typic Cryoboralf and Dustric Cryochrept) contained 83 percent sand, 12 percent silt and 5 percent clay, formed from weathered rhyolite. The main tree species, Douglas-fir and lodgepole pine (*Pinus contorta)* were harvested in 1993 using a ground-based skidding system in the upper third of the unit (which was divided by a road) and a cable-yarding system in the lower portion of the unit. The harvest objective was a clear-cut with snag replacements, leaving 7-12 trees per hectare.

The Slate Point burn was conducted on the evening of June 29, 1994, one year after timber was harvested. Hand-held drip-torches were used to ignite the top portion of the site in strips parallel to the contour. The portion below the road was ignited starting at the top using a chevron pattern. After ignition, the fire spread into the center of the unit and intensified as the heat increased. The portion above the road burned very slowly and coolly. As the portion below the road ignited, the heat generated caused the duff to dry out and the area above the road to reburn. Ignition technique, fuel moisture and weather during the burn produced an intense fire concentrated in the center of the unit. The result was a mosaic of fire severity with 65percent low severity and 15percent high severity (Robichaud, 2000; Phillips and Abercrombie, 1987; Ryan and Noste, 1983).

Round Up

Round Up is located on the Payette National Forest, northwest of New Meadows, Idaho (Figures 2, 5a.). The 2-ha site is located on a 50 percent slope, with a predominantly northwest-facing aspect. The elevation ranges from 1480 to 1600 m. The soils (Typic Crychrept) contained 35 percent sand, 40 percent silt and 25 percent clay, derived from basalt parent material. The main tree species, Douglas-fir and ponderosa pine, were clear-cut in 1991 using a ground-based skidding system. The small watershed had no defined channel, but a small spring was observed at the base of the harvest unit.

The Round Up burn was conducted in June, 1993, two years after the timber was harvested. The site was ignited using a helicopter-mounted drip torch. At the time of burning, the site was covered in shrub regrowth up to 1 m high (Elliot et al. 1996). The site did not ignite easily nor burn at a high intensity due to high fuel moisture content, resulting in a patchy mosaic of low severity and unburned areas. This site had eight bladed skid trails parallel to the contour on a sub-catchment length of 190 m, occupying approximately 17 percent of the area.

Data Collection

Climate, soil erodibility, and percent ground cover and slope inputs as well as watershed outputs, were measured or estimated for each of the three watersheds. These input data were compiled into the input files required to run the WEPP-based models.

Input File Generation

Climate Input Variables: Maximum and minimum air temperature, relative humidity, precipitation, solar radiation and wind speed were recorded for the duration that instrumentation was installed at each site, and stored in a data logger (See Table 1 for monitoring dates). These values were converted from hourly or minute data (depending on the sensor) into daily values as required by the WEPP model. Small data gaps caused by sensor malfunctions, were filled with weather data stochastically generated from Rock:Clime for the same location. These generated data may have included or excluded storms or temperatures that may have influenced erosion outputs. The climate data were compiled into a single climate file for all years that the watersheds were monitored.

Soil Input Variables: Observations from previous studies, (Robichaud, 2000), suggest that there are four main hydrologic/surface conditions that affect infiltration. These conditions include high severity burns, low severity burns, bare mineral soil (roads, skid trails, landings), and undisturbed (natural) conditions. Fire severity was classified by the methods of Phillips and Abercrombie (1987) and Ryan and Noste (1983) based on amount of ground cover and depth of duff remaining after each burn.

Soil and ground cover parameters were measured on 1-m^2 plots that were randomly located within each of the identified hydrologic/surface conditions at each study site

(Table 2). Interrill erodibility and hydraulic conductivity rates were determined from the volume of sediment and runoff collected on 1-m^2 plots using simulated rainfall with 30-minute intensities of approximately 94 mm/hr. These methods are described in detail by Robichaud (2000) and Elliot et al. (1996). Hydraulic conductivity was estimated from the Green-Ampt effective hydraulic conductivity equation used in the WEPP model based on rainfall amount, surface cover, and runoff (Alberts et al. 1995; Robichaud 1996). Interrill erodibility values were calculated from a modified version of the sediment delivery equation (Laflen et al. 1991; Robichaud 1996).

Measurements of rill erodibility have been conducted throughout the Interior Northwest within high and low burn severities and different soils types (sand, silt, clay and loam) (P.R. Robichaud, unpublished data, 2003. Moscow, ID: USDA Forest Service Rocky Mountain Research Station). These data include rill erodibility measurements taken on 3 m wide by 9 m long plots by running a continuous, calibrated stream of water down a slope and collecting the sediment and runoff at the bottom of the plot at specific time intervals. Appropriate values were selected from the database for each site based on burn severity and soil type (P.R. Robichaud, personal communication, January 2003).

The soil files were built in WEPP by entering the measured values of rill and interrill erodibility, hydraulic conductivity and soil texture. The first and second years were assigned the same soil parameters assuming little change would occur from the initial fall to the spring of the second year due to winter conditions. For the subsequent years, soil files were generated using values that were one level less severe than the previous year to represent recovery of the site after the burn. For example, if the first year was a high severity burn, the second year was the same, the third year was considered low severity, and the next year was considered fully recovered. Corresponding values of each soil parameter were used for each condition.

Management Input Variables: The management file specifies the amount of ground cover based on growth and mortality parameters. Percent ground cover (including vegetation, duff, litter, and woody debris) was measured immediately after each fire on the same plots used for rainfall simulations Measurements were taken using a grid frame with intersections at 100 mm intervals (Robichaud 1996). Ground cover in the years following the fire was estimated to increase by half of the difference between the previous year and the natural, undisturbed cover based on observations (W. J. Elliot, personal communication, February 2003). For example, if the unburned area had a cover of 100 percent, and last years cover was 60 percent, the following year cover was estimated to be 80 percent, and the next year to be 90 percent, and so on. For the three study sites, the management files were generated with an initial forest condition followed by a fire that killed and removed vegetation and residue to the percent ground cover that was measured following the fire. The interrill cover generated by WEPP changes each year based on the management file growth parameters, soil and climate (Figure 6). The biomass energy ratio in the management file was adjusted so that the desired amounts of ground cover for each site would be generated each year by the model. A management file was generated by WEPP on each watershed sub-catchment for every year of simulation.

Slope Input Variables: Watersheds (sub-catchments and channels) were derived from 30-m DEMs downloaded from the Natural Resources Conservation Service, Geo-spatial Data Gateway (NRCS, 2002) using TOPAZ. These watersheds were examined to determine how well they matched the actual watershed shape. Modifications to the MSCL, CSA and watershed outlet location were made in TOPAZ to generate the best fit watershed for each site. The three watersheds were delineated as shown in Figures 3b, 4b, and 5b.

Watershed Outputs

Runoff and sediment yield at each watershed outlet were measured for several years following each fire. A 1- m^3 sediment trap fitted with a calibrated, 1-foot, H-flume was constructed at the bottom of each watershed to measure runoff and sediment yield. Water flow at the watershed outlet was measured using pressure transducers and flow depth floats. If a rain event produced sediment in the trap, the sediment was shoveled into a bucket, weighed on site, and a sample was taken back to the lab to measure water content. Dry weights of sediment were determined in the lab for each sediment-producing event. For each site, a sum of the total sediment collected per year was generated. Data from each site were compiled into the separate years, corrected for instrument errors, and converted into the format and units used in the WEPP-based models.

Model Implementation

For each watershed, the sub-catchments were each designated as a specific hydrologic/surface condition based on observations made after each fire. The appropriate input files were assigned to each sub-catchment. Since GeoWEPP can not incorporate OFEs to represent the location of disturbances on each sub-catchment, the representation of spatial variability was limited to the sub-catchments generated by TOPAZ. Therefore, the spatial variability of surface conditions and the effects that they would have on runoff and erosion were not accurately represented.

The input files described previously were used to run GeoWEPP and the modified version of WEPP for forest conditions. The yearly outputs of each model were compared to the measured yearly outputs of runoff and sediment from each watershed. In addition, the monthly totals of runoff and sediment yield generated by the modified version of WEPP were also compared to the observed monthly values. GeoWEPP only generates yearly outputs, so no monthly comparisons were made for that model.

Analysis

The predictive ability of a model can be quantified by the Root Mean Squared Error and other components associated with it (Willmott 1981). This method has been used in other studies to validate WEPP predictions (Elliot et al. 1991; Povilaitis et al. 1995). The following assessment descriptors were used:

Observed and Predicted mean ($\overline{O}$ and $\overline{P}$ respectively).

Observed and Predicted standard deviations (s_o and $s_{p,}$ respectively).

Slope (*b*) and *intercept* (*a*) of a least-squares regression between predicted (dependent variable) and observed (independent variable) runoff and sediment. Systematic (linear) over- or under-estimations produce characteristic variations in *a* and *b*. For example, an over-estimation of the data would produce a y-intercept point greater than zero on the y-axis and a steep positive slope.

