Incorporating Variable Source Area Hydrology in the WEPP Model

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Authorization to Submit Thesis

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Abstract

In the continental United States of America there are over 201 million acres that are classified as having restrictive soil layers present. Saturation excess runoff occurs frequently in areas where restrictive layers are present in the soil, and in humid areas with low intensity long duration rainfall events. Variable source area hydrology based on saturation excess processes is currently represented in very few physically-based hydrology and erosion models. Saturation excess runoff processes were added to the WEPP model by the incorporation of multiple Overland Flow elements in the WEPP model. By incorporating multiple OFEs in the WEPP model convergence of lateral flow was achieved. With convergence of lateral flow sub-surface/surface water interactions can take place, successfully representing variable source area hydrology with saturation excess mechanisms. Hillslope drainage was validated with known hillslope drainage data Hewlett and Hibbert (1963). Watershed outflow hydrographs were compared for a 2800 ha watershed along with 8 nested watersheds. Watershed results showed an excellent result was achieved when a constant scaling factor was applied to the modeled outflow hydrographs. I theorize that this error is due to misrepresentation of the amount of flow through the restrictive soil layer. Integration of convergent sub-surface lateral flow allows variable source area hydrology to be included in the WEPP model. With the addition of lateral flow over and through a restricting layer, the WEPP model is now capable of simulating saturation excess runoff.

Acknowledgements

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INTRODUCTION

Non-point source pollution from agricultural lands continues to be a major concern in the United States and around the world (USEPA, 2003). The number of water bodies placed on the Clean Water Act 303(d) list for impairment of beneficial uses is staggering (USEPA, 2000). All states are in the process of developing Total Maximum Daily Load (TMDL) targets and water quality management plans. A major component of water quality management plans is the implementation of conservation practices or Best Management Practices (BMPs).

The geographic region targeted in this study is the Northwest Wheat and Range Region (NWRR) located in northern Idaho, eastern Washington, and north-eastern Oregon. The NWRR is one of the most productive as well as highly erodible dryland wheat-producing regions of the United States (Papendick, 1996). The Natural Resources Conservation Service (NRCS) has targeted the NWRR as critical for controlling erosion and nonpoint source pollution (NPS) (McCool, 1990). Despite a long history of research and extension activities to eliminate the erosion problems in the NWRR, a large number of streams in the NWRR are on the 303(d) list due to sediment problems.

Evaluation of effectiveness of conservation practices at the watershed scale requires a long-term data collection campaign, ideally covering pre- and post-implementation periods (Meals, 1996). Even with one long-term data set, however, the most optimal suite of conservation practices may not be revealed. A modeling approach therefore is recommended to complement long-term data sets.

Modeling approaches for non-point source pollution can be classified as empirical, physically-based, and conceptual. Erosion models based on empirical relationships such the USLE/RUSLE do not provide information on effects of land use changes, as their parameters are not physically-based. Empirical models, however, can provide long term estimations of erosion. These models do not directly compute runoff, and therefore erosion predictions are not sensitive to actual climatic variations. A high degree of accuracy in prediction of a hydrograph is needed to prevent errors in erosion computations (Kinnell, 2005). The SWAT (Soil Water Assessment Tool) model (Arnold et al., 1998) documentation states that it is physically-based and better predicts the effects of land management effects. Runoff in the SWAT model, however, is based on the SCS curve number method (USDA-SCS, 1972), which is an empirical method to simulate runoff for single storm events (Engel, 2004). Alterations to land use require changing the curve number for the area in question. Calibration of the SWAT model primarily relies on alteration of the SCS curve number (Leiw, 2003), therefore the curve number is a fitting parameter rather than a physically-based input to the model. To gain a better understanding of the behavior of processes within a physical system a model is desired that includes parameters with a basis that can be related to observations (Grayson, 1992). Evaluation of the effects of land use changes requires the interaction of parameters to be evaluated (Beven, 1989)

Physically-based and conceptual models appear most appropriate for evaluation of conservation practices at the watershed scale. Either they can be calibrated using observed data and then parameters can be adjusted when other scenarios are evaluated, or if the model does not require calibration, parameters can be estimated based on physical understanding of processes and the watershed system (e.g., topography, soils, land use, and climate). Few, if any, physically-based or conceptual models are able to simulate erosion and sediment delivery at the watershed scale.

A critical element of any erosion model is the incorporation of the dominant hydrological processes operating at the hillslope and watershed scales. Two processes are infiltration excess overland flow and saturation excess overland flow. Infiltration excess overland flow, commonly referred to as Hortonian overland flow, occurs when rainfall intensity is greater than the rate at which the soil can absorb the water. During low intensity rainfall events the rate at which the water is added to the soil may not be greater than the rate at which the soil can absorb the water, and as such the water will simply infiltrate into the soil. In areas with low intensity precipitation and high infiltration capacity soils, runoff will be generated when the soils become saturated (Dunne and Black, 1970; Dunne et al., 1975; Walter et al., 2000). This type of runoff is generally termed saturation excess runoff. Saturation excess runoff can occur frequently in the presence of restrictive layers in soils; therefore the hydropedological features of the watershed need to be considered when modeling saturation excess runoff (Gburek et al., 2005). According to the USDA-NRCS (Natural Resources Conservation Service) STATSGO database, perched water tables are present in over 201 million acres of land in the continental United States (Figure 1). The study watershed in this study in the Palouse Region of northern Idaho has over 50% of the soil containing a perched water table at some point throughout the year (NRCS STATSGO database) (Figure 2).

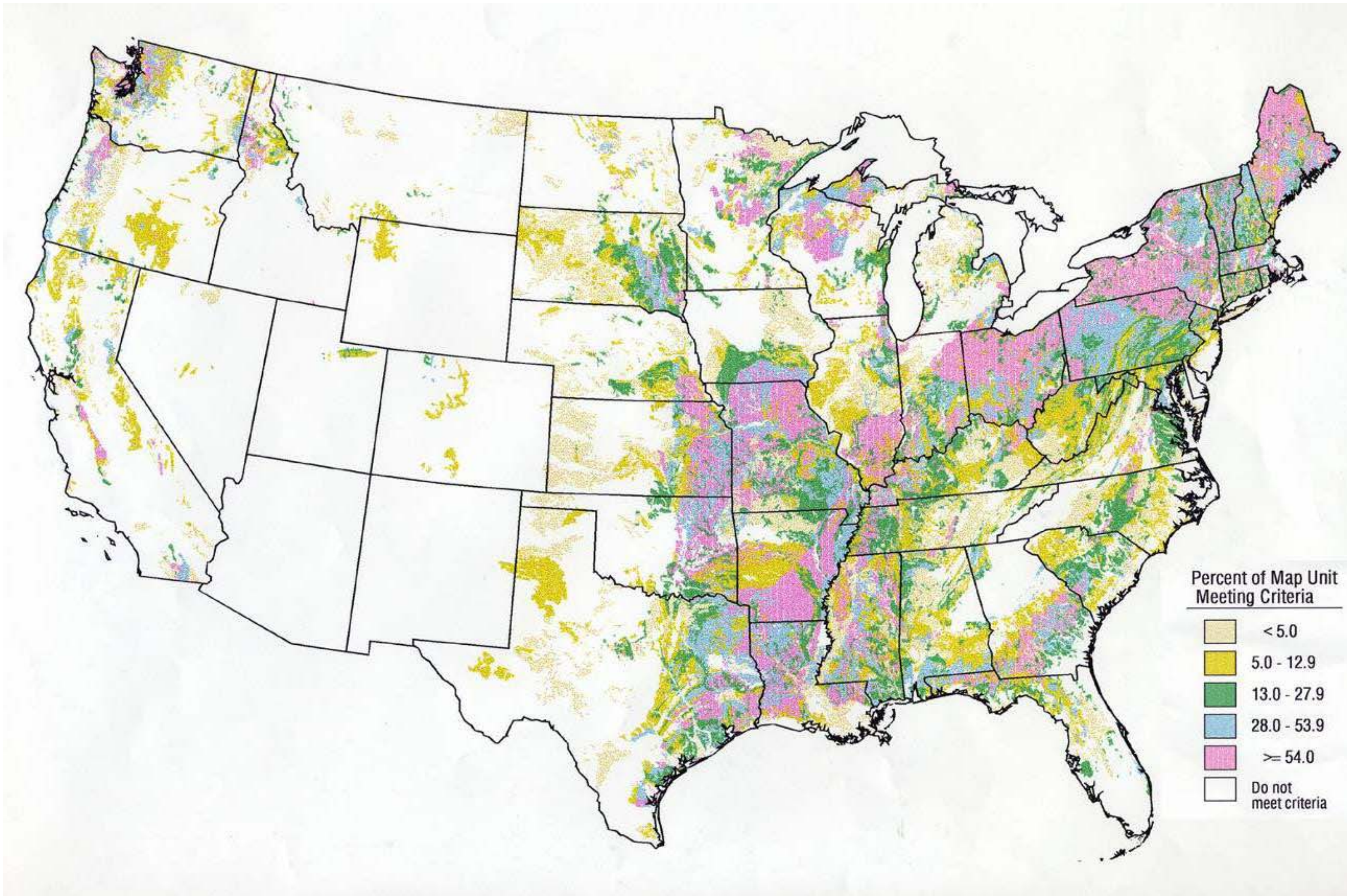

Figure 1 United Stated of America Perched water table map. Derived from the USDA-NRCS STATSGO

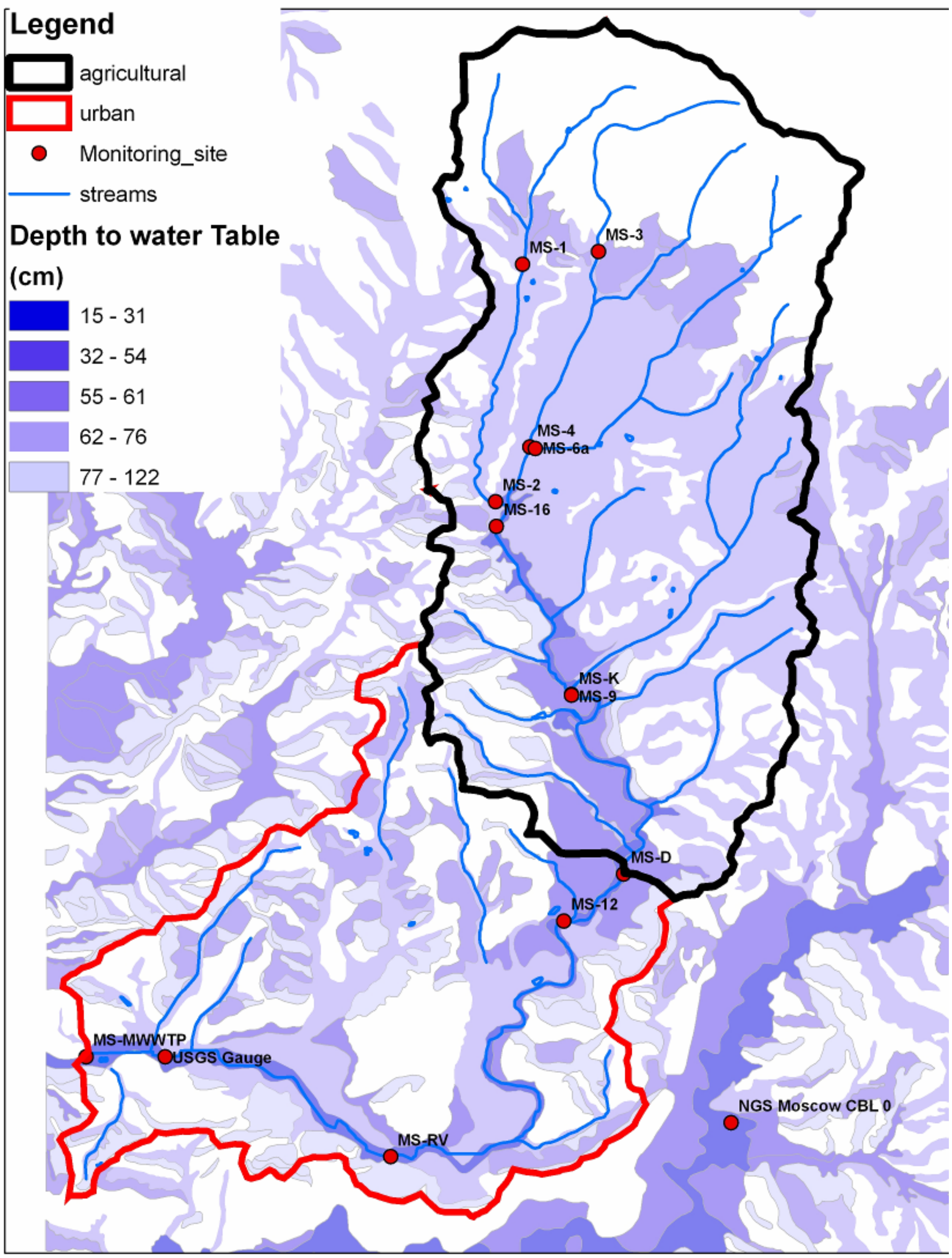

Figure 2 Perched Water Table Depth in Paradise Creek Watershed.

The majority of erosion models include infiltration excess overland flow (e.g., ANSWERS, KINEROS, SWAT, WEPP). Only the DHSVM erosion model to date incorporates saturation excess overland flow. DHSVM (Wigmosta et al., 1994) recently was modified to simulate erosion processes at the watershed scale (Doten et al., 2006). This model includes fundamental, physically-based hydrology and erosion algorithms, which, in turn, make model application a challenge. However, DHSVM has not been fully tested on observed data, and evidence of its accuracy is forthcoming.

A user friendly management model, the WEPP model, was developed with extensive field data at over 30 locations in the United States (Figure 3). WEPP has been validated with 1000 plot years of runoff and erosion data from 12 sites. Data from 15 different watersheds have also been used for validation of the WEPP model. The WEPP model has been applied to every continent on Earth except Antarctica (Laflen, 1997).

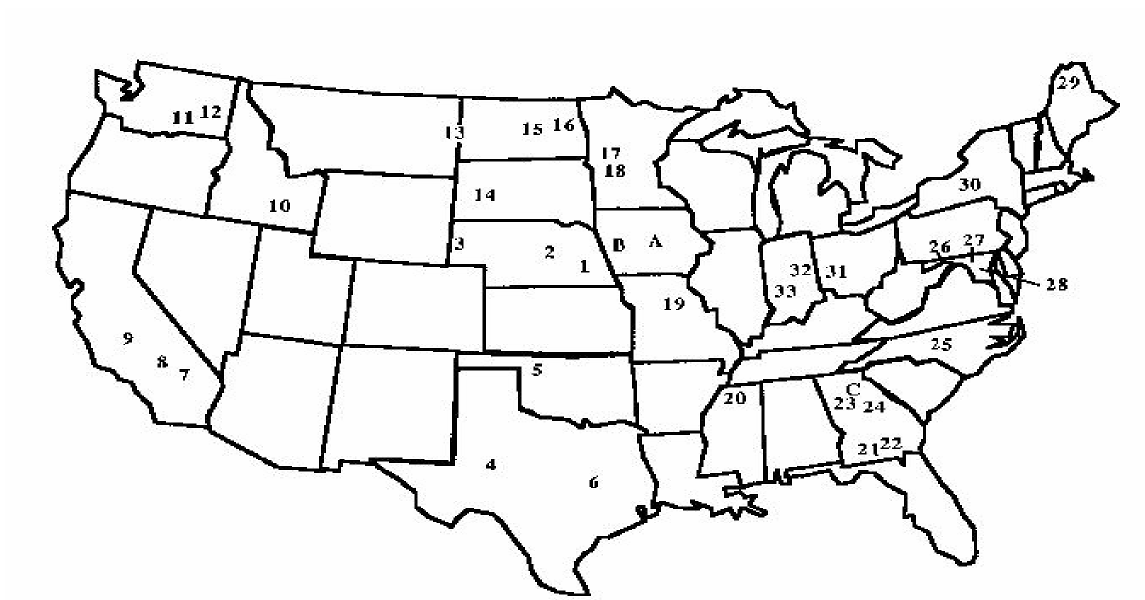

Figure 3 WEPP cropland erosion sites
(http://topsoil.nserl.purdue.edu/nserlweb/weppmain/comp/images/fig1.gif)

Interestingly, the original documentation of the WEPP model (Flanagan et al., 1995) described an algorithm for subsurface lateral flow based on work by Sloan and Moore

(1984), indicating the ability to simulate saturation excess overland flow. Versions of the WEPP model prior to 2003, however, did not simulate sub-surface lateral flow.

Wu et al. (2000) recently re-activated the subsurface flow algorithm, and found improved predictions for monthly water volumes. Dun et al. (2006) used one overland flow element for each hillslope in their work. Recent versions of the WEPP model include lateral flow, but they have not been validated on hillslope data (S. Dun, 2006). In this study, we expand on these modifications in WEPP with the purpose of creating the first operational erosion prediction model that can simulate both infiltration and saturation excess runoff. To capture the convergence of sub-surface lateral flow multiple overland flow elements must be used. Topographical features such as toe slopes can influence the formation of saturated areas (Grayson, 1992). Hence using multiple overland flow elements to delineate topographical break points is important for the incorporation of convergent sub-surface lateral flow. The convergence of sub-surface lateral flow allows for the incorporation of variable source area hydrology in the new WEPP model.

Specific objectives of this study were to 1) incorporate sub-surface lateral flow convergence into the WEPP model using multiple overland flow elements, 2) validate the hydrology components of the new WEPP model with hillslope drainage data from the Coweeta Hydrologic Laboratory (Hewlett and Hibbert, 1963), 3) validate the hydrology components of the new WEPP model on a mix-land use watershed in northern Idaho.

METHODS

This study validated the hydrological prediction of a modified version of the Water Erosion Prediction Project (WEPP) model at the hillslope scale and at the watershed scale.

Model:

The WEPP model simulates the water balance and predicts erosion at the hillslope scale and the watershed scale. The WEPP model is a daily time step model developed by the Forest Service, Agricultural Research Service, Natural Resources Conservation Service, Bureau of Land Management and Geological Survey to evaluate erosion from agricultural lands.

Physical processes included in the WEPP model are: infiltration and runoff, soil detachment, transport, and deposition; and plant growth, senescence, and residue decomposition (USDA Forest Service, 2005). The WEPP model uses the Green and Ampt method to estimate infiltration of water into soil. In the WEPP model, soil is detached and transported form the soil surface when the shear stress applied by the water is greater than the average shear stress required to remove soil (Flanagan et al., 1995).

Two methods can be used to run the WEPP model. The model can be run from either the Windows interface, or from the MSDos interface. Creation of input files for the WEPP model can be done manually, from watershed measurements or topographic maps, or with the GIS interface for the WEPP model, GeoWEPP (Renschler, 2003). Input to the GeoWEPP model includes: digital elevation maps, soil data, land use and climate data, minimum stream length, and critical source area. Critical source area is the minimum area required to generate runoff. GeoWEPP generates hillslope files as well as a stream network structure file. Structure files relate hillslopes to stream segments, and allow the user to determine which hillslopes contribute to stream segments. Watersheds in WEPP are represented by a representative group of rectangular hillslopes, the base of the hillslope delineating the stream channel bank.

In the MSDos version of the WEPP model, input is directed to the model by a "run" file. The run file is a text file that contains the names and locations of the input files as well as names and locations of the desired output files. The use of a run file allows multiple hillslopes to be run in WEPP without the user manually entering the file names and locations.

Input to the WEPP model consists of hillslope files, management files, soil files, and a climate file. Hillslopes generated by GeoWEPP require the input of a Digital Elevation Model (DEM), soil maps, land use maps, and a climate file. GeoWEPP then generates hillslopes based on the DEM. Hillslope information is stored in separate text files generated by GeoWEPP, which contain: slope length, width, aspect, and slope points from the DEM. The maximum number of slope points created by GeoWEPP is 19. Hillslopes can be further divided into overland flow elements (OFEs) that allow for different land use management as well as soil types. OFEs are discrete sections of a hillslope that can contain distinct soil or land use classifications.

Management files in the WEPP model can be generated in the Windows interface for combinations of crop rotations and tillage practices. Management files can be generated in the windows interface for the WEPP model, for up to 10 OFEs. Generation of management files for more that 10 OFEs is accomplished by manipulation of the management files in a text editor. The number of OFEs with distinct slope information is the same as the number of break points in GeoWEPP generated hillslopes, with a maximum of 19. WEPP requires the same number of OFEs represented in a hillslope file to be present in both the management file as well as the soil file. This dictates that a maximum of 19 separate files for every management and soil be created, one for each distinct combination. Soil files contain information on the soil physical properties. Soil files for every state in the United States are included in the database that is bundled with the WEPP Windows model. Climate files contain daily values for precipitation, storm duration, time to storm peak, rainfall intensity, minimum and maximum temperature, solar radiation, wind velocity and direction. The WEPP model allows the user to generate a climate file either from observed data, or from a database of climate files included with the climate generator CLIGEN.

Output from the WEPP model can include: a hillslope pass file, a soil loss file, a water balance file, a crop output file, a sediment distribution file, a winter output file, and a plant yield output. The hillslope pass file contains daily values for sediment concentrations as well as streamflow. Loss files contain a summary of the distribution of erosion on the hillslope. The water balance file contains the following daily values for each overland flow element: precipitation, snow melt, overland flow, plant evaporation, soil evaporation, deep percolation, overland flow from upslope OFEs, sub-surface lateral flow, and soil moisture content.

WEPP documentation (Savabi, 1995) indicates that the model calculates sub-surface lateral flow by Darcy's Law (Eq 1). To compute sub-surface lateral flow the thickness of the drainable layer must be calculated. According to the WEPP manual (Ch.

