APPLYING ONLINE WEPP TO ASSESS FOREST WATERSHED HYDROLOGY

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ABSTRACT. *A new version of the online Water Erosion Prediction Project (WEPP) GIS interface has been developed to assist in evaluating sediment sources associated with forests and forest management within the Great Lakes basin. WEPP watershed structure and topographical inputs for each watershed element are generated from the USGS 30 m National Elevation Dataset (NED), soil inputs are automatically retrieved from the USDA-NRCS SSURGO database, and land use and management inputs are selected from the WEPP database based on the USGS National Land Cover Database 2001 (NLCD2001). Additionally, ground cover and soil properties of the WEPP management and soil input files can be customized to represent site-specific conditions. Daily climate inputs are generated from long-term climate parameters using CLIGEN, a stochastic climate generator embedded in the online interface. Alternatively, a registered user can upload and use observed daily climate data for online WEPP simulation. Long-term observational data, including runoff and water chemistry, from two mature forest watersheds of the Fernow Experimental Forest in West Virginia were used to assess the online WEPP GIS interface. Online WEPP simulations were carried out using both observed and CLIGEN-generated climate inputs, and model performance was examined by comparing simulated and observed runoff and simulated and estimated (from measured water chemistry data) sediment yield. The online WEPP reasonably simulated average annual runoff and the annual maximum runoff series for both watersheds, but overpredicted sediment yield for the annual average and annual maximums. The online WEPP simulation results accurately reflected the differences between the two watersheds in their hydrological characteristics. The online WEPP GIS interface is a user-friendly, web-based computer package that can be used by scientists, researchers, and practitioners as a cost-effective simulation tool for watershed management.*

Keywords. *Forest watershed, GIS interface, Hydrologic modeling, Online WEPP, Water erosion.*

The U.S. Army Corps of Engineers (USACE) and the Great Lakes Commission are developing technologies and predictive tools to aid in watershed management with the ultimate goal of improving and preserving water quality in the Great Lakes basin. An online tool, the web-based Water Erosion Prediction Project (WEPP) GIS watershed interface, was developed to assist in evaluating sediment sources associated with forests and forest management within the basin (Frankenberger et al., 2011). The WEPP model is a physically based, distributed-parameter, continuous-simulation model for water erosion prediction developed by the USDA (Flanagan et al., 2001). The model predicts daily runoff and sediment yield from hillslopes and watersheds based on climatic, topographic, soil, and management inputs. In the WEPP model, a watershed is discretized into hillslopes and channel networks, and a hillslope can be further divided into overland flow elements (OFEs) of unique soil, vegetation, and management conditions. WEPP has been frequently used in forest applications for evaluating the hydrologic and erosion impacts of various management practices and natural disturbances, such as harvest, wildfire or prescribed burn, and forest roads (Elliot et al., 1995; Elliot and Hall, 1997; Elliot et al., 1999; Soto and Diaz-Fierros, 1998; Forsyth et al., 2006; Robichaud et al., 2007; Dun et al., 2009).

The online WEPP GIS interface (Frankenberger et al., 2011) uses OpenLayers and MapServer GIS software (OSGeo, 2009, 2010) with base image data from Google Maps (Google, 2011). WEPP inputs for watershed applications, including digital elevation model (DEM) data (USGS 30 m National Elevation Dataset; USGS, 2010), land cover maps (USGS National Land Cover Database 2001; Homer et al., 2007), and soil maps (NRCS

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SSURGO; USDA, 2010), are automatically retrieved from web servers. DEM data are used within the online interface for generating WEPP watershed structure and topographic inputs for each watershed element. Default land use and management files in the WEPP database are linked to polygons in the land cover map, and WEPP soil input files are generated on the server for the area of interest by querying the NRCS SSURGO soil database. For areas where NRCS SSURGO data are not available, information from the land cover map can be used to estimate soil characteristics, and default soil files in the WEPP database are linked to land cover map polygons. Ground cover and soil properties of the WEPP management and soil files can be further modified to represent site-specific conditions, and functions to substitute the defaults with user-specified land use and management or soil files for a subcatchment are provided. By default, daily climate inputs of the online WEPP GIS interface are generated from long-term climate statistical parameters of the nearest weather station using CLIGEN (Nicks et al., 1995), a stochastic climate generator embedded in the interface. Monthly climate parameters can be adjusted by using the gridded data of PRISM (Parameter-elevation Regressions on Independent Slopes Model; PRISMCG, 2010) to account for locations distant from CLIGEN stations (Frankenberger et al., 2011). Alternatively, a registered user can upload and use observed daily climate data for WEPP simulation. The online WEPP GIS interface is publicly accessible (http://WEPPOnlineGIS.bsyse.wsu.edu) and requires only an internet connection and web browser, with no installation or setup. All inputs for WEPP simulation can be selected from existing databases through pick-lists or from simple screen entries (Flanagan, 2010).

