ADAPTING WEPP (WATER EROSION PREDICTION PROJECT) FOR FOREST WATERSHED EROSION MODELING

By

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of SHUHUI DUN find it satisfactory and recommend that it be accepted.

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FOREST WATERSHED EROSION MODELING

Abstract

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There has been an increasing public concern over forest stream pollution by excessive sedimentation resulting from human activities. Adequate and reliable erosion simulation tools are urgently needed for sound forest resources management. Computer models for predicting watershed runoff and erosion have been developed in the past. These models, however, are often limited in their application due to inappropriate representation of the hydrological processes involved. The Water Erosion Prediction Project (WEPP) watershed model has proved useful in certain forest applications such as modeling erosion from a segment of insloped or outsloped road, harvested units, and burned units. Nevertheless, when used for modeling water flow and sediment discharge from a forest watershed of complex topography and channel systems, WEPP consistently underestimates these quantities, in particular, the water flow at the watershed outlet.

The main purpose of this study was to improve the WEPP watershed model so that it can be applied to adequately simulate forest watershed hydrology and erosion. The specific objectives were to: (1) identify and correct WEPP algorithms and subroutines that inappropriately represent forest subsurface hydrologic processes; and (2) assess the performance of the modified model by applying

it to a conceptual forest setting as well as a real forested watershed in the Pacific Northwest, USA.

In modifying the WEPP model, changes were primarily made in the approach to, and algorithms for modeling deep percolation of soil water and subsurface lateral flow. The modified model was verified using a conceptual data set, with model predictions from both the new and original codes compared. Additionally, the adequacy of the modified routines was evaluated by applying WEPP to Hermada watershed, a representative forest watershed located in the Boise National Forest in central Idaho, and comparing the WEPP-predicted and field-observed runoff and erosion. Conclusions of this study included: (1) compared to the original model, the modified WEPP more realistically and properly represents the subsurface hydrologic processes in a forest setting; and (2) application of the modified model produced satisfactory results, demonstrating the adequacy of the model modifications.

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CHAPTER ONE

INTRODUCTION

Recently, there has been an increasing public concern over forest stream pollution by excessive sedimentation resulting from human activities. Adequate and reliable erosion simulation tools are urgently needed for sound forest resource management. Computer models for predicting watershed runoff and erosion have been developed in the past. These models, however, are often limited in their applications due to inappropriate representation of the hydrological processes involved (Klemes, 1986). The Water Erosion Prediction Project (WEPP) watershed model, a physically-based erosion prediction software developed by the US Department of Agriculture (USDA), has proved useful in such forest applications as modeling erosion from a segment of insloped or outsloped road, or harvested or burned units of simple geometry (Morfin et al., 1996; Elliot and Hall, 1997; Tysdal et al., 1997). Nevertheless, when used for forest watersheds of complex topography and channel systems, WEPP consistently underestimates subsurface lateral flow and water discharge at the watershed outlet (J. Boll, University of Idaho, personal communication, 2001).

The WEPP watershed model, an extension of the WEPP hillslope model (Nearing et al., 1989; Laflen et al., 1997), was originally developed to evaluate the erosion effects of agricultural management practices, spatial and temporal variability in topography, soil properties, and land-use conditions within small agricultural watersheds (Ascough et al., 1995). Forest lands, on the other hand, are typified by steep slopes, and young, shallow, and coarse-grained soils, differing remarkably from common crop lands. In addition, the presence of dense canopy cover further differentiates forest from crop-, urban-, and range lands with respect to the rates and combinations of individual hydrologic processes (Luce, 1995). WEPP may be a reasonable tool in quantifying runoff and erosion from typical agricultural fields. For forest watershed applications, however, the model needs to be modified to properly represent the hydrologic processes involved. Figure 1 illustrates the differences in major characteristics of hydrologic processes in agricultural and forest settings.

An assessment of the WEPP model (v2002.7) with initial modifications to the subsurface lateral flow routines (Wu et al., 2000) but with flawed water balance algorithms was performed by Covert et al. (2005). In their study, WEPP was applied to three selected watersheds in the interior northwestern US. They concluded that the modifications to the lateral flow routines in WEPP improved runoff predictions in the study watersheds. Since their study, the WEPP model has been substantially refined. Major modifications incorporated into WEPP v2004.7 included corrected water balance routines and newly added Penman-Monteith evapotranspiration (ET) model (Wu and Dun, 2004).

The main purpose of this study was to continually improve the WEPP watershed model such that it can be used to properly simulate and predict forest watershed hydrology and erosion. The specific objectives were to:

(1) identify and correct WEPP algorithms and subroutines that inappropriately represent forest watershed hydrologic processes, in particular, the subsurface lateral flow process; and

(2) assess the performance of the modified model by applying it to a conceptual forest setting as well as a real forested watershed in the Pacific Northwest, USA.

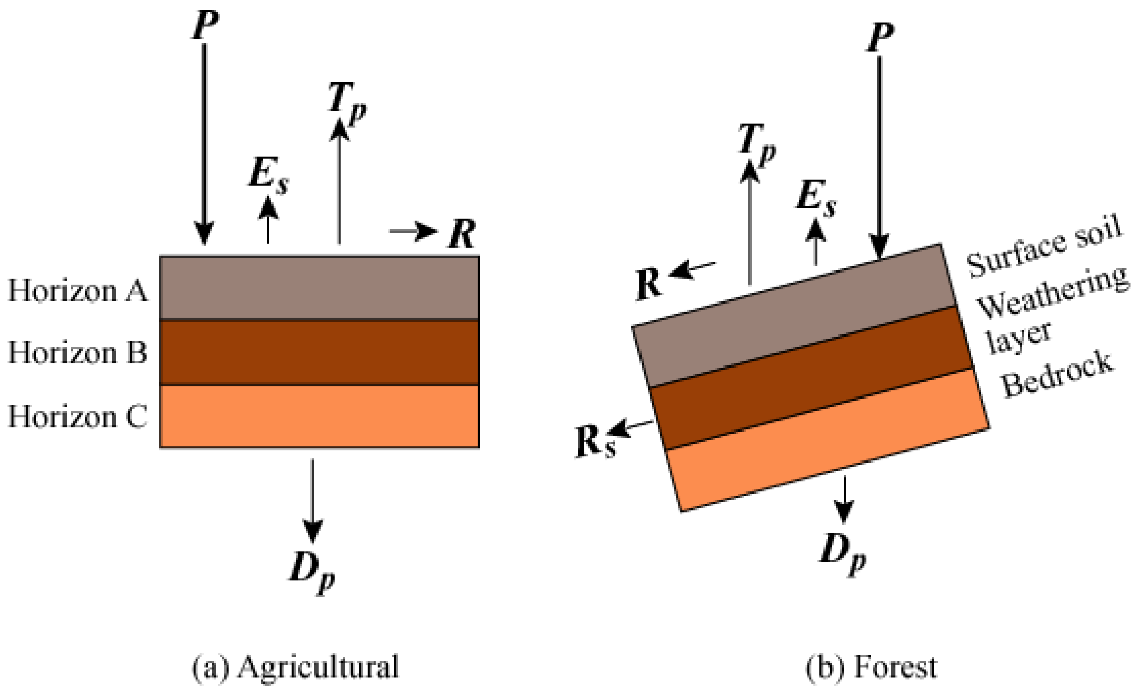

Figure 1. Diagram showing the difference in the rate of hydrologic processes between typical agricultural (a) and forest (b) settings. The size of the arrows reflects the relative magnitude or rate of the individual processes. *P*, precipitation, T_p, plant transpiration, E_s, soil evaporation, *R*, surface runoff, R_s, subsurface lateral flow, D_p, percolation through bottom of soil profile. (Adapted from Wu et al., 2000)

CHAPTER TWO

METHODOLOGY

2.1. Model Description

WEPP discretizes a watershed into such elements as hillslopes, channels, and impoundments. A hillslope can be further divided into overland-flow elements (OFEs), within which soil, cropping and management conditions are assumed homogeneous. Accordingly, the model contains three components simulating major hydrologic and erosion processes within these watershed elements. A recently developed geo-spatial interface, GeoWEPP, allows the use of digital elevation models (DEMs) to generate watershed configuration and topographic inputs for the WEPP model (Renschler, 2003). For completeness, important functions and routines in each WEPP model component are presented below following Ascough and Livingston (1995) and Flanagan et al. (1995).

The hillslope component of WEPP is divided into nine sub-components: climate generation, winter processes, irrigation, surface hydrology and water balance, subsurface hydrology, soils, plant growth, residue decomposition, overland-flow hydraulics, and erosion. Daily or single-storm climate can be generated for the WEPP model with CLIGEN, an auxiliary stochastic climate generator (Nicks et al., 1995). The winter processes account for soil frost and thaw development, snowfall and snow melting. The irrigation sub-component simulates stationary sprinkler and furrow irrigation systems. The surface hydrology and water balance routines use information on weather, vegetation and cultural practices, and maintain a continuous balance of the soil water on a daily basis. Infiltration is computed by a Green-Ampt Mein-Larson equation (Mein and Larson, 1973) modified for unsteady rainfall (Chu, 1978). ET is evaluated by using a modified Ritchie's model (1972), with reference potential ET estimated from the Penman equation (1963) or Priestly-Taylor method (1972) depending on the availability of wind and humidity data. Rainfall interception by canopy, surface depressional storage, soil water percolation, and subsurface lateral flow are also considered. The subsurface hydrology routines compute lateral flows following a mass continuity approach developed by Sloan and Moore (1984). The soil sub-component assesses effects of tillage on various soil properties. The plant growth routines calculate biomass production for both crops and rangeland plants. The plant residue decomposition routines model common residue management practices and the change of residue with time. The overland-flow hydraulics sub-component performs overland flow routing based on the solutions to the kinematic wave equations or their approximations. In addition, this sub-component estimates hydraulic properties as affected by surface soil and vegetation cover conditions. The erosion sub-component estimates interrill and rill erosion, with the former treated as soil detachment by raindrop impact and subsequent sediment delivery to rills, and the latter a function of sediment detachment and transport capacity of concentrated flow, and the load already in the flow.

The channel component of the WEPP watershed model consists of channel hydrology and erosion. Channel hydrology routines simulate hydrologic processes and compute water balance in the same way as the hillslope hydrology routines, and generate hydrographs by combining channel runoff with the surface runoff from upstream watershed elements, i.e., hillslopes, channels or impoundments. The channel erosion routines simulate soil detachment and deposition similar to the hillslope erosion routines. Watershed sediment yield is taken as a result of the detachment, transport, and deposition of sediment on both overland- and channel-flow areas. The WEPP watershed version can also model impoundments in channels. The major function of an impoundment is to trap sediment and reduce sediment yield. Impoundments generally include culverts, filter fences, straw bales, drop and emergency spillways, rock-fill check dams, and perforated risers. The impoundment component of the WEPP model calculates outflow hydrographs and sediment concentration for the impoundment structures.

WEPP uses pass files to transfer information between different model components. Upon completion of the execution of hillslope routines, information on surface runoff hydrograph and sediment graphs are stored in hillslope pass files and are incorporated into a watershed master pass file for use by the channel and impoundment components. Information on subsurface lateral flow generated from either a hillslope or a channel, however, is not saved.

*2.2. WEPP Limitations and Modification*s

Since the subsurface lateral flow calculated in the WEPP hillslope component is not included in the hillslope and watershed pass files, it is not added to the channel flow that ultimately discharges from the watershed outlet. On the other hand, WEPP's hillslope component tends to substantially overestimate percolation through the bottom of the soil profile (also referred to as deep percolation) and underestimate subsurface lateral flow for several reasons. First, WEPP allows the saturated hydraulic conductivity (K_{sat}) to be input for the surface soil layer only. The model estimates K_{sat} for the remaining soil layers using empirical functions of soil properties, in particular, the percentages of clay and sand as follows.

$$K = \frac{12.7 \times (100 - clay) \times ssl}{(100 - clay) + e^{(11.45 - 0.097 \times (100 - clay))}} \tag{1a}$$

$$ssl = 0.1 + \frac{0.0009 \times bd}{0.001 \times bd + e^{(bt1 + bt2 \times 0.001 \times bd)}} \tag{1b}$$

$$bt1 = \ln(0.0112 \times bdl) - bt2 \times bdl \tag{1c}$$

$$bt2 = \frac{\ln(0.0112 \times bdl) - \ln(8.0 \times bdu)}{bdl - bdu} \tag{1d}$$

$$bdl = 1.15 + 0.445 \times sand/100 \quad (1e)$$

$$bdu = 1.50 + 0.500 \times sand/100 \quad (1f)$$

where *sand* and *clay* are percent of sand and clay in the soil respectively; *bd* is soil bulk density in kg m^{-3}.

The empirical equations lead to a K_{sat} larger than that of most bedrock even under extreme conditions, e.g., for a soil with 1% sand content and 99% clay content, K_{sat} is about 1.5×10^{-4} m s^{-1}. Further, a lower limit of K_{sat} is set to 2.0×10^{-8} m s^{-1} in the model. Such a treatment of K_{sat} may be reasonable for agricultural lands with relatively uniform and deep soils or with subsurface drainage systems, but is likely invalid for most forest settings where soils are typically shallow and underlain by low-permeability bedrocks. Without subsurface drains to intercept percolated soil water, an overestimated K_{sat} value for the deeper soil layers simply signifies an overestimated deep percolation.

In the WEPP model, evaluation of the individual components of the water balance, such as surface runoff, ET, change in soil water, is performed sequentially. Prior to calculating deep percolation, WEPP estimates and adjusts for soil water content. If soil water content is greater than the water content at field capacity (θ_{fc}), percolation starts and the portion flowing through the bottom of the soil profile is removed from the water balance. Afterwards, if the soil water content is still greater than θ_{fc}, WEPP calculates the lateral flow following Darcy's law using the internally estimated K_{sat} adjusted for the present soil water content. In reality, percolation and lateral flow take place simultaneously. Therefore, if the two processes are simulated separately and if the deep percolation is incorrectly overestimated, the subsurface lateral flow would be underestimated. Another source for the underestimate was an error in the WEPP codes, which allows subsurface lateral flow to occur only when the top soil layer is saturated.

Second, WEPP assumes that the modeled soil layer is isotropic, i.e., the horizontal and vertical K_{sat} values are equal. This assumption, again, may be adequate for many agricultural fields but inadequate for forest lands where the layered structure of porous soil on top of low-permeability bedrock tends to lead to higher horizontal hydraulic conductivity and greater lateral flow (Brooks et al., 2004). Similarly, the duff layer and the A horizon in forest soils exhibit higher hydraulic conductivity than common soils, facilitating development of "conduits" along the interfaces of duff, the A horizon, and deeper soils (P.R. Robichaud, RMRS, USDA Forest Service, personal communication, 2005). Such unique hydraulic conditions cannot be properly represented by the soil property component in current WEPP with isotropic soil layers.

Modifications were made to correct these problems and to refine subsurface lateral flow routines in the WEPP model v2004.7 (Wu et al., 2005a,b). The modifications were extensively tested through numerous runs using a conceptual model watershed. Our modifications were also independently evaluated by WEPP researchers at the USDA National Soil Erosion Research Laboratory and ultimately accepted and included in the new WEPP v2006.5.

To correct the problem of overestimation of deep percolation, the soil input file was modified to add a new line providing information for a "restrictive" layer at the bottom of a soil profile. The modified codes allow a user to choose whether or not to use the restrictive layer with a character variable (solflag) in the soil input file. When solflag = 0, no restrictive layer is assumed and WEPP uses the original algorithms to estimate K_{sat} for deeper soil layers; otherwise, when solflag = 1, the restrictive layer is assumed and a user-specified K_{sat} is input for this restrictive layer. K_{sat} values for commonly occurring sedimentary and crystalline rocks can be found in Domenico and Schwartz (1997).

Currently, the user is allowed to specify a single anisotropy ratio next to solflg in the soil input file to describe the whole soil profile. In the future, an option to input the anisotropy ratio for different soil layers will be included.

As stated earlier, in the original WEPP codes, only surface runoff information, labeled as “EVENT”, is stored and passed to the watershed master pass file. To include the subsurface lateral flow information in the hillslope and watershed pass files, both conditions were considered: (i) when surface runoff and subsurface lateral flow occur on the same day, and (ii) only subsurface lateral flow occurs. For both conditions, it was assumed that subsurface lateral flow does not contribute sediment to the stream channels.