6), the drainable thickness was calculated as per Sloan and Moore (1984) (Eq 2), however, this equation was never used in the WEPP model. The WEPP model computes discrete thickness soil layers, the first layer is 10 cm, followed by 20 cm layers to a maximum soil depth of 1.8 m.

$$q = 86400 H_{(o)} K_{e(\Theta)} \sin(\alpha) \tag{1}$$

$$H_o(d) = \left(\frac{H_{(o)}(d-1)\left(L\Theta - 86400 c(\alpha) + 2L(Pe - (D + ET))\right)}{L\Theta_d + 86400 K_{e(\Theta)} \sin(\alpha)} \right) \tag{2}$$

where

q is sub-surface lateral flow in (m/day)

$H_{(o)}$ is the drainable thickness (m)

$K_{e(\Theta)}$ is horizontal hydraulic conductivity (m/sec)

Θ is the soil moisture content (-)

α is the average slope of the surface (-)

L is the length (m)

Pe is percolated water to lower layer (m/day)

ET is actual evapotranspration (m/day)

D is deep percolation out of the layer (m/day)

The saturated hydraulic conductivity of the soil layers was computed based on soil's sand and clay percentages as well as bulk density (Eq 3a-d) (Dun, 2006). WEPP v2006.5 (Dun, 2006) computes lateral flow with Darcy's law, factoring in the soil's saturated thickness (Eq 4). Unsaturated hydraulic conductivity v2006.5 is computed as a power function of the percent saturation (Eq 5).

$$K_{sat(mm/hr)} = \frac{12.7*(100-clay\%)*ssl}{(100-clay\%)+e^{(11.45-0.097*(100-clay\%))}} \quad (3a)$$

$$ssl = 0.1 + \frac{.0009*bd}{0.001*bd + e^{(bt1+bt2*.001*bd)}} \quad (3b)$$

$$bt1 = \ln(0.0112*(1.15+0.445*sand\%/100)) - bt2*(1.15+0.445*sand\%/100) \quad (3c)$$

$$bt2 = \frac{\ln(0.0112*(1.15+0.445*sand\%/100)) - \ln(8.0*(1.15+0.445*sand\%/100))}{(1.15+0.445*sand\%/100)-(1.50+0.500*sand\%/100)} \quad (3d)$$

where:

bd is bulk density in mg/cm^3

$$Sub\_lateral\_flow = \frac{drainabledepth*anisotropy\_ratio*Ksat*slope}{slope\_length} \quad (4)$$

$$K_{unsat} = K_{sat}*fffx \quad (5)$$

where: $fffx = \%saturated^{\left(\frac{-2.655}{\log\left(\frac{fc}{Ul}\right)}\right)}$

fc = field capacity

Ul = upper limit to soil moisture

WEPP v2006.5 computes effective hydraulic conductivity as a weighted average sum of both the saturated hydraulic conductivities of layers above field capacity as well as the unsaturated hydraulic conductivity of the soil layers below field capacity (Eq 6). Modifications in the new version of WEPP remove the unsaturated hydraulic conductivity power function and replace it with a linear function of the percent of the layer that is saturated (Eq 7). The fraction of the layer that is saturated multiplied by the hydraulic conductivity yields the total hydraulic conductivity for the layer.

$$K_{effective} = \sum_{i=1}^{soil\_layers} \frac{Ksat_i * fffx_i * depth_i}{totaldepth} \qquad (6)$$

$$fffx\ (new) = \frac{\Theta - \Theta_{fc}}{\Theta_{sat} - \Theta_{fc}} \qquad (7)$$

Previous versions of WEPP v2006.5 (Dun, 2006) allowed the following soil parameters to be specified in the soil input file: depth of layers, number of layers, albedo, initial saturation level, interrill erodibility, rill erodibility, critical shear, hydraulic conductivity, anisotropy ratio, sand percentage, clay percentage, organic matter percentage, cation exchange capacity, percent rock content, and restrictive layer saturated hydraulic conductivity. WEPP v2006.5 allowed for the input of saturated hydraulic conductivity as well as an anisotropy ratio; however, the hydraulic conductivity only applied to the top 10 cm of the soil profile while the anisotropy ratio applied to the entire soil profile.

The modified WEPP model in this study contains a soil file that allows the user to input the following additional soil properties for each soil layer: bulk density, saturated hydraulic conductivity, anisotropy ratio, field capacity, and wilting point. The hydraulic conductivity is specified by the user instead of calculated with Eq's 3a-d.

Hillslope Validation

The WEPP model was applied to a uniform hillslope measuring 0.9 m by 0.9 m by 15 m (3 ft by 3ft by 45 ft) with a slope of 40% as per Hewlett and Hibbert (1963), also known as the Coweeta Experiment (Figure 4). A soil file was created to contain the same soil properties that were used in Hewlett and Hibbert (1963) (Table 1 and 2). The soil was composed of 60% sand and 22% clay. A restrictive layer was placed at the bottom of the soil, 581 mm, to prevent percolation. Bulk density was set to 1.3 g/cm^3, with a saturated hydraulic conductivity of 168 mm/hr and an anisotropy ratio of 1.0. Initial soil moisture content was set to 75% to account for the sloping water table in the hillslope experiment. Field capacity was 0.25 with a wilting point of 0.001. The input climate file was set up with a minimum and maximum temperature of 1 and 2 °C, respectively. The dew point was set to 40 °C to prevent condensation. Solar radiation and wind speed were also set to 0. A grass management file was used from the WEPP database. Plant growth and ET were prevented by eliminating solar radiation and lowering the maximum temperature to below the necessary lower limit for growth. To account for antecedent conditions in hillslope simulations, initial soil moisture was set to 75% of saturation. The model was run for one year to allow the soils to reach a more realistic moisture level.

Output from the model included daily values of precipitation, snowmelt, stream flow, plant evaporation, soil evaporation, deep percolation, upstream flow (multiple OFEs only), sub-surface lateral flow, and soil moisture content. All these were saved in the water balance text file.

Drainage hydrographs were constructed for both the WEPP model output and the Soil Moisture Routing model (SMR) (Brooks et al. 2007; Frankenberger et al., 1999). Both cumulative drainage and discharge hydrographs were compared with observed data from Hewlett and Hibbert (1963).

Table 1 Coweeta Hydrologic Laboratory hillslope drainage soil properties.

%sand	60	bulk density (g/cm^3)	1.3
% silt	18	saturated Hydraulic conductivity (mm/hr)	168
% clay	22	% pore space	50

Table 2 WEPP soil file inputs for hillslope drainage experiment.

soil depth (mm)	914
% sand	60
% clay	22
bulk density (g/cm^3)	1.3
anisotropy ratio	1
saturation level	0.75
field capacity	0.25
wilting point	0.05
saturated hydraulic conductivity (mm/hr)	168
critical shear stress (N/m^2)	3.5
rill erodability (s/m)	0.007896
interrill erodability ($kg*s/m^4$)	4702762
Cation exchange capacity (meq/100 g soil)	23.3
% orgainc matter	3.5
% rock fragments	0
albedo	0.23
restrictive layer hydraulic conductivity (mm/sec)	1.00E-99

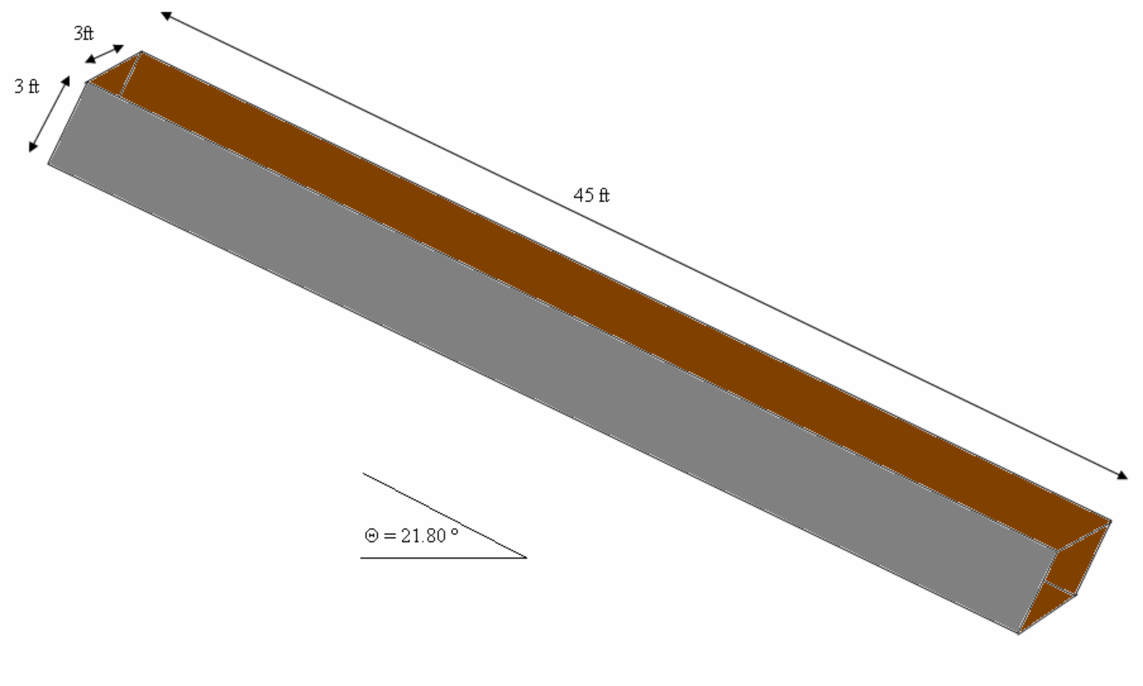

Figure 4 Coweeta Hydrological Laboratory hillslope configuration (based on Hewlett and Hibbert,1963)

Watershed Validation

Site Description:

For watershed scale testing. the WEPP model was applied to the Paradise Creek watershed, which is located in the Palouse region of the Pacific Northwest, near Moscow, Idaho (Figure 4). Paradise Creek watershed is a mixed land use watershed dominated by agricultural fields. Major agricultural crops produced in the region include: wheat, barley, peas, and lentils. The Palouse region is one of the most productive dryland agricultural regions due to the favorable soils and sufficient rainfall (Yang, 1998). Precipitation in the Palouse area averages about 23 inches per year (Barker, 1981). The majority of the precipitation occurs between the beginning of November and the end of May, comprising approximately 70% of the yearly total (McDaniel, 2001).

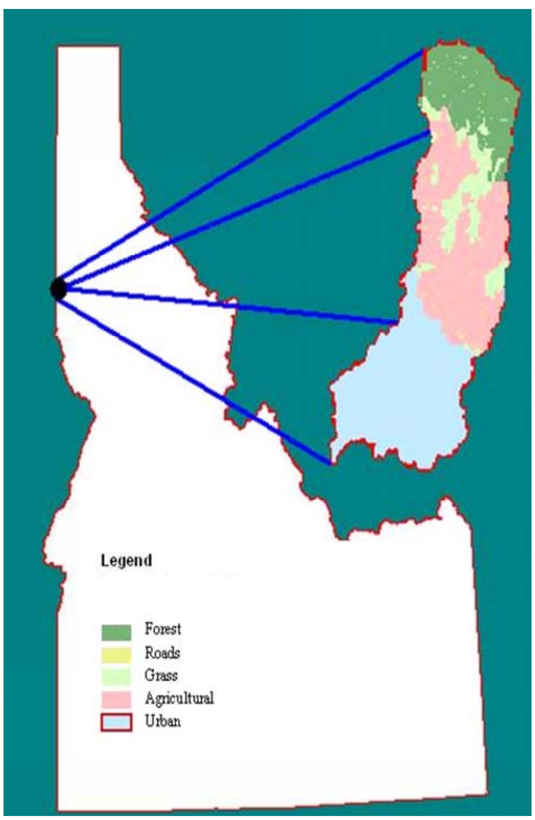

Figure 5 Location of Paradise Creek watershed.

Soils in the Paradise Creek watershed area are very deep, with moderate to steep rolling hills (Barker, 1981). Elevation ranges from approximately 700 m to 1000 m above sea level. The western portion of the county is composed of gently rolling hills that transition to steep tree covered mountains in the east and north. The Palouse region is composed of Pleistocene and Holocene loess soils. Perched water tables occur extensively in the Palouse Region due to the presence of Agrixerolls and Fragixeralfs that occupy approximately 30% of Latah County (McDaniel, 2001). In Latah County 51% of the soils contain perched water tables (McDaniel, 2007) (Figure 5).

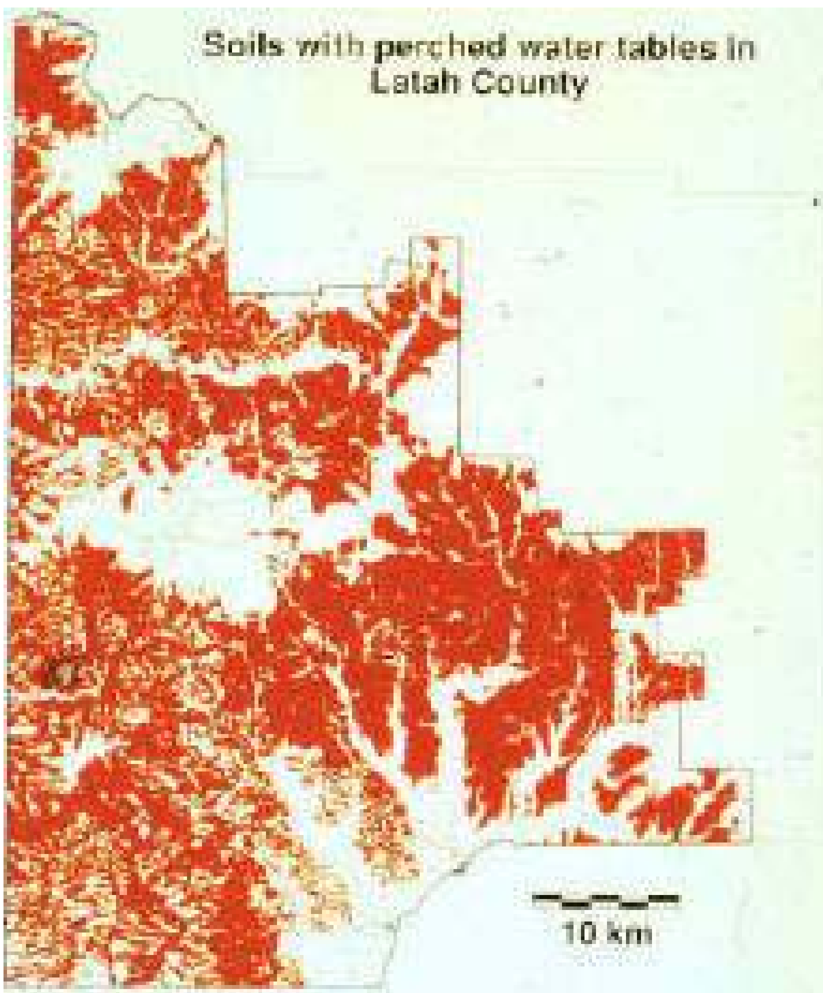

Figure 6 Perched water tables in Latah County, Idaho.

Stream flow measurements were obtained from nine monitoring stations in the agricultural portion of the Paradise Creek watershed (Figure 6). These monitoring stations provided 15-minute stream flow values as well as total suspended solid concentrations from water years 2005-2006. Continuous stream flow and turbidity data were also available from MS-3 and MS-D from 2000-2007.

The WEPP model was applied to the Paradise Creek watershed with the outlet set to a continuous monitoring station at the lower end of the agricultural area MS-D (Figure 6). Simulations were run for the years 2001 to 2006. Flow data were measured at eight points along Paradise Creek with automated Sigma 900 Max water samplers. Samples were taken during the rising and falling limbs of the hydrograph to determine TSS and turbidity. Water level was also measured at these locations and corresponding rating curves were developed to determine discharge. Five- minute discharge data were available from MS-D.

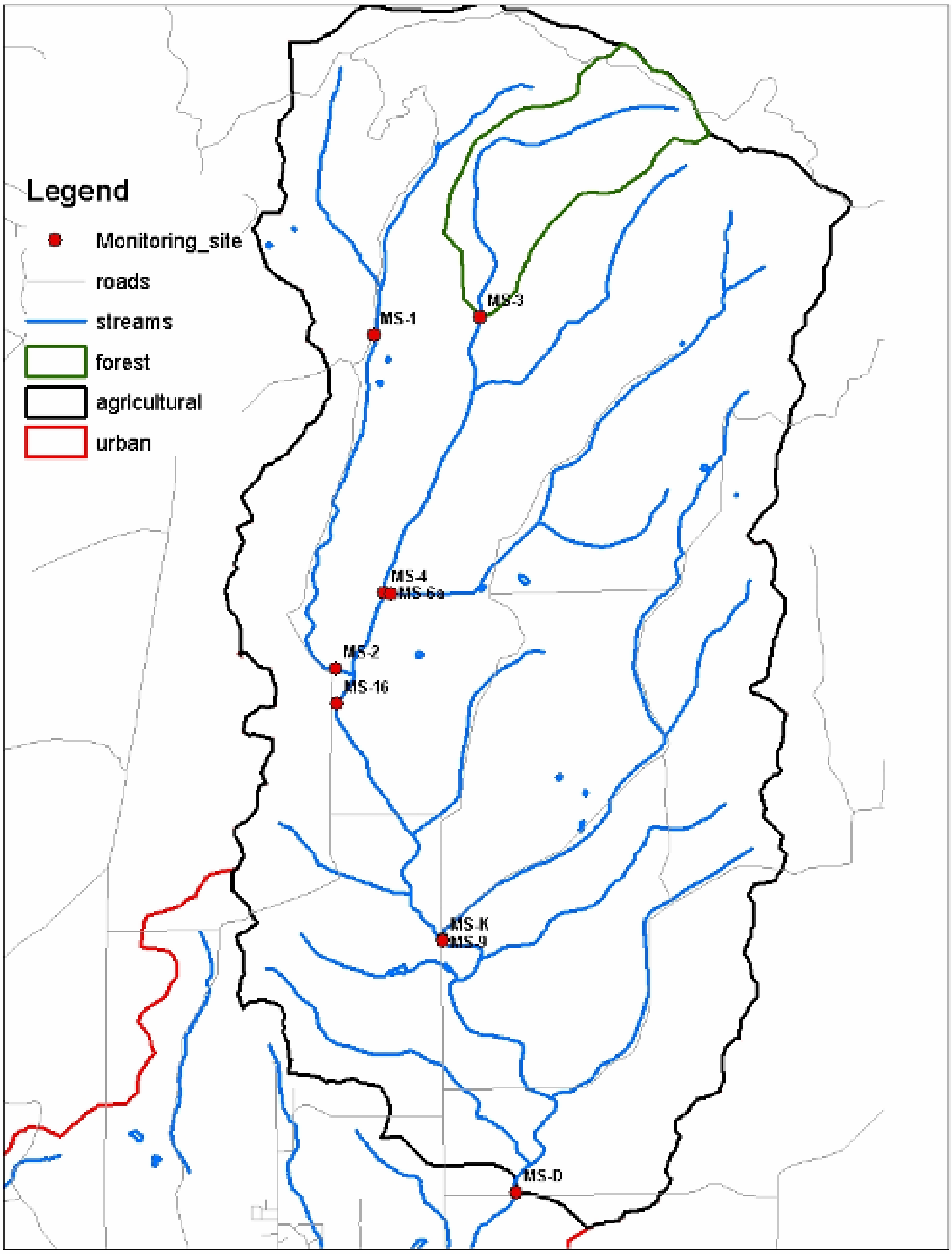

Figure 7 Paradise Creek agricultural monitoring sites.

Model Input:

Paradise Creek watershed was divided into hillslopes using the GIS interface to the WEPP model, GeoWEPP (Renschler, 2003). GeoWEPP used a 10 m resolution digital elevation model (DEM) and input of critical source areas as well as minimum channel lengths to delineate channel networks. After the channel network was established, a watershed outlet point was chosen. Two watershed delineation scenarios were tested in the Paradise Creek watershed: (1) 556 hillslopes based on a 5 ha critical source area and 100 m minimum stream length , and (2) 1309 hillslopes based on a 2 ha critical source area and a 50 m minimum stream length (Figure 7). The watershed outlet was selected at the continuous monitoring site MS-D (Figure 6). Hillslope files in GeoWEPP were broken up into multiple OFEs corresponding to break points included in the hillslope file (for the Perl script to automate this process see Appendix B).

Land use maps were created to generate management files for the input to the WEPP model. A 1 m resolution aerial photo was digitized to include all field boundaries in the watershed. Crops were verified by field inspection twice per year. Historic cropping practices were obtained from interviews with local farmers. Management files were created for each hillslope based on the crops in the watershed that composed the majority of the hillslope area. A data table was created with the hillslope numbers and soil and land use types. Separate management files were created for each crop rotation and overland flow element combination, for a total of 95 different management files (Appendix A). The WEPP model requires a unique management file for varying numbers of OFEs, therefore a hillslope with one OFE required a management file with one OFE, and a hillslope with 19 OFEs required a management file with 19 OFEs.

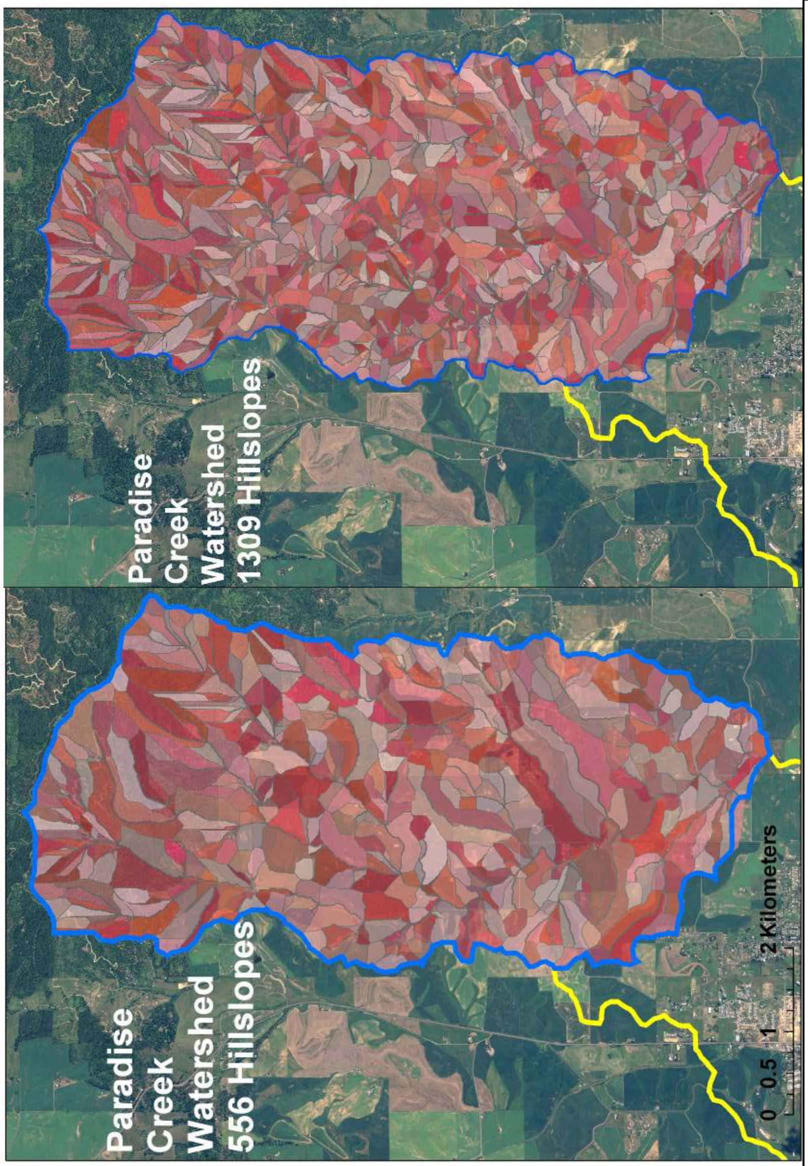

Figure 8 Paradise Creek watershed GeoWEPP generated Hillslopes.