The objective of this study was to examine the performance of the online WEPP GIS interface by applying it to selected forest watersheds. Specifically, two instrumented watersheds with long-term observation data at the Fernow Experimental Forest, West Virginia, were chosen for WEPP applications. For each watershed, two WEPP simulations were carried out: one using observed climate data to examine the capacity of the online WEPP GIS interface to simulate daily runoff and sediment yield, and the other using climate data generated by CLIGEN, the default stochastic climate generator, to evaluate the capacity of the interface to simulate long-term statistical characteristics of watershed runoff and sediment yield. Simulated runoff and sediment yield from the online WEPP were then compared with observed values on a daily or annual basis. In addition, simulated and observed runoff and simulated and estimated sediment yield for events with a return period of 2, 5, or 10 years were compared.

FERNOW EXPERIMENTAL FOREST

The Fernow Experimental Forest is located in Tucker County, West Virginia, approximately 1.3 km south of Parsons (fig. 1), in the Allegheny Mountain section of the Appalachian Plateau (USDA, 2011a). The forest is comprised of unglaciated, humid-mountainous topography sculpted by a series of hillslope and fluvial processes (Taylor and Kite, 1997). Bedrock is weathered and fractured sedimentary strata of interbedded sandstone and shale or interbedded marine limestones and calcareous shales with low dip angles (approx. 5° to 10° to the southeast) on broad, open folds (Taylor and Kite, 1997). Soils, originated from the bedrock, are mainly loam and silt loam soils with an average depth of about 1 m (USDA, 2010, 2011a).

At the Fernow Experimental Forest, mean annual precipitation is 1470 mm, distributed evenly throughout the year (USDA, 2011a). About 12% of the annual precipitation falls in the form of snow. Winter snowfall can be heavy, though the snowpack is intermittent (USDA, 2011a). The region is covered by a mixed hardwood forest (USDA, 2011a) with an annual average evapotranspiration (ET) of 640 mm (Adams et al., 1994; Wilson et al., 2001).

The USDA Forest Service has carried out watershed research at the Fernow Experimental Forest for six decades. In the Elklick Run watershed, seven subwatersheds (WS1 to WS7, fig. 1) under different forest managements have been gauged with 120° V-notch weirs instrumented with Belfort FW-1 water-level recorders since 1951 (USDA, 2011b). Daily runoff amounts during 1951-2007 were calculated from the observed water levels using an empirical equation calibrated to each installation (USDA, 2011b). Water samples were collected weekly or biweekly with high-density polyethylene bottles from a plastic pipe placed in the channel above the weir pond at each subwatershed during 1980-2007 and were analyzed at the Timber and Watershed Laboratory for water chemistry, including concentrations of Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Cl^{-}, NO_3^{-}, and SO_4^{2-} (USDA, 2011b). Precipitation was observed using a network (fig. 1) of four recording rain gauges (Belfort 780 series) and seven standard rain gauges (8 in., Belfort model 5-400). The Thiessen polygon method was applied to calculate the daily precipitation for the period of 1951-2007 for each watershed (USDA, 2011b). Daily maximum and minimum air temperature data for the same period have been collected at the weather station at the mouth of WS5 (fig. 1, USDA, 2011b). All the aforementioned data (Edwards and Wood, 2011) are available online (USDA, 2011a, 2011b).

WS1 and WS4 are small watersheds with collection areas of 30 and 34 ha, respectively. There has been no tree cutting for WS1 since a clearcut with 74% basal area removal during 1957-1958, and for WS4 since the last known harvesting during 1905-1910 (USDA, 2011b). The only operations in WS1 since 1958 were aerial application of urea fertilizer (560 kg ha^{-1}) in May 1971 and Dimilin pesticide (0.03 kg ha^{-1}) in May 1992. There have been no management operations in WS4 since 1910. Both WS1 and WS4 have been completely covered with mature forest for the last two decades (USDA, 2011b). Water chemistry was sampled biweekly for WS1 and weekly for WS4 (USDA, 2011b). We chose these two watersheds for WEPP application considering their relatively uniform and uncomplicated land use and management conditions.