Under the first condition, the surface runoff was assumed to dominate the water flow and sediment transport processes, and the subsurface lateral flow is simply added to the surface runoff by volume without changing the sediment amount in it. This approach is consistent with field observations and a preliminary analysis of WEPP simulation results that indicated that surface runoff occurs much less frequently but can produce much greater amount of flow compared to subsurface lateral flow on an event basis. For the second situation, the hillslope pass files were modified to include subsurface lateral flow events, named “SUBEVENT” and with a presumed 24-hr flow duration. Relevant subroutines were modified to transfer information on subsurface lateral flow from the hillslope pass files to the watershed master pass file, which in turn passes the information to the channel or impoundment components for subsequent routing.

In the original WEPP codes, the channel or impoundment component does not route flow when there is no storm, irrigation, or surface runoff. Modifications were made to route subsurface lateral flow under these water input and runoff conditions. Generally, the amount of subsurface lateral flow (by volume) generated by an upstream hillslope was assumed to be evenly distributed along the channel. Upon entering a channel, however, the subsurface lateral flow adds to the channel flow without sediment, thus increasing the transport capacity of the channel and potential channel erosion. Hence, the modified WEPP potentially predicts higher channel erosion than the original model.

Accordingly, modification was made to add the information on subsurface lateral flow from hillslopes to the watershed output file, allowing comparison between WEPP-predicted and field-observed hillslope and watershed discharge.

Finally, changes were made to the crop growth subroutine to enhance the flexibility of WEPP in representing the physiological processes of vegetation in forested watersheds. In the original model, a user-specified perennial vegetation will continually grow year after year, as in tree growth, only if the dates for planting, stop of growth, and start of senescence are all set to zero. However, if the date of senescence is zero, leaves would not fall and no residue accumulation is calculated. On the other hand, if the date of senescence is not zero then no vegetation growth is calculated for any time during the year. Therefore, one could not simulate continuous vegetation growth and residue accumulation as in the forest settings using the original WEPP. The codes were modified such that vegetation growth is calculated for any Julian day before it reaches the senescence date. The modified codes, along with a summary of soil input changes, are included in Appendix A.

2.3. Model Verification

The modified WEPP watershed model was applied to a conceptual Pacific Northwest forest watershed. The watershed was composed of three hillslopes and one channel, with a total area of 6.6 ha. Hillslopes 1 and 2 were on the left and right sides of the channel, respectively, and Hillslope 3 was on the top of the channel. Dimensions of the hillslopes and the channel are given in Table 1.

Major WEPP inputs include climate, soil, topography, and management practice data. The climate data consisted of a 30-year stochastic weather sequence for St. Maries, Idaho, generated by

Table 1. Dimensions of the components of the conceptual watershed used in model verification.

	Hillslope 1	Hillslope 2		Hillslope 3			Channel
OFE	1	1	2	1	2	3	1
Length, m	29	28	30	68	105	72	187
Width, m	187	187		205			1
Area, m^2	5,423	10,846		50,225			187

the CLIGEN program. Soil and management data were adapted from the WEPP database for forest conditions developed by the Rocky Mountain Research Station, USDA Forest Service (USDA, 2006b). The soil and management inputs for individual OFEs on multi-OFE hillslopes were set to be different for model verification purposes (Table 2). The surface effective hydraulic conductivity was increased from the default values of 5.6×10^{-6}–1.1×10^{-5} m s^{-1} to 4.2×10^{-5} m s^{-1} to better represent forest conditions. A basalt bedrock, typical of the Pacific Northwest region, was assumed to form the restrictive layer. K_{sat} for basalt ranges 4.2×10^{-7}–2.0×10^{-11} m s^{-1} (Domenico and Schwartz, 1997). An intermediate value of 1.0×10^{-9} m s^{-1} was used for this study. A recent study by Brooks et al. (2004) suggest that lateral saturated hydraulic conductivity is strongly scale-dependent, with the value at hillslope scales one to two orders of magnitude greater than small-scale, soil core measurements. K_{sat} based on small-scale measurements was used for calculating vertical water flow in the model. An anisotropy ratio for K_{sat} of the soil profile was set to 25 following Zhang et al. (2006) to simulate subsurface lateral flow.

The topography data was developed from DEMs in the USDA Natural Resources Conservation Service Geospatial Database (NRCS, 2006a) for St. Maries, Idaho (Figure 2). GeoWEPP was applied to generate the watershed structure and channel inputs for the conceptual watershed.

Model runs were made using the original as well modified WEPP model. Additionally, sensitivity of crucial model outputs, in particular, runoff and erosion, to soil inputs, was evaluated.

Table 2. Soil and management inputs used in model verification.

		Soil	Management
Hillslope 1	OFE 1	silt loam	20-yr forest
Hillslope 2	OFE 1	sandy loam	5-yr forest
	OFE 2	clay loam	20-yr forest
Hillslope 3	OFE 1	sandy loam	5-yr forest
	OFE 2	silt loam	5-yr forest
	OFE 3	clay loam	20-yr forest
Channel		silt loam	20-yr forest

Figure 2. Topography and configuration of the conceptual watershed for model verification.

2.4. Model Application

2.4.1. Study Site

Hermada watershed, one of the three watersheds evaluated in Covert et al. (2005), was chosen as the watershed for testing the modified WEPP model in this study. The Hermada watershed is located in the Boise National Forest, Idaho at latitude 43.87°N and longitude 115.35°W. It is 9-ha in size and has an elevation ranging 1760–1880 m. Trees were harvested in 1992 using cable-yarded technique and was burned by prescribed fire on October 17, 1995. The watershed was extensively monitored for runoff and erosion during November 3, 1995–September 30, 2000 (Covert et al., 2005).

2.4.2. WEPP Inputs

The period of field monitoring was used as the simulation time for this study. Input data for WEPP simulations were partly from those developed by Covert et al. (2005) while changes were also made to improve the inputs as described in detail below.

2.4.2.1. Topography

The watershed structure and slope files for the WEPP model were adapted from Covert et al. (2005). The watershed was delineated into one channel section and three single-OFE hillslopes to the south, north and the west of the channel (Table 3). The prescribed fire on October 17, 1995 produced an overall low-severity burn on the west and north slopes while leaving the south slope and channel unburned (Robichaud, 2000).

Table 3. Configuration of the Hermada watershed in the WEPP model.

Hillslope	West	North	South	Channel
Length, m	240	242	129	120
Width, m	142	175	175	1
Area, m^2	34,200	42,298	22,500	120

2.4.2.2. Climate

Field-observed climate data for the Hermada watershed contained two sets of measurements: one by a tipping-bucket rain gage in one-minute intervals, and the other by a weighing-bucket gage in 15-minute intervals (R.E. Brown, RMRS, USDA Forest Service, personal communication, 2006). The weighing-bucket gage was equipped with shielding wings, more suitable to and effective in catching snow in winter. In addition to precipitation, the weighing-bucket gage measured temperature, relative humidity, solar radiation, wind velocity, and wind direction.

The climate data used in Covert et al. (2005) were re-processed in this study. First, data from the two gages were thoroughly examined and evaluated in order to develop daily precipitation data. Recordings from the weighing-bucket gage exhibited frequent abnormal fluctuations, while data from the tipping-bucket rain gage were more consistent. Hence, daily precipitation was prepared based on the tipping-bucket data and was substituted with data from the weighing-bucket gage when it generally caught more during winter seasons.

Additionally, faulty data due to equipment malfunction was identified and adjusted. Small gaps of precipitation and daily maximum and minimum temperature (6% of the data) were filled with data for the same period from the closest SNOTEL site, the Graham Guard station at 43.95°N and 115.27°W, 1734 m a.s.l. in the State of Idaho (NRCS, 2006b). Small gaps of other data considered less sensitive in WEPP, including solar radiation and wind, were generated using CLIGEN based on the observed daily precipitation, maximum and minimum temperatures for the study site and long-term statistics of climate parameters for Deadwood Dam at 44.32°N and 115.63°W, 1639 m a.s.l. in the state of Idaho (USDA, 2006a). The Deadwood Dam station is about 55 km from the study site, and is the closet climate station with long-term climate data and at an elevation similar to that of the study site.

The recorded temperature data for the year of 2000 considerably exceeded the values for the other years and PRISM-estimated normal ranges (OCS, 2006). Hence, the temperature data for 2000 were estimated based on data for the same period from the Graham Guard station using a linear regression function relating monthly averages of daily maximum and minimum temperatures for the two sites. Additionally, anomalies of solar radiation and wind data for 1998 were replaced with CLIGEN-generated data. Detailed description of procedures used to re-process the climate data is included in Appendix B.

The re-processed precipitation data were considered realistic and adequate for the study area as shown in Figure 3, which compares monthly precipitation for the monitored period re-processed in this study with those from PRISM estimation and SNOTEL observations at the Graham Guard station, respectively. Figure 4 illustrates the climate inputs for the WEPP application.

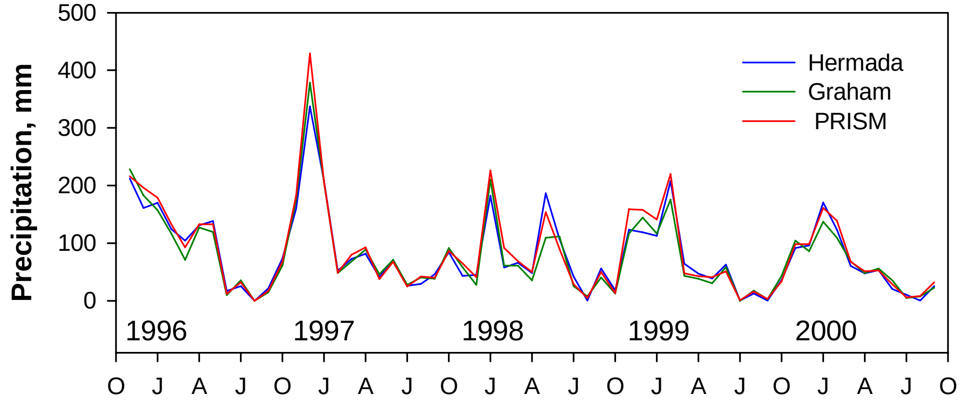

Figure 3. Comparison of monthly precipitation for the Hermada watershed: re-processed data in this study, Graham, SNOTEL observations, and spatially interpreted data by PRISM.

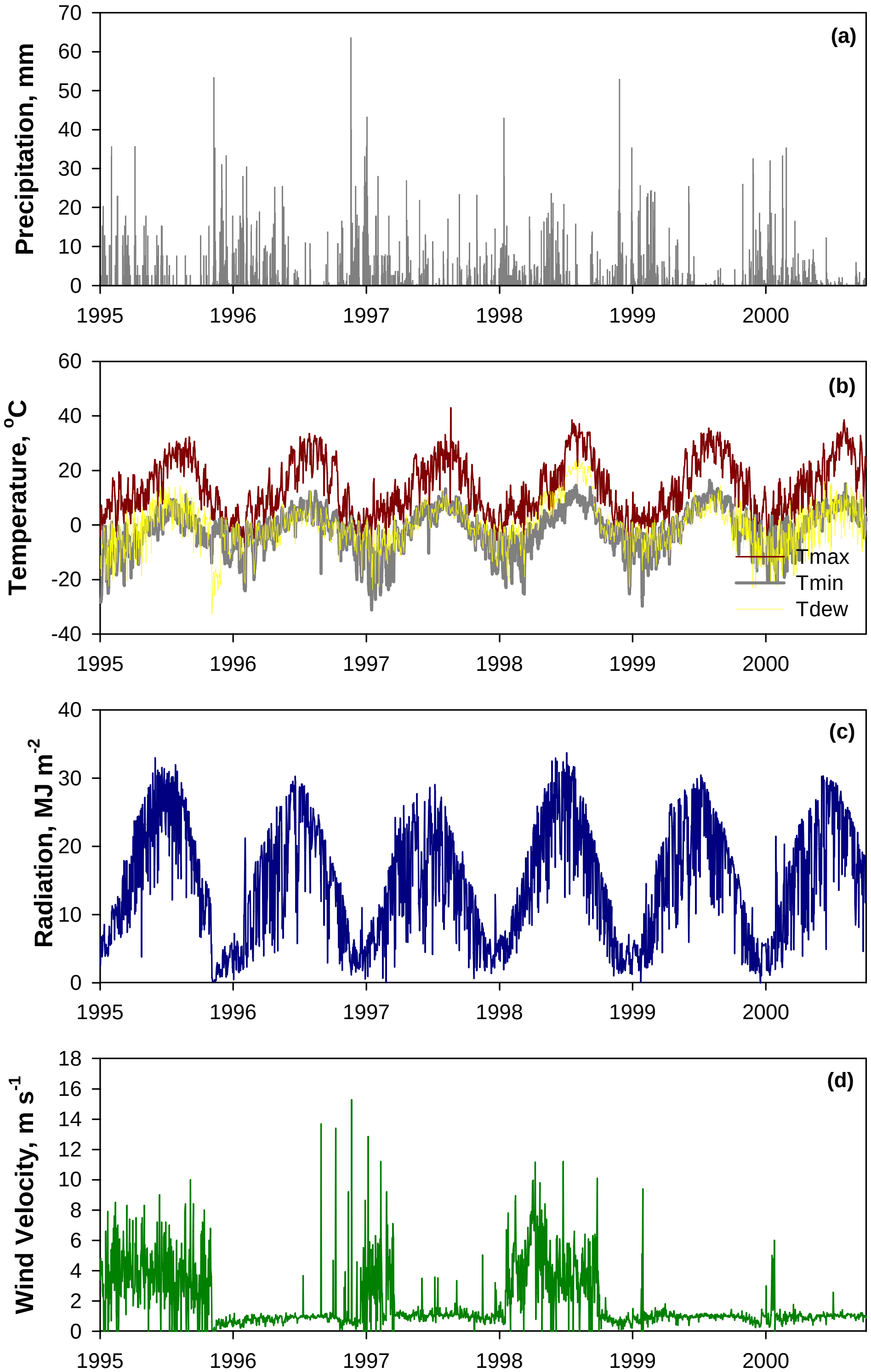

Figure 4. Hermada watershed daily climate inputs to WEPP, (a) precipitation, (b) maximum, minimum, and dew-point temperature, (c) solar radiation, and (d) wind velocity.

2.4.2.3. Soil

Soil input was mainly adapted from Covert (2003). A single layer with a depth of 500 mm, consistent with field observation, was used. An anisotropy ratio of 25 for the soil profile was specified to account for the difference between horizontal and vertical hydraulic conductivities following Zhang et al. (2006) and Brooks et al. (2004). The initial soil saturation level was changed from 75% as in Covert (2003) to 45%, considering the effect of the prescribed fire in late fall of the first year of simulation. This setting was also consistent with the soil conditions after a relatively dry year of 1994 (OCS, 2006) based on the results from a preliminary WEPP run.

Other changes made were on the depth to non-erodible layer in mid-channel, from the default of 0.50 m to 0.05 m; and the depth to non-erodible layer along the side of the channel, from 0.10 m to 0.01 m, based on field conditions.

2.4.2.4. Management

Considerable changes were made to the management input file. Original WEPP was unable to simulate a perennial vegetation with an increasing living biomass as well as an increasing residue cover. In Covert et al. (2005), annual crop, instead of perennial vegetation, was used to represent trees. WEPP-simulated ground cover by residue was reasonable yet the simulated growth curve, with annual peaks, appeared unrealistic for forest conditions. In this study, perennial vegetation was used, together with the modified vegetation growth routines in WEPP v2006.5. The parameters of the modified management file and major soil input are presented in Table 4.

Table 4. Major soil and management parameter list for WEPP application to Hermada watershed.