Total Root Mean Squared Error (RMSE) represents the actual size of the error or difference between the observed and predicted values. It is the square root of the mean squared error (MSE) and is easily interpreted because it has the same units as the predicted and observed values (Willmott 1981). RMSE is expressed as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{N}} \qquad (1)$$

Where

N = number of paired observations,

P = predicted value, and

O = observed value.

Systematic and unsystematic components of the root mean squared error ($RMSE_s$ and $RMSE_u$, respectively). The systematic error shows how far the data fluctuate from the 1:1 line in a plot of predicted versus observed values indicating errors due to model under- or over predictions. The unsystematic error is the amount of error not accounted for in the systematic error and represents random errors associated with the data. When the systematic error is minimized the model is predicting at maximum accuracy.

$$RMSE_s = \sqrt{\frac{\sum_{i=1}^{N}(\hat{P}_i - O_i)^2}{N}} \qquad (2)$$

$$RMSE_u = \sqrt{\frac{\sum_{i=1}^{N}(P_i - \hat{P}_i)^2}{N}} \qquad (3)$$

Where $\hat{P}_i = a + bO_i$

The index of agreement (d) reflects the degree to which the observed variate is accurately estimated by the simulated variate. It varies between 0.0 and 1.0, where a computed value of 1.0 indicates perfect agreement between observed and predicted observations and 0.0 indicates complete disagreement. It is a measure of the degree to which the model's predictions are error free. It is more desirable than a simple r or r^2 because these coefficients do not accurately reflect the effects of additive or systematic error (Willmott, 1981). It is written as:

$$d = 1 - \frac{\sum_{i=1}^{N} (P_i - O_i)^2}{\sum_{i=1}^{N} [|P_i'| + |O_i'|]^2} \qquad (4)$$

Where $P_i' = P_i - \overline{O}$, and $O_i' = O_i - \overline{O}$.

Elliot and Foltz (2000) suggest using a 90% confidence interval as an acceptable measure of model performance when comparing predicted and observed outputs. If the confidence intervals of the predicted and observed values overlap, then the prediction is a reasonable approximation of the observed value.

Both of these methods were used to obtain a representation of how well the models predicted the observed values.

Results and Discussion

Field Data

Values of all measured input variables and watershed outputs are shown in Tables 3, 4, and 5 for Hermada, Slate Point, and Round Up respectively. Runoff was measured at each site, yet very little sediment was produced in any year on any of the three sites.

Due to the high sand content at both Hermada and Slate Point and the low impact harvest techniques, the sites were not severely impacted by harvesting. The road through the Slate Point site was an out-sloped road that allowed water to flow off it evenly across the hillslope rather than being concentrated into a ditch. This technique along with low severity burns also contributed to low observed erosion rates. The higher runoff rates relative to sediment yield at all sites was most likely due to subsurface lateral flow which did not contain large amounts of sediment due to the filtering effect of the soil it flows through (Wu et al. 2000). Round Up produced more sediment than the other two sites which is likely due to the high impact caused by the multiple skid trails across the watershed, and the higher clay content in the soil leading to greater compaction and increased erosion. The severity of the burn was very low and was not likely the cause of the higher erosion values.

Model Outputs

The GeoWEPP model and the modified WEPP model for forest conditions were run with the same input files. The results of each simulation are discussed below.

GeoWEPP

The GeoWEPP simulations, using the measured input parameters described previously, predicted no runoff and sediment yield on all sites for all years with the exception of a small amount observed in one year on both the Slate Point and Hermada sites. These results indicate that the GeoWEPP model considerably under-predicted the actual runoff and sediment yield (Table 6). The simulations produced RMSE, $RMSE_u$ and $RMSE_s$ results for all sites that showed that the majority of the error was due to systematic error which indicates large fluctuations of the data from the 1:1 line and poor model predictions (Table 7). Systematic error can be corrected for with adjustments to the model. The water output generated by WEPP showed that the majority of the precipitation was being allocated to deep percolation rather than shallow subsurface lateral flow, which follows with the observations of Wu et al. (2000).

WEPP Modified for Forests

The WEPP model with modified algorithms for deep percolation and subsurface lateral flow typical of forest conditions (Wu et al. 2000), was tested with the same inputs files and the slope profiles generated by TOPAZ that were used in the GeoWEPP simulation.

Saturated hydraulic conductivity for different bedrock types were found in a list of measured values compiled by Domenico and Schwartz (1990). A bedrock type and hydraulic conductivity value was selected for each site based on the observed parent material.

The modified WEPP was run for individual hillslopes and for watersheds (hillslopes and channels combined). The runoff values were equal for both the hillslope and watershed versions, though the estimated sediment for all sites was slightly higher for the watershed version. These higher values for watershed sediment are due to an error in the WEPP code that distributes the total daily subsurface lateral flow to the channel over the period of one hour rather than a more realistic 24-hour period. The force of the excess flow of water is greater than the soils critical shear stress causing the channel to erode at an unrealistically high rate, therefore only the hillslope values were analyzed here. The outputs of sediment yield are shown for both the hillslope and watershed versions (Table 8), though only the hillslope values were used in the analysis. The results of each run on a yearly and monthly time interval are presented by site in the following paragraphs.

Hermada: The approximate hydraulic conductivity for weathered granite (5.2e-5 mm/hr) (Domenico and Schwartz 1990) was used for this site.

Runoff – For yearly totals the modified WEPP model resulted in an over-prediction of runoff, but with a similar trend as the observed (Table 8 and Figure 7a). The overall error was lower for the modified WEPP than for the GeoWEPP outputs, but with higher random error because the predicted values are no longer zero and had more fluctuation (Tables 7 and 9). The systematic error is lower indicating an improvement in the predictions over the GeoWEPP model. The index of agreement was 0.8 indicating good model predictions and the overlapping range of values of observed and predicted runoff indicated that the model prediction are acceptable at a confidence level of 90 percent (Table 9).

On the monthly time interval runoff was not predicted as well as yearly runoff (d = 0.5). Figure 10a shows that there is a time lag between some of the observed and predicted flow periods. The model seems to route runoff from rain events down the hillslope faster than what actually occurs on the hillslope. Rain-on-snow events release more water over a shorter period of time and are more aligned with the model predictions. These differences indicating a need to assess the timing and release of flow by the model. The range of values at 90 percent confidence do not overlap indicating that runoff is slightly over-predicted.

Sediment - The yearly watershed outputs were slightly over-estimated 1997 and 1998 by less than 0.5 Mg/ha (Table 8). The index of agreement was 0.0 resulting from the fluctuations of predicted values from the low observed values. However, at a 90 percent level of confidence these values are within an acceptable range (Table 9).

The monthly values are also acceptable and have an index of agreement of 0.8 (Figure 10b and Table 10).

Slate Point: For this site, a permeable basalt bedrock layer was used (K_{sat}=1.0e-2 mm/hr) based on the observed parent material.

Runoff – The yearly predicted runoff values showed a closer relationship to the observed values (Figure 8a) than were measured with the GeoWEPP model. The low RMSE of 22 mm, and the low systematic error indicates a good relationship between the observed and predicted values (Table 9). The index of agreement is 0.9 indicating very good accuracy in the model predictions. The overlapping confidence intervals also indicate that the values are acceptable predictions.

The monthly values of runoff show d = 0.5 and 90 percent confidence that the predicted and observed means will be equal (Figure 11a and Table 10).

Sediment Yield– All years of simulation (except 1998) predicted 0 Mg/ha, which is equal to the observed values (Table 8). The average error was 0.02 Mg/ha due to the last year of simulation for which the model predicted 0.01 Mg/ha of sediment (Table 9). The index of agreement value was 0.4, which shows no change from the GeoWEPP outputs.

Monthly values show improved accuracy with d = 0.6 and 90 percent confidence that the predicted and observed means will be equal. Although the sediment predicted did not occur at the same time as the observed sediment, the values are only slightly greater than zero and do not greatly influence the results (Figure 11b and Table 10).

Round Up: For this site, a basalt bedrock layer was used (K_{sat}=2.0e-11).

Runoff - The higher error at this site can be attributed to instrument error. The high predicted value in 1995 corresponds to the higher precipitation, though the low observed value does not (Table 8). Instrument errors resulted in a loss of some runoff data in 1995, which may explain the low observed values of runoff (Figure 9a and Table 9). The index of agreement is only 0.3 due to the differences between the observed and predicted values in 1995 and 1996 yet the values are within acceptable range based on the 90 percent confidence interval (Table 9).

Monthly values show a greater difference between the observed and predicted values. The index of agreement dropped to 0.2 for monthly predictions and the means are not equal at a 90 percent confidence interval (Figure12a and Table 10).

Sediment - The yearly values of predicted and observed sediment yield were very close to zero and, with the 90 percent confidence interval the means were equal (Table 8). The resulting value of d = 0.4 was a result of the slight under-prediction by the model (Figure 9b and Table 9).

The monthly values were also very close to zero and acceptable even though d = 0.2 (Figure 12b and Table 10).