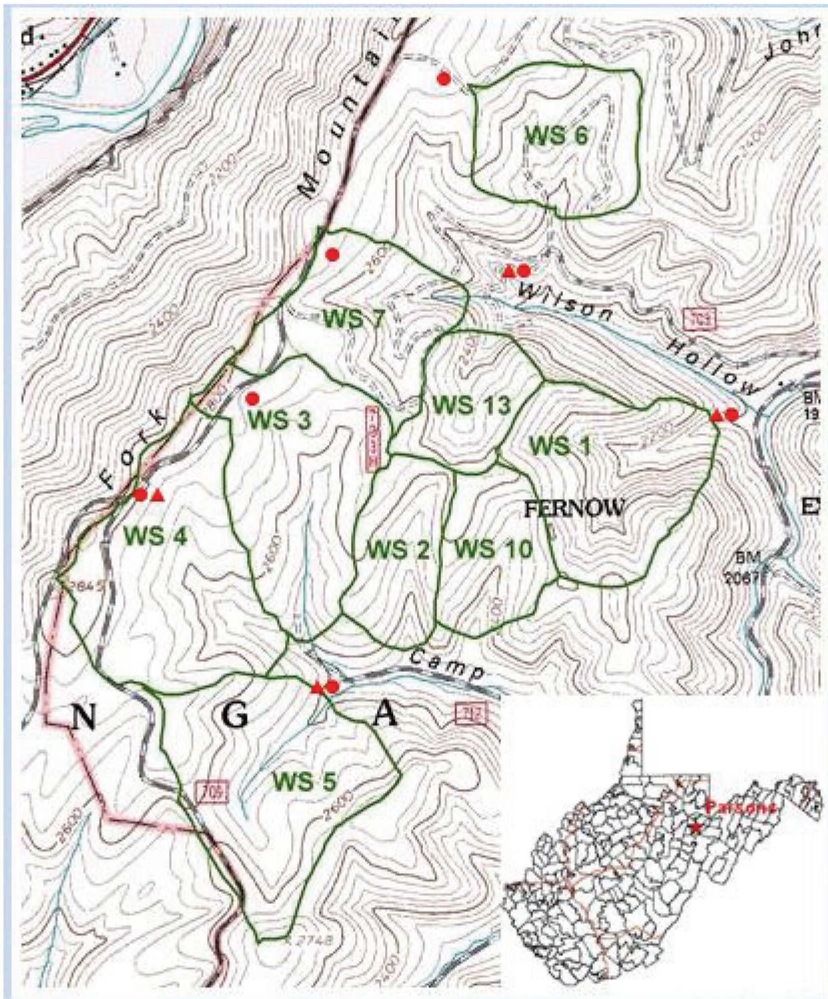

Figure 1. Monitored watersheds in the Fernow Experimental Forest (adapted from USDA, 2011b). Triangles and circles represent recording and standard rain gauges, respectively.

Patric (1976) reviewed forest erosion studies in the eastern U.S. where average annual precipitation exceeds 750 mm and concluded from the study results that eroded materials from well managed forestlands consisted of roughly equal parts of particulate and dissolved matter. He also compared these results with measured erosion losses at the Fernow Experimental Forest. The erosion data were obtained for 1958-1973 from four watersheds (WS2, WS3, WS4, and WS5; fig. 1) where particulate and dissolved matter were measured regularly, with larger particles trapped and measured intermittently. The larger particles averaged 0.001 t ha^{-1} $year^{-1}$, particulate matter 0.012 t ha^{-1} $year^{-1}$, and dissolved matter 0.016 t ha^{-1} $year^{-1}$.

In our study, we estimated sediment yield using observed stream chemistry data. We assumed HCO_3^- to be the only unmeasured dissolved matter and calculated the concentration of dissolved matter from the measured anion and cation concentrations, with the unmeasured HCO_3^- accounted for by valence balance. Based on Patric (1976), we assumed that the amount of eroded dissolved matter equals the amount of eroded particulate matter. In the WEPP model, transported sediment consists only of particulate matter; therefore, the watershed sediment yield was regarded as the same as the amount of dissolved matter. This assumption may lead to an overestimation of sediment at low runoff and an underestimation at high runoff. Daily sediment yield was estimated as the product of the concentration of the dissolved matter and streamflow. The concentration of dissolved matter for the days between any two measurements was estimated by linear interpolation. Annual sediment yields were calculated from the estimated daily sediment yields.

WS1 and WS4 are close to each other, yet they are slightly different hydrologically. The soils are mainly Calvin channery silt loam in WS1, and Calvin channery silt loam, Dekalb channery loam, and Ernest cobbly silt loam in WS4 (USDA, 2010). The underlying bedrocks are weathered and fractured shale for both watersheds (USGS, 2011). For the last 20 water years (Oct.-Sept.) of the observation period, mean annual precipitation in WS1 (1517 mm) was greater than that in WS4 (1440 mm), whereas runoff from WS1 (610 mm) was less than that from WS4 (659 mm). The sediment yield estimated from water chemistry data for WS1 (0.14 t ha^{-1} $year^{-1}$) was more than that for WS4 (0.08 t ha^{-1} $year^{-1}$). In this study, we attempted to evaluate the response of the online WEPP to these varying hydrological conditions.

WEPP Simulations and Model Performance Evaluations

WEPP Simulations

The online WEPP GIS interface was applied to WS1 and WS4 to compare simulated and observed (or estimated) daily, annual, and statistical characteristics (mean and annual maximums for different return periods) of runoff and sediment yield. For each watershed, two WEPP simulations were carried out: one using observed climate data from 1987 to 2007 to assess the performance of the online WEPP interface in simulating daily and annual runoff and sediment yield, and the other using 20 years of CLIGEN-generated stochastic climate inputs to evaluate the capacity of the interface to simulate long-term statistical characteristics of watershed runoff and sediment yield. The later years of the full observation period (1951-2007) were chosen for model performance assessment because these years had less missing data. In discretizing the watersheds into hillslopes and channel segments within the online WEPP GIS interface, we used the default values of 60 m and 4 ha for minimum source channel length and critical source area, respectively. Eight hillslopes and three channel segments were delineated for WS1, and 12 hillslopes and five channel segments were delineated for WS4 (fig. 2, table 1). Default WEPP land use and management files (mature-forest files) of the online WEPP were used.