Parameters	UB[†]	LB
Soil		
Soil depth, mm	500	
Sand, %	85	
Clay, %	2	
Organic matter, % volume	5	
Cation exchange capacity, cmol kg^{-1}	1.5	
Rock fragments, % volume	20	
Albedo	0.1	
Initial soil saturation, %	45	
Baseline interrill erodibility, kg s m^{-4}	2.7×10^{6}	4.0×10^{6}
Baseline rill erodibility, s m^{-1}	1.0×10^{-5}	3.4×10^{-4}
Baseline critical shear, N m^{-2}	0	0
Effective hydraulic conductivity of surface soil, m s^{-1}	4.8×10^{-6}	4.6×10^{-6}
Saturated hydraulic conductivity of restricted layer, m s^{-1}	1.4×10^{-9}	
Soil anisotropy ratio	25	
Vegetation		
Land use	Crop land	
Dominant plant	Tree	
Cropping system	Perennial	
Canopy cover coefficient	5.2	
Parameter value for canopy eight equation	3	
Biomass energy ratio	10	
Base daily air temperature, °C	2	
Parameter for flat residue cover equation, m^2 kg^{-1}	5	
Growing degree days to emergency, °C	5	
Fraction canopy remaining after senescence	0.95	
Plant stem diameter at maturity, m	0.25	
Heat unit index when leaf area index start to decline	0.25	
Fraction of biomass remaining after senescence	0.9	
Radiation extinction coefficient	0.9	

Standing to flat residue adjustment factor	0.99	
Maximum Darcy-Weisbach friction factor for living plant	15	
Maximum canopy height	2.5	
Decomposition constant for above-ground biomass	2.0×10^{-3}	
Decomposition constant for root biomass	6.0×10^{-3}	
Optimal temperature for plant growth, °C	20	
Plant drought tolerance factor, fraction	0.1	
In-row plant spacing, m	0.4	
Maximum root depth, m	2.0	
Root to shoot ratio	0.33	
Maximum root mass for a perennial crop, kg m^{-2}	0.5	
Period over which senescence occurs, d	365	60
Maximum temperature that stops growth of a perennial crop, °C	40	
Critical freezing temperature for a perennial crop, °C	−40	
Maximum leaf area index	3	
Row width, m	1.2	
Senescence date	300	
Perennial plant date	0	
Perennial stop growth date	0	
Crop management	no disturb	
Initial Condition		
Initial cropping system	perennial	
Bulk density after last tillage (g cm^{-3})	1.1	
Initial canopy cover	1.0	0.995
Days since last tillage	1000	
Days since last harvest	1000	
Initial frost depth, m	0	
Initial interrill cover	0.95	0.90
Cumulative rainfall since last tillage, mm	1000	
Initial ridge height after last tillage, m	0.1	
Initial rill cover	0.95	0.90
Initial ridge roughness after last tillage	0.1	

Rill spacing, m	0
Rill width type	temporary
Initial snow depth, m	0
Initial depth of thaw, m	0
Depth of secondary tillage layer, m	0.1
Depth of primary tillage layer, m	0.2
Initial rill width, m	0
Initial total dead root mass, kg m^{-2}	0.5
Initial total incorperated residue mass, kg m^{-2}	0.5

† UB, unburned; LB, low-burn severity.

2.4.3. Model Evaluation

Data from literature and field observation were used to evaluate the simulation results of the modified WEPP on Hermada watershed. Annual living biomass growth rate was compared with literature data, while residue ground cover was compared with the field-observed data. Simulated stream flow and sediment yield were compared with both field observations at the study site as well as data from a nearby USGS gaging station. In evaluating the performance of the modified WEPP model, the Nash-Sutcliffe coefficient K (Nash and Sutcliffe,1970) was calculated for daily runoff predictions from both WEPP v 2006.5 and 2004.7, using the following equation.

$$K = 1 - \Sigma_{t=1}^{T}(Q_o^t - Q_m^t)^2 / \Sigma_{t=1}^{T}(Q_o^t - Q_{oa})^2 \qquad (2)$$

where Q_o^t and Q_m^t are observed and simulated discharges, respectively, for day t; Q_{oa} is observed average.

CHAPTER THREE

RESULTS AND DISCUSSION

3.1. Model Evaluation Using the Conceptual Watershed

The 30-year average annual runoff and erosion simulated by WEPP v2004.7 and the v2006.5 with modified crop growth routine are shown in Table 5. Water balances for individual hillslopes and the whole conceptual watershed are shown in Table 6.

In the case using WEPP v2004.7, surface runoff and subsurface lateral flow from the hillslopes were 7 –12 mm and 0.3–1.8 mm, respectively. Watershed discharge was only 8.2 mm, or about 1.1% of average annual precipitation. However, the observed runoff from larger watersheds in this area may reach 1 mm per day, or about 30% of annual precipitation (W.J. Elliot, RMRS, USDA Forest Service, personal communication, 2004). Apparently, WEPP v2004.7 underestimated watershed discharge for the conceptual forest conditions.

Watershed discharge from WEPP v2006.5 increased dramatically, from 8.2 mm to 272.3 mm. Notice that discharge from the hillslopes was mainly in the form of subsurface lateral flow as observed in typical forests. Sediment yield from this version appears adequate as well (Figure 5). The slight increase in sediment yield was due to increase in channel erosion caused by elevated channel flow.

Table 5. Predicted runoff and sediment loss of the conceptual watershed from using WEPP v2004.7 and v2006.5.

WEPP	Hillslope Q[†], mm			Hillslope Q_s, mm			Hillslope SL, t ha^{-1}			Watershed Output		
Version	H1[‡]	H2	H3	H1	H2	H3	H1	H2	H3	Q, mm	Q_s, mm	SL, t ha^{-1}
2004.7	11.6	11.5	7.5	1.8	1.4	0.3	10	15	4	8.2	0.0	0.0
2006.5	0.0	1.4	27.7	303.8	289.6	241.4	0	0	0.1	272.3	3.2	0.1

[†] Q, surface runoff; Q_s, subsurface lateral flow; SL, soil loss.

[‡] H1, Hillslope 1; H2, Hillslope 2; H3, Hillslope 3.

Table 6. Thirty-year average annual water balance (in depth, mm) from the original v2004.7 and modified WEPP v2006.5. Shown in parentheses are percentages of average annual precipitation.

		P[†]	*RM*	*Q*	E_p	E_s	*ET*	D_p	Q_s	*SC*
2004.7	H1[‡]	750.7	747.3	11.5	325.7	98.2	423.9	308.4	1.8	1.7
		(100.0)	(99.5)	(1.5)	(43.4)	(13.1)	(56.5)	(41.1)	(0.2)	(0.2)
	H2	750.7	748.1	11.6	317.9	109.0	426.9	306.4	1.4	1.9
		(100.0)	(99.6)	(1.5)	(42.3)	(14.5)	(56.9)	(40.8)	(0.2)	(0.2)
	H3	750.7	749.5	7.5	315.1	112.7	427.9	312.4	0.3	1.8
		(100.0)	(99.8)	(1.0)	(42.0)	(15.0)	(57.0)	(41.6)	(0.0)	(0.2)
	W	750.7	749.1	8.2	316.5	111.0	427.4	311.3	0.0	1.8
		(100.0)	(99.8)	(1.1)	(42.2)	(14.8)	(56.9)	(41.5)	(0.0)	(0.2)
2006.5	H1	750.7	747.3	0.0	340.0	97.9	437.9	3.5	303.8	2.1
		(100.0)	(99.5)	(0.0)	(45.3)	(13.0)	(58.3)	(0.5)	(40.5)	(0.3)
	H2	750.7	748.1	1.4	338.7	108.7	447.4	5.6	291.1	2.5
		(100.0)	(99.6)	(0.2)	(45.1)	(14.5)	(59.6)	(0.7)	(38.8)	(0.3)
	H3	750.7	749.5	27.7	344.7	112.8	457.4	20.0	241.4	2.7
		(100.0)	(99.8)	(3.7)	(45.9)	(15.0)	(60.9)	(2.7)	(32.2)	(0.4)
	W	750.7	749.1	272.3	343.5	110.9	454.4	16.4	3.2	2.6
		(100.0)	(99.8)	(36.3)	(45.8)	(14.8)	(60.5)	(2.2)	(0.4)	(0.3)

[†] *P*, precipitation; *RM*, sum of snowmelt and rainfall; *Q*, surface runoff; E_p, plant transpiration; E_s, soil evaporation; *ET*, total evapotranspiration; D_p, deep percolation; Q_s, subsurface lateral flow; *SC*, change in soil water storage.

[‡] H1, Hillslope 1; H2, Hillslope 2; H3, Hillslope 3; W, watershed.

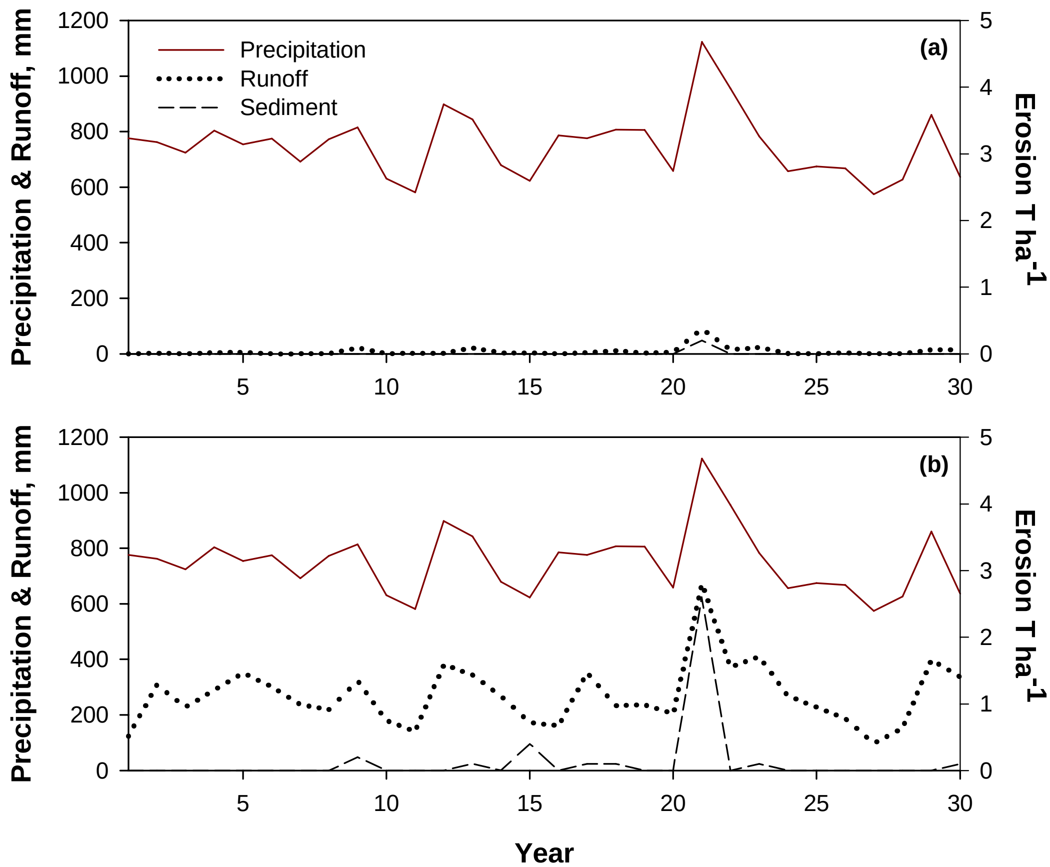

Figure 5. Predicted watershed discharge and sediment yield for the conceptual watershed from (a) v2004.7 and (b) v2006.5.

Evidently, with the presence of a restrictive layer, deep percolation decreased dramatically, from more than 40% to less than 3% of average annual precipitation. As a result, watershed discharge increased substantially from about 1% to 36% of average annual precipitation (Table 6). The high surface effective hydraulic conductivity facilitated much greater infiltration and the large anisotropy ratio led to substantially increased subsurface lateral flow and minimal saturation-excess runoff. For instance, for Hillslope 3, the longest among the three hillslopes, subsurface lateral flow accounted for 32% of annual precipitation, and surface runoff was less than 4% of annual precipitation. Consequently, hillslope soil erosion and watershed sediment yield were also low.

3.2. Model Application to Hermada Watershed

3.2.1. Vegetation

Simulated above-ground living biomass growth and ground cover using WEPP v2006.5 for the burned and unburned conditions are plotted in Figure 6. The simulated annual growth rate of the above-ground living biomass is 0.3–0.4 kg m^{-2}. Schultz and McAdoo (2002) discover that annual growth of above-ground biomass range 0.08–0.25 kg m^{-2} in a sagebrush steppe area in Nevada, USA. Suárez et al. (2004) report that the above-ground biomass annual growth rate may reach 0.5 kg m^{-2} for a tropical wet forest. Hence, the vegetation growth rate in our study area likely falls in between these values. The simulated annual living biomass growth rate was then considered reasonable.

Detailed field observation of ground cover is documented in Robichaud (1996). WEPP-simulated ground cover is highly agreeable with the field observation (Figure 6). The adequately simulated living biomass growth curve and residue ground cover cumulation curve suggest the adequacy of the change made to the crop growth routines.

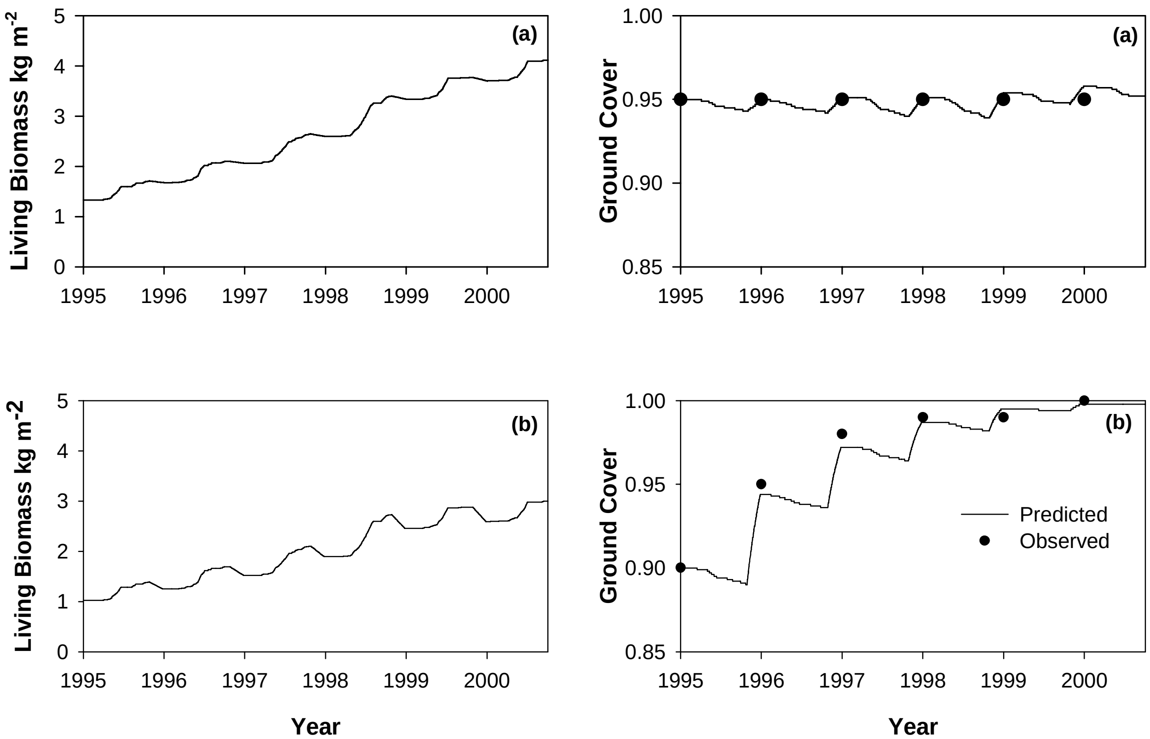

Figure 6. Above-ground living biomass and ground cover predicted for Hermada watershed by WEPP v2006.5. (a) unburned. (b) low-severity burn.

3.2.2. Water Flow and Sediment Yield

Simulated water balance using WEPP v2006.5 for the Hermada watershed is shown in Table 7. Average annual precipitation is 954 mm for the monitored period. Out of this amount, stream flow accounts for approximately 30%, and plant transpiration 70%, while soil evaporation and deep percolation was negligible. On a hillslope scale, WEPP predicted substantially greater subsurface lateral flow than surface runoff as observed in the field.

Comparison of modeled and observed runoff and erosion is presented in Table 8. There was insignificant erosion during the monitoring period as WEPP simulated and corroborated by field observation. It appeared that WEPP v2006.5 overestimated watershed discharge for the first two monitored years. For the remaining years, the predicted runoff was generally agreeable with observed values. A likely reason was that field observation may be incorrect due to difficulties in properly measuring runoff by flumes in winter. Water years 1995–1996 and 1996–1997 were both wet years with annual precipitation exceeding 1100 mm, much higher than the multiple-year average of 954 mm. Yet the field-observed runoff was only one fourth of the runoff in the water year of 1997–1998, a year slightly dryer than average. While runoff is governed by a multitude of factors, including the characteristics of storms (type, timing, intensity), under-recording due to ice accumulation and freezing of water in the measuring flume is not uncommon for mountainous study areas at high elevations (R.E. Brown, RMRS, USDA Forest Service, 2006, personal communication).