A Climate file for the WEPP simulation was created manually with locally observed 15-minute precipitation data, minimum and maximum temperatures, wind speed and direction, and observed solar radiation (Appendix A). Storm duration and time to storm peak was derived from 15-minute precipitation data. The soil files for the WEPP model were created using the soils database in the WEPP model, with the addition of an anisotropy ratio and the hydraulic conductivity for the restrictive layer. Nineteen soil files for each soil type were created to account for multiple OFEs (Appendix A).

An MsDOS batch file was created to run the WEPP model (Appendix A). The WEPP model was run in single hillslope mode for every hillslope in the watershed. Each hillslope therefore had its own run file to call the corresponding slope file, soil file, management file as well as the climate file. The batch file contained a list of the run files used for each hillslope.

Model Output:

Output from the WEPP model (the water balance files as well as the loss files) was combined with extensive Perl scripting files using the stream structure file created by the GeoWEPP program (Appendix B). Channel processes were excluded from the model as only the hillslope version of the model was used. No channel processes were included in this study. Hydrographs were generated at the watershed outlet and at the eight monitoring stations (Figure 6) representing nested watershed comparisons.

Several different scenarios were used in the modeling of Paradise Creek watershed. Evaluation of the effect of hillslope size on streamflow generation was completed by comparison of hydrographs from the watershed using 556 hillslopes and 1309 hillslopes. To evaluate the effect of adding multiple OFEs, the model was run using one OFE, and multiple OFEs, based on breakpoints in GeoWEPP generated slope files.

Evaluation of the model was accomplished by comparing the predicted hydrographs with the measured hydrographs from eight monitoring stations, corresponding to nested watersheds, as well as at the watershed outlet at MS-D. Nash-Sutcliff coefficients were computed for each nested watershed to determine the accuracy of the predicted hydrographs (Nash and Sutcliffe, 1970).

RESULTS AND DISCUSSION

Hillslope validation

Prediction of hillslope drainage with the WEPP model compared well to measured data. Cumulative drainage from Hewlett and Hibbert (1963) was 1.26 m^3 with 76% draining during the first 5 days, 19% during days 6 to 50, and the remainder after 50 days. WEPP predicted 1.22 m^3 of drained water over 24 days with 81.2% occurring during the first five days, and 18.8% draining during the following 19 days. Discharge and cumulative drainage predicted with the Soil Moisture Routing Model compared reasonably well with the measured data (Figures 9 and 10). Initial values for drainage from the WEPP model are not shown as the WEPP model operates on a daily time step, therefore, predicted discharge from the first 1440 minutes are not available.

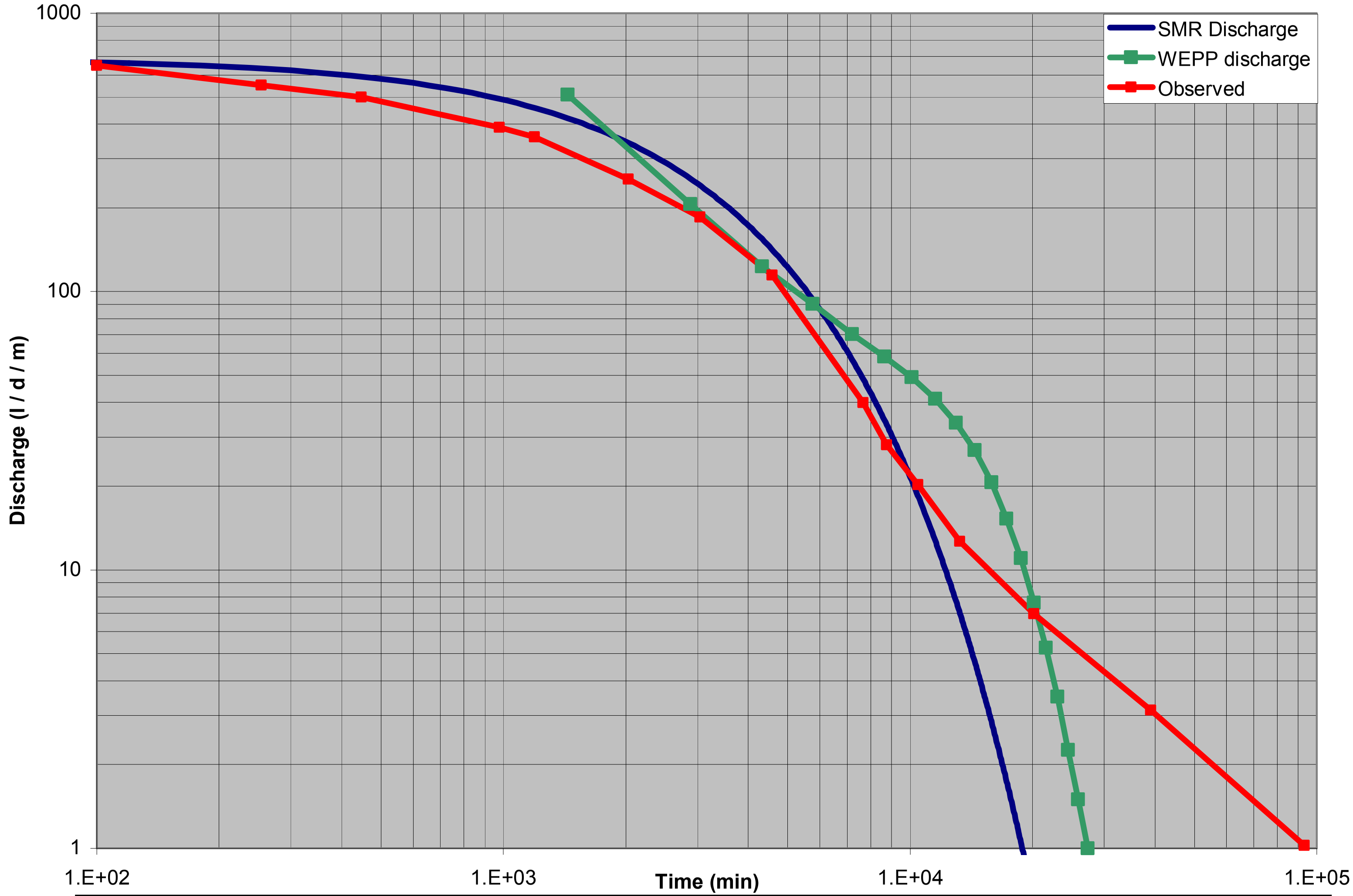

Figure 9 Hillslope plot discharge (liters/day/meter)

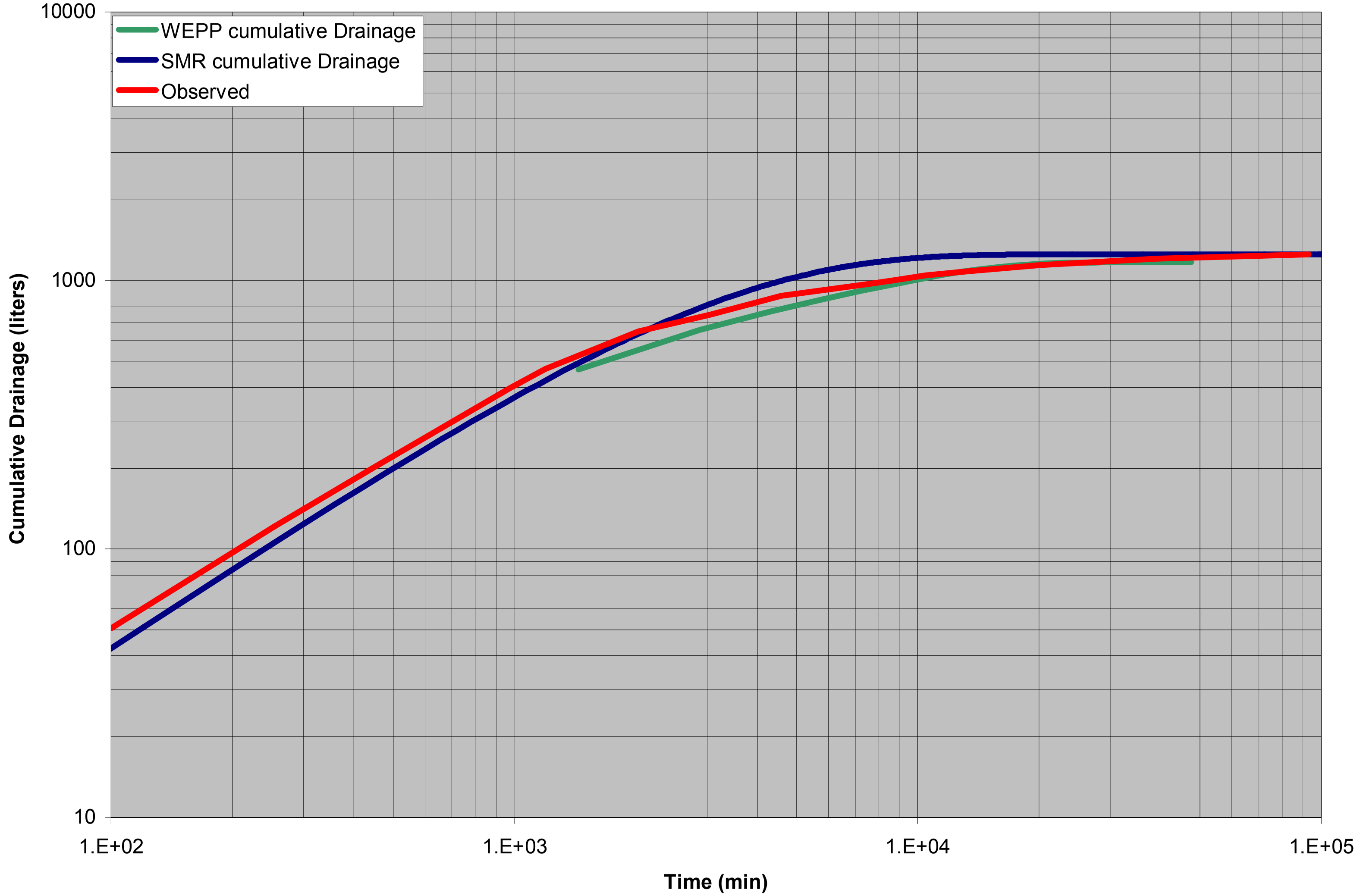

Figure 10 Hillslope plot cumulative drainage (liters).

Effects of Multiple OFEs

WEPP output of runoff, sub-surface lateral flow, evapotranspiration, and runoff re-infiltration along the length of the hillslope showed the effect of spatial variability when multiple OFEs were used. The comparison of a single OFE and multiple OFEs is illustrated using five slop configurations: toe slope (a steep section that abrubtly transitions to a flat section), convex slope, concave slope, shelf slope (two consecutive toe slopes), and a clay knob (a convex slope with low impermeable material on the upper portion of the hillslope).

Toe slope:

Runoff distribution is greatly influenced by the number of OFEs. Runoff generated from one OFE and 19 OFEs on a toe slope is shown in Figure 11. Total runoff from a hillslope is minimally affected by the number of OFEs. Differences in annual streamflow over an 8-year period for 19 OFEs vs. one OFE totaled 0.64% per year. Streamflow in this model is defined as the output of sub-surface lateral flow and surface runoff at the end of the last OFE. Distribution of runoff on the hillslope, however, is greatly affected by the use of multiple OFEs. Using the WEPP model with only one OFE forces the model to compute sub-surface lateral flow using an average slope. Use of an average slope eliminates slope changes, and therefore produces a uniform distribution of runoff and sub-surface lateral flow over the entire hillslope (Figure 12). Use of multiple OFEs allows the changes in slope to influence the runoff generation as well as sub-surface lateral flow. Transition from a steep slope to a shallow slope causes sub-surface lateral flow to become surface runoff, as the sub-surface lateral flow gradient of the shallower downhill slope is less than that of the steeper slope. This transition from sub-surface lateral flow to surface flow is evident when comparing lateral flow to surface flow. Small changes in slope also produced variation in surface runoff as shown in Figure 11 at slope distance 50 meters. Reducing the slope from 15% to 10% caused an increase in runoff, as the subsurface lateral flow is converted to surface runoff. This convergence of sub-surface lateral flow allowed the model to accommodate saturation excess hydrology because the runoff and sub-surface lateral flow interact as a function of moisture content of the soil at the location of the slope change. This changing moisture content caused shrinking and swelling of saturated areas as the moisture content changed over time. With single OFE simulations the entire hillslope was given the same moisture content, therefore the hillslope was either at field capacity, allowing sub-surface lateral flow, or below field capacity which did not allow sub-surface lateral flow.

Accurate spatial distribution of runoff at the hillslope scale is important, as erosion computations are dependent on the amount of runoff generated as well as the location of runoff on the hillslope. Soils in areas with saturation excess generated runoff can have greatly increased erodibility (Rockwell, 2002). Erosion can increase by an order of magnitude at a seepage face due to the interaction of shear stress on pore water content (Rockwell, 2002).

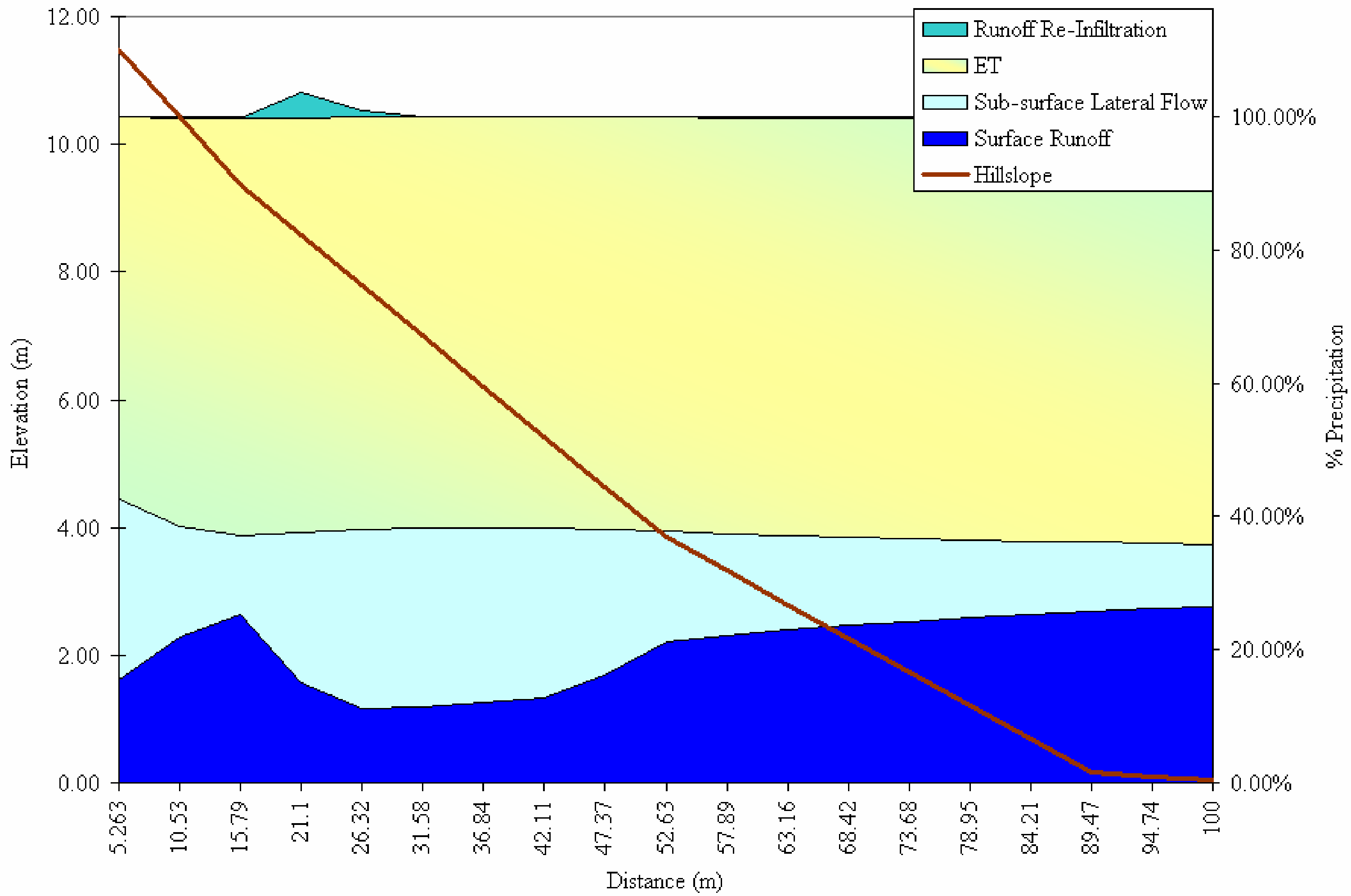

Figure 11 Eight year average distribution of runoff, sub-surface lateral flow, evapotranspiration, and runoff re-infiltration on along a toe slope using 19 OFEs in WEPP.

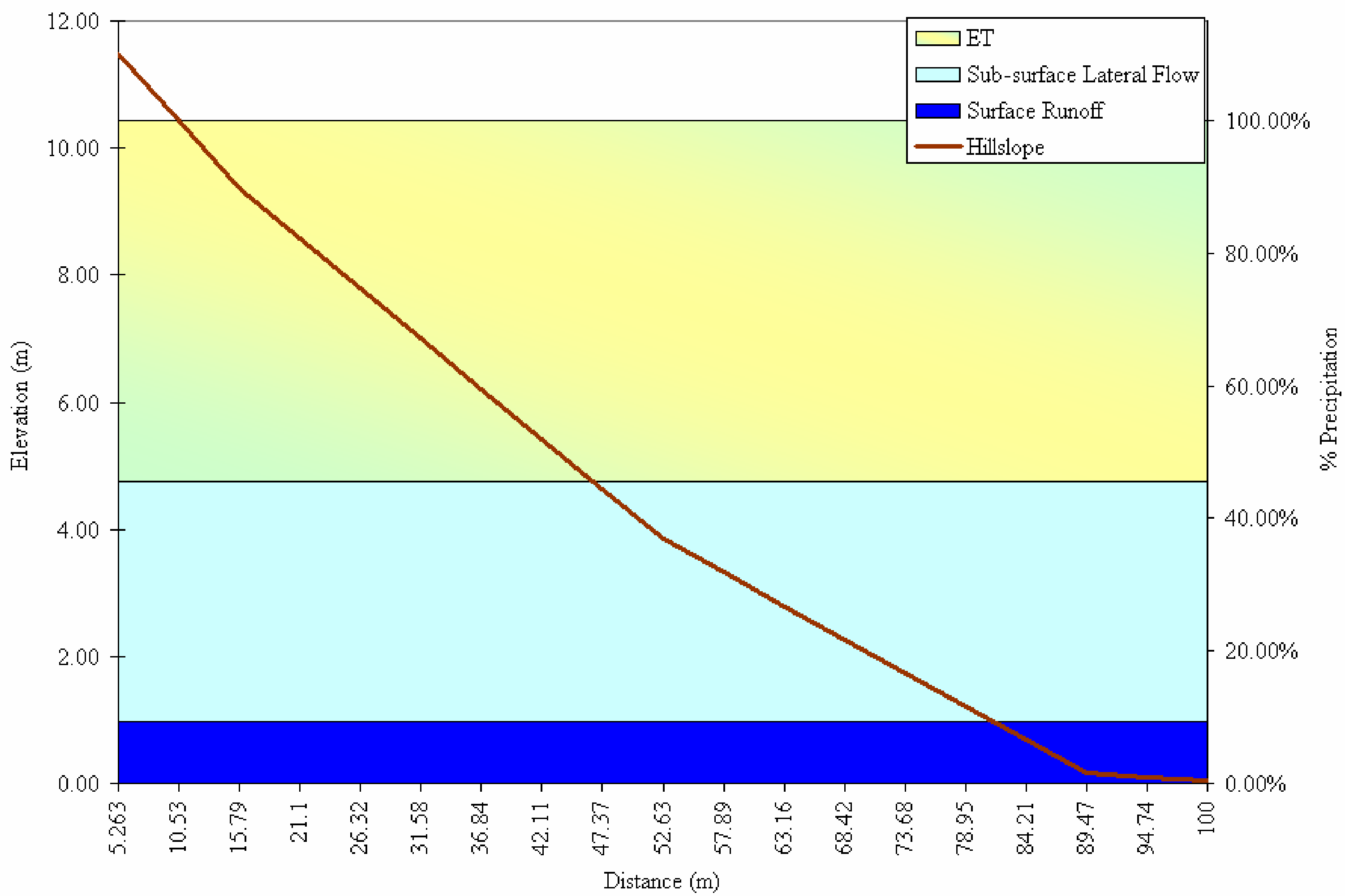

Figure 12 Toe Slope. Eight year average distribution of runoff, sub-surface lateral flow, and evapotranspiration on along a toe slope using one OFE in WEPP.