For WEPP simulations using CLIGEN-generated data, all the daily climate inputs were generated based on the PRISM-adjusted long-term climate statistics for the nearest NOAA weather station (Rowlesburg 1, WV, COOP ID: 467785; 32 km north of the watersheds). For WEPP simulations using observed climate data, daily climate inputs included field-measured daily maximum and minimum air temperatures (same for WS1 and WS4) and precipitation data (different for each watershed). The inputs related to precipitation (i.e., storm duration, peak intensity, and time to peak intensity) and the remaining climate inputs (i.e., wind velocity and direction, dewpoint temperature, and solar radiation) were generated using the function for generating missing data in CLIGEN based on the observed precipitation and air temperatures, as well as the long-term climate statistics for the Rowlesburg 1 NOAA station.

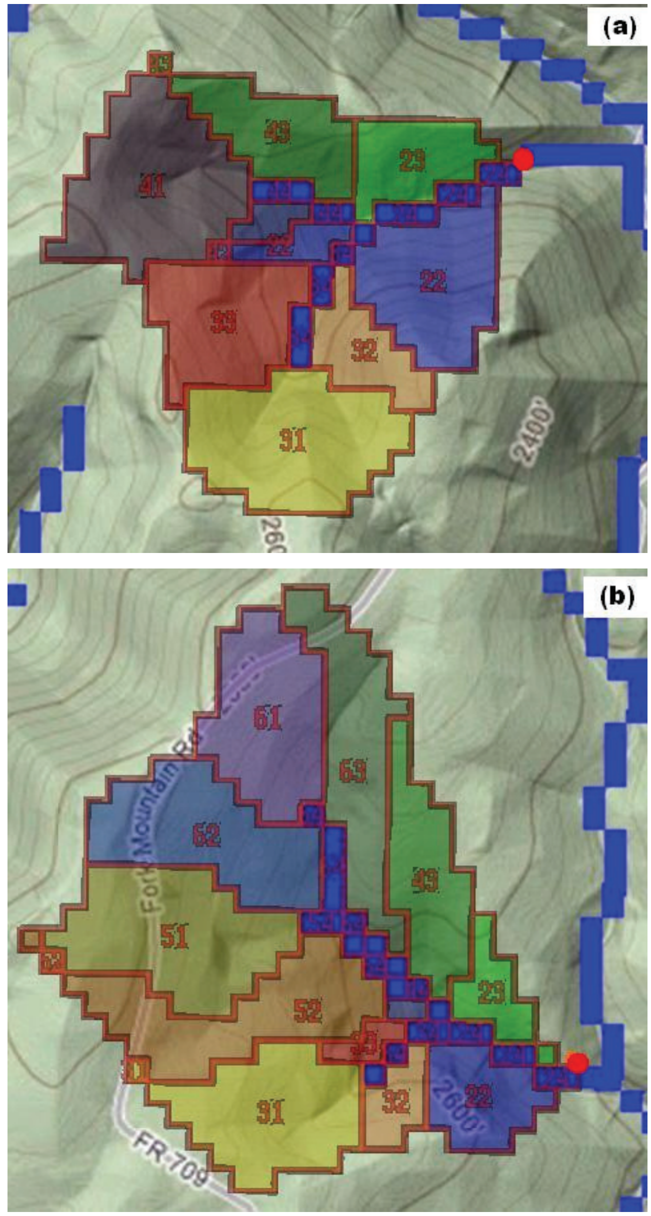

Figure 2. Watershed delineation with the online WEPP GIS interface for (a) WS1 and (b) WS4. Numbers in the map units denote hillslope or channel segment IDs. Red dot is the watershed outlet.

Table 1. Configurations of the delineated hillslopes and channels.

Hillslopes and Channels	Watershed WS1 Map (unit)	Width (m)	Length (m)	Aspect	Avg. Slope (m m^{-1})	Watershed WS4 Map Unit	Width (m)	Length (m)	Aspect	Avg. Slope (m m^{-1})
H1	22	350	69	18	0.37	23	205	66	22	0.13
H2	23	350	162	198	0.46	22	205	123	158	0.23
H3	32	175	77	248	0.42	33	115	39	34	0.30
H4	31	175	144	68	0.34	31	160	247	124	0.15
H5	33	283	239	158	0.34	32	85	297	45	0.16
H6	42	213	245	68	0.35	43	85	170	135	0.19
H7	43	175	154	22	0.42	42	145	180	27	0.19
H8	41	175	57	158	0.42	51	161	352	63	0.16
H9	-	-	-	-	-	52	145	56	153	0.17
H10	-	-	-	-	-	63	235	249	27	0.18
H11	-	-	-	-	-	61	290	118	117	0.19
H12	-	-	-	-	-	62	290	65	63	0.10
C1	44	1	175	68	0.24	64	1	290	27	0.14
C2	34	1	175	158	0.24	54	1	145	63	0.19
C3	24	2	350	108	0.12	44	2	85	45	0.08
C4	-	-	-	-	-	34	1	115	124	0.19
C5	-	-	-	-	-	24	2	205	68	0.09