Summary

The GeoWEPP model did not accurately predict runoff or sediment yield in the small forested watersheds, yet the modified WEPP model for forest conditions showed improvements to yearly predictions of runoff and sediment yield when used with the same input files. The results for both runoff and sediment yield from the modified WEPP for forests were generally within an acceptable range of values at a 90 percent confidence level. Monthly predictions showed improvement in the accuracy of sediment yields and a slight decrease in the accuracy of runoff predictions though the values are within acceptable range for two of the three study sites. Overall the results show that the modified WEPP generates acceptable model predictions and the lower accuracy of the results from Round up is most likely due to a loss of runoff data in 1995 resulting from instrument malfunction.

The modified WEPP significantly reduced the amount of water being lost to deep percolation and increased the total runoff value by adding the subsurface lateral flow to the overland flow resulting in a more realistic representation of forest soils. The low predicted sediment values are consistent with the observed sediment generated by few overland flow events.

The modified WEPP seemed to work better for predicting larger runoff values generated by rain-on-snow events. During these times the values of observed and predicted runoff were more closely matched in their timing and magnitude (Figures 10 and 11). Yet these event only generated responses in the runoff. Very low amounts of sediment were measured or predicted throughout the course of each monitoring period at all of the sites.

Size and shape of watersheds was an important consideration in GeoWEPP. Koopman (2002) found that TOPAZ could not accurately delineate watersheds less than 3 ha in size when using DEMs with 30-m^2 pixel size. These observations were supported by the 2-ha Round Up site that was not well defined by TOPAZ. Although the larger Hermada site (9 ha) was well defined, the Slate Point site (7 ha) was more difficult to define due to its narrow shape rather than its size. The large scale of the 30-m DEMs is better suited to larger watersheds (greater than 10 ha), and may produce less errors in channel size and watershed area.

The spatial variability of each watershed was also not well represented by GeoWEPP. GeoWEPP is currently not capable of incorporating multiple overland flow elements as WEPP does, which limits the ability of the user to apply spatial variation to the watershed sub-catchments delineated by TOPAZ. Further development of GeoWEPP is currently underway to incorporate other spatial digital data, including ortho-photos, soil surveys maps, climate data, and land use maps which may help to incorporate more realistic spatial variability within sub-catchments (Renschler 2002). The use of overland flow elements in the modified model was not tested in this study.

Conclusion

The GeoWEPP model incorporates digital elevation data to quickly generate runoff and sediment outputs in textual and digital formats on small watersheds with limited spatial variability. Significant under-predictions of runoff and sediment yield by the GeoWEPP model found in this study showed that changes need to be made to improve how GeoWEPP models forest hydrologic processes and to incorporate spatial variability within hillslopes. The WEPP model, which is used in GeoWEPP, has been successfully tested in agricultural settings to accurately predict runoff and sediment yield (Elliot et al. 1991; Povilaitis et al. 1995), but has not been proven to accurately predict erosion in forest conditions (Elliot et al. 1996a; Koopman 2002). Wu et al. (2000) modified the algorithms of deep percolation and subsurface lateral flow in WEPP and found significant improvements in how WEPP models forest hydrology when using a simulated watershed. This study showed that the modified WEPP (Wu et al. 2000) generates more accurate predictions of runoff and sediment yield on a yearly basis than the GeoWEPP model in three small harvested and burned forest watershed. It also showed that the outputs are within an acceptable range of values based on a 90 percent confidence level. Monthly outputs of runoff and sediment yield by the modified version of WEPP are also within an acceptable range of values, though there is some variation in the timing of predicted and observed runoff events. Further investigation should be conducted on shorter time scale to investigate the delay in some of the runoff events.

Currently, GeoWEPP predictions for small forest watersheds should not be relied upon for management decisions until the model has been modified to improve predictions in forest conditions.

Literature Cited

Alberts, E.E., M.A. Nearing, M.A. Weltz, L.M. Risse, F.B. Pierson, X.C. Zhang, J.M. Laflen, and J.R. Simanton. 1995. Soil component. In *USDA-Water Erosion Prediction Project: Hillslope Profile and watershed model documentation*, chapter 7. D.C. Flanagan, and M.A. Nearing, eds. NSERL Report No. 10. West Lafayette, IN.: USDA-ARS National Soil Erosion Research Laboratory.

ArcView. 2000. *ArcView*. Ver. 3.2a. Environmental Research Systems Institute, Inc. Redlands, CA.

Baker, M.B. Jr. 1990. Hydrologic and water quality effects of fire. Gen. Tech. Rep. RM-191. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 11 p.

Benkobi, L., M.J. Trlica, and J.L. Smith. 1993. Soil loss as affected by different combinations of surface litter and rock. *Journal of Environmental Quality* 22(4): 657-661.

Croke, J., P. Hairsine, and P. Fogarty. 1999. Runoff generation and re-distribution in logged eucalyptus forests, south-eastern Australia. *Journal of Hydrology* 216(1/2): 56-77.

Croke, J., P. Hairsine, and P. Fogarty. 2001. Soil recovery from track construction and harvesting changes in surface infiltration, erosion and delivery rates with time. *Forest Ecology and Management* 143: 3-12.

Daly, C., R.P. Neilson, and D.L. Phillips. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. *Journal of Applied Meteorology* 33(2): 140-158.

DeBano, L.F., D.G. Neary, and P.F. Ffolliott. 1998. *Fire's Effects on Ecosystems*. New York, NY: John Wiley & Sons. 333 p.

Domenico, P.A., and F.W. Schwartz. 1990. *Physical and Chemical Hydrogeology*. New York, N.Y.: John Wiley & Sons. 528 p.

Elliot, W.J., A.V. Elliot, W. Qiong, and J.M. Laflen. 1991. Validation of the WEPP model with rill erosion plot data. ASAE Paper No. 91-2557. St. Joseph, MI: American Society of Agricultural Engineers. 11 p.

Elliot, W.J., and M. Foltz. 2001. Validation of the FS WEPP interfaces for forest roads and disturbance. Sacramento CA. ASAE Paper No. 01-8009. St. Joseph, MI: American Society of Agricultural Engineers. 13 p.

Elliot, W.J., and D.E. Hall. 2000. *Rock:Clime Beta CD Version Rocky Mountain Research Station Stochastic Weather Generator Technical Documentation*. Available at: http://forest.moscowfsl.wsu.edu/fswepp/docs/0007RockClimCD.html. Accessed 9 September 2003.

Elliot, W.J., D.E. Hall, and D.L. Scheele. 1999a. *FS WEPP: Forest Service Interfaces for the Water Erosion Prediction Project Computer Model*. Available at: http://forest.moscowfsl.wsu.edu/fswepp/docs/fsweppdoc.html. Accessed 8 October 2002.

Elliot, W.J., D.E. Hall, and D.L. Scheele. 2002. *Disturbed WEPP: WEPP interface for Disturbed Forest and Range Runoff, Erosion and Sediment Delivery*. Available at: http://fsweb.moscow.rmrs.fs.fed.us/fswepp/docs/distweppdoc.html. Accessed 9 September 2003.

Elliot, W.J., C.H. Luce, and P.R. Robichaud. 1996. Predicting sedimentation from timber harvest areas with the WEPP model. In *Proc. Sixth Federal Interagency Sedimentation Conf.,* 46-53. Las Vegas, NV.

Elliot, W.J., D. Page-Dumroese, and P.R. Robichaud. 1999b. The effects of forest management on erosion and soil productivity. In *Soil Quality and Soil Erosion,* Chapter 12. R. Lal, ed. Boca Raton FL: CRC Press.

Elliot, W.J., and A.D. Ward. 1995. *Environmental Hydrology*. Boca Raton, FL.: CRC Press, Inc. 462 p.

Flanagan, D.C., J.C. Ascough II, A.D. Nicks, M.A. Nearing, and J.M. Laflen. 1995. Overview of the WEPP erosion prediction model. In *USDA-Water Erosion Prediction Project: Hillslope Profile and Watershed Model Documentation*. Flanagan, D.C., and M.A. Nearing, eds. Ch 1. NSERL Report No. 10. USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN. 131 p.

Flanagan, D.C., and S.J. Livingston eds. 1995. WEPP user summary: USDA-Water Erosion Prediction Project (WEPP). NSERL Report No. 11.: USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN.

Garbrecht, J. and L.W. Martz. 1997. *TOPAZ: Topographic Parameterization Software.* Available at: http://grl.ars.usda.gov/topaz/TOPAZ1.HTM. Accessed 9 September 2003.

Koopman M. 2002. Geo-spatial prediction tools in forest management: Modeling post-burn hydrology of soil erosion in three western forests. Unpublished MA thesis. Buffalo, NY: State University of New York. Department of Geography. 60 p.

Laflen, J.M., W.J. Elliot, D.C. Flanagan, C.R. Meyer, and M.A. Nearing. 1997. WEPP-predicting water erosion using a process-based model. *Journal of Soil and Water Conservation*. 52: 96-103.