Figure 7 shows the comparison of annual stream flow at the Hermada watershed and the nearby USGS 13186000 SF Boise River NR Featherville gaging station (at 43.50°N and 115.31°W, 1286 m a.s.l.) in the state of Idaho (USGS, 2006). The gaging station has a drainage area of roughly 1.6×10^{-5} ha. The similar trend between the WEPP-simulated runoff and monitored stream flow at the USGS gaging station suggests the adequacy of the model simulation.

Table 7. Annual water balance (in depth, mm) for Hermada watershed from the modified WEPP. Shown in parentheses are percentages of average annual precipitation.

Water Year	Slope	$P^{\dagger}$	Q	E_p	E_s	D_p	Q_s	SW
1995–1996	West	1106 (100)	0 (0)	615 (56)	0 (0)	56 (5)	460 (42)	122
	North	1106 (100)	0 (0)	670 (61)	0 (0)	49 (4)	399 (36)	114
	South	1106 (100)	0 (0)	616 (56)	0 (0)	41 (4)	466 (42)	104
	Watershed	1106 (100)	432 (39)	639 (58)	0 (0)	50 (5)	3 (0)	115
1996–1997	West	1200 (100)	57 (5)	709 (52)	0 (0)	43 (4)	470 (39)	106
	North	1200 (100)	33 (3)	666 (59)	0 (0)	39 (3)	419 (35)	96
	South	1200 (100)	0 (0)	643 (54)	0 (0)	32 (3)	523 (44)	88
	Watershed	1200 (100)	491 (41)	666 (56)	0 (0)	39 (3)	3 (0)	98
1997–1998	West	919 (100)	2 (0)	652 (71)	0 (0)	22 (2)	246 (27)	84
	North	919 (100)	0 (0)	739 (80)	0 (0)	15 (2)	166 (18)	62
	South	919 (100)	1 (0)	667 (72)	0 (0)	15 (2)	239 (26)	72
	Watershed	919 (100)	208 (23)	692 (75)	0 (0)	18 (2)	2 (0)	72
1998–1999	West	809 (100)	0 (0)	533 (66)	0 (0)	33 (4)	245 (30)	76
	North	809 (100)	0 (0)	575 (71)	0 (0)	30 (4)	205 (25)	69
	South	809 (100)	0 (0)	502 (62)	0 (0)	28 (3)	280 (35)	68
	Watershed	809 (100)	233 (29)	544 (67)	0 (0)	30 (4)	2 (0)	71
1999–2000	West	737 (100)	0 (0)	608 (83)	0 (0)	16 (2)	112 (15)	68
	North	737 (100)	0 (0)	665 (90)	0 (0)	9 (1)	63 (9)	51
	South	737 (100)	0 (0)	597 (81)	0 (0)	12 (2)	128 (17)	62
	Watershed	737 (100)	92 (13)	630 (86)	0 (0)	12 (2)	2 (0)	59

†*P*, precipitation; *RM*, sum of snowmelt and rainfall; *Q*, surface runoff; E_P, plant transpiration; E_s, soil evaporation; D_P, deep percolation; Q_s, subsurface lateral flow; and *SW*, average soil water storage.

Table 8. Comparison between observed and WEPP-simulated water discharge and sediment yield for Hermada watershed.

	Observed			Simulated				
		Watershed		Hillslope			Watershed	
Water Year	Precipitation (mm)	Discharge (mm)	Sediment (t ha^{-1})	Surface unoff (mm)	Lateral flow (mm)	Sediment (t ha^{-1})	Discharge (mm)	Sediment (t ha^{-1})
1995–1996	1106	87	0	0	441	0	432	0.0
1996–1997	1200	89	0	0	471	0	491	0.2
1997–1998	919	322	0	45	217	0	208	0.0
1998–1999	809	172	0	1	243	0	233	0.0
1999–2000	737	142	0	0	101	0	92	0.0
Average	954	162	0	9	295	0	291	0.0

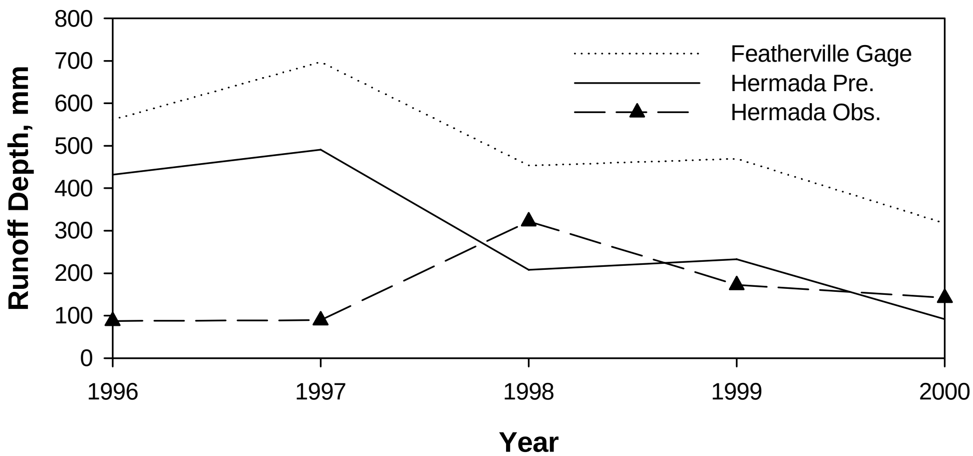

Figure 7. Comparison of stream flow at the Hermada watershed outlet and at the Featherville USGS gaging station.

Comparison of WEPP-simulated and field-observed hydrographs indicates that the majority of observed stream flow occurred in the spring snowmelt season (Figure 8). For the first water year that spanned October 1995–September 1996, both simulated and observed hydrographs included winter and spring runoff with agreeable timing. However, the simulated runoff was nearly five times greater than the observed.

For the second water year of 1996–1997, though field observation only shows a spring peak, the modeled runoff had a high winter runoff peak and a later spring high peak. The simulated high peak in winter corresponded to the west coast 1996–1997 winter flooding due to heavy rain and snow as well as warm temperature in that winter which was reported by Lott et al. (1997). The latter spring high peak was primarily due to the rapid snowmelt simulated.

The third water year of 1997–1998 was rather special with substantial summer runoff. The observed hydrograph exhibited two peaks. WEPP simulated substantial summer runoff and two peaks. However, WEPP underestimated the yearly runoff. The simulated runoff was much lower than the observed for early spring. Yet a high peak was predicted for late spring as a result of concentrated rainfall events and rapid snowmelt. WEPP even predicted hillslope surface runoff due to saturation of the soil profile. It appears that the simulated snowmelt season started much later than occurred in reality. The concentrated snowmelt predicted for late spring possibly led to a joint spring and summer hydrograph.

In the last two water years, the observed runoff seems to have mainly originated from spring snowmelt. WEPP predicted somewhat larger amount of winter runoff for these two years, suggesting that the winter hydrology routines in WEPP may not be appropriate.

Small amount of runoff was observed during the fall of 1999. Nonetheless, the simulated soil water content during this time was low (0.01 $m^3\ m^{-3}$). The amount of rainfall was not sufficient to replenish soil water and to generate runoff in the simulation. A possible reason for some runoff to occur when the entire watershed is still dry is that the lower part of the watershed has reached saturation (W.J. Elliot, RMRS, USDA Forest Service, personal communication, 2006). The use of multiple OFEs may help to more properly represent such conditions.

There was essentially no difference in predicted and observed sediment yield. The small amount of simulated sediment yield for 1997 was due to the two simulated high peak flows. The predicted runoff mainly originated from hillslope subsurface lateral flow. Overall, hillslope soil erosion was negligible and watershed sediment yield was low, consistent with field observations.

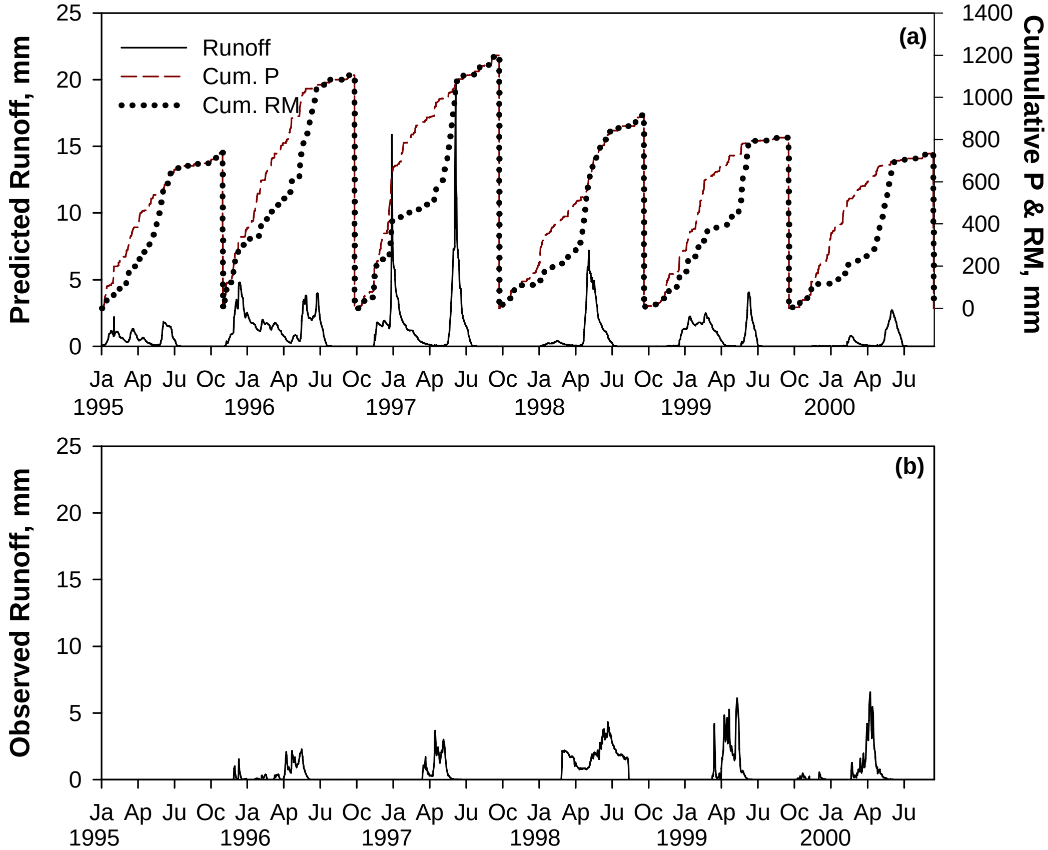

Figure 8. (a) predicted and (b) observed hydrograph for Hermada watershed. In (a), dashed lines represent cumulative precipitation, and dotted lines represent cumulative liquid water input (rain and snowmelt) that can directly cause runoff.

3.2.3 Statistic Analysis

No runoff or sediment yield was simulated from WEPP v2004.7 for the Hermada watershed using the same inputs as for WEPP v2006.5. However, simulation results from WEPP v2004.7 had a less negative Nash-Sutcliffe coefficient (−0.2) than that from WEPP v2006.5 (−2.7), even though simulated yearly runoff from v2006.5 was much more reasonable than that from v2004.7.

One reason for the more negative Nash-Sutcliffe coefficient from v2006.5 simulation results may be due to the rather low observed stream flows for the first two water years of simulation. Nash-Sutcliffe coefficient would improve substantially if it was calculated using only data for the last three water years, for which simulated and observed annual runoff was in good agreement. In this case, the resultant Nash-Sutcliffe coefficient was −0.7. A likely reason for the negative coefficient was that the timing of WEPP-simulated and field-observed runoff events was not in agreement. For the Hermada watershed, major runoff events were mainly observed during the spring snowmelt season. However, WEPP simulated larger winter runoff and later spring runoff events than the observed. In order to better predict runoff timing, future efforts should be devoted to systematically examining the snow cumulation and snowmelt routines in the WEPP model.

CHAPTER FOUR

SUMMARY AND CONCLUSIONS

Reliable models for predicting water flow and sediment discharge from forest watersheds are needed for sound forest management. WEPP, a process-based, continuous erosion prediction model, was adapted for forest watershed applications. Modifications were made in the approach to, and algorithms for, modeling deep percolation of soil water and subsurface lateral flow. Changes were also made to the crop growth routines in order to more realistically represent perennial vegetation growth and residue accumulation under forest conditions. The refined WEPP model has the ability to appropriately partition infiltrated water between deep percolation and subsurface lateral flow through the use of a restrictive layer specified by the user. Further, it is capable of transferring subsurface lateral flow from the hillslopes to watershed channels, and then routing it to the watershed outlet. Compared to the original model, the modified model represents the hydrologic processes in forest settings more realistically and properly.

Verification of the modified model (v2006.5) using a conceptual watershed produced satisfactory results for subsurface lateral flow on the hillslopes and stream flow from the watershed outlet. Application to Hermada watershed, a representative, small forest watershed in central Idaho, yielded good agreement between model predictions and field observations for residue ground cover, vegetation growth, stream flow and sediment yield, demonstrating the improvement of the modified model.

Future efforts should be devoted to evaluating the suitability of the modified WEPP for applications to forest watershed under a wide range of climatic, plant and soil conditions. In addition, the snow cumulation and snow melt in winter hydrology routines of WEPP should be thoroughly evaluated for reliable application to forest settings.

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APPENDIX

A. CODE MODIFICATIONS AND SOIL INPUT CHANGES

A summary of code modifications was developed jointly by Shuhui Dun and Jim Frankenberger, Computer Specialist at the USDA-ARS National Soil Erosion Research Laboratory. The summary is included below.

Code Comparison of WEPP v2004.7 and v2006.5

The following files have been modified for WEPP version 2006.5

ANNCHN.FOR	INIDAT.FOR	WATBAL.FOR
ASPECT.FOR	INPUT.FOR	WINTER.FOR
CANGIE.INC	INTRPL.FOR	WSHCQI.FOR
CASE12.FOR	MAIN.FOR	WSHDRV.FOR
CHNERO.FOR	MONCHN.FOR	WSHINP.FOR
CONTIN.FOR	PERC.FOR	WSHPAS.FOR
CTEMP.INC	PMXPND.INC	WSHPEK.FOR
ENDCHN.FOR	SCON.FOR	WSHRED.FOR
ENRPRT.FOR	SEDOUT.FOR	
HYDCHN.FOR	SLOSS.FOR	
INFILE.FOR	SOIL.FOR	
INFPAR.FOR	STROUT.FOR	

ANNCHN.FOR

The subroutines ANNCHN.for and ENDCHN.for were changed to include the information about subsurface flow in the watershed erosion output file.

Line 127 — WSU change for output of subsurface runoff.

Line 263 — Fix for converting feet to meters for particle diameter when writing to channel erosion output.

Line 347 — WSU added subsurface runoff to format statement.

Line 356, 357 — Format statement for larger hillslope and channel id's from i2 to i3.

ASPECT.FOR

WSU made changes to compute aspect for individual OFE's. Added OFE parameter to aspect subroutine. Variable radinc now accessed as an array.

CANGIE.INC

WSU's change, radiation inclination (radinc) is now an array stored for each OFE instead of a single value.

CASE12.FOR

Line 176 — WSU change, changed equation to include absolute value when computing xde.

xde(k) = x(i-1) * abs(1.0 - (1+phi(k))/phi(k)*du(k)/(dtcdx(k)-dlat(k))) ** (1.0/(1.0+phi(k)))

CHNERO.FOR

Line 101 — WSU change (only for v2006.5 format soil files), changes chnlef and toplen if top to lateral volume ratio is greater than 100,000.

CONTIN.FOR

Line 374 — Contour flag set to 0.

Line 801 — Added current OFE number to aspect subroutine call, see aspect.for.

CTEMP.INC

Three variables have been added to the include file CTEMP.inc. These variables are: a flag indicating the type of soil input file (0 — without the restrictive layer, 1 — with a restrictive layer, Ksat input by user); a variable for the Ksat input; and a variable for the anisotropy ratio of the soil profile (when the user gives a negative value, a default value of 25 would be used.)

Added slflag, kslast, anisrt variables. These are all arrays of mxplan. Slflag — flag to use restricting rock layer in 2006 format soil files, kslast — hydraulic conductivity of last rock layer. Anisrt — anisotropy ratio for the whole soil profile.