Convex slope:

Modeling a convex slope configuration shows surface and sub-surface flow interactions occur at multiple locations on the slope when multiple OFEs are used (Figure 13). Flat slopes at the top of a convex hillslope decreased lateral flow gradients, producing an increase in surface runoff. As the slope begins to increase, lateral flow increased and surface runoff generated upslope re-infiltrated into the soil. Re-infiltration is shown in Figure 12 occurring at 21.1 m. As the slope increases, lateral flow converged at the base of the slope to form surface runoff. Runoff at the base of the slope also increased because the soils at the base of the slope remained saturated for a greater portion of the year. Any rain falling on saturated soils immediately became surface runoff as it could not infiltrate.

The simulation using a single OFE on the same convex slope shows the impact of additional OFEs on lateral flow convergence (Figure 14). Total surface runoff exiting the convex hillslope with one OFE was 22.95% of the total precipitation, compared to 9.75% with multiple OFEs. Total flow, sub-surface lateral flow and runoff combined, varied only by 2.49% or 0.31% per year.

Spatial variability of evapotranspiration (ET) can also be predicted by the use of multiple OFEs. Figure 13 shows the variation of ET over the length of the hillslope. ET was lower at the top of the slope as the available water was reduced due to drainage to downslope OFEs.

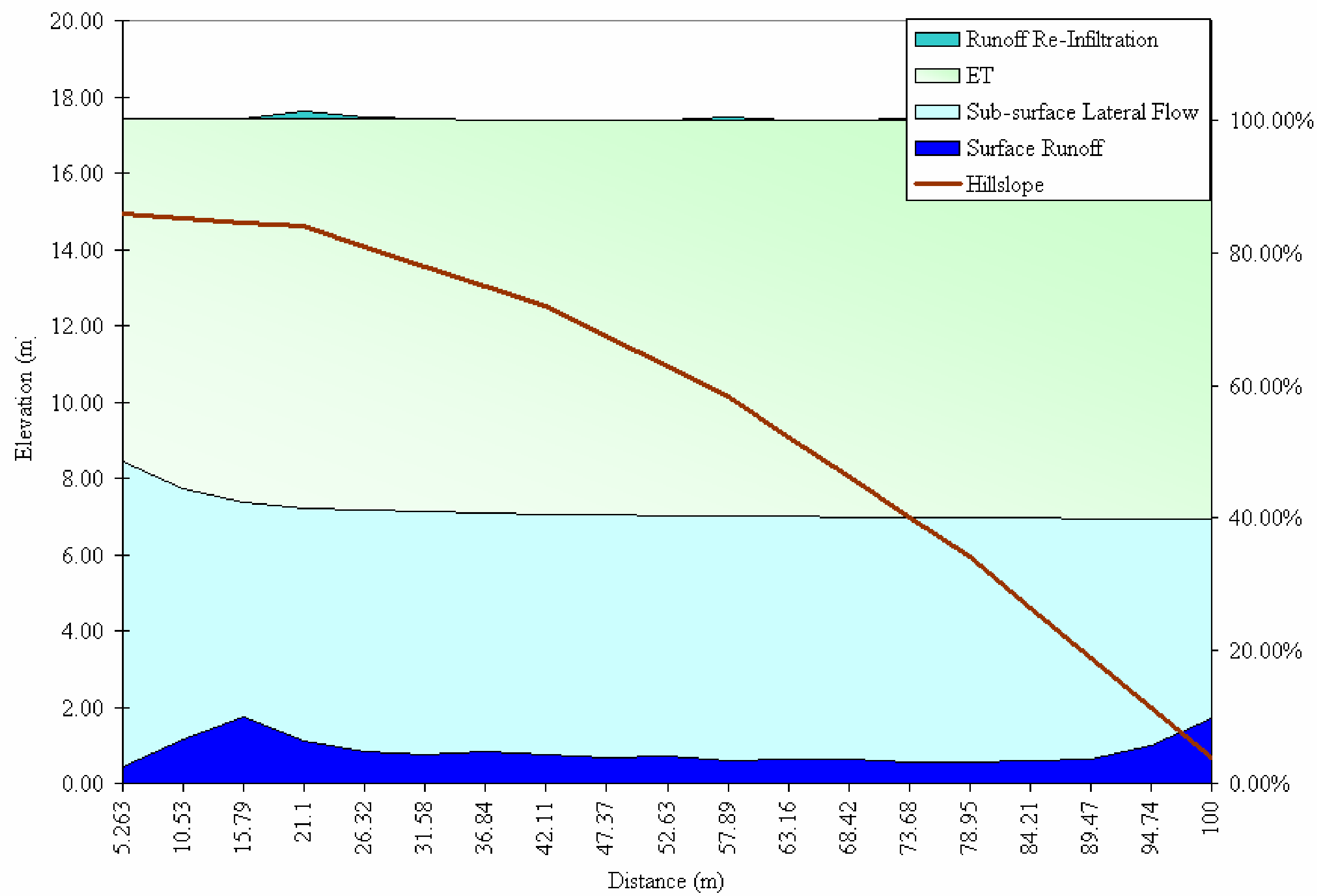

Figure 13 Eight year average distribution of runoff, Sub-surface lateral flow, evapotranspiration, and runoff re-infiltration on a convex hillslope using 19 OFEs in WEPP.

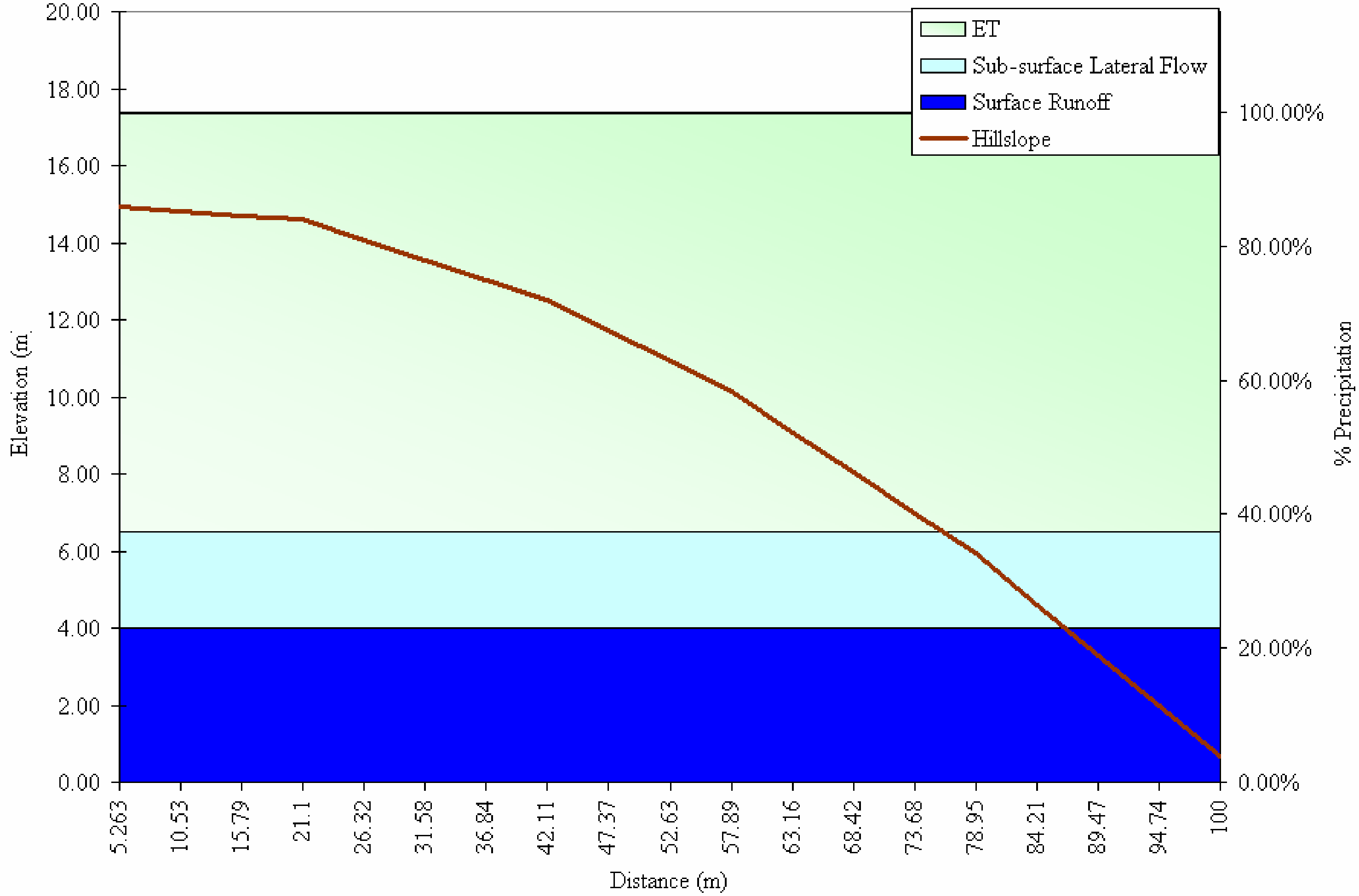

Figure 14 Eight year average distribution of runoff, Sub-surface lateral flow, and evapotranspiration on a convex hillslope using one OFE in WEPP.

Concave slope:

Simulation of a concave slope demonstrates the convergence of sub-surface lateral flow generating surface runoff. Sub-surface lateral flow decreased down the length of the hillslope due to the decrease in the gradient caused by the change in land slope (Figure 15). Sub-surface lateral flow also decreased down the hillslope due to the conversion of sub-surface lateral flow to surface runoff. Shallow slopes at the base of the hillslope also contributed to the increase in surface runoff. Low sub-surface lateral flow gradients caused the sub-surface lateral inflow from the upstream OFEs to be greater than the capacity of the lower OFE, causing conversion of sub-surface lateral flow to surface runoff.

Single OFE results for the concave hillslope configuration show greatly increased runoff at the top of the slope, however; surface runoff from the end of the hillslope was 44% less than that of the multiple OFE simulation (Figure 16). Increase in surface runoff at the top of the slope is due to decreased lateral flow gradient, from single OFE averaged slope values, effectively slowing down the sub-surface lateral transport of water on the top of the hillslope. Decreased surface runoff at the end of the hillslope was caused by the lack of convergence of lateral flow at the base of the hillslope. Total streamflow exiting the concave hillslope with one OFE was 44.04% of the total precipitation, compared to 40.68% with multiple OFEs. Lateral flow exiting the hillslope from the single OFE simulation is 32.23% of the total precipitation, whereas the sub-surface lateral flow exiting the multiple OFE hillslope is 19.55%. In the concave hillslope profile one OFE decreased overall surface runoff and streamflow when compared to multiple OFEs.

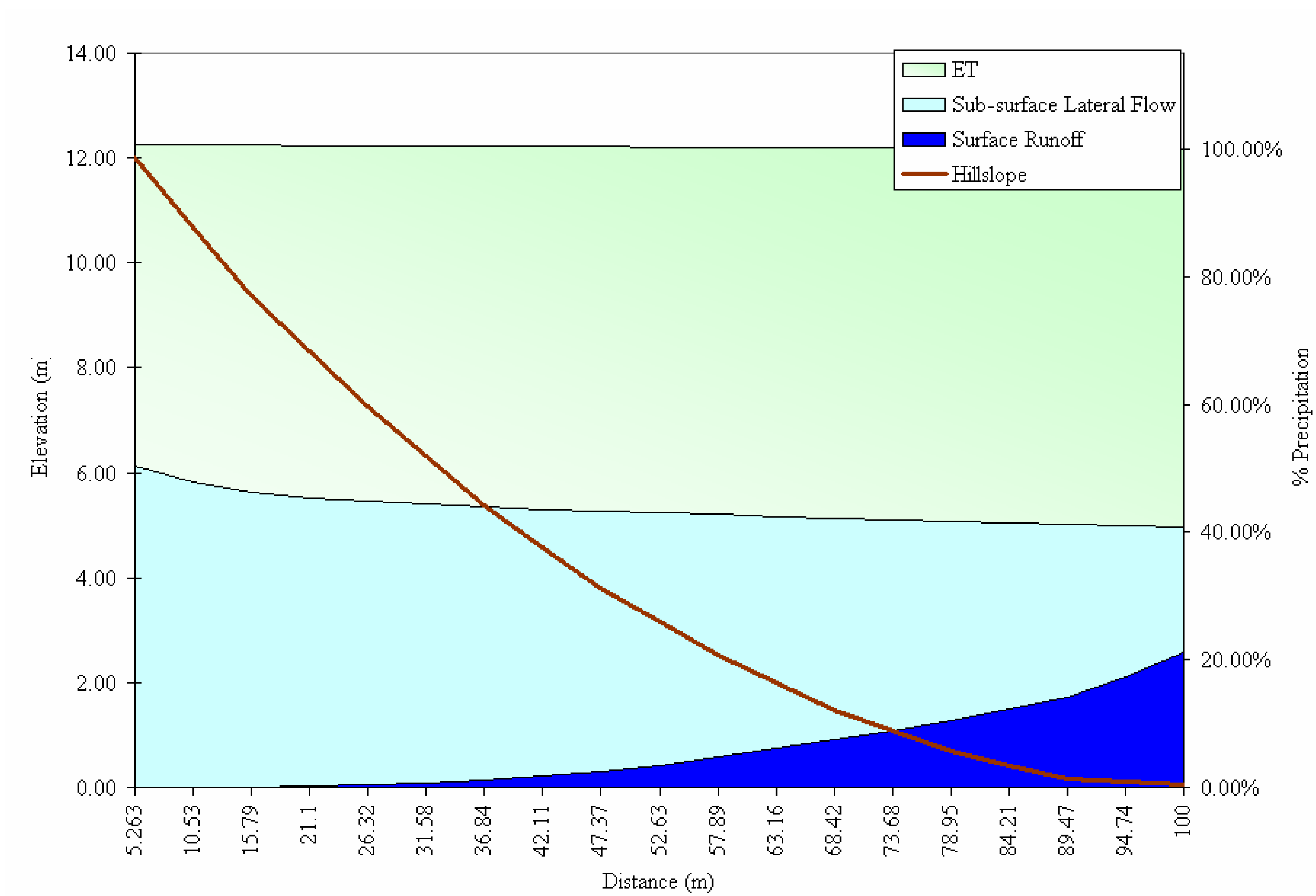

Figure 15 Eight year average distribution of runoff, sub-surface lateral flow, evapotranspiration, and runoff re-infiltration on a concave hillslope using 19 OFEs in WEPP.

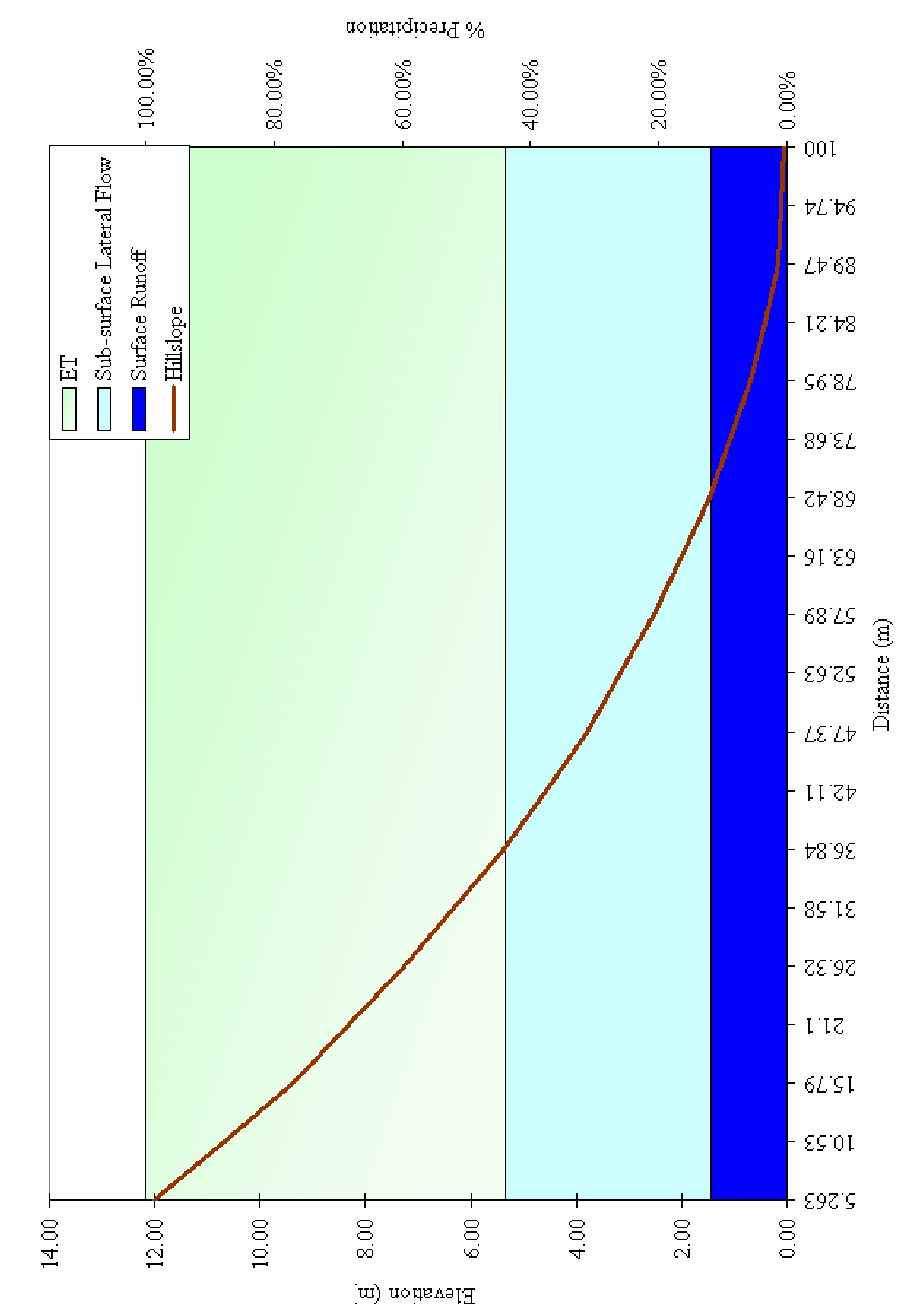

Figure 16 Eight year average distribution of runoff, sub-surface lateral flow, and evapotranspiration on a concave hillslope using one OFE in WEPP.

Shelf slope:

Runoff distribution on a shelf slope (Figure 17) was simulated with a 100 m slope transitioning from 10% to 0.1% then 10% to 0.1%. Distribution of surface runoff, lateral flow and ET is shown in Figure 17. Runoff increased at 21 m at the first transition from 10% to 0.1%. Runoff also increased at 68.4 m where sub-surface lateral flow was converted to surface runoff. Re-infiltration of surface runoff occurred at the transition from 0.1% to 10% as the increased sub-surface lateral flow gradient increased the sub-surface lateral flow capacity. Sub-surface lateral flow decreased sharply in correspondence to the change in slope from 10% to 0.1%. Water exiting the hillslope totaled 35.7% of total precipitation, with 0.22 % resulting from direct sub-surface lateral flow input.

Single OFE simulation of the 10% to 0.1% to10% to 0.1% hillslope configuration (Figure 18) resulted in a dramatic increase in sub-surface lateral flow. Lateral flow exiting the slope totaled 52.5% of the total precipitation. Surface runoff from the slope, however, was 7.9% of precipitation. Total water entering the stream amounted to 60.5% of precipitation, leaving only 39.7% for ET. Sub-surface lateral flow leaving the hillslope with a toe slope of 0.1% was greatly overestimated as the averaged slope is much greater than the 0.1% slope at the base of the hillslope. Sub-surface lateral flow contribution to streamflow in the simulation with one OFE was 233% greater than the sub-surface lateral flow contribution to streamflow from the 19 OFE simulation (Figure 18). Surface Runoff with 19 OFEs resulted in a contribution of 34.49% to streamflow; single OFE surface runoff contributed 7.96% of precipitation to streamflow. The increase in surface runoff from the multiple OFE simulation is due to the convergence of lateral flow at the transition zones from 10% slope to 0.1% slope. ET distribution is also shown for both the single OFE simulation and the 19 OFE simulation. Average ET with the multiple OFE simulation was 60.66% whereas the average ET from the single OFE was 39.76%. Distribution of ET for the multiple OFE simulation is shown in Figure 17. ET decreased at the top of the slope as water was transported both from surface runoff and sub-surface lateral flow. A slight increase in ET occurred at the transition zone from 0.1% to 10% as re-infiltrated surface runoff added moisture to the soil profile. This increase in ET was counter affected by the increase in lateral flow gradient on the 10% section.