Laflen, J.M., L.L. Lane, and G.R. Foster. 1991. WEPP, a new generation of erosion prediction technology. *Journal of Soil and Water Conservation* 46(1): 34-38.

Lindeburgh, S.B. 1990. Effects of prescribed fire on site productivity: A literature review. BC Ministry of Forests, Land Management Report No. 66. Victoria BC, Canada: Crown Publications. 15 p.

Lousier, J.D. 1990. Impacts of forest harvesting and regeneration on forest sites. B.C. Ministry of Forests, Land Management Report No. 67. Victoria BC, Canada: Crown Publications. 92 p.

NRCS. 2002 Geo-spatial Data Gateway. Available at: http://lighthouse.nrcs.usda.gov/gateway. Accessed 5 October 2002.

Phillips, D.R. and J.A. Abercrombie. 1987. Pine-hardwood mixtures – a new concept in regeneration. *Southern Journal of Applied Forestry* 11(4) 192-197.

Povilaitis, A., P. Robichaud, A. Dumbrauskas, R. Tumas, and J. Ruseckas. 1995. Erosion prediction in the republic of Lithuania with the WEPP model. In *Proc. Water Quality Modeling,* 333-340. Orlando, FL. St Joseph, MI: American Society of Agricultural Engineers.

Renschler, C. 2002. *Geo-spatial Interface for the Water Erosion Prediction Project – GeoWEPP ArcX 07/12/02. User manual & case study.* Available at: http://www.geog.buffalo.edu/~rensch/geowepp/GeoWEPP%20Manual_files/frame.htm. Accessed 15 October 2002.

Rice, R.M. 1999. Erosion on logging roads in Redwood Creek, northwestern California. *Journal of the American Water Resources Association* 34(5): 1171-1182.

Robichaud, P.R. 1996. Spatially-varied erosion potential from harvested hillslopes after prescribed fire in the interior Northwest. Ph.D. diss. Moscow, ID: University of Idaho, Department of Agricultural Engineering. 219 p.

Robichaud, P.R. 2000. Fire effects on infiltration rates after prescribed fire in Northern Rocky Mountain forests, USA. *Journal of Hydrology*. 231/232: 220-229.

Robichaud, P.R. and W.J. Elliot. 2003. *Erosion Risk Management Tool*. Available at: http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/ermit/ermit.pl. Accessed 21 October 2003.

Robichaud, P.R. and S.M. Miller. 1999. Spatial interpolation and simulation of post-burn duff thickness after prescribed fire. *International Journal of Wildland Fire* 9(2): 137-143.

Robichaud, P.R. and T.M. Monroe. 1997. Spatially-varied erosion modeling using WEPP for timber harvested and burned hillslopes. Minneapolis MI. ASAE Paper No. 97-5015. St. Joseph, MI: American Society of Agricultural Engineers. 8 p.

Ryan, K.C. 2002. Dynamic interactions between forest structure and fire behavior in boreal ecosystems. *Silva Fennica* 36(1): 13-39.

Ryan, K.C. and N.V. Noste. 1983. Evaluating prescribed fires. In *Symposium and Workshop of Wilderness Fire*, 230-429. J.E. Lotan, B.M. Kilgore, W.C. Fischer, and R.W. Mutch (Tech. Coord.). Gen. Tech. Rep. INT-182. Ogden, Utah: USDA Forest Service, Intermountain Research Station.

Tiedemann, A.R., C.E. Conrad, J.H. Dietrich, J.W. Hornbeck, W.F. Megahan, L.A. Viereck, and D.D. Wade. 1979. Effects of fire on water: a state-of-knowledge review. Gen. Tech. Rep. WO-10. Washington, D.C.: USDA Forest Service. 28 p.

USDA Agricultural Research Service and USDA Forest Service. 2003. *CLIGEN Weather Generator, Expand and Improved.* Available at: http://horizon.nserl.purdue.edu/Cligen/. Accessed 9 September 2003.

Wade, D.D. and J.D. Lunsford. 1989. *A Guide for Prescribed Fire in Southern Forests*. R8-TP 11. Available at: http://flame.fl-dof.com/Env/RX/guide/. Accessed 15 November 2003.

Wells, C.G., R.E. Campbell, L.F. DeBano, C.E. Lewis, R.L. Fredriksen, E.C. Franklin, R.C. Froelich, and P.H. Dunn. 1979. Effects of fire on soil: a state-of-knowledge review. Gen. Tech. Rep. WO-7. Washington DC: USDA Forest Service. 26 p.

Westervelt, J. 2000. *Simulation Modeling for Watershed Management*. New York, N.Y.: Springer. 190 p.

Willmott, C.J. 1981. On the validation of models. *Physical Geography* 2(2):184-194.

Wu, J.Q., A.C. Xu, and W.J. Elliot. 2000. *Adapting WEPP (Water Erosion Prediction Project) for forest watershed erosion modeling:* Milwaukee WI. ASAE Paper No. 002069. St. Joseph, MI: American Society of Agricultural Engineers. 9 p.

Tables

Table 1. Summary management dates and years monitored for each study site.

Site Parameters	Hermada	Slate Point	Round-Up
Location (decimal degrees)	43.87N, 115.35W	45.71N, 114.27W	45.12N, 116.38W
Size (ha)	9	7	2
Harvest Year & Technique	1992 cable yarded	1993 lower cable yarded; upper ground-based skid	1991 ground-based skid
Burn Date	October 17, 1995	June 29, 1994	June 15, 1993
Dates Monitored	November 3, 1995 - September 30, 2000	July 6, 1994 - June 9, 1998	July 6, 1993 - July 22, 1996

Table 2. Number of 1-m^2 plots in each surface condition used for hydraulic conductivity, interrill erodibility and ground cover measurements for Hermada, Slate Point, and Round Up.

Surface Condition	Total Area (%)	No. of Plots
Hermada		
Unburned-undisturbed	40	3
Low severity burn	55	3
High severity burn	5	5
Slate Point		
Unburned-undisturbed	20	2
Low severity burn	65	8
High severity burn	15	4
Round Up		
Unburned-undisturbed	60	2
Low severity burn	23	10
Bladed skid trail	17	8

Table 3. Hermada input values for model simulations, observed yearly watershed outputs, and observed yearly precipitation.

Site/ Year	Sub-Catchment	Surface Condition	Rill Erodibility (s/m)	Interrill Erodibility ($kg*s/m^4$) *1000	Hydraulic Conductivity (mm/hr)	Ground Cover (%)	Observed Runoff (mm)	Observed Sediment (Mg/ha)	Observed Precipitation (mm)
1995	West/North	Low	0.00034	3994	17.1	90	8	0.0	207
	South	Unburned	0.00001	2715	16.6	95			
1996	West/North	Low	0.00034	3994	17.1	95	78	0.0	870
	South	Unburned	0.00001	2715	16.6	95			
1997	West/North	Low	0.00001	1436	16.6	98	89	0.0	673
	South	Unburned	0.00001	1436	16.6	95			
1998	West/North	Low	0.00001	1436	16.6	99	322	0.0	1196
	South	Unburned	0.00001	1436	16.6	95			
1999	West/North	Low	0.00001	1436	16.6	99	179	0.0	474
	South	Unburned	0.00001	1436	16.6	95			
2000	West/North	Low	0.00001	1436	16.6	100	136	0.0	528
	South	Unburned	0.00001	1436	16.6	95			

Table 4. Slate Point input values for model simulations, observed yearly watershed outputs, and observed yearly precipitation.

Site/ Year	Sub-Catchment	Surface Condition	Rill Erodibility (s/m)	Interrill Erodibility ($kg*s/m^4$) *1000	Hydraulic Conductivity (mm/hr)	Ground Cover (%)	Observed Runoff (mm)	Observed Sediment (Mg/ha)	Observed Precipitation (mm)
1994	East/South	Low	0.0004	3279	14	97	0	0.0	221
	West	High	0.0006	5572	13.9	69			
1995	East/South	Low	0.0004	3279	14	98	43	0.0	568
	West	High	0.0006	5572	13.9	85			
1996	East/South	Low	0.00037	1202	16.1	99	53	0.0	519
	West	High	0.0005	3279	14	92			
1997	East/South	Low	0.00034	1202	16.1	100	97	0.0	714
	West	High	0.0004	3279	16.1	96			
1998	East/South	Low	0.0003	1202	16.1	100	33	0.0	242
	West	High	0.00037	1202	16.1	98			

Table 5. Round Up input values for model simulations, observed yearly watershed outputs, and observed yearly precipitation.