Developing Site-Specific Soil Inputs

Table 2 shows the WEPP soil inputs for the predominant soil (Calvin channery silt loam) of the simulated watersheds. The soil inputs generated from the SSURGO soil database were refined to reflect site-specific conditions using the functions in the online WEPP GIS interface. SSURGO soil texture profiles were first combined with the hydraulic and erosion parameters in the forest loam soil file of the WEPP database to reflect site-specific surface conditions. We further adjusted the soil inputs by including an anisotropy ratio of the soil hydraulic conductivity, and K_{sat} for a restrictive layer to represent the bedrock underneath. The soil anisotropy ratio is an important hydraulic property in the WEPP model for calculating subsurface lateral flow, which is often a dominant process under forest settings (Dun et al., 2009).

Deep percolation, which is largely controlled by the saturated hydraulic conductivity (K_{sat}) of the restrictive bedrock layer under the soil profile, directly affects the simulated subsurface lateral flow and channel runoff in WEPP. To properly simulate deep percolation and to best reproduce the observed runoff, we calibrated the K_{sat} value as follows. First, the observed climate data for WS1 and WS4 were uploaded and used to run the online WEPP. The restrictive layer K_{sat} was then adjusted to minimize the difference between the simulated and observed average annual runoff.

All the soil inputs (except the soil anisotropy ratio and K_{sat} of the restrictive layer) were generated automatically in the online WEPP GIS interface. The default value of 35 mm h^{-1} for surface effective hydraulic conductivity in the WEPP database was used to simulate infiltration into typical forest loam soils. A soil anisotropy ratio of 25 was chosen for the following reason. The baseline soil effective hydraulic conductivity (K_b) is internally estimated in WEPP using a pedotransfer function (Flanagan and Nearing, 1995):

$$
\begin{aligned}
K_b &= -0.265 + 0.0086 \times Sand^{1.8} + 11.46 \times \mathrm{CEC}^{-0.75} && Clay \le 40 \\
K_b &= 0.0066 \times \mathrm{e}^{(244/Clay)} && Clay > 40
\end{aligned}
\tag{1}
$$

Table 2. Major WEPP soil inputs for Calvin channery silt loam.

Parameters	Effective Hydraulic Conductivity (mm h^{-1})	Interrill Erodibility (kg s m^{-4})	Rill Erodibility (s m^{-1})	Critical Shear Stress (Pa)
Surface soil	35	1e+5	1e-5	1

Soil texture profile

Depth (mm)	Sand (%)	Clay (%)	Organic Matter (%)	CEC (meq per 100 g soil)	Rock Fragments (%)
130	29.1	17.5	6.6	14	10
790	22.4	22.5	0.26	16	12
1190	22.4	22.5	0.18	13	13

Other parameters

Anisotropy Ratio (unitless)	Restrictive Layer (K_{sat}, mm h^{-1}) WS1	Restrictive Layer (K_{sat}, mm h^{-1}) WS4
25	0.036	0.008

Table 3. Major channel hydraulic and erosion parameters.

Channel Hydraulic and Erosion Parameters	Values
Channel cross-sectional shape	Naturally eroded
Manning roughness coefficient (unitless):	
For bare soil	0.04
For channel with vegetation	0.30
Channel erodibility (s m^{-1})	6E-4
Channel critical shear stress (N m^{-2})	10.0
Depth to nonerodible layer in mid-channel (m)	0.5
Depth to nonerodible layer along channel side (m)	0.1

where *Sand* and *Clay* are the percentages of sand and clay, and CEC (meq per 100 g) is the cation exchange capacity of the soil. The WEPP-estimated K_b for the soil is 4 mm h^{-1}. The saturated hydraulic conductivity for the Calvin channery series ranges from 50 to 150 mm h^{-1} in SSURGO (USDA, 2010), roughly 25 times K_b.

The study watersheds are small headwaters. Hence, the soil and management inputs for the channels were assumed the same as for the hillslopes. Important channel hydraulic and erosion parameters were the default values in the WEPP database, as shown in table 3.