ENDCHN.FOR

The subroutines ANNCHN.for and ENDCHN.for were changed to include the information about subsurface flow in the watershed erosion output file.

Line 123 — WSU change to include output for subsurface runoff.

Line 244 — Fix for converting feet to meters for particle diameter when writing to channel erosion output.

Line 321 — WSU added subsurface runoff to format statement.

Line 329, 330 — Format statement for larger hillslope and channel id's from i2 to i3

ENRPRT.FOR

Line 177 — Format statement change, i2 to i3.

HYDCHN.FOR

Line 131, 204 — Added checks to prevent divide by zero.

INFILE.FOR

Line 1790 — Removed out-of-date comments.

INFPAR.FOR

Line 492 — For v2006.5 format soil files Ksat is limited to 3.0e-14, for other files the limit is 1.94e-08 (the same as in WEPP 2004.7)

INIDAT.FOR

Line 322, 323, 324 — New version number and date

INPUT.FOR

The subroutine INPUT.for was changed to read in the information about the restrictive layer.

Line 512 — Removed out-of-the-date comments.

Line 550 — For 2006 format soil files limit Ks values to a minimum 0.000000108 mm/h for other soil files the lower limit remains 0.07 mm/h (same as in WEPP 2004.7).

Line 587 — New code to read in extra parameters in v2006.5 format soil files — flag (indicates if restricting layer is present) anisotropy (for each OFE), Ksat value if a restrictive layer is present.

Line 630 — New variable solbtm initialized solbtm = solth1(nslorg(iplane),iplane)

Line 641, 650 — For 2006 format soil files set up thickness of restricting layer.

Line 680 — Set flag if ssc2 value less than 3.0e-14 for v2006.5 format soil files. For other soil files the flag is only set if ssc2 is less than 1.0e-14.

Line 740 — Set flag if ssc2 value less than 3.0e-14 for v2006.5 format soil files. For other soil files the flag is only set if ssc2 is less than 1.0e-14.

Line 800 — If flag is set value of initial saturated hydraulic conductivity to 0.000000108 / 3.6e6 for v2006.5 format soil files and 0.07 / 3.6e6 for other soil files.

INTRPL.FOR

Line 48 — WSU change, check to prevent the error of divided by zero.

MAIN.FOR

Line 101 — Print number of channels in main banner to indicate if this is the 1000 channel build or the 75 channel build.

Line 221 — Used mxhill to check for maximum number of hillslopes instead of hardcoded value.

Line 278 — Added close statement for a file handle not used after an open.

Line 405 — Format statement changed to avoid using hardcoded hillslope limit.

Line 423 — Format statement added number of watershed channels to banner to indicate if this is the 1000 channel build or the 75 channel build.

MONCHN.FOR

Line 274 — Fix the conversion factor for converting feet to meter for particle diameter when writing to channel erosion output.

Line 357 — Format statement fixed grammar.

Line 358,359 — Format statement for larger hillslope and channel ids.

PERC.FOR

The subroutine PERC.for was changed to utilize the input information about the restrictive layer.

Line 149, 150 — WSU change, to handle bottom rock layer if there exists a restrictive layer, then set saturated hydraulic conductivity.

Line 161 — For v2006.5 format soil files with a restrictive layer do not update saturated hydraulic conductivity.

Line 194 — Removed out-of-the-date comments.

PMXPND.INC

Line 7 — WSU change to mxpond — the original value was 65. S. Dun, May 19, 2005 changed it to equal mxtime for fixing the 'Array Bound Exceeded' bug

SCON.FOR

Line 231 — Corrected rock adjustment factor, provided by Susan Skirvin.

Line 393 — WSU change, check for hydraulic conductivity, different values for v2006.5 format soil files (0.00000010801) and previous versions (0.0701).

Line 429 — WSU change, to limit saturated hydraulic conductivity. For v2006.5 format soil files the lower limit is 0.000000108, and previous versions 0.07.

SEDOUT.FOR

Line 444, 463 — Format statement changed to handle larger ids.

SLOSS.FOR

Line 139 — Changed array initialization to use mxplan instead of hardcoded 75 or 1000. This allows the same file to be used when building the 1000 channel version as the regular WEPP executable.

SOIL.FOR

Line 642 — WSU change, to limit frozen ground factor. Only applies to v2006.5 format soil files.

STROUT.FOR

Line 182 — Format statement for larger channel id.

WATBAL.FOR

The subroutine WATBAL.for was changed in order to change the anisotropy ratio of Ksat.

Line 412–424 — WSU change for lateral flow, do not include check for unsaturated depth with v2006.5 soil files.

Line 452–505 — WSU change, fine-tune lateral hydraulic conductivity, only applied if v2006.5 format soil files are used. If other soil files are used it is the same as in WEPP v2004.7

Line 511–516 — WSU changes, radiation inc is by OFE, latk is multipled by fffx if v2006.5 format soil files are used.

Line 520–521 — Anisotropy value used in computation of subq.

Line 524 — If v2006.5 soil files are used subsurface lateral flow is not updated, it is still updated if older soil versions are used.

Line 535–538 — if v2006.5 soil files are used fcdep is not updated, it is still updated if older soil versions are used.

Line 550–551 — WSU change, accumulate subsurface runoff if v2006.5 format soil files are used.

Line 593–597 — WSU change, soil profile could not drain out that much water could potentially flow. Adjust subsurface flow only for v2006.5 soil files.

Line 653–656 — WSU change, set flag if runoff only from subsurface flow.

Line 659–661 — Adjust effective flow length if it is 0 and v2006.5 soil files are used.

Line 665–669 — Always indicate runoff, only for v2006.5 format soil files. Other soils will check surdra > 1.0e−6 before setting runoff flag.

Line 852, 857 — Format statement changes.

WINTER.FOR

Line 446 — Format statement change.

WSHCQI.FOR

The subroutine WSHCQI.for was changed to add the subsurface flow from hillslopes to the channel runoff.

Line 69, 90 — WSU change, subsurface flow from upstream hillslopes is added into the channel.

WSHDRV.FOR

The subroutine WSHDRV.for was changed in order to accommodate the special cases when there is only subsurface runoff. In these cases, channel erosion due to the subsurface inflow is regarded as negligible and would not be calculated. Therefore, the subroutine CHNERO.for (for calculating channel erosion) would not be called in such cases. However, this treatment may be modified in the future.

Line 561 — Loop for initialization was sped up by only initializing the elements that could possibly be used.

Line 650 — Added OFE index to call to aspect subroutine.

Line 969 — Always call chnero for v2006.5 format soil files.

Line 1263, 1265 — Format statement changes

WSHINP.FOR

Line 126 — Commented out hardcoded values for hillslope, channel and impoundment strings. These are not computed from their numeric values.

Line 234 — Code prints out hillslope, channel and impoundment ids based on numeric value. Allows code to be used for 1000 channel builds.

Line 404, 406, 426 — Format statement changes.

WSHPAS.FOR

The subroutine WSHPAS.for was changed to record the subsurface runoff information into a hillslope pass file. Changes were also made to read the hillslope pass file and write the watershed pass file.

Line 134 — WSU change, accumulate subsurface runoff for output in hillslope pass file.

Line 169 — WSU change, updated write statement for including subsurface flow in pass file.

Line 176 — WSU change, write out subevent for subsurface lateral flow.

Line 289 — WSU change, read subsurface values in pass file.

Line 295 — WSU change, read subevent fields in pass file

Line 364 — WSU change, write out subsurface flow and lateral subsurface flow for a hillslope.

Line 373 — WSU change, write out subsurface flow and lateral subsurface flow for a hillslope.

Line 402, 405, 410, 419 — Format statement changes

WSHPEK.FOR

The subroutine WSHPEK.for was changed to calculate the peak runoff for a subsurface flow event.

Line 255 — WSU change, calculate peek runoff for channel

WSHRED.FOR

The subroutine WSHRED.for was changed to read the subsurface flow information from the watershed pass file.

Line 92 — Only initialize elements of array that could be used.

Line 123 — WSU change, read daily subsurface lateral flow and subsurface volume from hillslope pass file.

Line 149 — WSU change, subsurface lateral flow and subsurface volume.

Line 162–172 — WSU change, subsurface lateral flow and subsurface volume

Code Changes on WEPP v2006.5

Changes were made on WEPP v2006.5 to better simulate forest vegetation growth and residue cover. Only one file **GROW.FOR** was changed.

GROW.FOR

In the subroutine GROW.FOR, under the established perennial crop case, codes were changed to call crop growth estimation before the Julian day reaches the senescence date.

Line 424 — WSU change, estimate crop growth when Julian day is less than senescence date

SOIL INPUT FILE

The soil input file was changed in order to read in the information about the restrictive layer and the soil anisotropy ratio. The new format is identified with the v2006.5 tag on line 1 of the soil file. The following is an example indicating the changes to the original soil input file.

```
2006.2
#
#    Created on 18May95 by `WSOL', (Ver. 15Apr95)
#    Author: YourNameHere
#
xxx
1    0
'Forest Soil'    'Sandy Clay'    2    0.02    0.95    2.17e+5    0.0004 2    10.5
300     55. 10. 5.     25.     10.
800.    15. 85. 0.5    20.     20.
1    25    0.0001
```

The line after the last soil defines how the restricting layer. The first value is a flag, 0 indicates no restricting layer, 1 indicates a restricting layer. The second value is the ansitrophy value, the third value is the Ksat value. For multiple OFE soil files each OFE may have a different restricting layer, or no restricting layer.

B. ANALYSIS OF FIELD-OBSERVED CLIMATE DATA

Precipitation Data

There were two sets of field-observed precipitation data. One set was measured using a tipping bucket and the other was measured with a weighing bucket, both in cumulative form. Data were observed from November 3, 1995 to September 30, 2000. Both data sets were inspected and unreasonable readings due to equipment malfunction were corrected.

The tipping bucket recorded the precipitation in one-minute intervals from November 3, 1995 to January 2, 1999, and in 10-minute intervals afterwards. The data was generally in good quality without abnormal fluctuations for the first four years of observation. However, essentially no precipitation data was recorded for 2000. Large step increase of precipitation (e.g., 0.02 in.) was inspected, and unreasonable data (e.g., 19:30 pm to 19:31 pm in November 8, 1995 step increase was 0.64) were corrected. One-minute data were converted to 10-minute and daily data by summation for the period of 1995–1999. The 10-minute data were used to obtain climate inputs in the WEPP model, i.e., time to peak and peak intensity. The tipping bucket cumulative precipitation depth and step increases in 10-minute interval were graphed (Fig. A1.1–A1.5).

The data from the weighing bucket were in 15-minute intervals, and exhibited numerous anomalies. The observed values and step increases were graphed (Fig. A2.1–A2.6). Typical step increases ranged (−0.2–0.2 inch), and readings substantially exceeding the typical step increases were regarded as caused by equipment failure (e.g., February–March, September–November, 1998). Occasionally, the resultant daily precipitation was negative due to the normal noise of the observation. Such negative values were added to either the precipitation of the previous day or the next day.

The weighing-bucket gage was equipped with shielding wings, more suitable to and effective in catching snow in winter (R.E. Brown, RMRS, USDA Forest Service, personal communication, 2006). However, recordings from the weighing-bucket gage exhibited frequent abnormal fluctuations, while data from the tipping-bucket rain gage were more consistent. Hence, daily precipitation was prepared based on the tipping-bucket data and was substituted with data from the weighing-bucket gage when it caught more during winter seasons except for year 2000. The weighing bucket precipitation data were directly used for 2000 because no precipitation was recorded from the tipping-bucket gage possibly due to malfunctioning of battery.

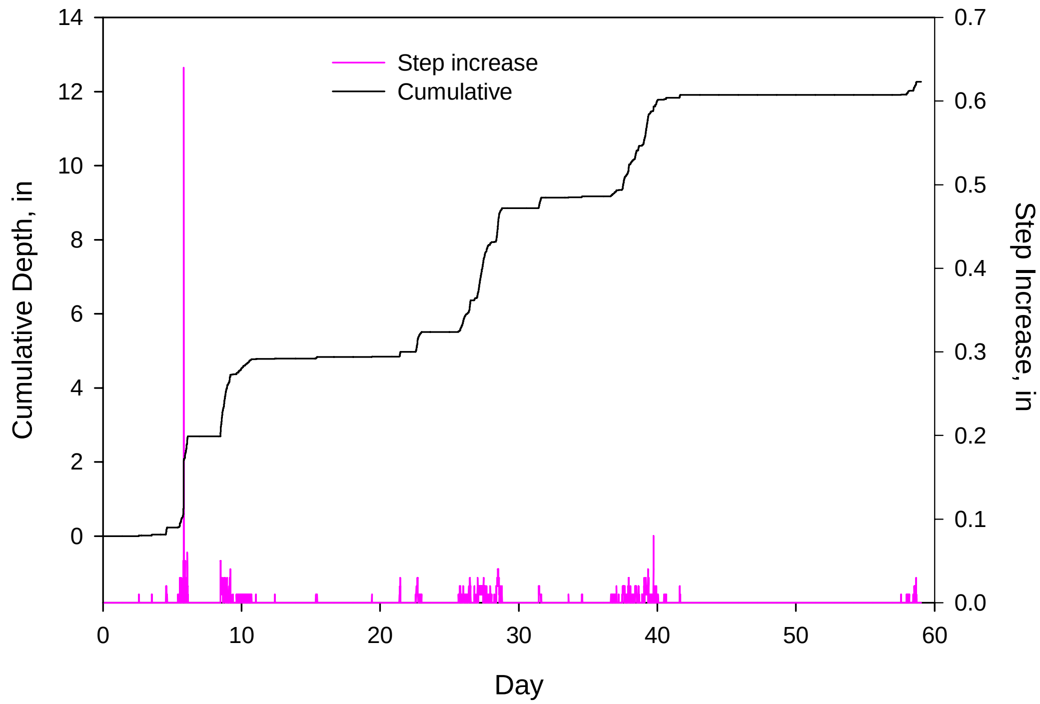

Figure A1.1 Tipping bucket precipitation data for 1995.

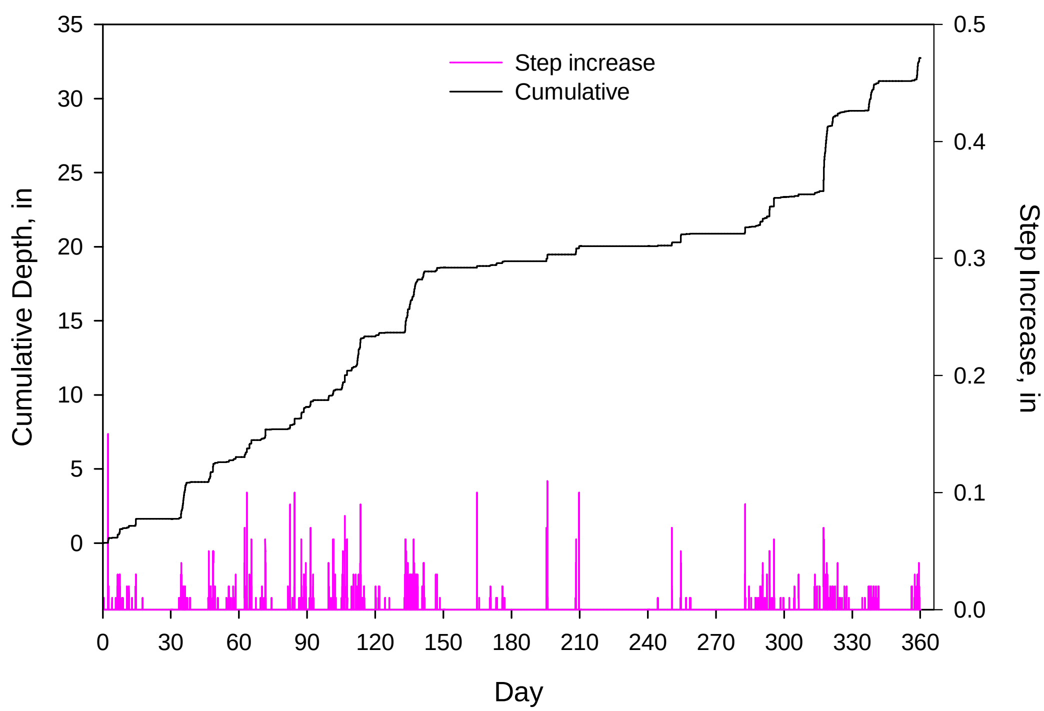

Figure A1.2 Tipping bucket precipitation data for 1996.