Site/ Year	Sub-Catchment	Surface Condition	Rill Erodibility (s/m)	Interrill Erodibility (kg*s/m^4) *1000	Hydraulic Conductivity (mm/hr)	Ground Cover (%)	Observed Runoff (mm)	Observed Sediment (Mg/ha)	Observed Precipitation (mm)
1993	South	Burned	0.00035	3000	11	84	0	0.0	190
	West	Unburned	0.00015	200	80	100			
	North	Skid Trail	0.00055	1000	12	58			
1994	South	Burned	0.00035	3000	13	92	51	0.1	300
	West	Unburned	0.00015	200	80	100			
	North	Skid Trail	0.00055	1000	14	79			
1995	South	Burned	0.00025	1000	15	96	13	0.1	537
	West	Unburned	0.00015	150	80	100			
	North	Skid Trail	0.00035	800	18	89			
1996	South	Burned	0.00015	1000	18	98	32	0.1	265
	West	Unburned	0.00015	150	80	100			
	North	Skid Trail	0.00033	800	20	95			

Table 6. Observed and predicted runoff and sediment from GeoWEPP simulations for the three watersheds.

Site (size) Year	Runoff (mm)		Sediment (Mg/ha)	
	Observed	Predicted	Observed	Predicted
Hermada (9 ha)				
1995	8	0	0.00	0.00
1996	78	0	0.00	0.00
1997	89	0	0.00	0.00
1998	322	1	0.00	0.08
1999	179	0	0.00	0.00
2000	136	0	0.00	0.00
Slate Point (7 ha)				
1994	0	0	0.00	0.00
1995	43	0	0.00	0.00
1996	53	0	0.04	0.00
1997	97	0.2	0.01	0.00
1998	33	0	0.01	0.00
Round Up (2 ha)				
1993	0	0	0.00	0.00
1994	51	0	0.06	0.00
1995	13	0	0.07	0.00
1996	32	0	0.09	0.00

Table 7. The confidence intervals and root mean squared error analysis for observed runoff and sediment yield versus GeoWEPP predicted runoff and sediment yield.

	Runoff (mm)		Sediment (Mg/ha)	
	Observed	**Predicted**	**Observed**	**Predicted**
Hermada				
Mean	135	0	0.00	0.01
Standard deviation	108	0	0.00	0.03
90% confidence interval	72	0	0.00	0.02
Upper limit	208	0	0.00	0.04
Lower limit	63	0	0.00	0.00
RMSE	31		0.01	
Systematic error	24		0.00	
Unsystematic error	19		0.01	
Index of Agreement	0.5		0.8	
N	6		6	
Slate Point				
Mean	45	0	0.01	0.00
Standard deviation	35	0	0.01	0.00
90% confidence interval	26	0	0.01	0.00
Upper limit	71	0	0.02	0.00
Lower limit	19	0	0.00	0.00
RMSE	55		0.02	
Systematic error	55		0.02	
Unsystematic error	0		0.00	
Index of Agreement	0.4		0.4	
N	5		5	
Round Up				
Mean	24	0	0.06	0.00
Standard deviation	22	0	0.04	0.00
90% confidence interval	18	0	0.01	0.00
Upper limit	42	0	0.06	0.00
Lower limit	5	0	0.00	0.00
RMSE	31		0.06	
Systematic error	31		0.06	
Unsystematic error	0		0.00	
Index of Agreement	0.5		0.4	
N	4		4	

Table 8. Observed runoff and sediment yield compared to runoff and sediment yield generated by the modified WEPP model for forests (Wu et al. 2000).

Site (size) Year	Runoff (mm)		Sediment (Mg/ha)		
	Observed	Predicted	Observed	Predicted	
				Watershed	Hillslope
Hermada (9 ha)					
1995	8	9	0.00	0.09	0.00
1996	78	251	0.00	1.38	0.00
1997	89	285	0.00	0.24	0.08
1998	322	476	0.00	0.74	0.45
1999	179	209	0.00	0.04	0.00
2000	136	238	0.00	0.01	0.01
Slate Point (7 ha)					
1994	0	7	0.00	0.19	0.00
1995	43	31	0.00	1.01	0.00
1996	53	94	0.00	1.16	0.00
1997	97	115	0.00	0.16	0.00
1998	33	19	0.00	0.05	0.01
Round Up (2 ha)					
1993	0	9	0.00	0.29	0.00
1994	51	29	0.06	0.86	0.00
1995	13	94	0.07	1.77	0.00
1996	32	118	0.09	0.62	0.00

Table 9. The confidence intervals and root mean squared error index for *yearly* observed runoff and sediment yield versus runoff and sediment predicted by the modified WEPP for forests (Wu et al. 2000).

	Runoff (mm)		Sediment (Mg/ha)	
	Observed	**Predicted**	**Observed**	**Predicted**
Hermada				
Mean	135	245	0.00	0.09
Standard deviation	108	150	0.00	0.18
90% confidence interval	72	120	0.00	0.14
Upper limit	208	364	0.00	0.24
Lower limit	63	125	0.00	0.00
RMSE	131		0.188	
Systematic error	111		0.055	
Unsystematic error	70		0.220	
Index of Agreement	0.8		0.0	
N	6		6	
Slate Point				
Mean	45	53	0.01	0.00
Standard deviation	35	48	0.01	0.01
90% confidence interval	26	35	0.00	0.00
Upper limit	71	89	0.01	0.01
Lower limit	19	18	0.01	0.00
RMSE	22		0.02	
Systematic error	11		0.02	
Unsystematic error	19		0.00	
Index of Agreement	0.9		0.4	
N	5		5	
Round Up				
Mean	24	63	0.06	0.00
Standard deviation	22	52	0.04	0.00
90% confidence interval	18	43	0.03	0.00
Upper limit	42	106	0.09	0.00
Lower limit	5	20	0.03	0.00
RMSE	61		0.06	
Systematic error	41		0.06	
Unsystematic error	45		0.00	
Index of Agreement	0.3		0.4	
N	4		4	

Table 10. The confidence intervals and root mean squared error index for *monthly* observed runoff and sediment yield versus runoff and sediment predicted by the modified WEPP for forests (Wu et al. 2000).

	Runoff (mm)		Sediment (Mg/ha)	
	Observed	**Predicted**	**Observed**	**Predicted**
Hermada				
Mean	14	28	0.00	0.00
Standard deviation	25	20	0.00	0.01
90% confidence interval	5	4	0.00	0.00
Upper limit	19	32	0.00	0.01
Lower limit	8	24	0.00	0.00
RMSE	31		0.01	
Systematic error	24		0.00	
Unsystematic error	19		0.01	
Index of Agreement	0.5		0.8	
N	59		59	
Slate Point				
Mean	5	10	0.00	0.00
Standard deviation	12	9	0.01	0.01
90% confidence interval	3	2	0.00	0.00
Upper limit	8	12	0.00	0.00
Lower limit	2	7	0.00	0.00
RMSE	14		0.01	
Systematic error	22		0.01	
Unsystematic error	17		0.01	
Index of Agreement	0.5		0.6	
N	48		48	
Round Up				
Mean	2	14	0.01	0.00
Standard deviation	9	14	0.02	0.00
90% confidence interval	2	4	0.00	0.00
Upper limit	4	18	0.01	0.00
Lower limit	0	10	0.00	0.00
RMSE	16		0.02	
Systematic error	14		0.02	
Unsystematic error	14		0.00	
Index of Agreement	0.2		0.2	
N	37		37	