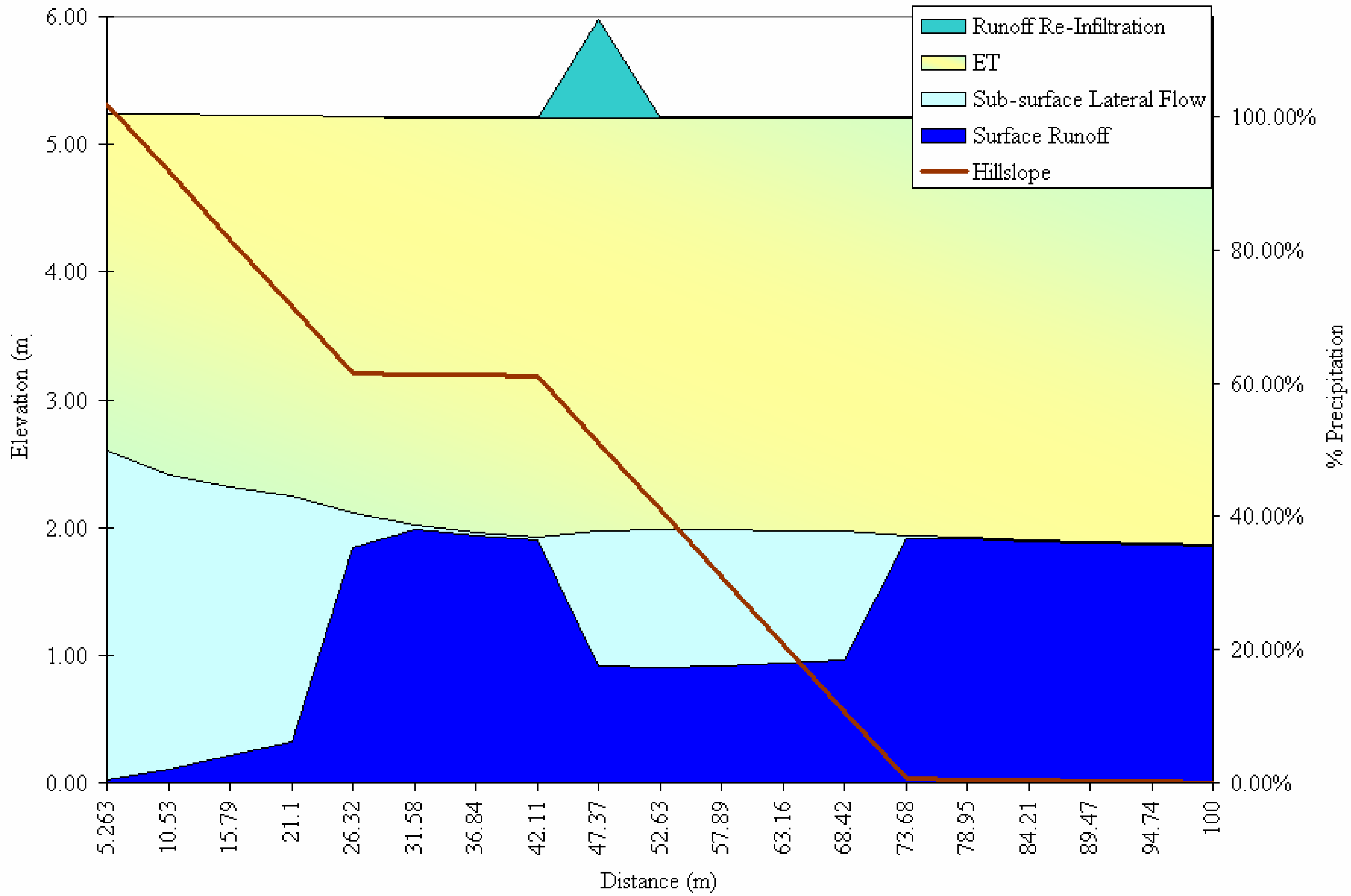

Figure 17 Shelf Slope Eight year average distribution of runoff, Sub-surface lateral flow, evapotranspiration, and runoff re-infiltration on a hillslope with 19 OFEs.

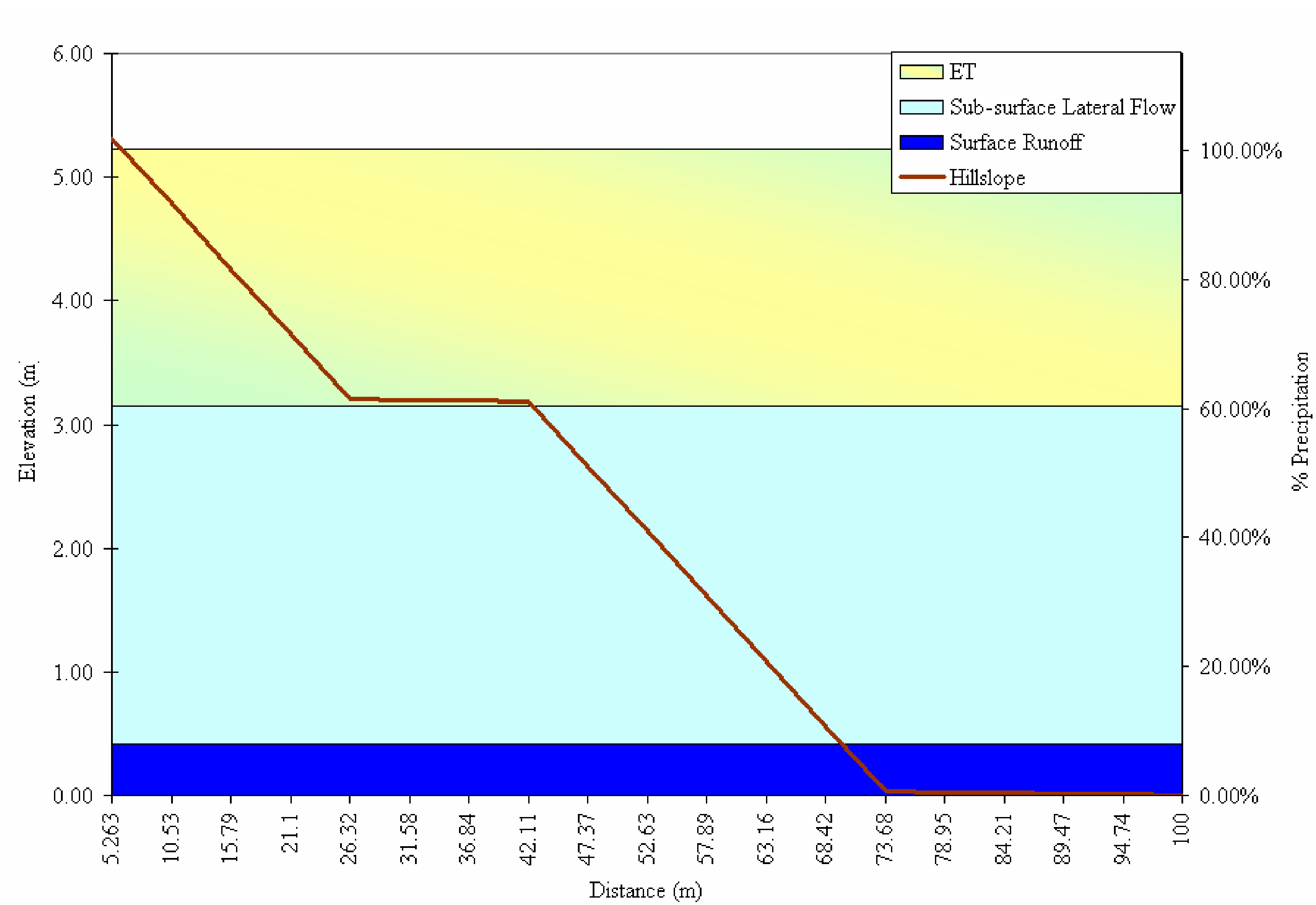

Figure 18 Eight year average runoff and lateral flow distribution on a shelf slope using one OFE in WEPP. Slope 10% to 0.1% to 10% to 0.1%.

Clay knob:

Multiple OFEs allowed the simulation of a hillslope with a partially restrictive layer present. Single OFE simulations could not account for the presence of a partial restrictive layer because only a single soil file is allowed on each OFE. To model a partial restrictive layer on a hillslope with a single OFE, the entire hillslope had to be classified as restrictive. In the clay knob simulation a shallow Southwick silt loam soil was placed on the top four OFEs of the convex hillslope with deep Palouse silt loam soils on OFEs 5 through 19 (Figure 19).

Runoff distribution during the Clay knob simulation shows the majority of the runoff was generated at the top of the slope where the restrictive layer is present. Runoff was generated due to the low lateral gradient and the presence of the restrictive soil layer. As the sub-surface lateral flow gradient was low, water added to the soil through precipitation could not flow laterally quickly, therefore surface runoff was generated. Surface runoff is re-infiltrated within 15 m downslope of the 4th OFE where the restrictive layer ends (Figure 19) as the sub-surface lateral flow gradient increased. Deep percolation occurred on this hillslope because OFEs 5 through 19 contain the deep Palouse silt soil. ET in the clay knob simulation averaged 64.85%. However, ET varied from 45% at the top of the hillslope with the shallow restrictive soil, to 75% at the bottom of the hillslope where sub-surface lateral flow from the upslope OFEs maintained a greater soil moisture content. Low ET at the top of the hillslope is due to the shallow soil, as well as the removal of water from the soil by sub-surface lateral flow and surface runoff.

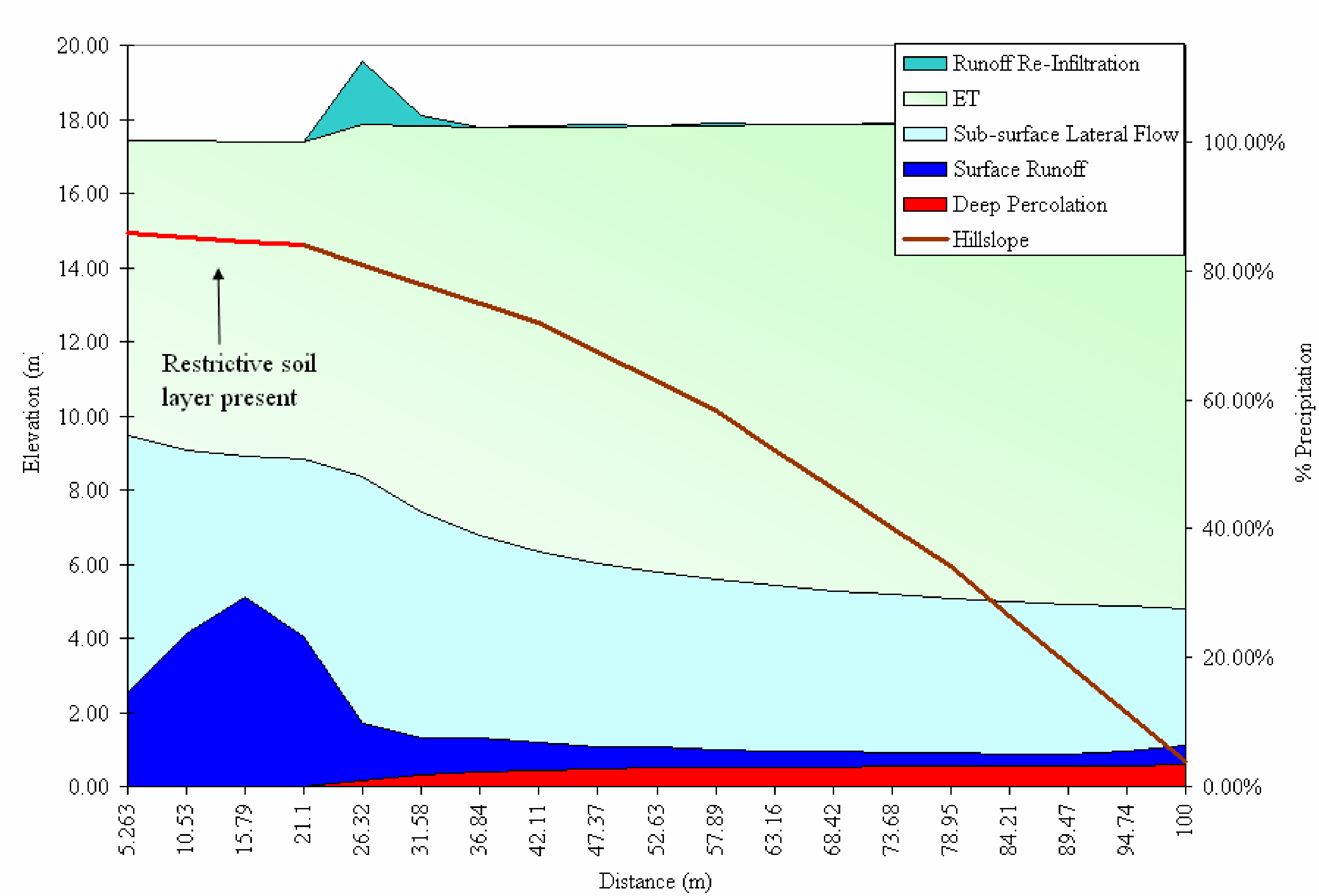

Figure 19 Eight year average distribution of runoff, Sub-surface lateral flow, evapotranspiration, deep percolation, and runoff re-infiltration on a hillslope with a clay knob using 19 OFEs in

Watershed Results

Application of the WEPP model to the Paradise Creek watershed yielded reasonable results when comparing observed and measured streamflow. Predicted and measured discharge for the period 2001 to 2006 for MS-D is shown in Figure 20,and for individual years in Figures 21 through 26. Nash-Sutcliffe coefficients ranged from 0.21 to -34.42, with R^2 values ranging from 0.1397 to 0.7697 (Table 3). WEPP consistently over-predicted streamflow with bias ranging from 16 to 91.

Table 3 Nash-Sutcliffe, R^2 and percent bias for observed and predicted daily discharge at MS-D for years 2001-2006.

Year	N.S	R^2	Bias
2001	-3.31	0.5135	21
2002	-0.55	0.1397	49
2003	-5.06	0.7697	62
2004	0.21	0.3907	16
2005	-34.42	0.6863	34
2006	-16.71	0.6397	91

Examination of errors in streamflow measurement was done for the worst Nash-Sutcliffe coefficient year, 2005. The errors discussed below apply to all years modeled, however, the extremely poor correlation with observed data in 2005 made that year ideal for error analysis. In Table 3, the low Nash-Sutcliffe coefficient in 2005 was likely due to rain on snow events and snowmelt timing in the WEPP model. A representative 100 m by 100 m hillslope with a 20% slope and a Southwick silt soil with a 20 year old forest management was modeled to analyze snow processes in WEPP. A representative hillslope was used because separate winter output files for each hillslope became increasingly large in long simulations with multiple OFEs.

In WEPP's winter output, snow depth on January 16th at 1:00 am was 47.36 mm with a density of 228.22 kg/m^3 (Figure 27). On hours 15 through 17 a total of 76.2 mm of additional snow was accumulated with a new density of 149.58 kg/m^3. The following day, January 17th an additional 15.24 mm of rain was added to the snowpack on hours 16-21. WEPP predicted that all of the rainfall added to the hillslope left as runoff. The density of the snow was not affected by the addition of this rainfall. On January 18th an additional 22.89 mm of rain was added to the snowpack, the density of the snow was not affected, and all of the rainfall added was immediately translated into runoff.

As a result of the lack of interaction of the rainfall with snow density (i.e., poor simulation of the snow dynamics in WEPP), runoff on days when rainfall was added to snowpack was dramatically over-predicted by the WEPP model. Every rain on snow event in WEPP produced runoff without affecting the density of the snowpack. Over-prediction of runoff on March 27, 2005 was partially because snow density did not change during a rain on snow event (Figure 28). During this event 25 mm of snow was present on the ground surface. Addition of 40.65 mm of rain over a 15 hour period had no effect on the density of the snow. All of the rainfall that fell on that day was considered available for surface runoff.

Over-prediction of the peak streamflow may also have been caused by the constant surface albedo of 0.5 for all snow surfaces in WEPP. Ranges of albedo in snow pack vary with the age of the snow surface, from 0.98 for fresh snow to 0.4 for old snow (Gray and Male, 1981). The lower the albedo of the snow, the greater the rate at which it melts. By arbitrarily assigning an albedo of 0.5 to snow, WEPP predicts that fresh snow will melt faster and old snow will melt slower than in actuality. Snow water equivalent for the year 2005 is shown in Figure 29. On January 21-22, 18 mm of snow water equivalent was converted to surface runoff.

A possible source of error in the simulations on Paradise Creek is that temperature change with elevation is neglected in the WEPP model. Slight decreases in temperature will effect the generation of snowfall during a storm. In the Paradise Creek watershed the headwaters often receive snow while the outlet receives rain. Separate weather files can be used to reduce this problem, however; with a large watershed delineation of separate climate files for different hillslopes is tedious and time very consuming. By not including elevation effects on temperature the model predicts rainfall in the higher elevations when in reality snowfall would be occurring.

Percolation routines in the WEPP version used in this study contain an adjustment for unsaturated hydraulic conductivity that is used when a discrete soil layer is not completely saturated. This adjusted hydraulic conductivity (Eq 5) causes a reduction in vertical water movement as the soil moisture content in the discrete soil layer was reduced. In turn, as moisture content in a soil layer was decreased, this entire layer was assigned a new hydraulic conductivity calculated using the exponential function in Equation 5, approaching zero as the field capacity of the soil was reached. The exponential decrease in hydraulic conductivity reduced vertical movement of water to the lower soil layers as soil moisture content approached field capacity. Sub-surface lateral flow continued, however, as it is being computed using the new linear adjusted hydraulic conductivity (Equations 6 and 7). By using the adjusted hydraulic conductivity with the linear relationship in Equation 7 for sub-surface lateral flow, the ratio of lateral flow to vertical percolation was dramatically increased.

Analysis of the decreased percolation showed the presence of a scaling effect in the outflow hydrographs. Increased percolation would cause a decrease in runoff and sub-surface lateral flow, as soil moisture would decrease. When a scaling factor of 3.5 was applied uniformly to the runoff from MS-D, the overall Nash-Sutcliffe coefficient for years 2001-2006 increased from -2.85 to 0.41. For year 2003 the Nash-Sutcliffe was increased from -5.06 to 0.77. Scaled Nash-Sutcliffe values are shown in Table 4. With uniform spatial reduction of the streamflow predicted discharge compare well to observed streamflow. By incorporating increased percolation with correct spatial distribution in the watershed, as an alternative to the uniform percolation simulated with the scaling factor, a better representation of streamflow would be achieved. The increase in deep percolation would provide the same decrease in streamflow as the scaling factor produced.

Table 4 Nash-Sutcliffe, R^2 and percent bias for observed and predicted daily discharge at MS-D for years 2001-2006, Modeled streamflow valued reduced by 28.3% .

Year	N.S	R^2	Bias
2001	0.50	0.5135	2
2002	0.36	0.1397	-21
2003	0.77	0.7697	2
2004	0.13	0.3907	-13
2005	-1.09	0.6863	8
2006	0.43	0.6397	4

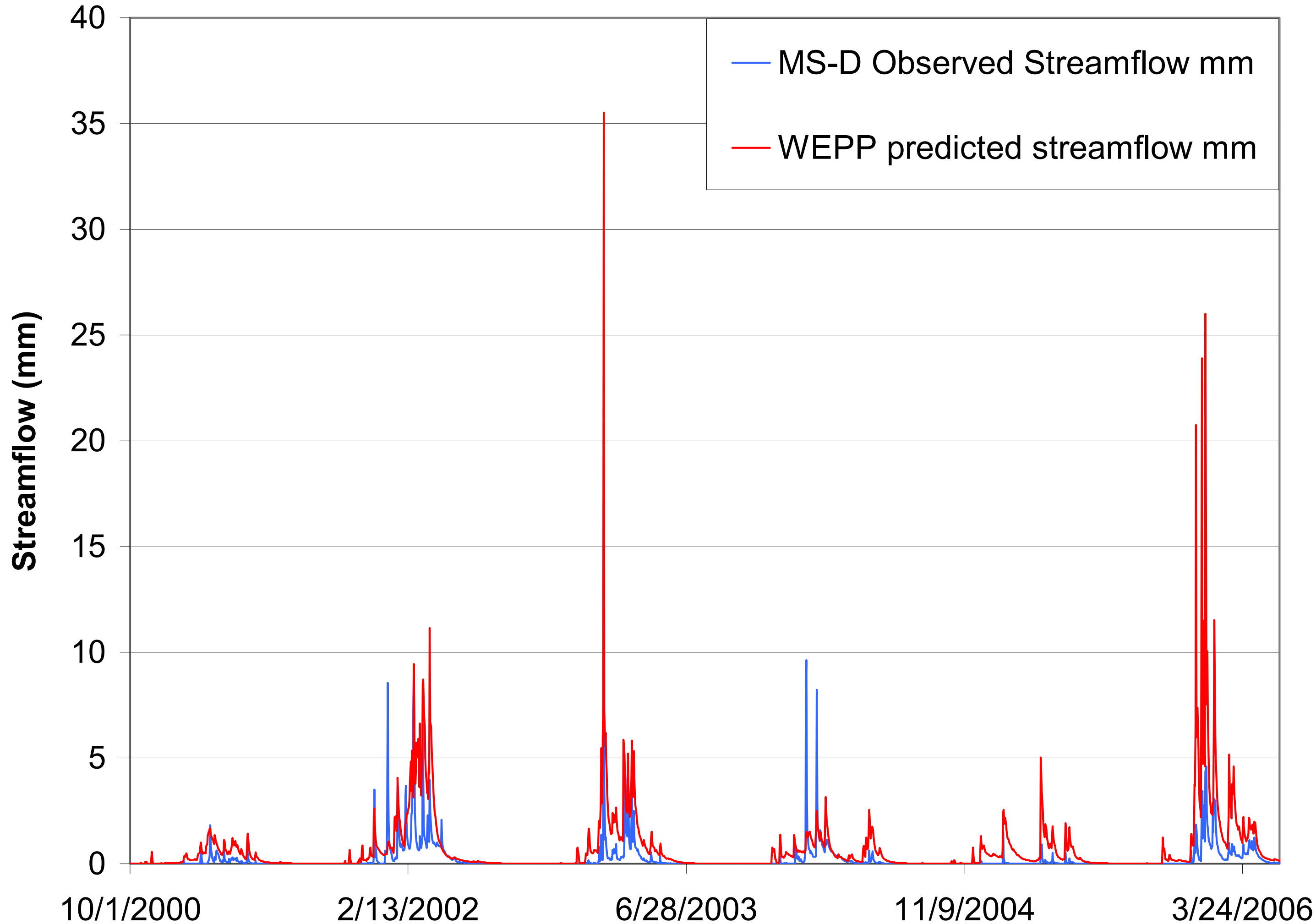

Figure 20 Predicted and observed discharge in mm for MS-D for years 2001 to 2006.