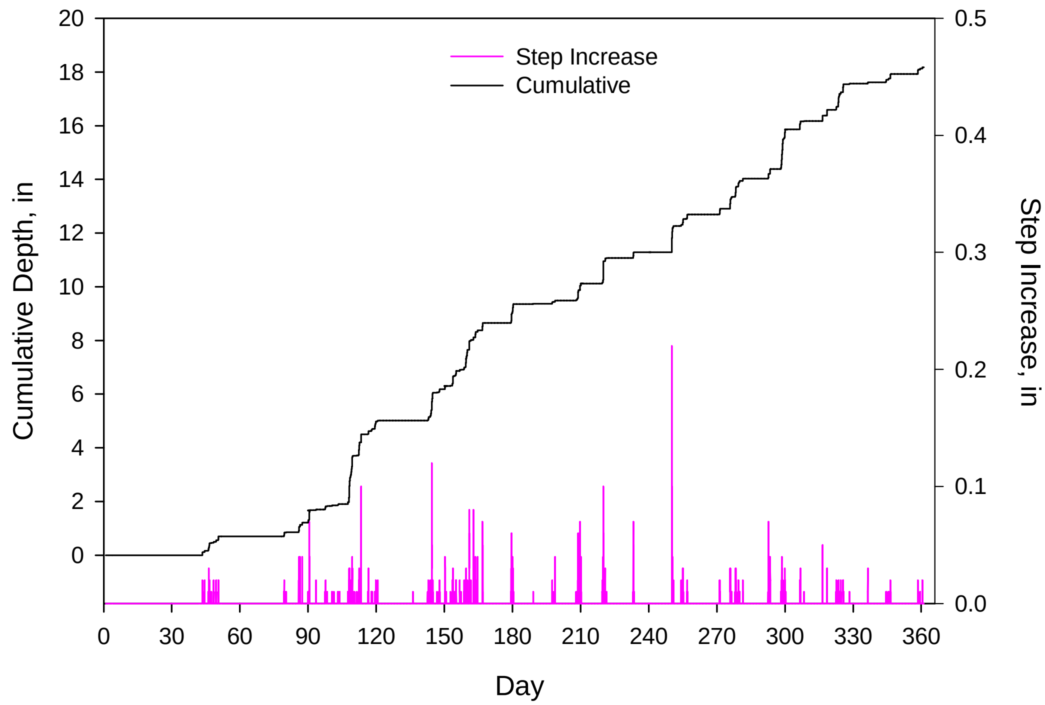

Figure A1.3 Tipping bucket precipitation data for 1997.

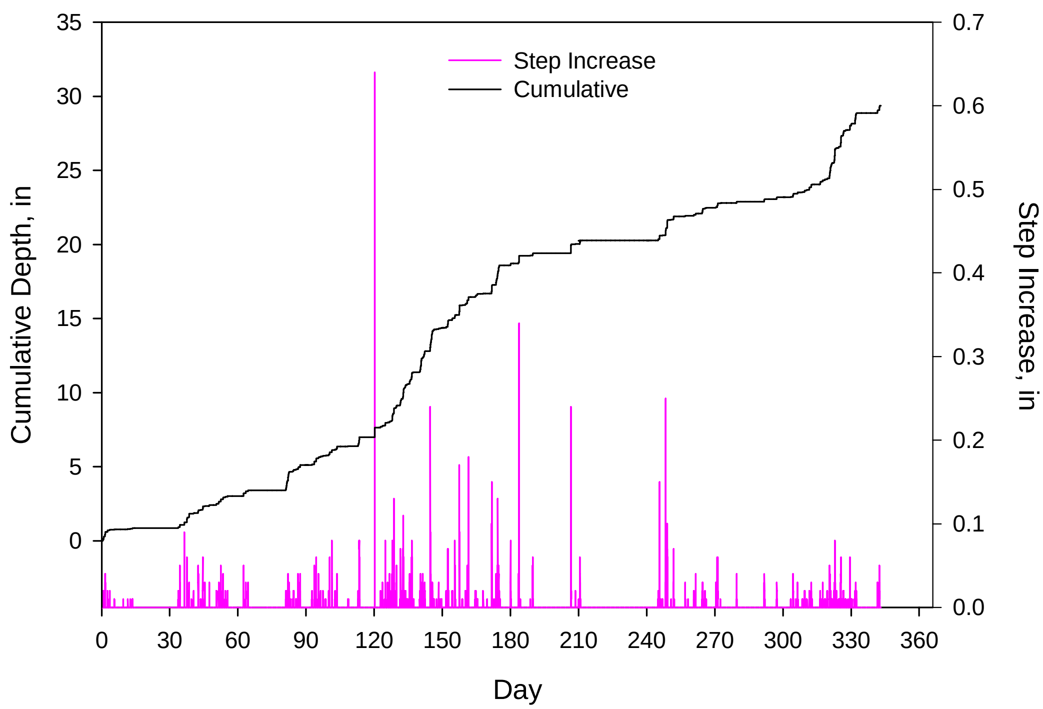

Figure A1.4 Tipping bucket precipitation data for 1998.

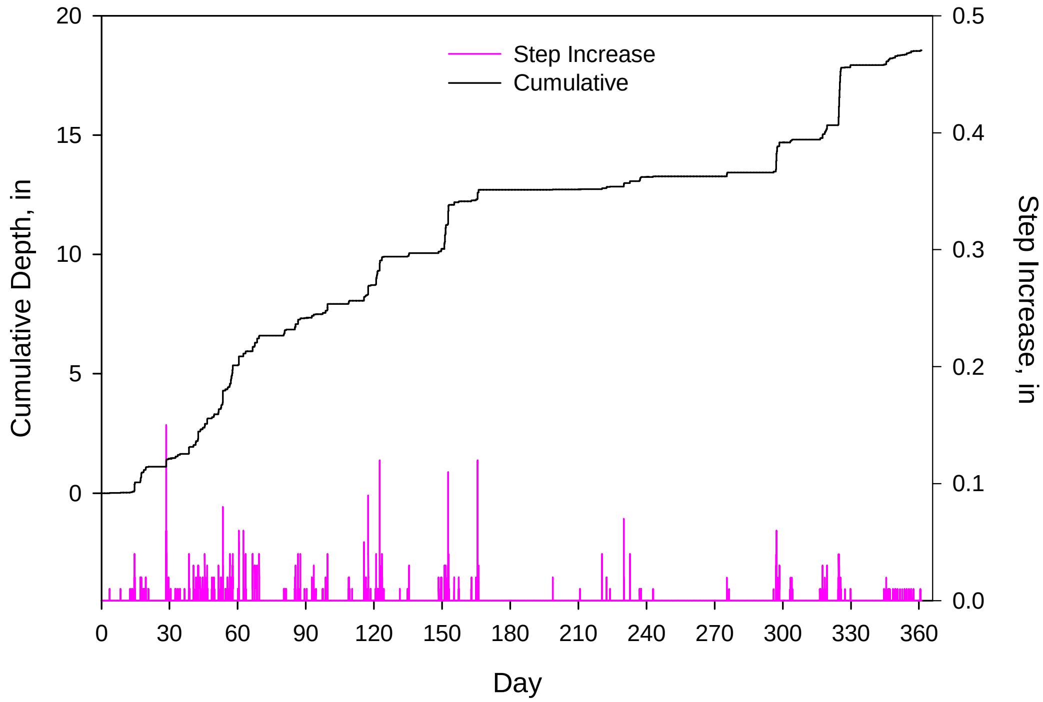

Figure A1.5 Tipping bucket precipitation data for1999.

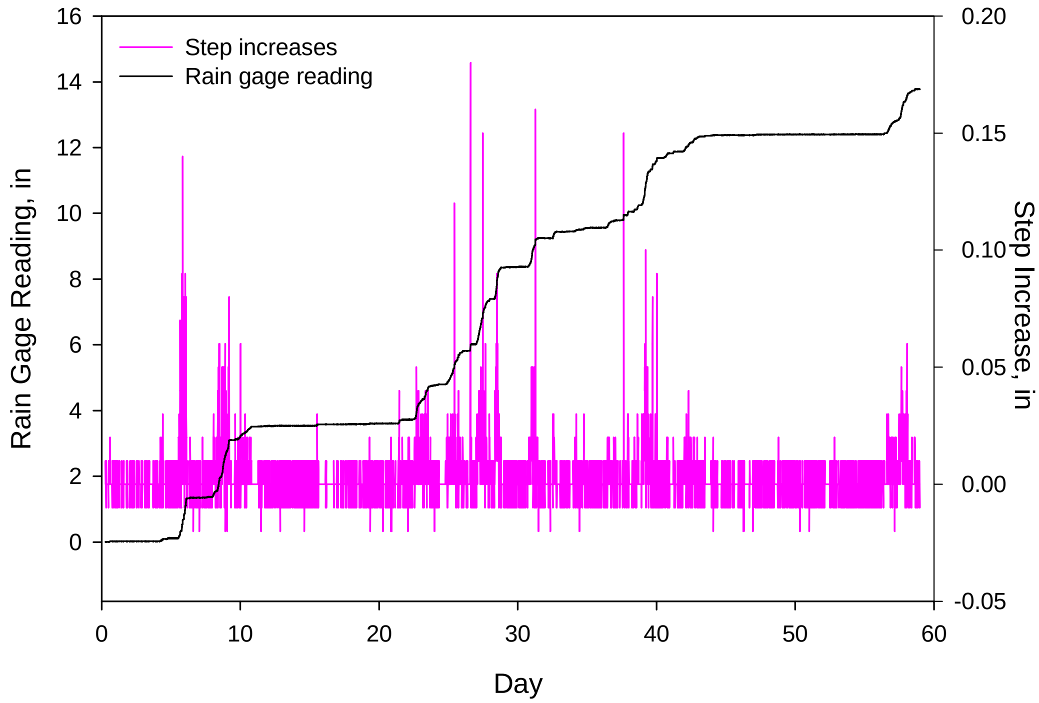

Figure A2.1 Weighing bucket precipitation data for 1995.

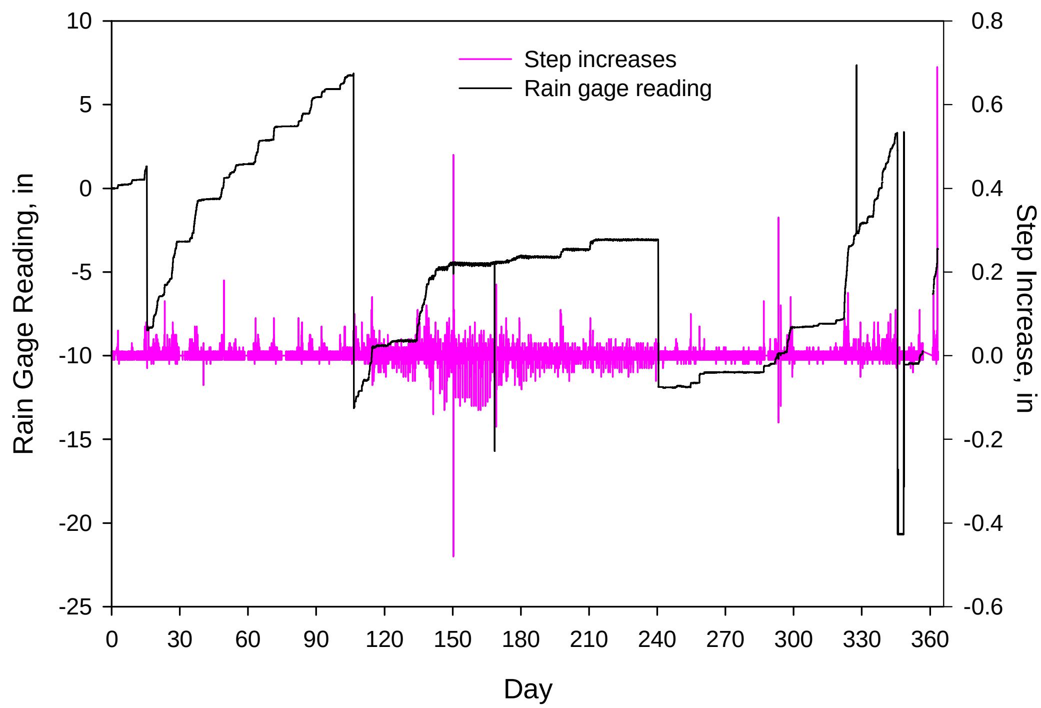

Figure A2.2 Weighing bucket precipitation data for 1996.

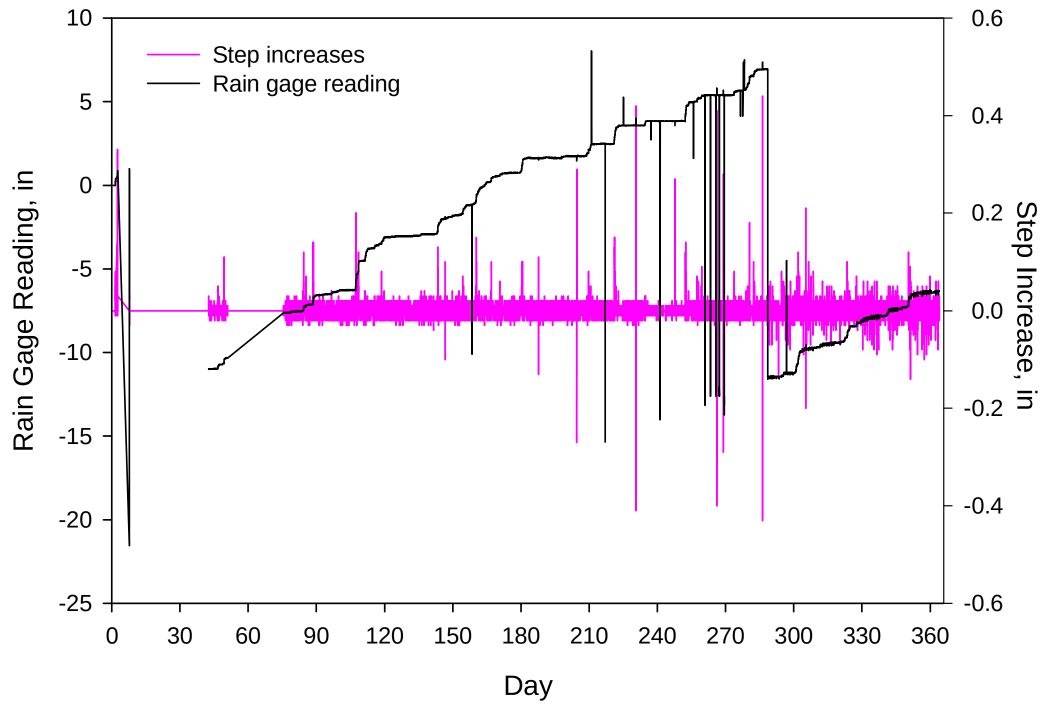

Figure A2.3 Weighing bucket precipitation data for 1997.

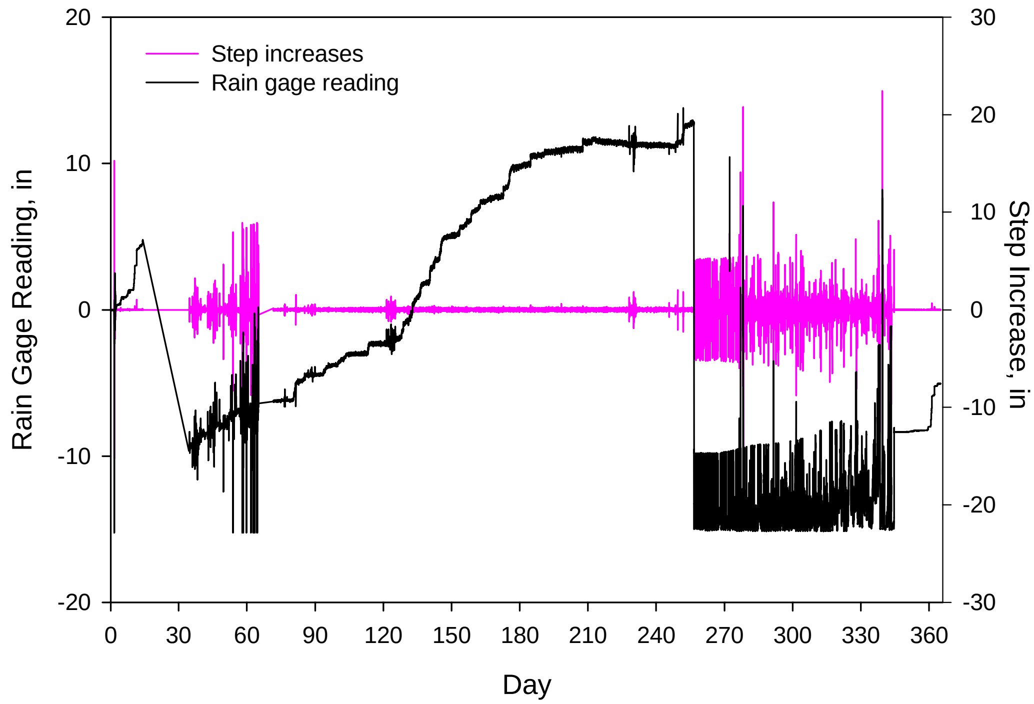

Figure A2.4 Weighing bucket precipitation data for 1998.