Figures

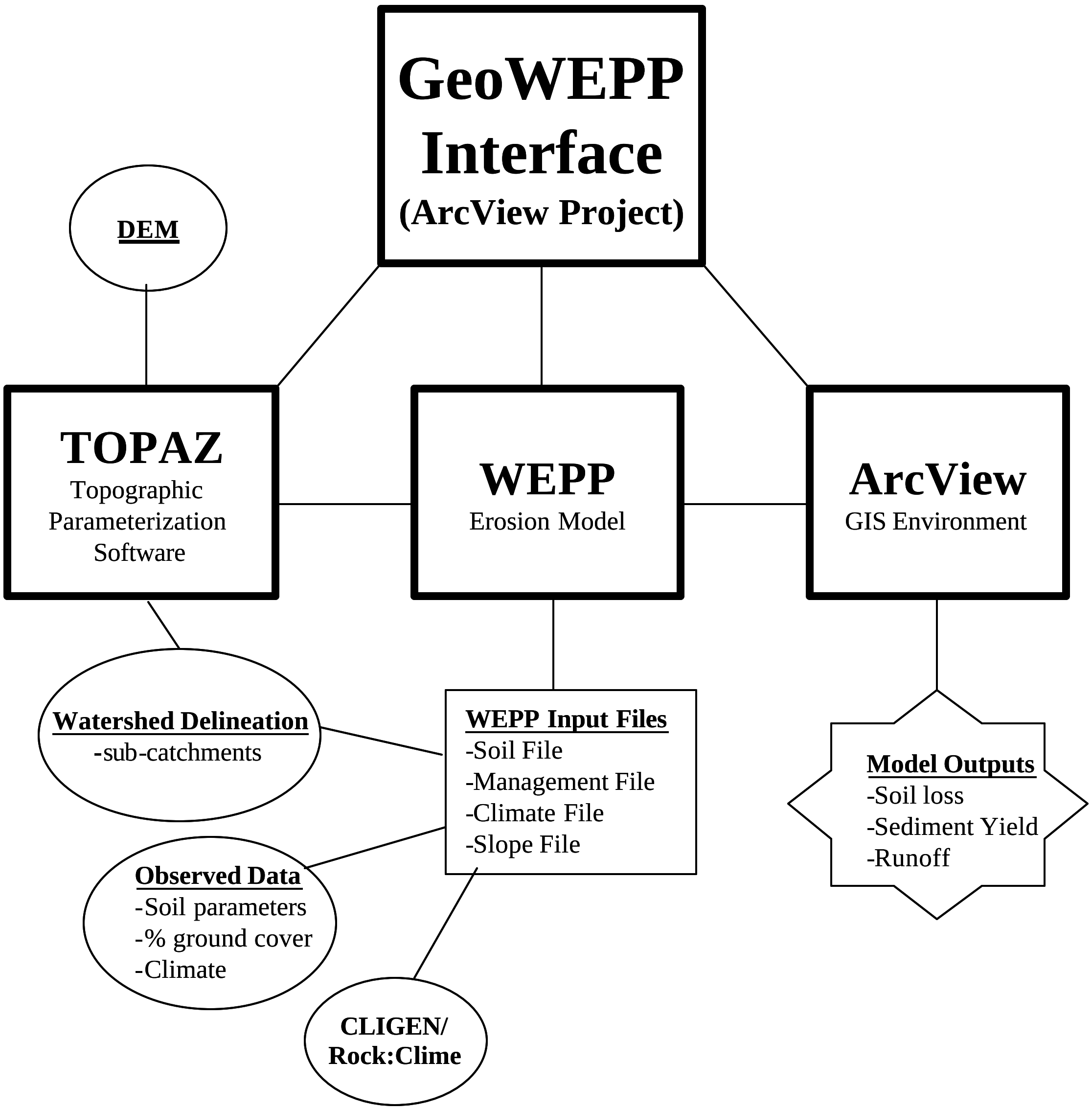

Figure 1. Schematic diagram of GeoWEPP and its components, inputs and outputs.

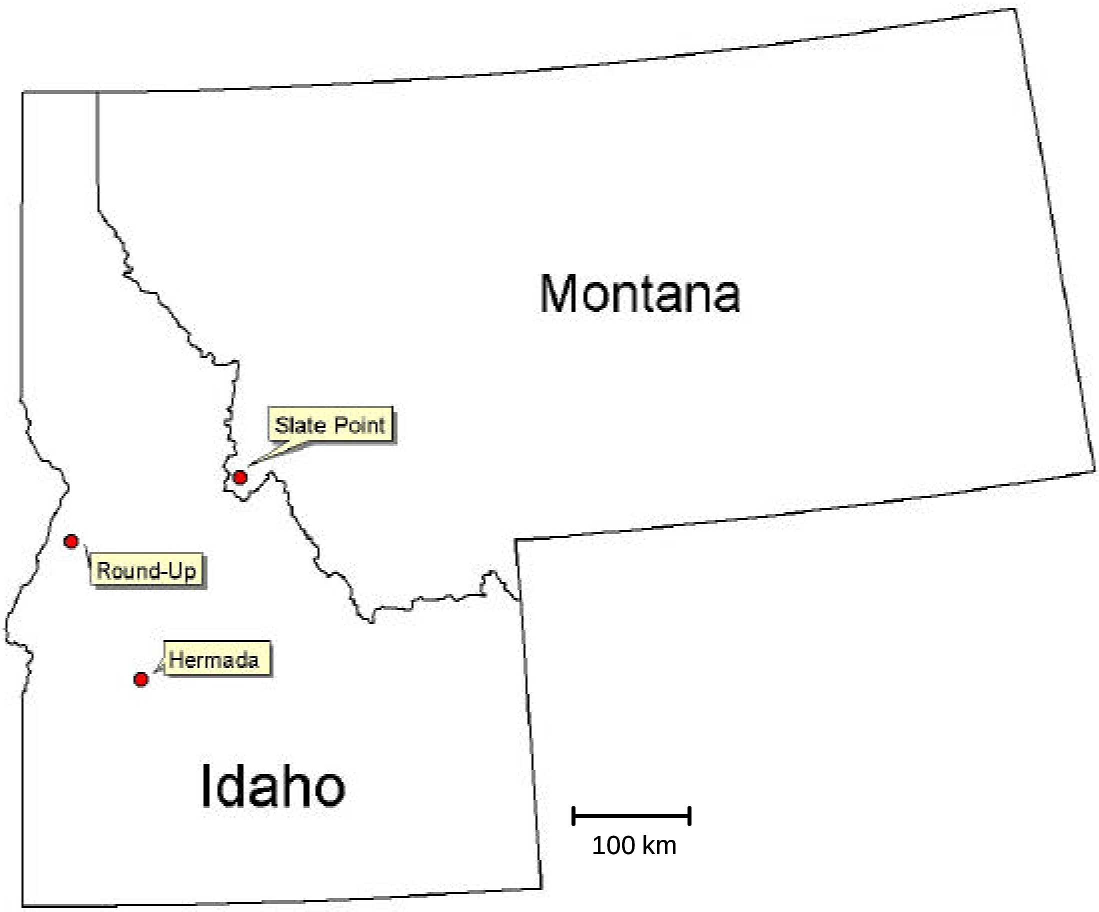

Figure 2. Locations of the three managed watersheds used in this study.

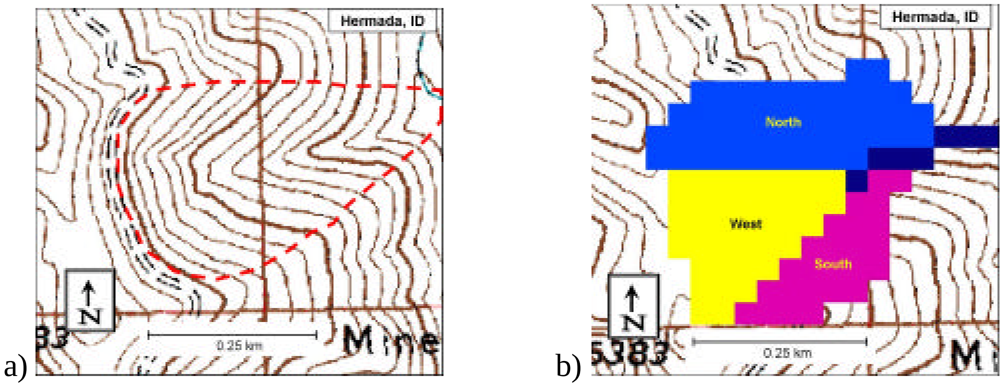

Figure 3. a) Hermada watershed outlined on 20-ft contour map (6.1 m), b) sub-catchments delineated by TOPAZ.

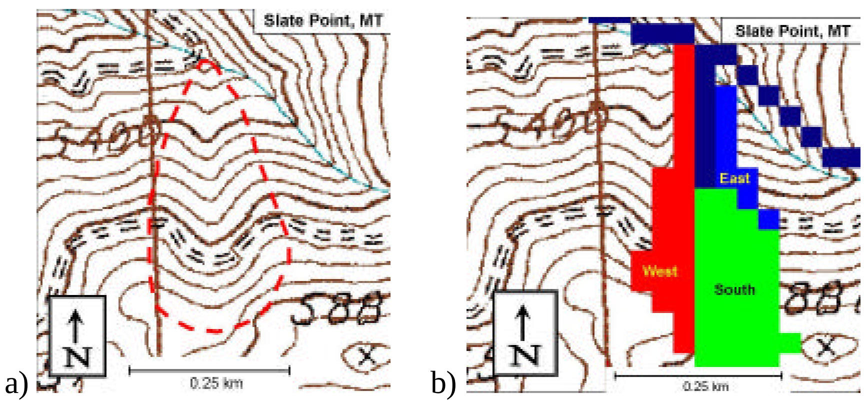

Figure 4. a) Slate Point watershed outlined on 20-ft contour map (6.1 m), b) sub-catchments delineated by TOPAZ.

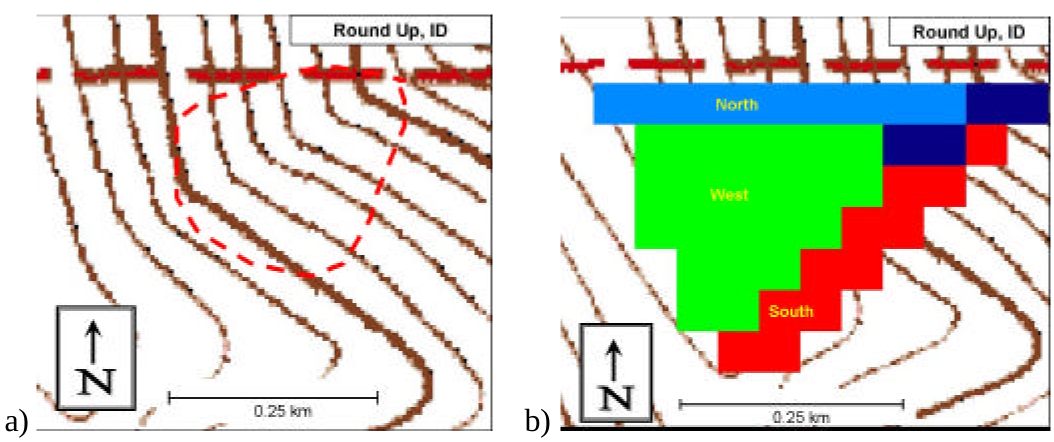

Figure 5. a) Round Up watershed outlined on 20-ft contour map (6.1 m), b) sub-catchments delineated by TOPAZ.