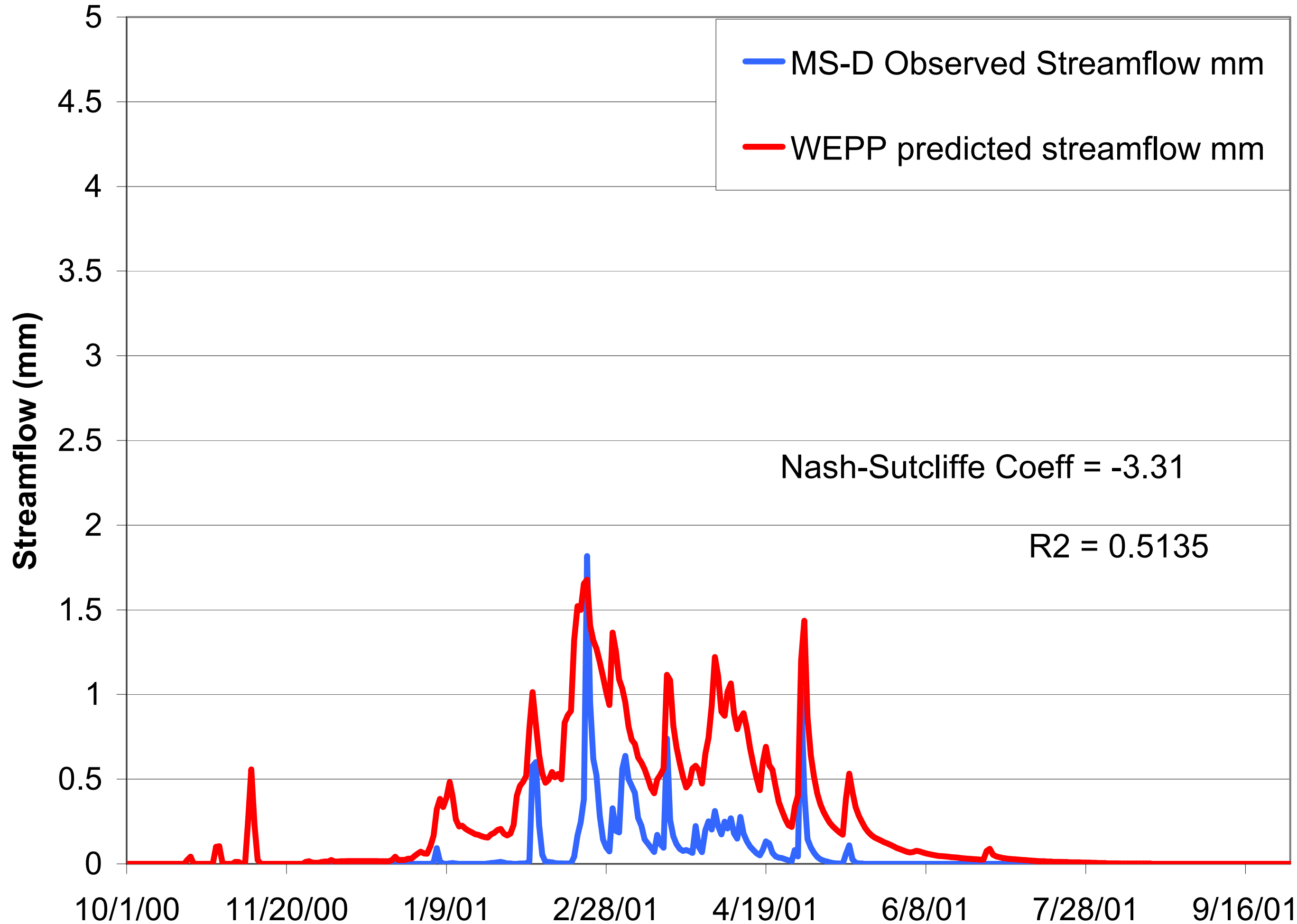

Figure 21 Predicted Streamflow and observed streamflow in mm for MD-D for year 2001.

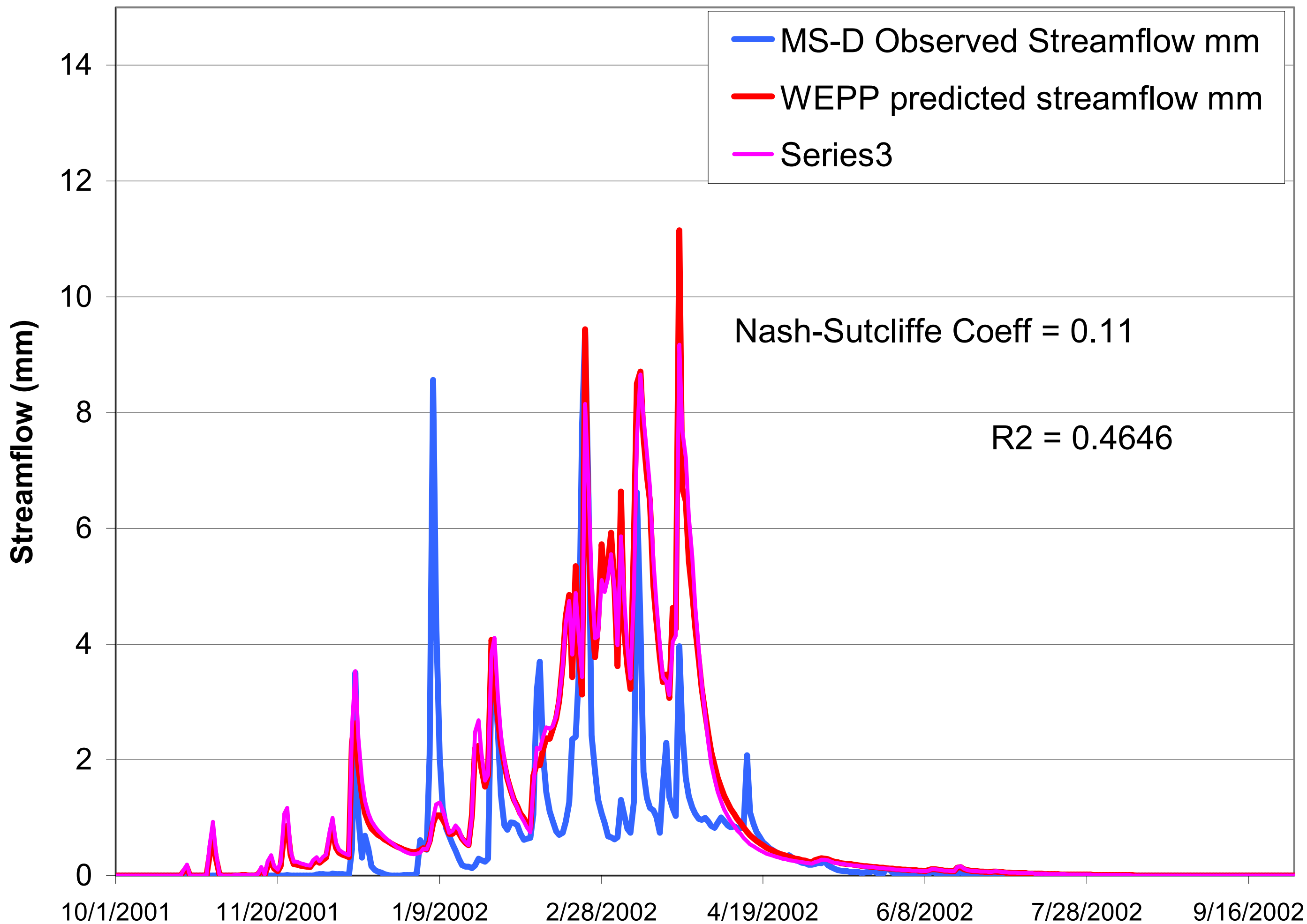

Figure 22 Predicted Streamflow and observed streamflow in mm for MD-D for year 2002.

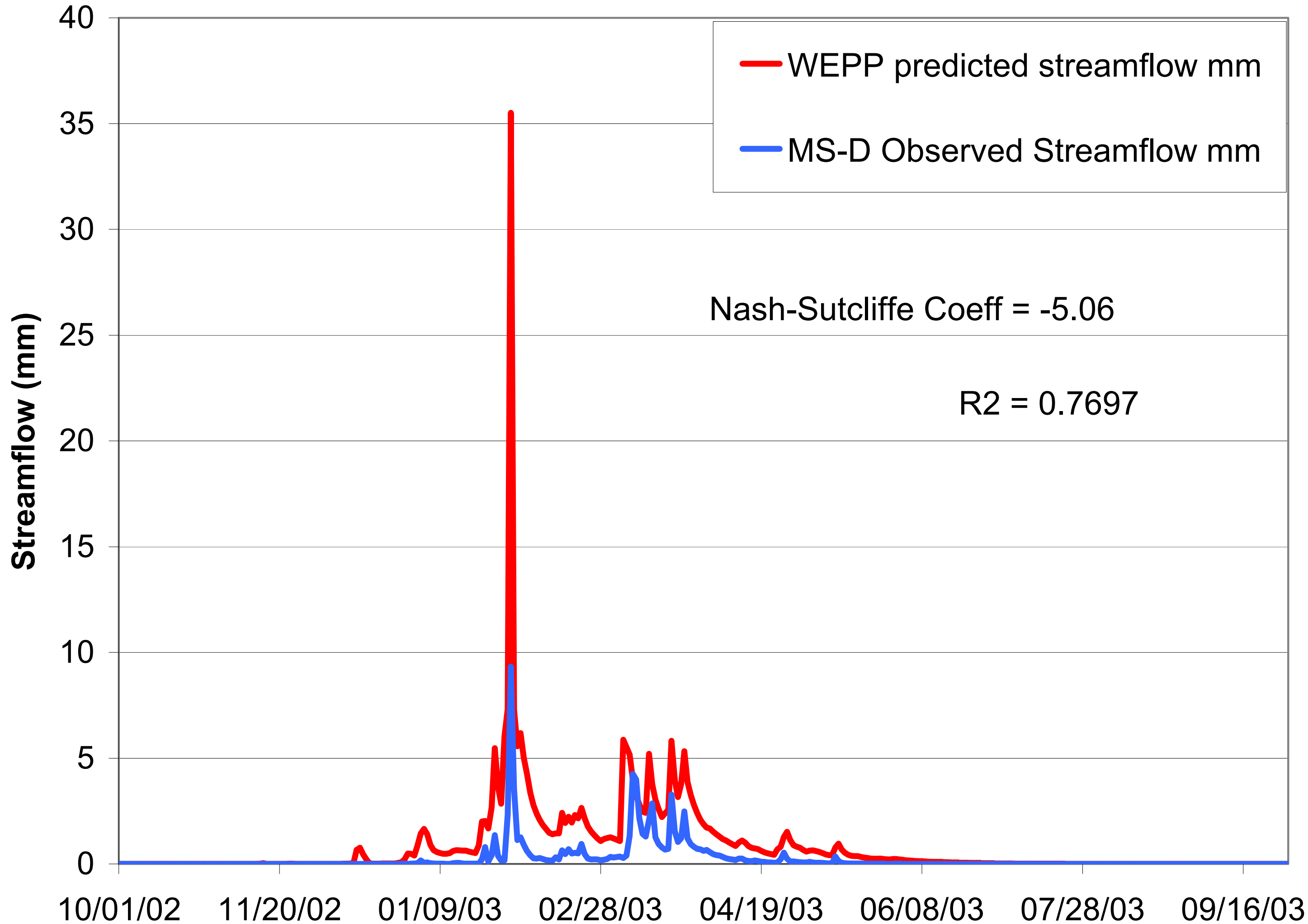

Figure 23 Predicted Streamflow and observed streamflow in mm for MD-D for year 2003.

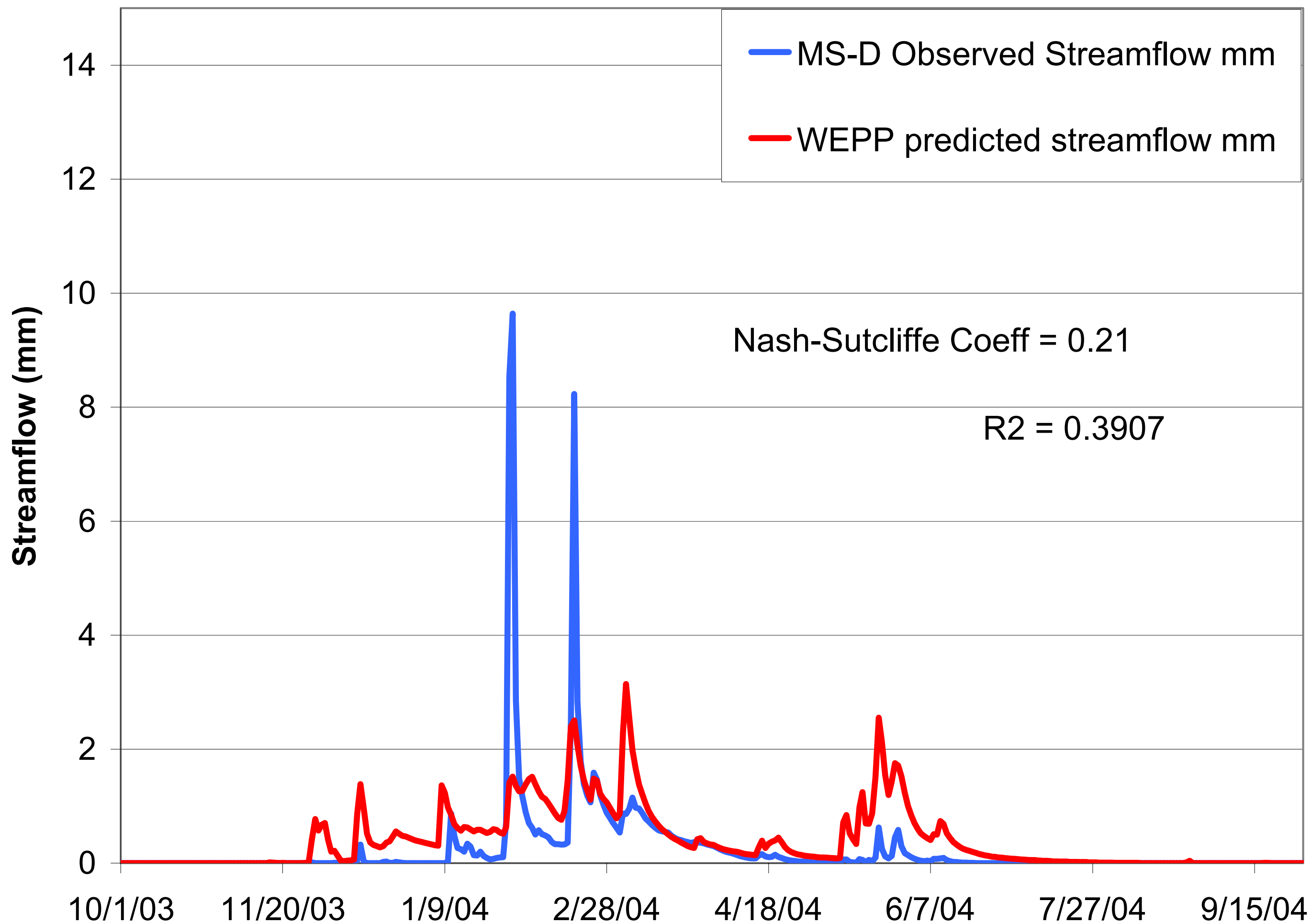

Figure 24 Predicted Streamflow and observed streamflow in mm for MD-D for year 2004.

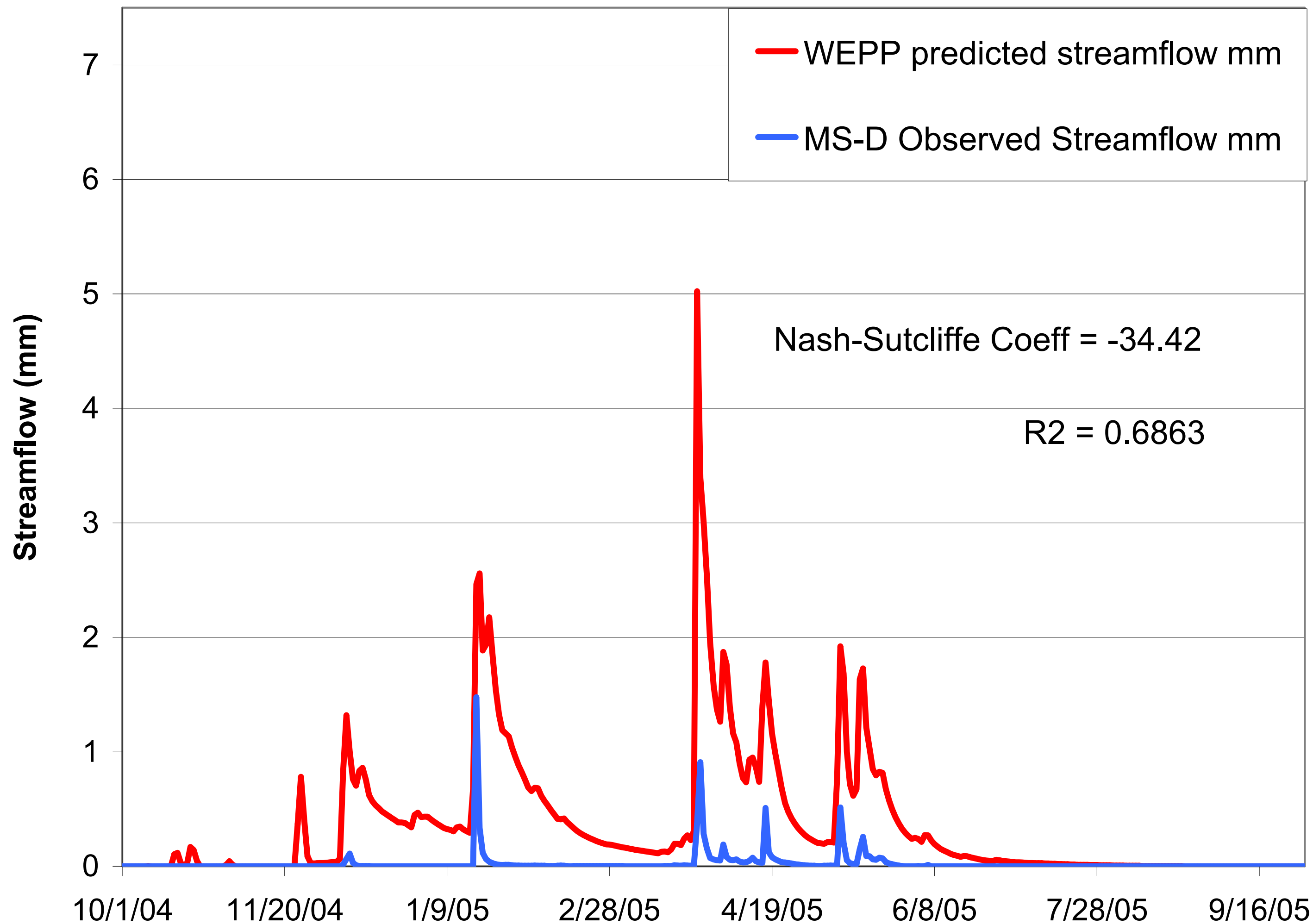

Figure 25 Predicted Streamflow and observed streamflow in mm for MD-D for year 2005.

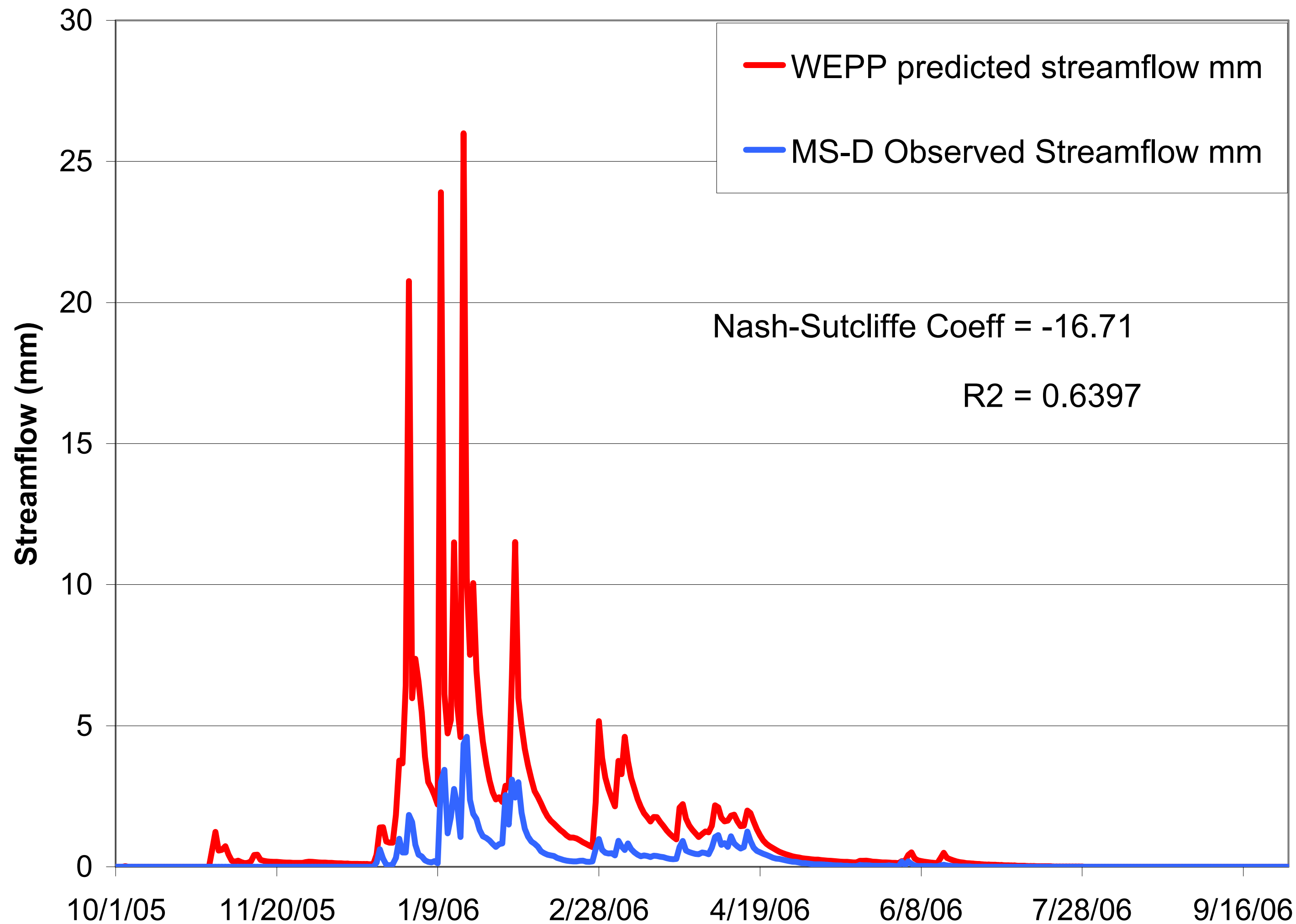

Figure 26 Predicted Streamflow and observed streamflow in mm for MD-D for year 2006.