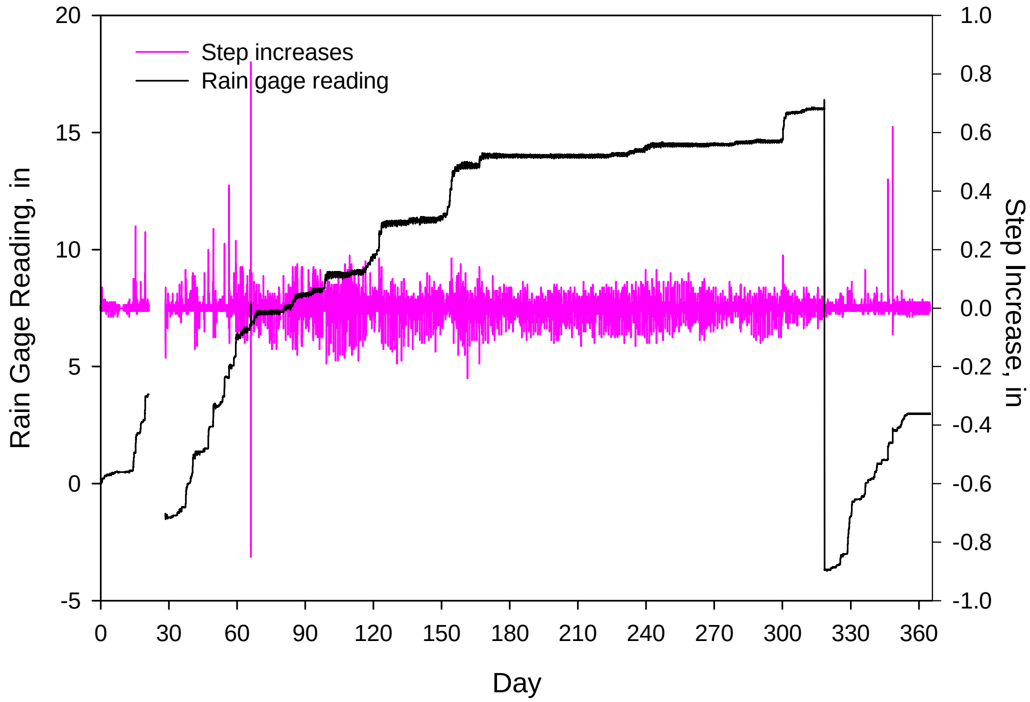

Figure A2.5 Weighing bucket precipitation data for1999.

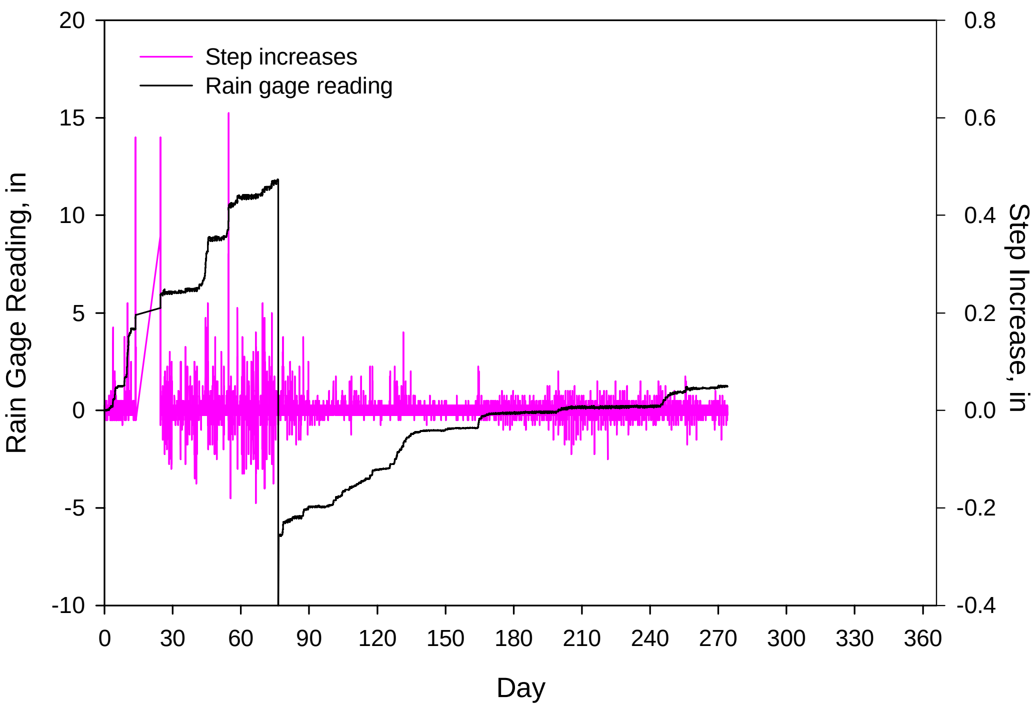

Figure A2.6 Weighing bucket precipitation data for 2000.

Other Climate Data

Other climate data observed included temperature, solar radiation, relative humidity wind velocity and wind direction. These data were in 15-minute interval. For temperature process, non-valid data was skipped, unreasonable resulting data was checked out manually. Solar radiation was also recorded in a cumulative manner. The processing procedure was similar with precipitation data processing. The observation value and step increase value were graphed first. The time step increases were corrected for equipment resetting and equipment malfunction. Negative and step increase values exceeding 20 MJ m^{-2} were inspected. The daily summary of solar radiation was based on the corrected step increase values. For wind velocity and wind direction, A negative wind velocity was set to 0 and wind velocity record exceeds 100 miles per hour was inspected and treated as invalid number. The upper limit wind speed of typhoon is around 100miles per hour (Kobayashi N. and Shimamura M., 2003). A single 15-minute extreme high wind speed was considered as equipment malfunction. Wind direction was divided into eight directions. Which direction has the highest cumulative wind run in miles was set as the dominant wind direction.

The data processing procedures were shown in the last section of this document. Monthly precipitation, average daily maximum minimum and dew point temperature for the study site were compared with the data estimated from PRISM (OCS, 2006) and the data from the closest SNOTEL Graham Guard station at 43.95°N and 115.27°W, 1734 m a.s.l. in the state of Idaho (NRCS, 2006)

Data Gaps

During the observation period, each year there were a few days no data recorded due to equipment maintenance or malfunction. Data gaps were 6% of total monitored data (Table 1).

Table 1. Data gaps.

Break	Starting Time	Ending Time	Days
1	23/12/1996	26/12/1996	4
2	31/12/1996	1/1/1997	2
3	5/1/1997	8/1/1997	4
4	10/1/1997	12/2/1997	34
5	23/2/1997	17/3/1997	23
6	16/1/1998	3/2/1998	19
7	8/3/1998	12/3/1998	5
8	22/1/1999	28/1/1999	7
9	15/1/2000	24/1/2000	10

Precipitation data and daily maximum and minimum temperature of the data gaps were filled with data collected at the closest SNOTEL station at Graham Guard, ID, for the same period. The other climate data for the data gaps including dew point temperature, solar radiation and wind information were filled with CLIGEN stochastically generated data based on the known daily precipitation, maximum and minimum temperatures for the study site and long-term statistics of climate parameters for Deadwood Dam at 44.32°N and 115.63°W, 1639 m a.s.l. in the state of Idaho (USDA, 2006). The Deadwood Dam station is about 55 km from the study site, and is the closet climate station with long-term climate data and at an elevation similar to that of the study site.

Preliminary results

A comparison of annual precipitation data from tipping bucket, weighing bucket, a combination of data from the weighing gage and tipping-bucket gage, PRISM and SNOTEL Station at Graham Guard is shown in Table 2. The comparison of monthly average of daily maximum, minimum and dew-point temperature from field observation at the study site, PRISM estimation and the field observation at the SNOTEL Station at Graham Guard is shown in Table 3.

The annual precipitation data from two data sets has some difference. Basically weighing bucket could catch more snow and recorded more precipitation. Hence, the combination of data from the weighing gage and the tipping-bucket gage on daily basis was considered in this study. The combined data from the weighing- and tipping-bucket gages was comparable with PRISM estimation of annual precipitation for the study site and the observation of the closest SNOTEL station.

The monthly average of daily maximum, minimum and dew-point temperature agree well with PRISM-estimated and the SNOTEL-recorded monthly temperature except for year 2000. The observed daily temperatures (Figure A3) also showed problems in the observed temperature data.

The observed solar radiation and wind velocity are shown in figure A4 and figure A5.The solar radiation curve shows big fluctuation from 0 to over 80 MJ m^{-2} from day to day in year 1998. Wind velocity curve from June 4, 1998–October 9, 1998 shows a few large than 10 m/s data, however most of the data was 0. These were unreasonable phenomena for this site. It should be due to malfunction of equipment for solar radiation and wind.

Table 2. Comparison of annual precipitation in mm.

Year	Weighing Bucket	Tipping Bucket	Combined Weighing and Tipping	PRISM	SNOTEL Graham Guard Sta.
1995	334	311	373	412	411
1996	1167	831	1304	1411	1267
1997	544	462	801	836	812
1998	1268	767	1059	1095	937
1999	780	471	772	796	716
2000	436	0	513	547	490

Note: Observed data for 1995 was from 3/11/1995 to 31/12/1995; Observed data for 2000 was from 1/1/2000 to 30/9/2000.

Table 3. Comparison of monthly averages of daily temperature in °C.

Year	Month	Obs. Tmax	Obs. Tmin	Obs. Tdew	PRISM Tmax	PRISM Tmin	PRISM Tdew	Graham Guard Tmax	Graham Guard Tmin
1995	11	6.67	−1.57	−18.65	5	−4	−5	7.22	−5.06
1995	12	0.89	−8.38	−5.20	1	−11	−7	3.79	−13.29
1996	1	0.16	−9.13	−6.35	3	−8	−8	2.24	−13.19
1996	2	3.36	−8.19	−6.51	3	−10	−9	5.94	−13.28
1996	3	7.00	−4.53	−3.81	8	−5	−5	9.55	−9.81
1996	4	9.29	−1.75	−1.84	12	−4	−3	12.06	−5.44
1996	5	12.70	0.53	0.08	13	−1	−1	13.10	−1.49
1996	6	21.95	3.54	2.65	21	3	1	21.80	0.73
1996	7	27.99	7.01	4.44	29	7	4	28.46	3.72
1996	8	27.10	5.32	2.06	27	6	2	27.57	2.71
1996	9	19.05	1.46	−0.72	20	1	−1	19.37	−2.16
1996	10	12.52	−1.60	−1.96	11	−3	−4	14.30	−5.88
1996	11	5.29	−4.42	−2.44	5	−7	−6	7.36	−8.17
1996	12	−0.30	−8.55	−5.13	−1	−10	−6	1.36	11.78
1997	1				2	−11	−8	3.41	−15.48
1997	2				4	−12	−9	5.96	−15.70
1997	3				9	−8	−8	9.32	−11.89
1997	4	7.88	−3.26	−2.89	11	−5	−5	10.97	−7.26
1997	5	18.21	2.24	1.67	19	0	0	17.98	−1.02
1997	6	19.28	4.26	5.66	21	3	3	20.16	2.82
1997	7	27.77	5.93	6.75	25	5	6	24.50	3.19
1997	8	27.90	6.70	6.08	27	5	5	26.29	3.82
1997	9	21.55	4.49	4.41	23	3	3	22.06	1.73
1997	10	11.50	−1.36	−1.11	12	−4	−4	12.88	−4.33
1997	11	6.59	−4.18	−2.47	6	−6	−7	8.11	−8.45
1997	12	0.83	−10.77	−7.92	1	−13	−9	4.06	−17.96
1998	1				3	−10	−5	4.25	−12.02
1998	2	6.96	−13.62	−3.69	4	−11	−7	6.66	−14.85
1998	3	7.32	−8.68	−1.47	7	−9	−5	9.57	−11.25
1998	4	10.06	−2.66	3.93	11	−5	−3	13.35	−6.66
1998	5	14.15	1.99	7.99	14	−1	2	14.36	−0.02
1998	6	19.44	4.57	12.14	17	1	4	17.29	0.93

1998	7	32.34	10.55	19.97	29	8	8	28.85	5.85
1998	8	30.59	7.91	19.69	28	6	5	28.28	3.57
1998	9	23.27	6.31	10.29	23	4	6	23.37	3.43
1998	10	33.33	−1.80	−1.61	13	−4	−4	14.34	−5.49
1998	11	4.19	−3.33	−1.18	5	−6	−5	4.97	−6.09
1998	12	−0.62	−9.29	−6.86	0	−13	−9	1.84	−13.75
1999	1	2.52	−7.67	−4.35	2	−11	−7	4.31	−13.82
1999	2	1.94	−9.21	−5.19	2	−13	−8	4.11	−14.71
1999	3	6.41	−6.19	−5.61	7	−9	−7	9.95	−11.80
1999	4	9.19	−3.47	−3.46	10	−7	−5	12.29	−8.65
1999	5	14.92	0.77	0.17	15	−3	−2	15.15	−2.65
1999	6	20.99	6.30	6.08	19	2	1	19.38	1.86
1999	7	28.75	9.18	5.59	27	4	1	26.05	1.35
1999	8	29.20	10.86	8.32	27	6	5	27.61	3.82
1999	9	25.17	7.38	2.04	21	0	−3	21.80	−3.07
1999	10	19.86	4.50	0.03	16	−3	−6	17.33	−6.17
1999	11	14.54	4.46	3.36	9	−4	−7	10.59	−6.42
1999	12	11.96	5.85	6.97	2	−10	−8	5.44	−13.49
2000	1	14.16	9.19	10.07	1	−12	−7	3.10	−13.52
2000	2	22.94	15.46	15.25	5	−9	−5	8.33	10.51
2000	3	22.92	16.07	13.92	8	−9	−6	10.62	−12.18
2000	4	29.38	21.08	18.88	13	−3	−2	14.04	−4.71
2000	5	32.77	25.00	21.81	16	0	0	15.56	0.04
2000	6	43.64	35.77	28.92	21	3	0	21.33	0.60
2000	7	50.44	43.92	33.23	28	6	3	27.84	3.30
2000	8	52.53	46.79	34.56	29	6	2	28.89	3.09
2000	9	46.45	40.67	33.97	20	0	1	20.51	−1.05

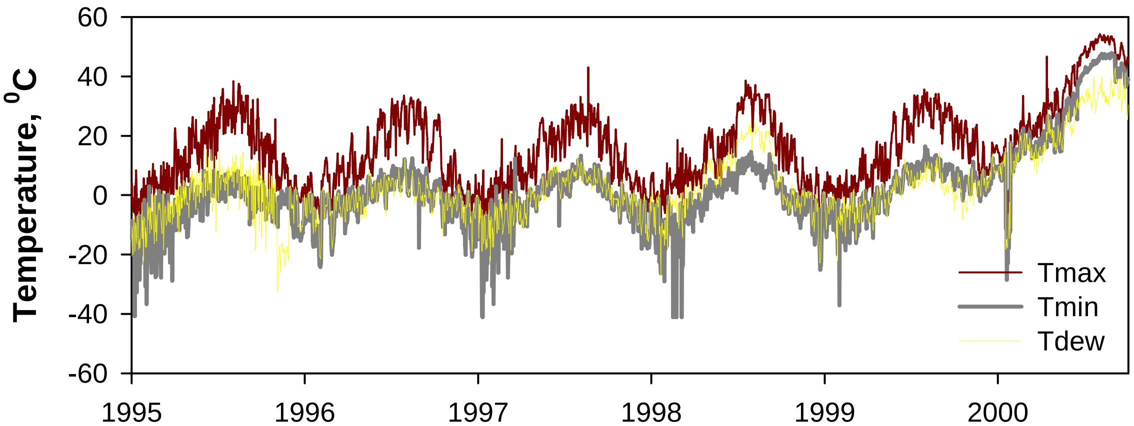

Figure A3. Observed daily maximum, minimum and dew-point temperature.