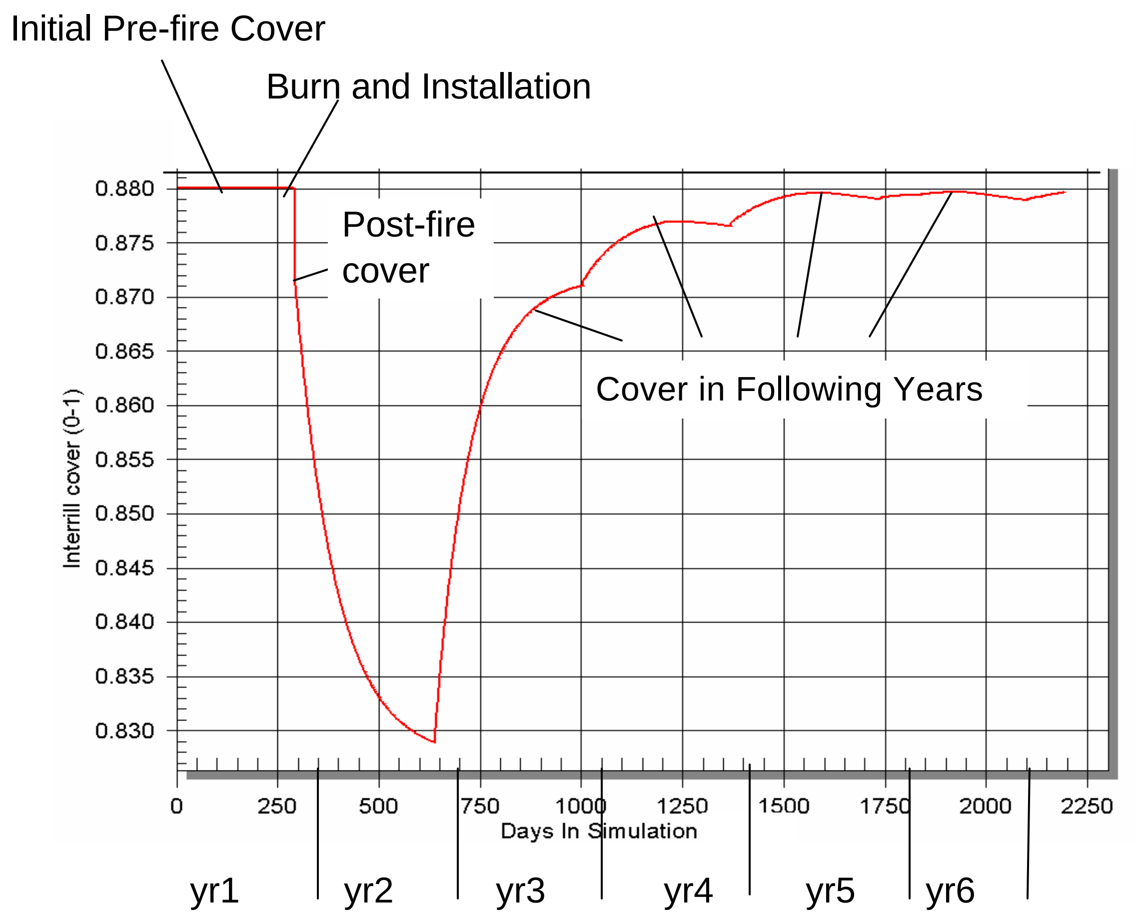

Figure 6. Example of ground cover generation for each year from Hermada management file.

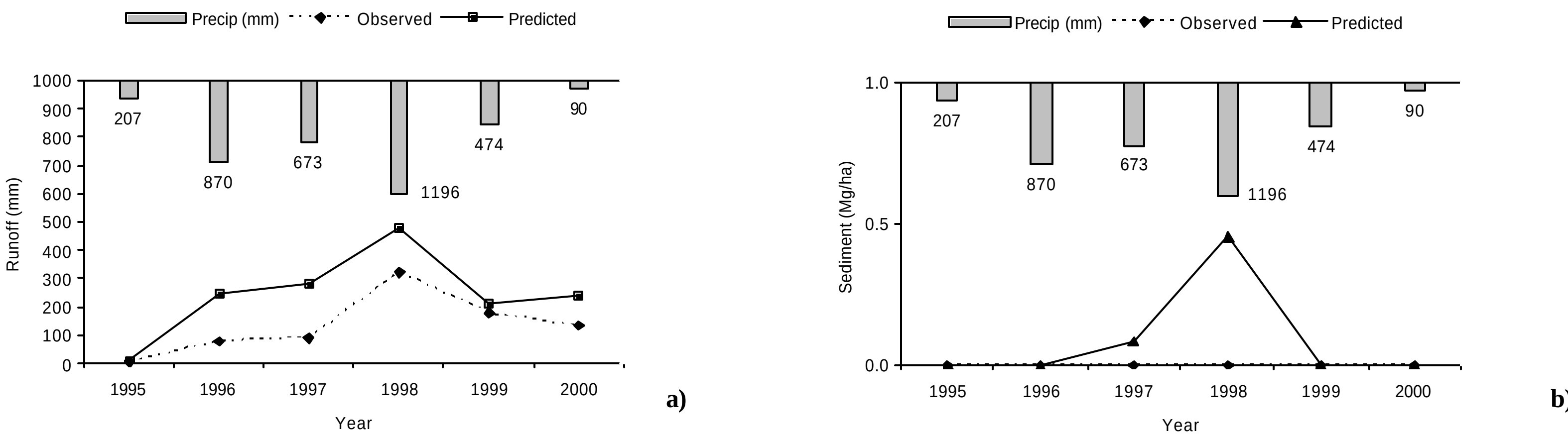

Figure 7. Comparison of total yearly observed and predicted a) runoff and b) sediment for Hermada hillslopes.

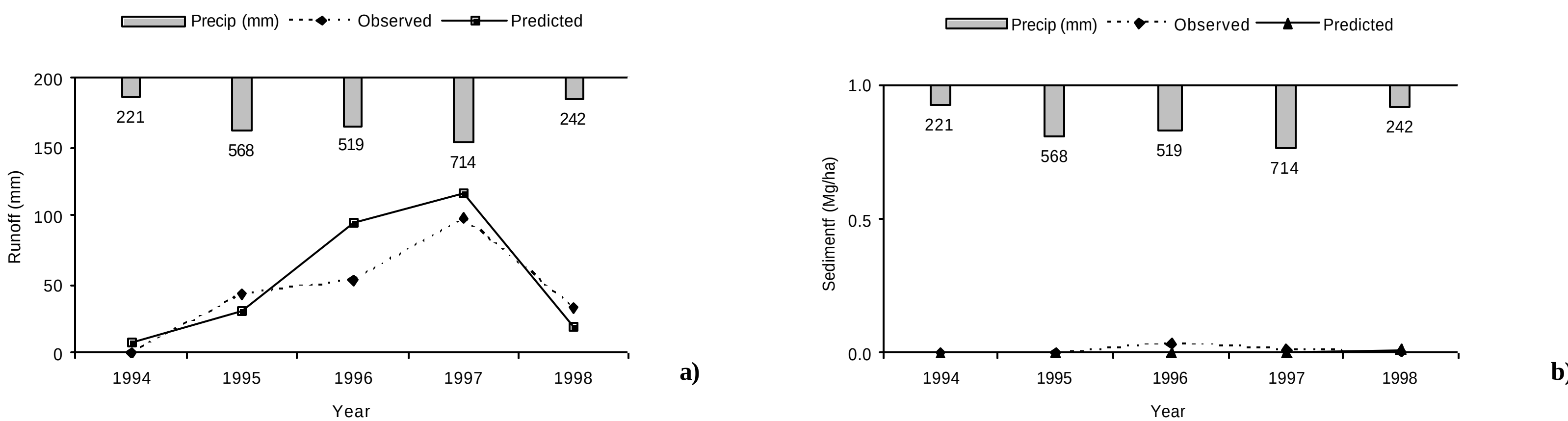

Figure 8. Comparison of total yearly observed and predicted a) runoff and b) sediment for Slate Point hillslopes.