Figure 27 WEPP predicted snow density, depth, and rainfall input for January 16-17, 2005.

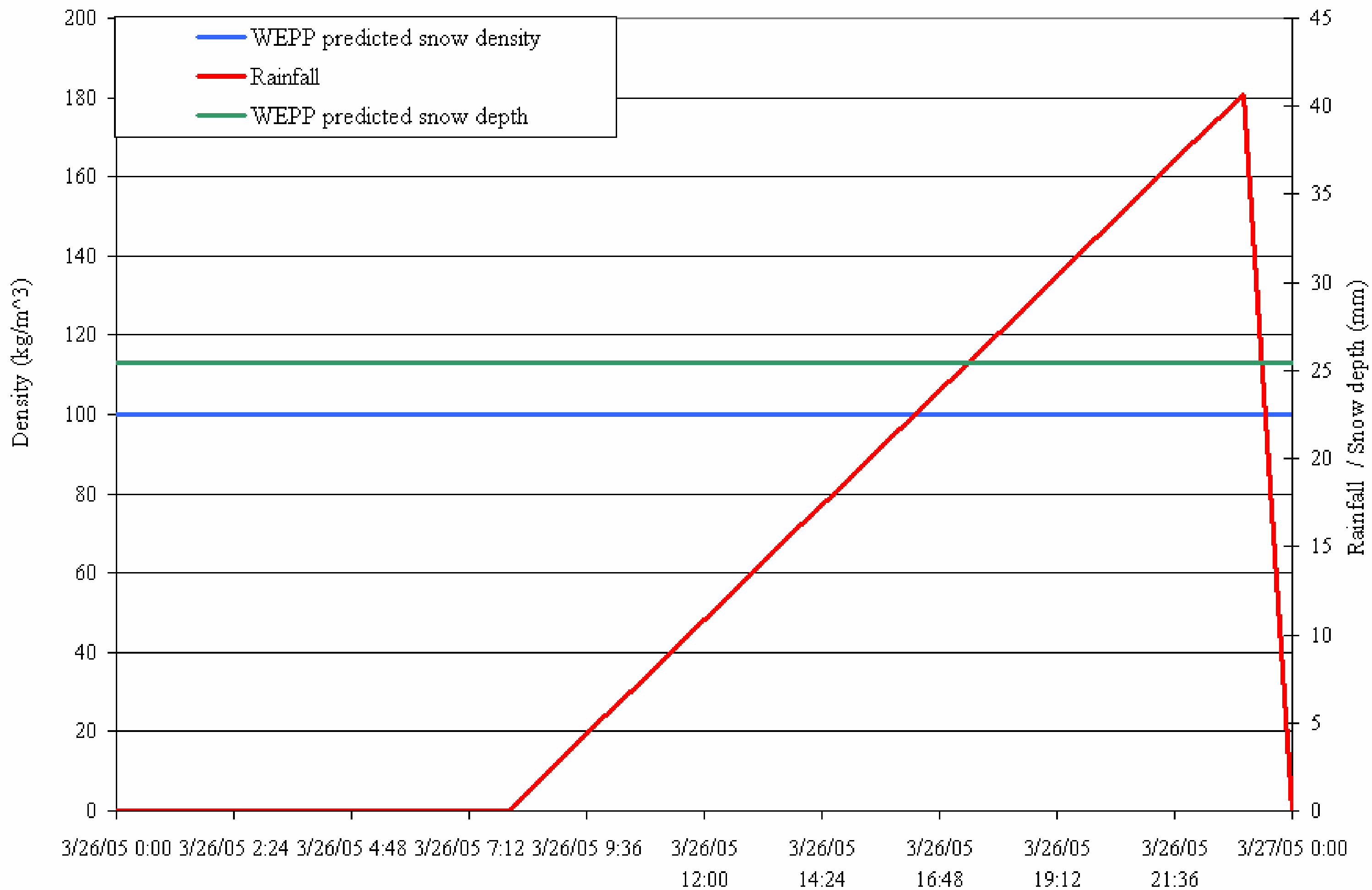

Figure 28 WEPP predicted snow density during addition of 40.65 mm of Rainfall over a period of 15 hours.

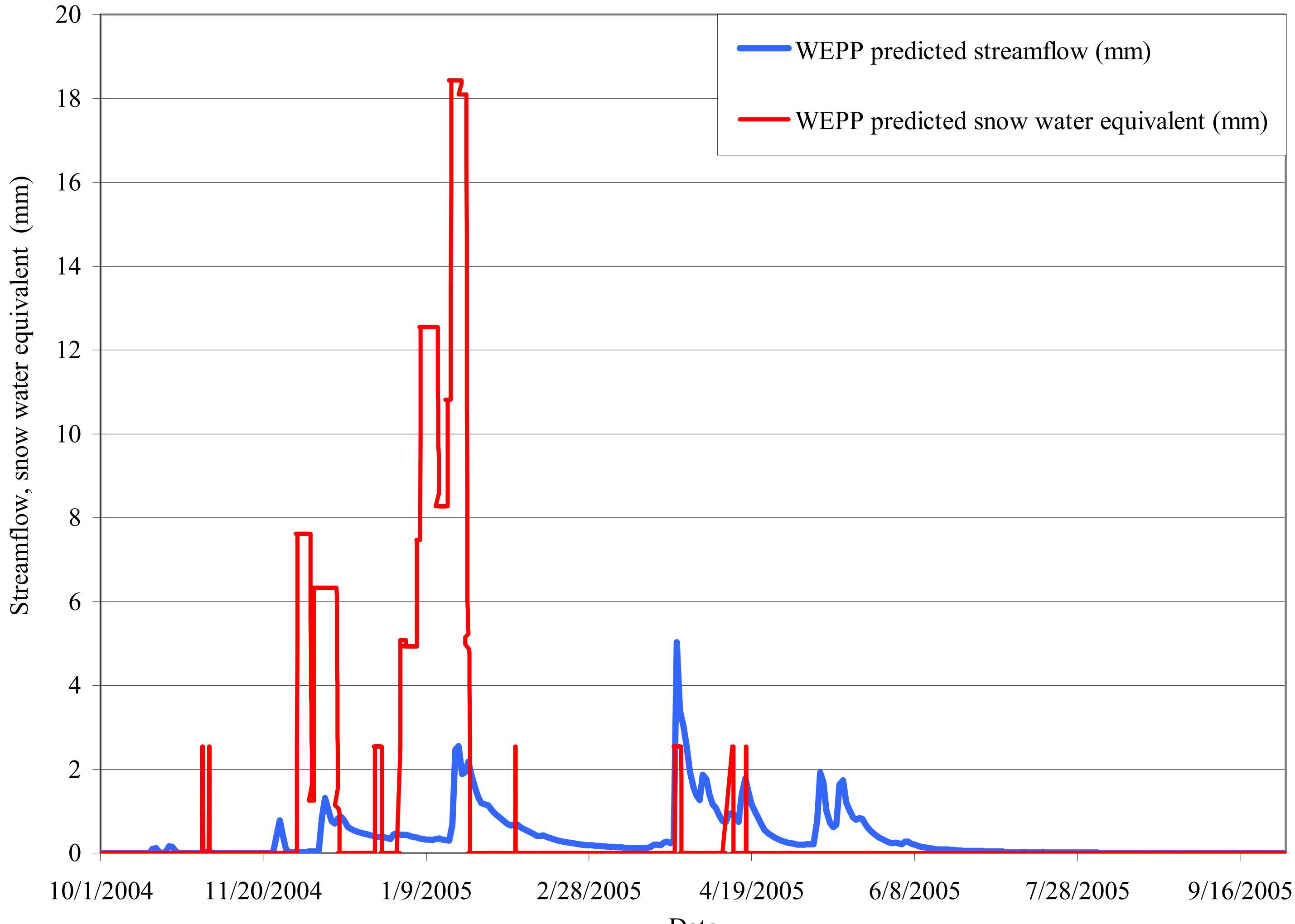

Figure 29 Representative hillslope snow water equivalent and predicted runoff in 2005.

Effect of decreased hillslope size:

Decreasing hillslope size by increasing the number of hillslopes from 556 to 1309 in Paradise Creek watershed had a very minimal effect on the streamflow produced by the WEPP model. Total streamflow decreased by 0.09% per year, while the magnitude of sub-surface lateral flow was increased and surface runoff decreased. The increase in sub-surface lateral flow in the 1309 hillslope simulation was minimal at 1.2% due to the shorter distance water had to travel to reach a stream channel. The shorter travel distance in smaller hillslopes allowed the soil to drain faster, therefore decreasing the soil moisture content and causing a decrease in surface runoff. Surface runoff n the 1309 hillslope simulation decreased by 5.3% per year. Surface runoff decreased due to reduced sub-surface drainage of water into the stream channels, and the effect of convergence of sub-surface lateral flow at toe slopes in the smaller hillslopes.

Decreasing the hillslope size also decreased the total area of the watershed because the stream channels are not accounted for when WEPP is run in single hillslope mode. Increase in channel area accounted for a total decrease in precipitation input of 1.21%. Positive effects of the reduction of the hillslope size include the reduced effect of convergence of flow over the width of the hillslope. By extending the channel network and reducing the hillslope size, a more detailed representation of the channel network is achieved.

Nested Watersheds

Streamflow comparisons in nested watersheds show the same trends as those observed at the outlet of the agricultural watershed, MS-D. Results from the 8 nested watersheds are located in Figures 30-37. Peaks were overestimated in the nested watersheds due to rain on snow events as described above. Nash-Sutcliffe coefficients were all negative with only MS-6a showing a high R^2 value (Table 5). Results from all nested watersheds were better than the entire watershed for the year 2006. The results from MS-3 and MS-6a were poor because these watersheds are comprised mainly of forested areas. In forested areas, decreased percolation from the adjusted hydraulic conductivity function in the percolation routine causes the lateral flow to increase as the available water for lateral flow is greater. Increased peaks in streamflow predicted by the model also correspond to rain on snow events. Due to the lack of interaction of rain on snow density, all the rain that fell on the snow pack was considered runoff. Snowmelt on new snow also occurred rapidly as the WEPP model used the constant 0.5 albedo for snowpacks.

Table 5 Observed and Predicted daily Nash-Sutcliffe, R2 and percent bias for nested watershed in Paradise Creek for the year 2006.

	Daily flow volume		
	N.S	**R^2**	**Bias**
MS-1	-0.08	0.02	-17
MS-2	-0.05	0.03	-13
MS-3	-25.51	0.20	132
MS-4	-0.08	0.03	-5
MS-6a	-7.94	0.76	178
MS-9	-0.05	0.03	-21
MS-16	-0.08	0.04	-3
MS-k	-0.06	0.04	-4

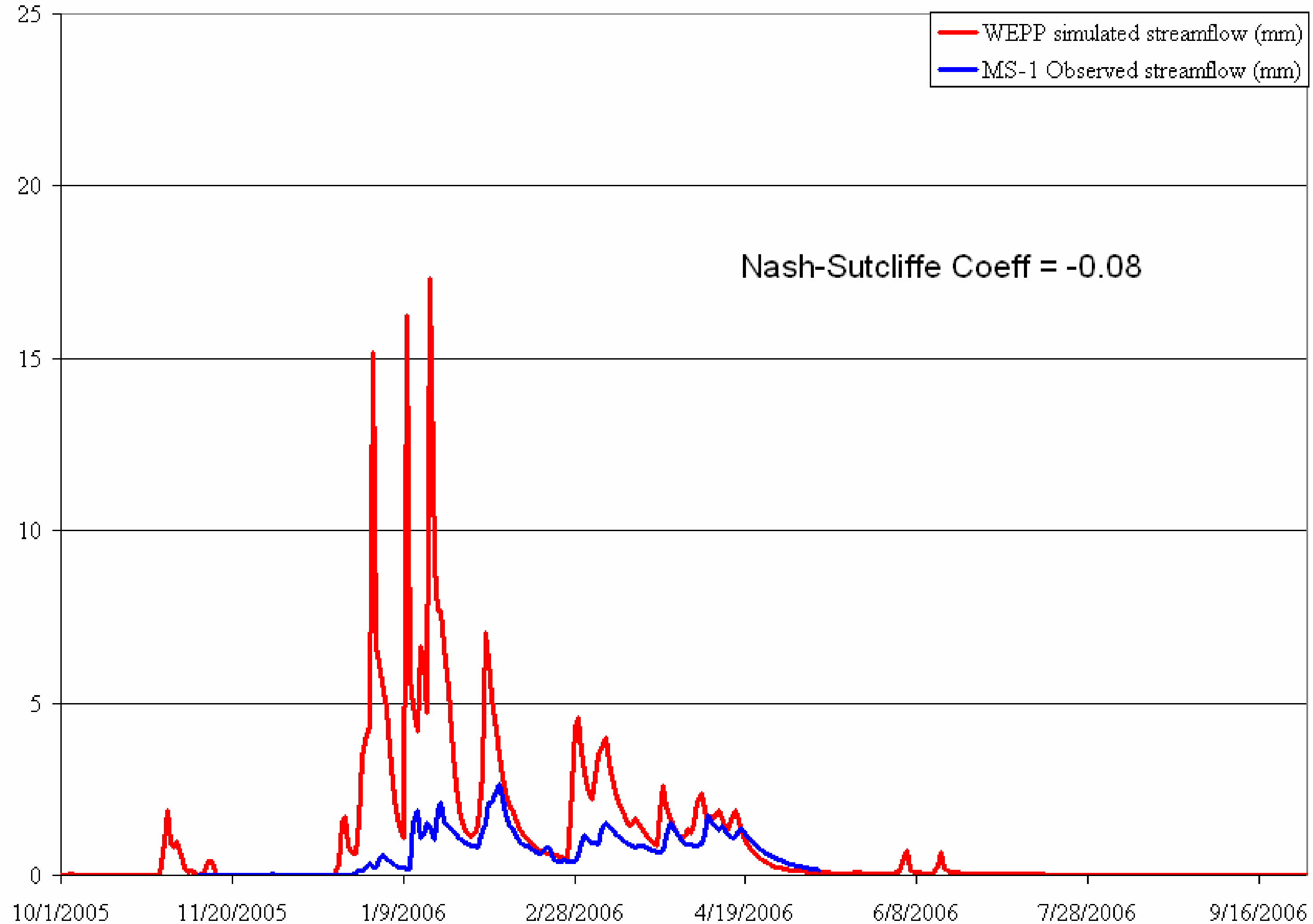

Figure 30 Observed and predicted discharge at station MS-1.

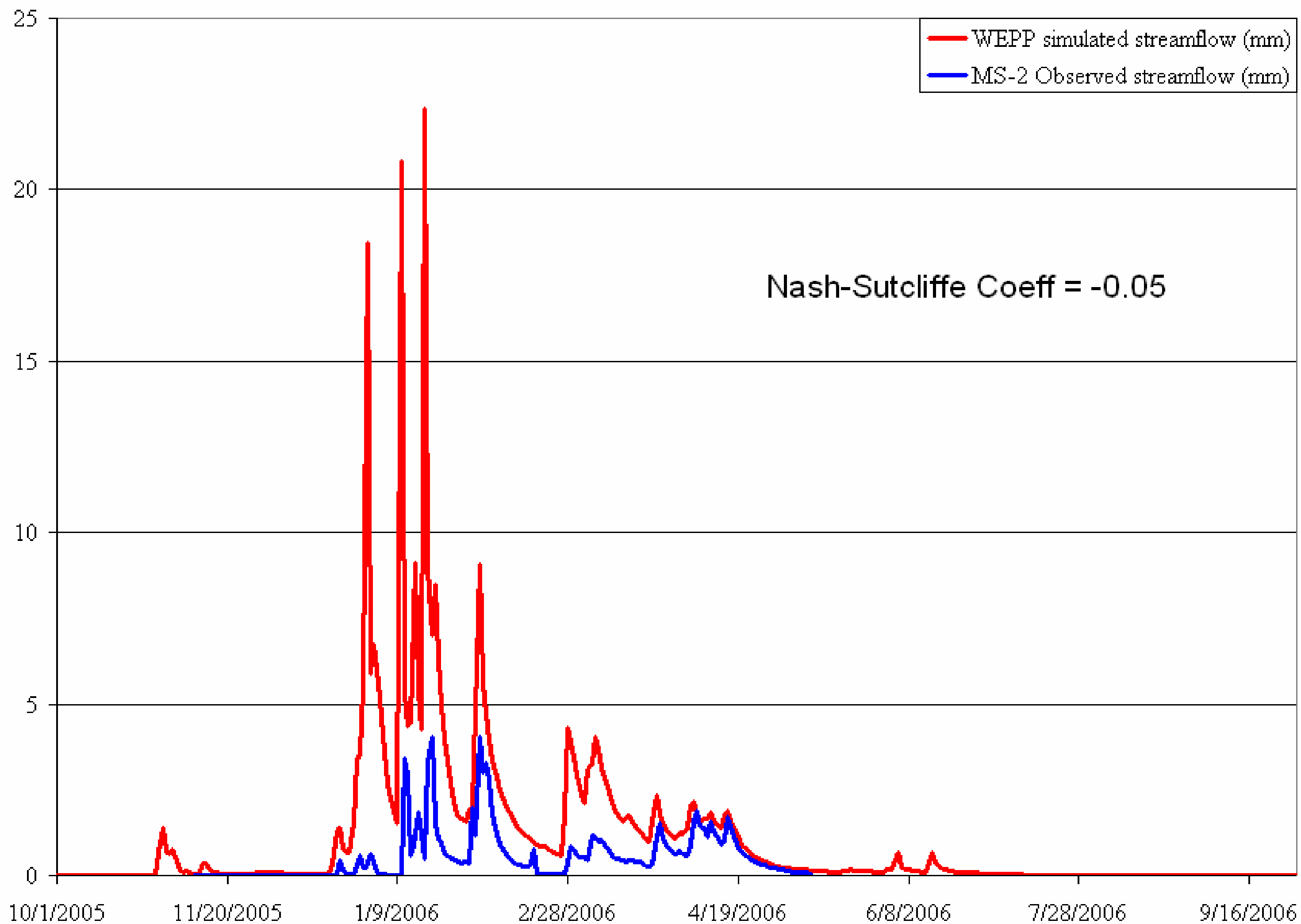

Figure 31 Observed and predicted discharge at station MS-2.