Penman Equation vs. FAO Penman-Monteith Method for Simulating ET

WEPP includes both the Penman (1963) equation and the FAO Penman-Monteith method (Allen et al., 1998) for estimating ET (Flanagan and Nearing, 1995; Dun et al., 2003). Annual average ET estimated using the Penman equation was about 1000 mm for WS1 and WS4, a value that is much higher than that observed (640 mm) from the hardwood forests of the region. The FAO Penman-Monteith method (Wu and Dun, 2006) was therefore chosen for ET estimation in the WEPP simulations of this study. The crop coefficient for middle growth season in the FAO Penman-Monteith equation (Allen et al., 1998) was set to 0.71 in this study. The annual average of the simulated ET for both study watersheds using the observed climate data was 650 mm.

Model Performance Evaluation

WEPP-simulated runoff and sediment yield were statistically compared with the field-observed runoff and estimated sediment yield. For WEPP simulations using observed climate data, Nash-Sutcliffe model efficiency coefficients (NSE; Nash and Sutcliffe, 1970) and percent of bias (PBIAS; Gupta et al., 1999) were obtained for daily and annual runoff and sediment yield for WS1 and WS4, respectively. Additionally, paired t-tests were made on daily values of simulated and observed runoff and simulated and estimated sediment yield for each water year at a significance level $\alpha = 0.01$. For WEPP simulations using CLIGEN-generated or observed climate data, simulated and observed runoff and simulated and estimated sediment yield for events with a return period (T) of 2, 5, or 10 years were compared, with T calculated as:

$$T = (N+1)/m \tag{2}$$

where N is the number of simulation years (N = 20, for 1988-2007 in this study), and m is the rank of the annual maximum events in descending order. The return-period analyses were helpful in further assessing the performance of the online WEPP in simulating the statistical characteristics of the long-term watershed runoff and erosion.

RESULTS AND DISCUSSION

Table 4 shows a comparison of annual (1988-2007) simulated and observed runoff and simulated and estimated sediment yield for WS1 and WS4. Figures 3 (WS1) and 4 (WS4) show a comparison of simulated and observed daily runoff and simulated and estimated daily sediment yield for 1996-1999. This four-year period was selected for illustration as it covered a broad range of hydrologic conditions of the study watersheds, including the wettest (1996), driest (1999), and average water years of the 20-year simulation period (table 4). WEPP simulations using observed climate data (table 4) reproduced the average annual runoff values and the seasonal trends of daily runoff for both watersheds. The simulated watershed runoff was mainly from subsurface lateral flow from the hillslopes. Hillslope surface runoff was primarily due to saturation excess and accounted for a relatively small portion of the total runoff (averaging 10% and 15% for WS1 and WS4, respectively, table 4).

The NSE coefficients for daily runoff for the entire simulation period (water years 1988-2007) were -0.08 and 0.06 for WS1 and WS4, respectively. The low NSE coefficients reflected considerable discrepancies between the simulated and observed daily hydrographs. For the selected period of 1996-1999 (figs. 3 and 4), the NSE coefficients were -0.19 and -0.005 for WS1 and WS4, respectively, reflecting even poorer agreement between simulated and observed runoff. Figures 3 and 4 show that the major reason for the low NSE coefficients for daily runoff was that simulated timing for large runoff events often did not coincide with observed timing. The errors in simulated timing may be attributed to the following reasons. First, some of the simulated snowmelt events occurred later than observed, possibly because of the use of stochastic dewpoint temperature and solar radiation, which directly affect WEPP snow simulation in forested areas. Second, for certain observed precipitation events, the observed runoff events were lagged by one day. Third, a number of observed daily precipitation events appeared too large to produce the low observed runoff. Fourth, a few observed precipitation events appeared too small to generate the high observed runoff. Errors associated with precipitation are possibly caused by the rain gauge not recording the same event as occurring on the site. The number of days within the whole simulation period with absolute error exceeding 10 mm in the simulated daily runoff for each watershed is shown in table 5.

The NSE coefficients for daily sediment yield for the entire simulation period (1988-2007) were -19 and -48 for WS1 and WS4, respectively. These values indicate a poor agreement between the WEPP-simulated and estimated daily sediment yields, which may be attributed to the following reasons. For low-flow events, WEPP did not predict any erosion because the stream hydraulic shear was below the critical shear stress; however, during the low-flow season, streamflow was primarily from subsurface lateral flow carrying with it dissolved matter of high concentration. For high-flow events, WEPP overpredicted sediment yield. On one hand, our method for estimating watershed sediment yield using stream chemistry data may lead to an underestimation at high flows; on the other hand, WEPP tends to overpredict channel peak flow (Conroy et al., 2006), which can lead to overprediction of channel

Table 4. WEPP-simulated and observed (or estimated) annual runoff and sediment yield.[a]