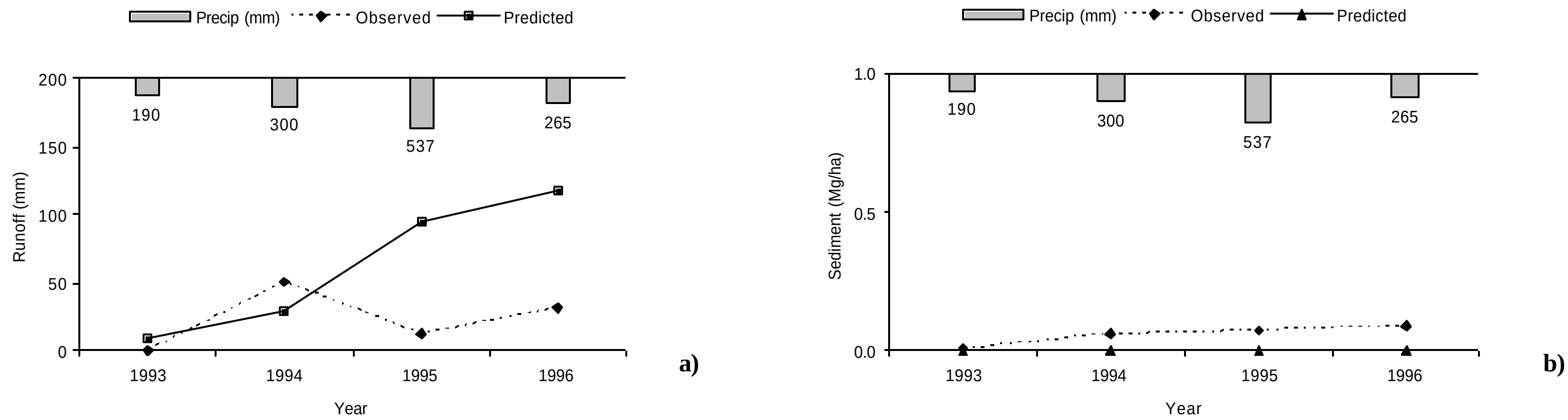

Figure 9. Comparison of total yearly observed and predicted a) runoff and b) sediment for Round Up hillslopes.

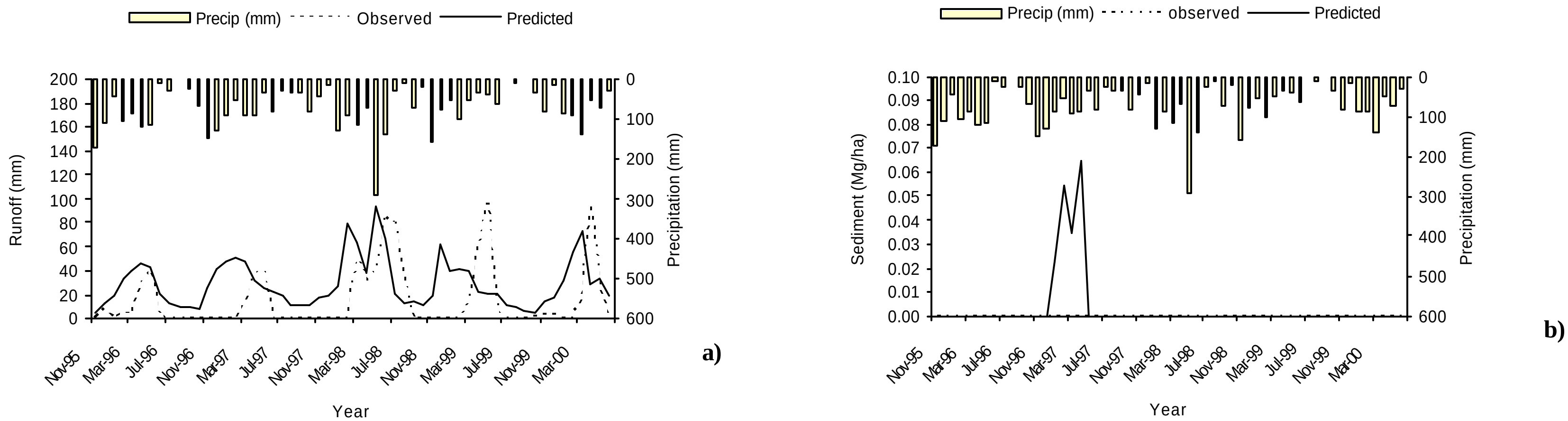

Figure 10. Comparison of total monthly observed and predicted a) runoff and b) sediment for Hermada hillslopes.

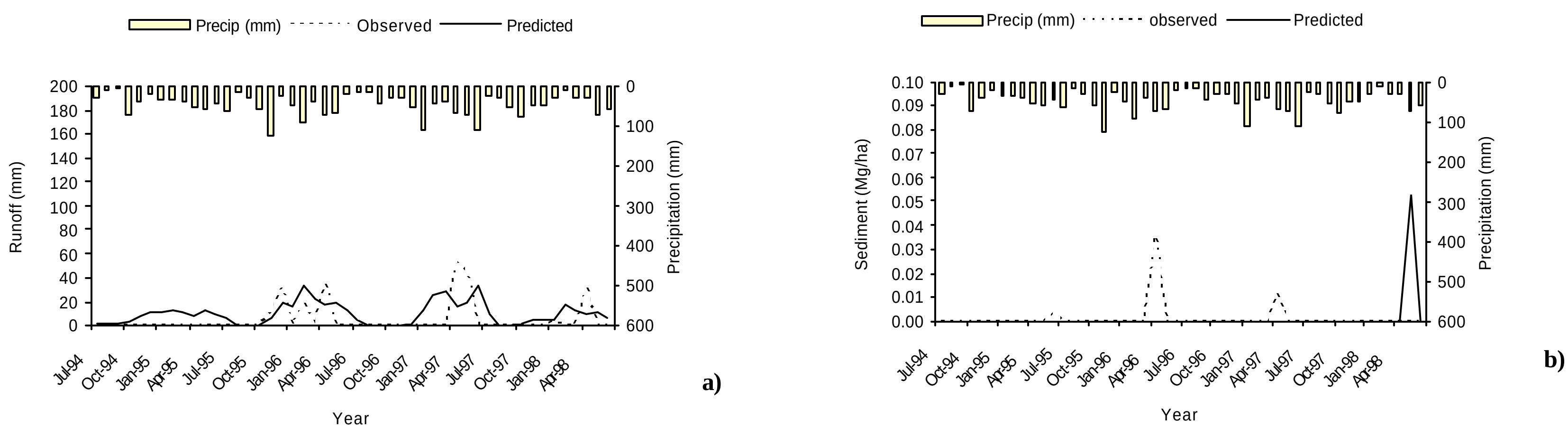

Figure 11. Comparison of total monthly observed and predicted a) runoff and b) sediment for Slate Point hillslopes.

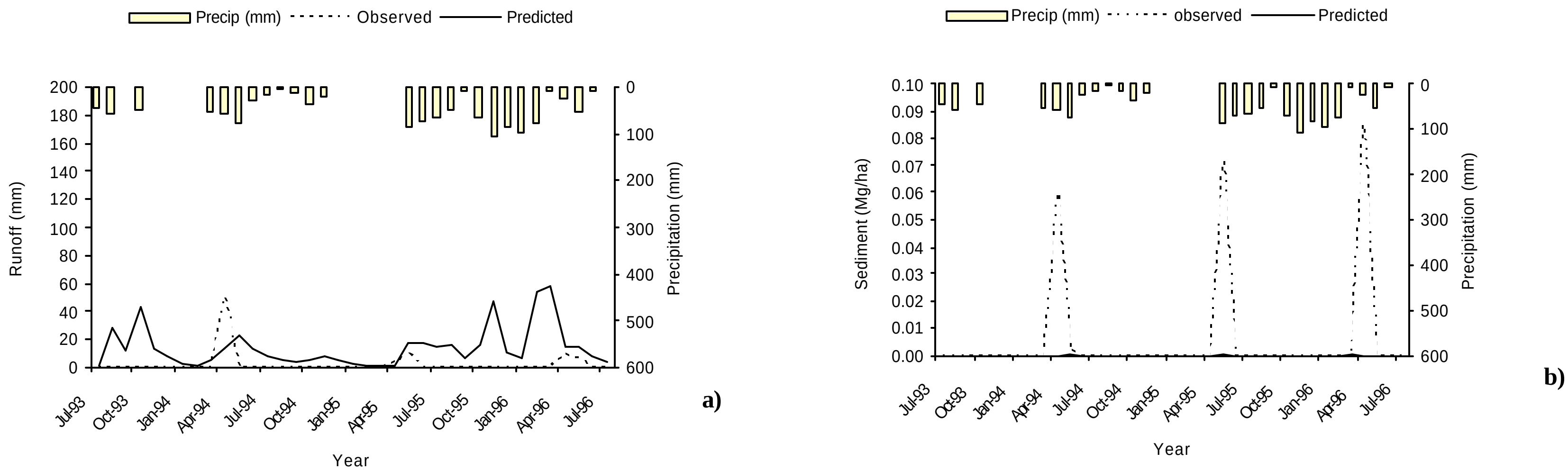

Figure 12. Comparison of total monthly observed and predicted a) runoff and b) sediment for Round Up hillslopes.