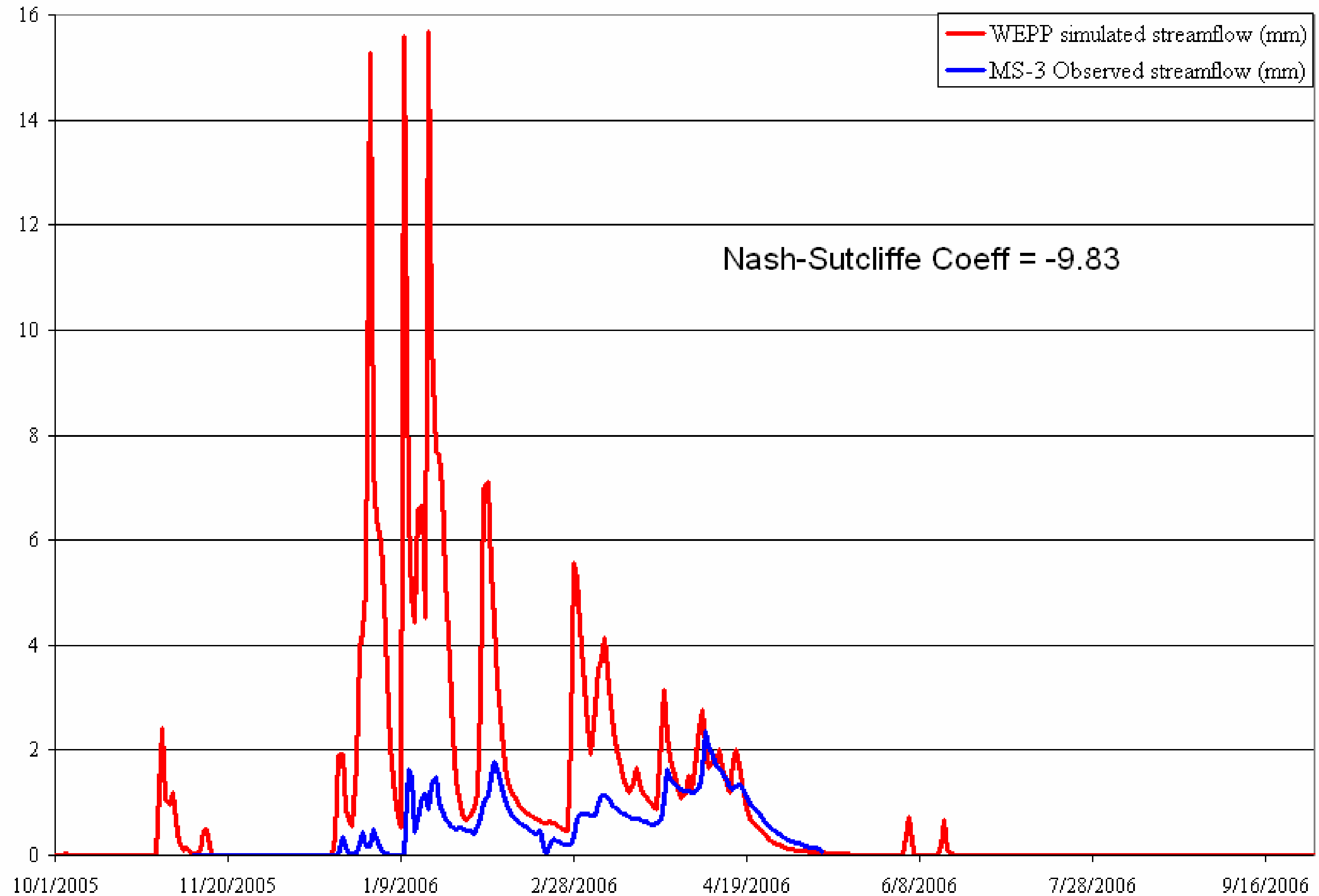

Figure 31 Observed and predicted discharge at station MS-3

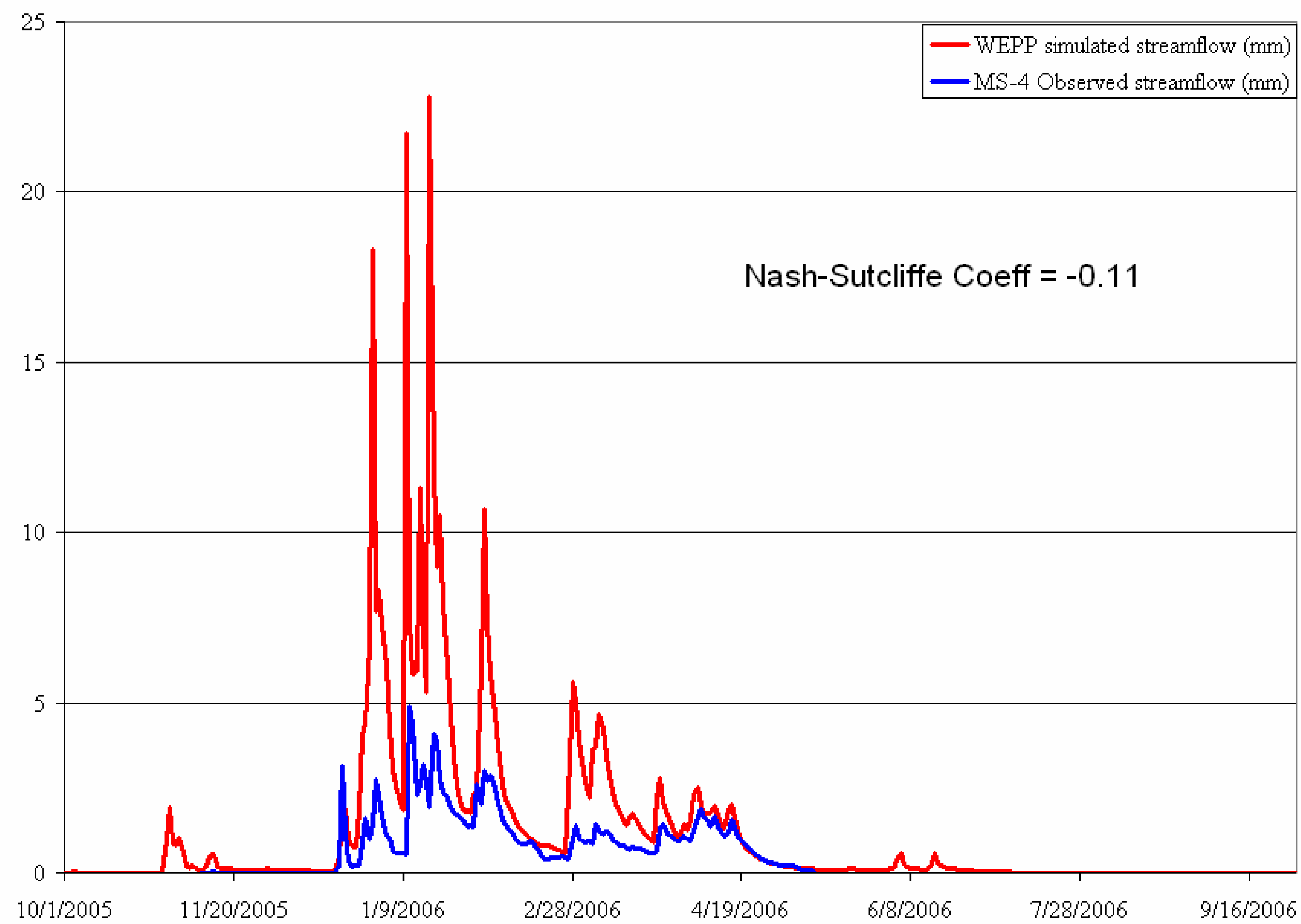

Figure 32 Observed and predicted discharge at station MS-4

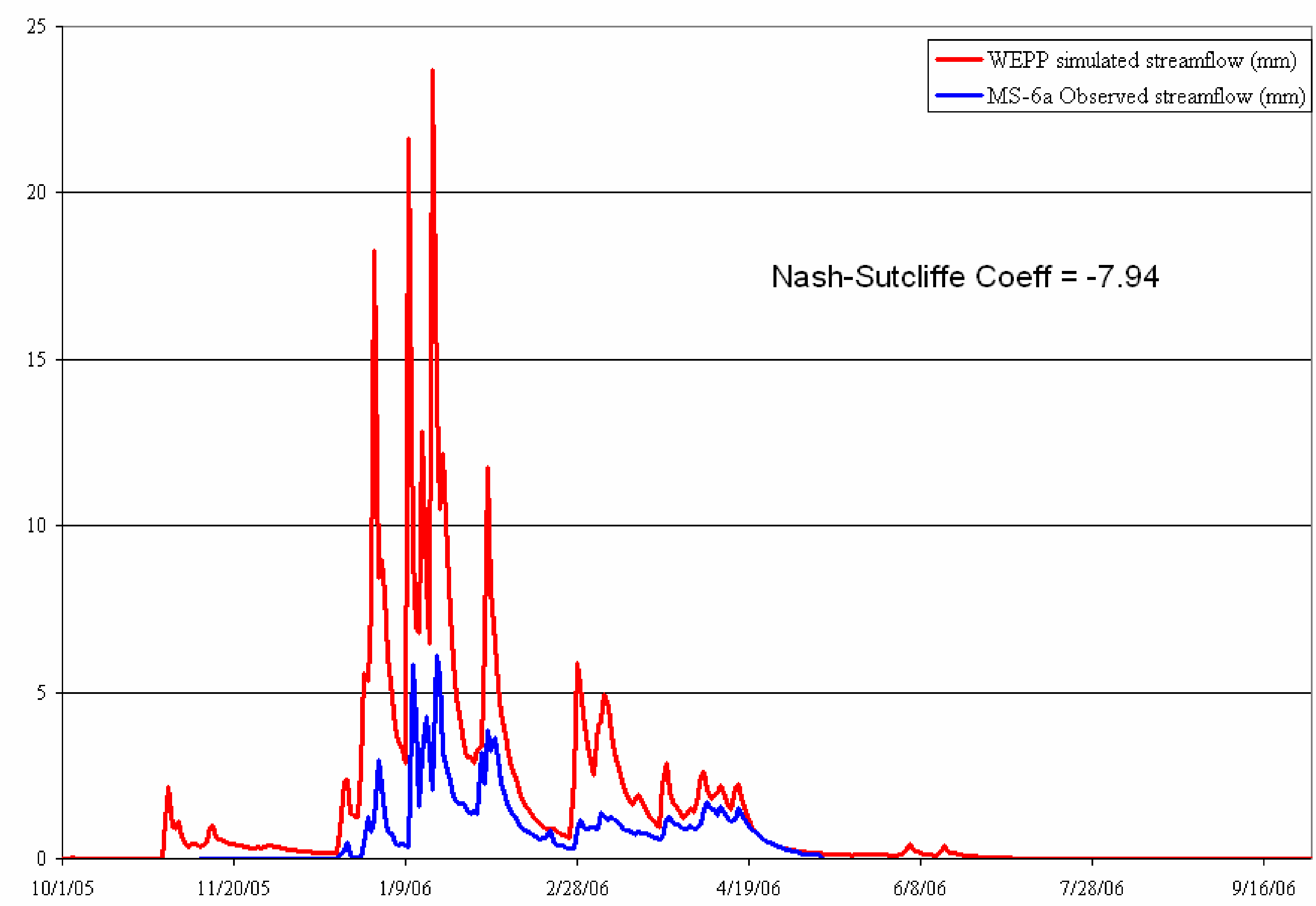

Figure 33 Observed and predicted discharge at station MS -6a

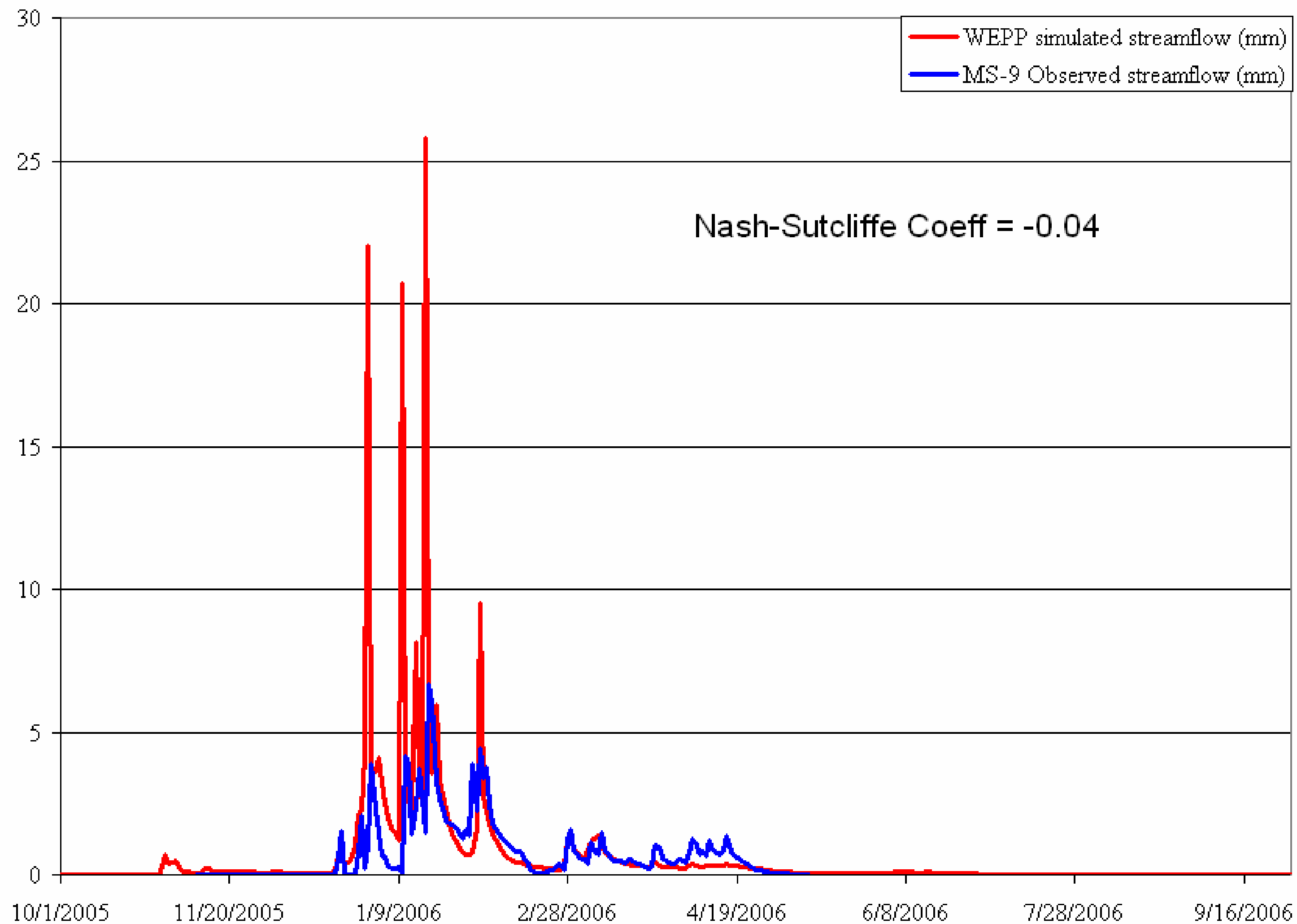

Figure 34 Observed and predicted discharge at station MS -9

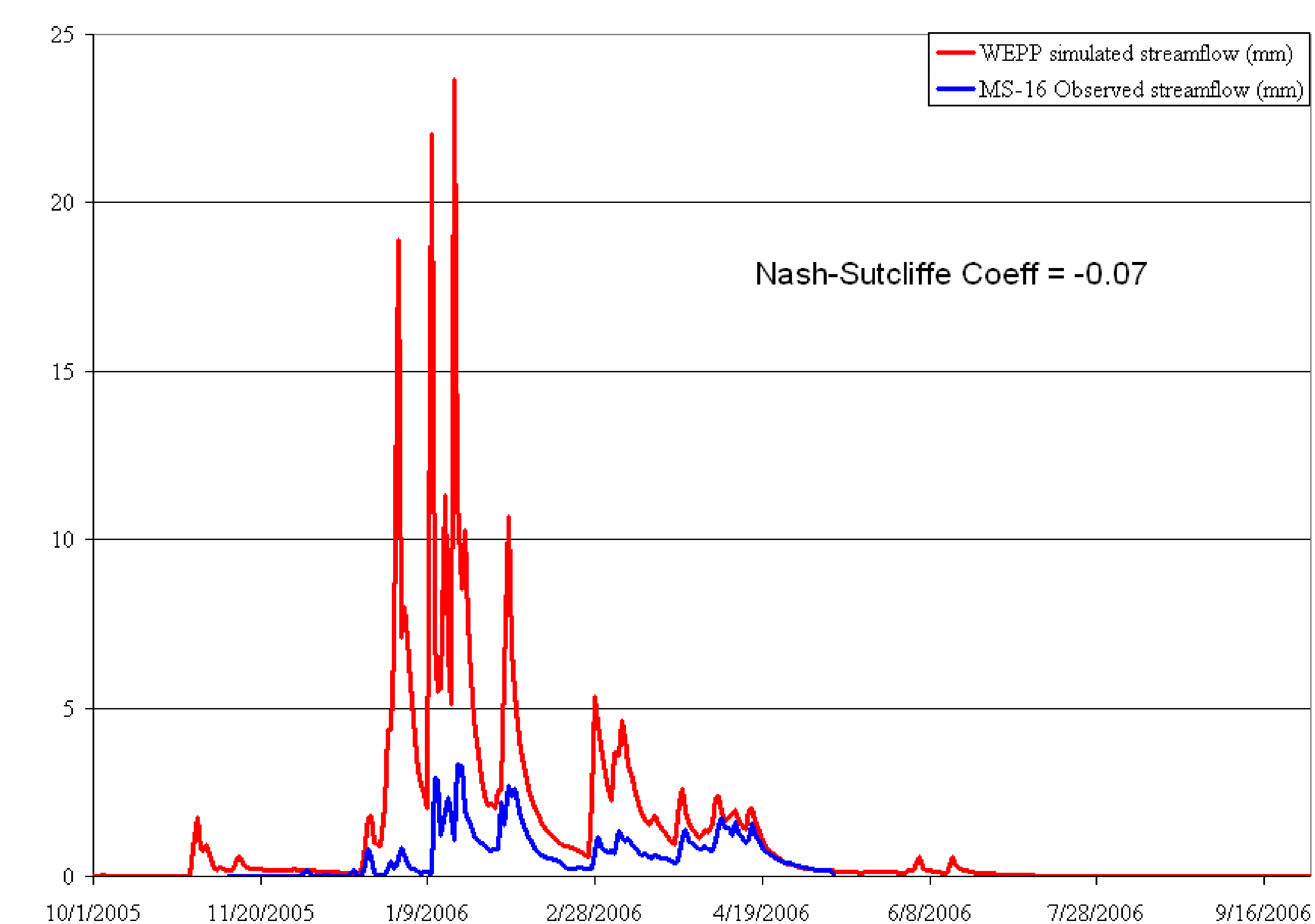

Figure 36 Observed and predicted discharge at station MS -16

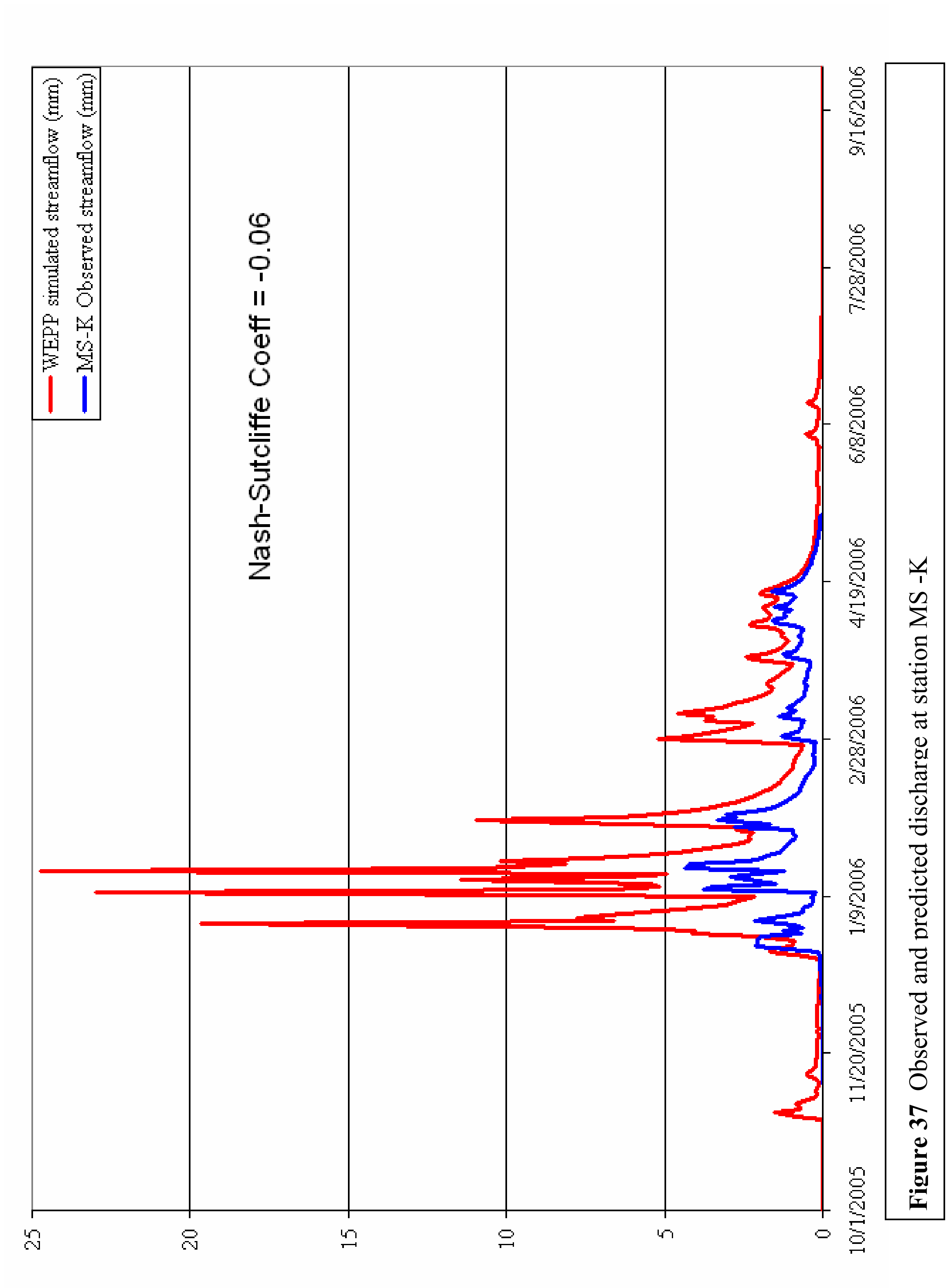

Figure 35 Observed and predicted discharge at station MS –K

Conclusions

Incorporation of convergent sub-surface lateral flow with multiple OFEs in the WEPP model was accomplished. With changes in slopes with multiple OFEs the WEPP model simulated saturation excess variable source area hydrology as well as Hortonian overland flow. Spatial distribution of surface runoff, surface runoff re-infiltration, sub-surface lateral flow, percolation, and evapotranspiration were modeled within a hillslope using multiple OFEs in the WEPP model. Total streamflow was minimally affected by the addition of multiple OFEs. The ratio of overland flow to sub-surface lateral flow as well as the spatial distribution of runoff and lateral flow was affected. The importance of multiple OFEs was visible when slope transition points occurred over the length of a hillslope.

The sub-surface lateral flow routines in the WEPP model reasonably simulated drainage of water from the Coweeta Hydrologic Laboratory experiment by Hewlett and Hibbert (1963). Both cumulative drainage and discharge were comparable with measured data.

Results at the watershed scale for the Paradise Creek watershed in northern Idaho gave reasonable Nash-Sutcliffe coefficients. Reduction of predicted streamflow by a 3.5x scaling factor provided a good fit with observed streamflow data. Good correlations with the scaling factor show that the main hydrological processes were represented in the model, however, adjustments to the model may still be required.

Recommendations

Percolation algorithms in the WEPP model should be examined and altered to allow realistic predictions of percolation. Sub-surface lateral flow should be restricted such that it can only occur when a soil layer has reached saturation. Incorporation of the Sloan and Moore equation for drainable thickness as described in Chapter 6 of the WEPP manual would be a good addition to the WEPP model. Computation of the Sloan and Moore drainable thickness for the soil profile would eliminate the need for adjustment of hydraulic conductivity based on soil moisture content because a discrete separation of saturated and unsaturated zones would be defined.

Snowmelt processes in WEPP should be inspected to determine the reason for the lack of interaction of rainfall on snow density. Integration of a variable albedo based on the age of the snow should be considered to better represent snowmelt processes.

Erosion computations should be examined now that variable source area hydrology is incorporated into the WEPP model. Additional data on spatial variation of erodibility of soils in saturation excess areas could also be added to the model. Evaluation of the effect of land use changes on erosion could be modeled with the new variable source area capable WEPP model.

Multiple processor support should be added to the WEPP model to decrease model runtime. Multiple hillslope simulations could be spread over several processors because each hillslope is independent from the others for all computations. Incorporation of output file manipulation into the WEPP model would eliminate the need for post processing of data and reduce overall computation time over 60%.

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Appendix A:

(Included in attached CD)

1) Ms-Dos Batch file
2) Run file
3) Climate file
4) Management files
5) Soil files

Appendix B

(Included in attached CD)

1) Perl Scripts
    a) Soil File Creator
    b) Run file Creator
    c) WEPP output file manipulation