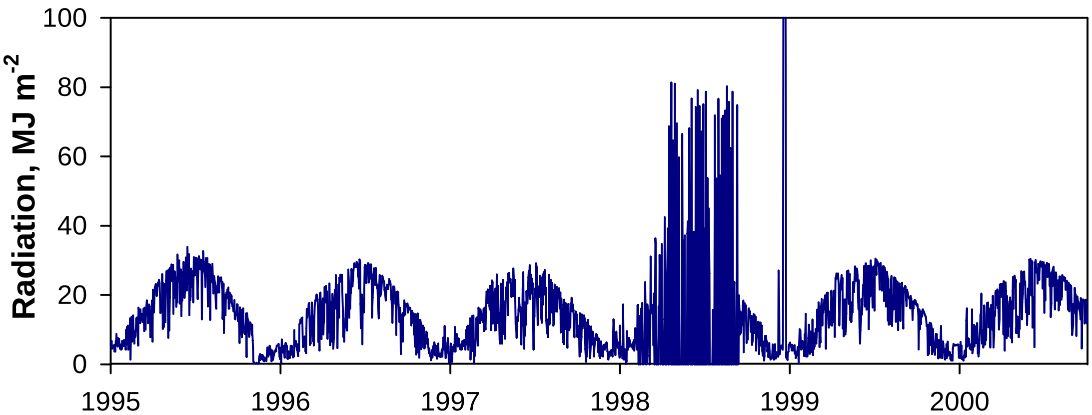

Figure A4. Observed solar radiation.

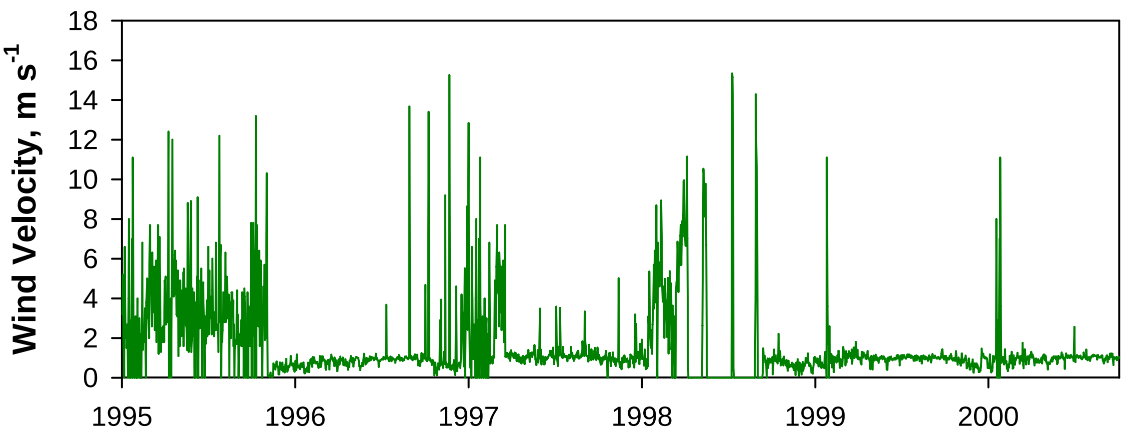

Figure A5. Observed wind velocity.

Data Adjustment

Precipitation Data

Daily precipitation from the weighing bucket had some negative values due to the fluctuation of the recorded data. It was not easy to correct them one by one. However, daily precipitation from the tipping-bucket gage were generally in good quality. The daily precipitation was then based on the data from the tipping-bucket gage. However, during winter time when the weighing gage generally caught more precipitation, precipitation events recorded from the weighing gage were compared with the tipping bucket records and data collected at the SNOTEL Station at Graham Guard, ID. When it is confirmed that the precipitation was not abnormal, daily precipitation data from the weighing gage was used. Because no precipitation data were collected by the tipping-bucket gage for year 2000, the daily precipitation data for 2000 was directly from the recorded of the weighing gage.

Year 2000 temperature

The abnormal temperature data for the year of 2000 were replaced by estimated data based on daily observation for the same period from the Graham Guard station using a linear regression function (Figure A6) relating monthly averages of daily maximum and minimum temperatures for the two sites.

Year 1998 solar radiation and wind velocity

The unreasonable solar radiation and wind velocity data in year 1998 were substituted by the CLIGEN-generated data based on known daily precipitation, maximum and minimum temperature and long-term statistic parameters as described in the section of filling climate data gap in the thesis.

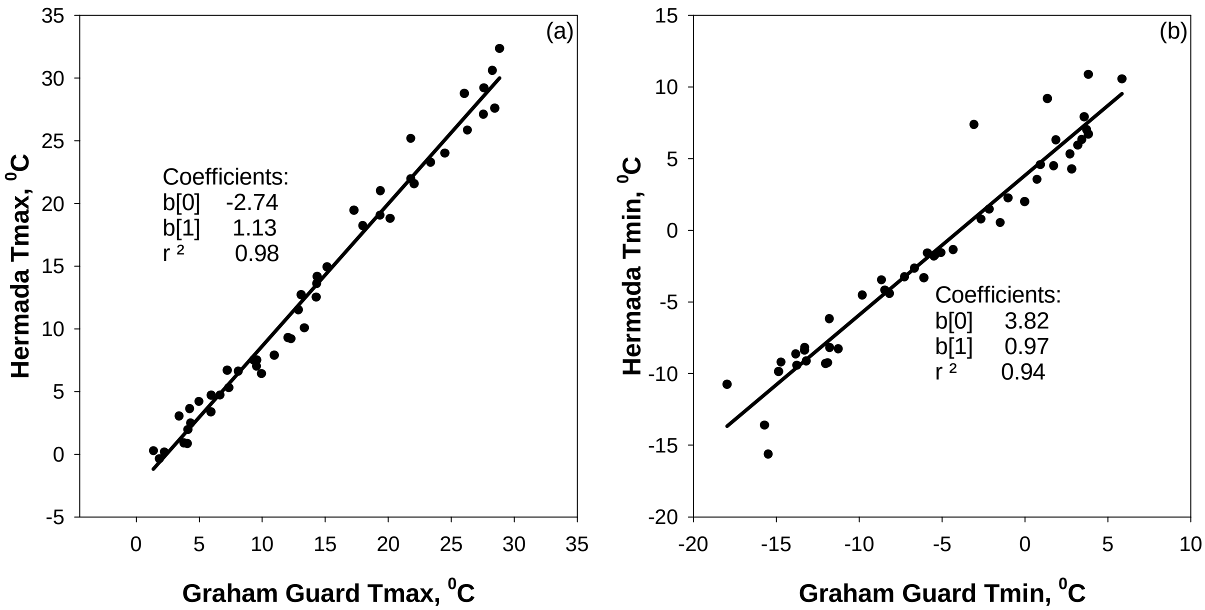

Figure A6. Linear regression on the monthly average of daily maximum and minimum temperature between Hermada watershed and SNOTEL Graham Guard station. (a) daily maximum temperature and (b) daily minimum temperature.

Results

The re-processed precipitation data were considered realistic and adequate for the study area as shown in Figure A7, which compares monthly precipitation for the monitored period between re-processed in this study with those from PRISM estimation and SNOTEL observations at the Graham Guard station, respectively. Figure A8 illustrates the climate inputs for the WEPP application. The consistency and clear patent of the watershed precipitation, temperature, solar radiation and wind velocity curve indicated that the re-processed climate data was adequate to represent the climate condition of the modeling domain.

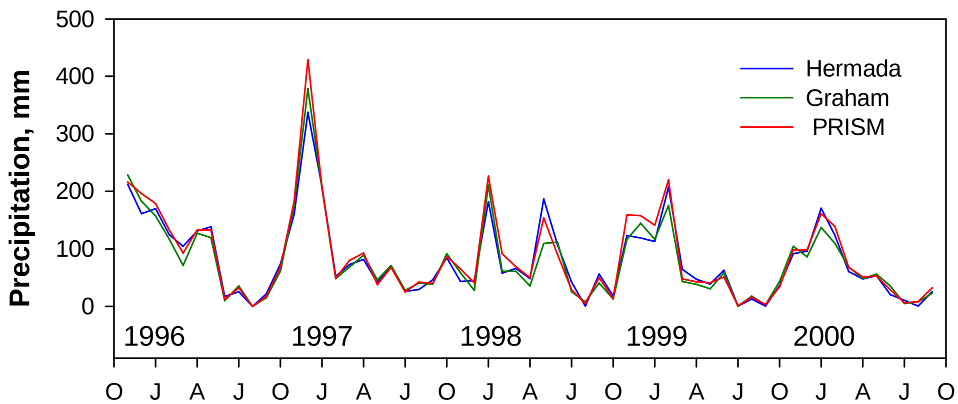

Figure A7. Comparison of monthly precipitation between re-processed data in this study, SNOTEL observations at Graham Guard, and spatially interpreted data by PRISM.

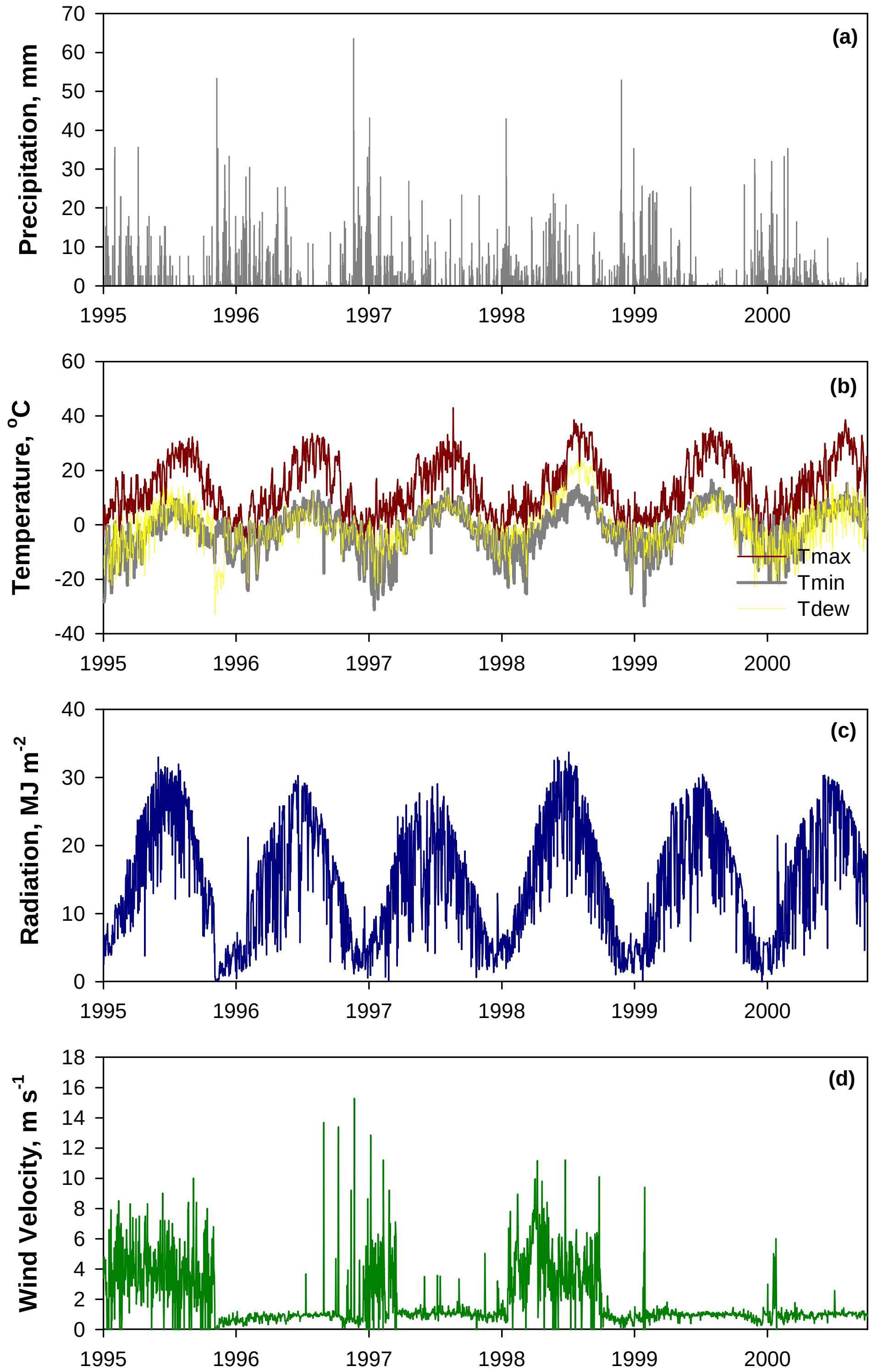

Figure A8. Hermada watershed daily climate data, (a) precipitation, (b) maximum, minimum, and dew-point temperature, (c) solar radiation, and (d) wind velocity.

Data Processing Procedure

The observations of a tipping bucket were recorded in the hrmi_pf_year.dat files. From November 3, 1995–January 2, 1999, the records were in one minute interval. After that the observations were in 10 minutes interval. For year 2000, this type of file did not record any rainfall.

The major file for processing hrmi_pf_year.dat is RainMacro.xls

1. Open hrmi_pf_year.dat with Microsoft word
2. Copy about 2 month data and paste it on notepad and save this notepad file as hrmi_pf.txt. The reason for step 1 and 2 is an excel can only open 65536 recoeds.
3. Open RainMacro.xls. Ctrl+r will read in the data in hrmi_pf.txt and preprocessing the data. When the prompt window asking if you need save the changed data for the txt file, say no. You should end in the RainMacro.xls file
4. Copy the title in the “title” page in the RainMacro.xls file to the “work” page. Word “Begin” should be in column A1.
5. This step is for manually check unreasonable data. Select column H. On Excel menu, under data, go for filter then autofilter. When the selection menu button shows in column H, click and select “custom” . We filter the records which is greater than 0.02 inch/minute. Color them yellow. Go back to un-filtered mode. Manually check if these data were caused by malfunction of the equipments. If it is true, adjust the data in the manual check column – column I. The Macro for summary 10 minutes data would read from Column I.
6. Run Macro P10min and then CumulP.
7. Copy the work sheet into a new excel file and save as Rfdshyear_No.xls.

The 15-minutes data include precipitation, temperature, solar radiation, wind velocity and wind direction data. The data is stored in met_year.dat files. The precipitation and solar radiation data in these files fluctuates a lot.

The major file for processing met_year.dat is RhumMacro.xls.

1. Copy a met_year.dat as met.dat.
2. Open RhumMacro.xls. Ctrl+r will read in the data in the met.dat file into an excel sheet. Copy this sheet to the "work" sheet in RhumMacro.xls.
3. Run Macro "Average" will calculate the dew-point temperature.
4. Copy the precipitation data into "process" sheet and graph and manually adjust the step increases. Copy the manually adjusted step increases to column "AG" in the "work" sheet.
5. Copy the solar radiation data into "SQ" sheet and do the same as processing precipitation data. Copy the manually adjusted step increases to column "AH" in the work sheet.
6. In the work sheet, filter "B" column (temperature data) with which contains "-" symbol. Replace all the bad data using "999999" which means invalid data in the Macro. Filter the negative values in column "H" (wind velocity data) and replace them with "999999" also. Manually check all the wind speed data exceeds 100mph and set un-valid data accordingly.
7. Run Macro "CumlP" to get the daily climate data for the WEPP model.
8. Manually check the results.

Results from weighing bucket and tipping bucket were combine manually in the excel file COMBINE.xls. Data gaps were filled with SNOTEL Graham Guard Station observations and CLIGEN-generated data in excel file NEWCLI.xls. Final data adjustment was also completed in NEWCLI.xls in APPENDIX C.

References

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C. DATA AND WEPP RUNS

(included in the attached CD):

1. Original data and data processing for Hermada watershed

DataPro folder

2. WEPP runs for the conceptual model watershed and the real Hermada watershed

WEPPrun folder