	Watershed WS1							Watershed WS4						
		Runoff (mm)			Sediment Yield (t ha^{-1})				Runoff (mm)			Sediment Yield (t ha^{-1})		
Water Year	Precipitation (mm)	Obs.	Sim. WS	Sim. Avg. HSLP	Obs.	Sim. WS	Sim. Avg. HSLP	Precipitation (mm)	Obs.	Sim. WS	Sim. Avg. HSLP	Obs.	Sim. WS	Sim. Avg. HSLP
1988	1324	460	428	21	0.12	0.18	0.016	1257	480	467	36	0.06	0.19	0.028
1989	1701	726	731	37	0.17	0.29	0.012	1646	809	846	133	0.10	0.33	0.051
1990	1548	632	582	15	0.17	0.16	0.007	1484	670	692	52	0.09	0.13	0.012
1991	1377	574	508	5	0.15	0.14	0.000	1314	600	583	48	0.09	0.12	0.015
1992	1376	466	452	7	0.12	0.10	0.002	1266	489	501	9	0.07	0.04	0.000
1993	1352	467	451	13	0.11	0.14	0.000	1306	506	483	59	0.06	0.06	0.000
1994	1943	966	991	145	0.20	0.37	0.104	1894	1038	1135	299	0.12	0.24	0.057
1995	1181	381	327	20	0.08	0.06	0.010	1131	413	383	41	0.05	0.06	0.031
1996	2082	970	1018	159	0.22	0.41	0.170	2023	1069	1128	328	0.14	0.38	0.218
1997	1610	659	636	68	0.15	0.15	0.062	1520	714	728	95	0.09	0.12	0.059
1998	1604	723	708	57	0.14	0.17	0.078	1562	803	864	99	0.09	0.12	0.045
1999	1156	411	372	54	0.10	0.08	0.006	1074	434	363	57	0.06	0.03	0.000
2000	1441	464	490	73	0.10	0.14	0.077	1393	504	519	76	0.06	0.07	0.034
2001	1430	584	526	50	0.14	0.17	0.093	1349	645	570	90	0.08	0.11	0.064
2002	1334	444	439	52	0.10	0.11	0.042	1229	502	426	63	0.06	0.05	0.018
2003	1636	709	737	89	0.14	0.17	0.041	1557	797	784	123	0.10	0.09	0.026
2004	1820	844	885	129	0.18	0.21	0.057	1699	907	964	224	0.11	0.14	0.048
2005	1319	527	476	14	0.11	0.03	0.000	1187	584	510	17	0.07	0.01	0.001
2006	1630	644	655	97	0.12	0.20	0.111	1533	625	666	139	0.07	0.14	0.099
2007	1474	560	567	52	0.12	0.08	0.038	1383	594	605	59	0.07	0.03	0.003
Average	1517	610	599	58	0.14	0.17	0.046	1440	659	661	102	0.08	0.12	0.040

[a] WS = watershed, HSLP = hillslope, Obs. = observed, Sim. = simulated, and Avg. = average.

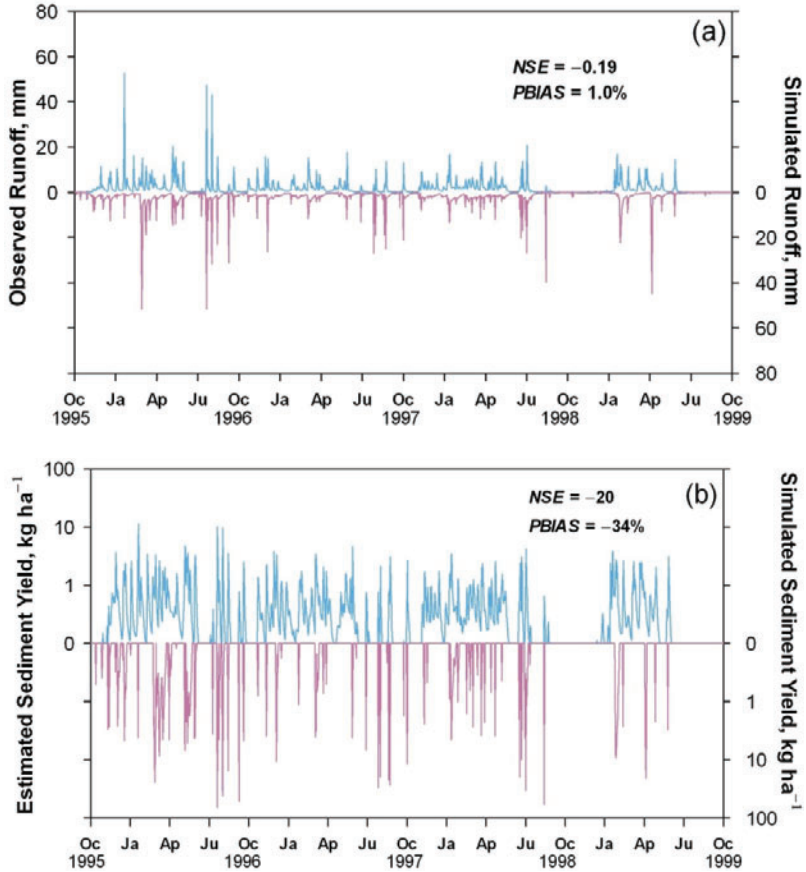

Figure 3. (a) WEPP-simulated and observed daily runoff and (b) WEPP-simulated and estimated daily sediment yield for WS1, Fernow Experimental Forest (water years 1996-1999). Note that NSE and PBIAS are for the graphed period only.

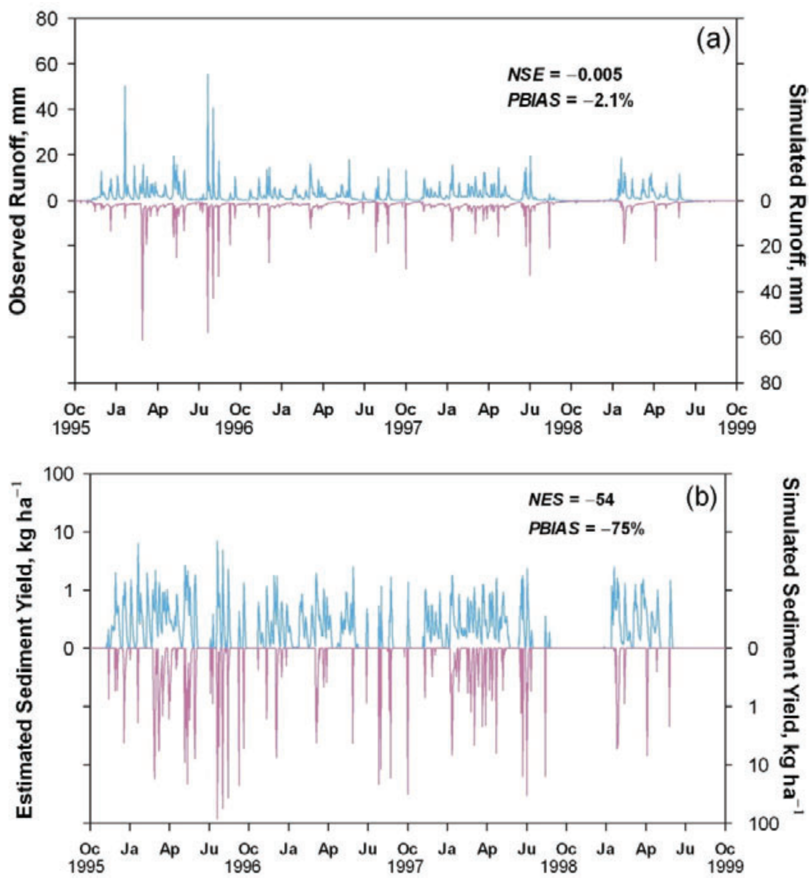

Figure 4. (a) WEPP-simulated and observed daily runoff and (b) WEPP-simulated and estimated daily sediment yield for WS4, Fernow Experimental Forest (water years 1996-1999). Note that NSE and PBIAS are for the graphed period only.

Table 5. Possible causes of large errors in simulated daily runoff.

	WS1	WS4
Total days simulated	7671	7671
Total days with absolute error > 10 mm	161	139
Days of simulated snowmelt later than observed	87	72
Days with runoff lagging by one day	41	38
Days with large precipitation and low runoff	32	16
Days with low precipitation and large runoff	1	13

erosion. In addition, the simulated and observed high-flow events often did not coincide (figs. 3 and 4), which also contributed to the low NSE coefficients for sediment yield. Online WEPP overprediction at high flows and underprediction at low flows suggest that WEPP erodibility parameters, especially the channel parameters, need to be evaluated and refined. We did not attempt to calibrate the erodibility parameters in this study for two reasons: (1) daily watershed sediment yields estimated from the observed weekly or biweekly stream water chemistry data were not necessarily equal to the actual values, and (2) the discrepancies between the simulated and observed daily runoff inevitably led to errors in simulating sediment yield.

Overall, WEPP simulations using observed climate data reproduced cumulative runoff over the entire simulation period with PBIAS of 1.9% for WS1 and -0.27% for WS4. The NSE coefficients for annual runoff were 0.95 and 0.93 for WS1 and WS4, respectively. Paired t-tests on the mean values of simulated and observed daily runoff for each water year showed that the means and therefore the annual values of simulated and observed runoff were not significantly different at $\alpha = 0.01$ for both watersheds. The average p-value was 0.61 for WS1, with the smallest value of 0.08 for the year 1991, and 0.53 for WS4, with the smallest value of 0.02 for the year 2002. WEPP overpredicted cumulative sediment yield with PBIAS of -23% for WS1 and -52% for WS4. The NSE coefficients for annual sediment yield were -2.4 for WS1 and -8.7 for WS4. Paired t-tests for each water year showed no significant difference for WS1 for all but water year 2005 with an average p-value of 0.45. For WS4, significant difference was found for 1989, 1992, 1994, 2005, and 2007 with an average p-value of 0.35.

Sediment yield from these two undisturbed forest watersheds was low compared with those from cropland, rangeland, and disturbed forest sites (Flanagan et al., 2007) where extensive field experimentation has been conducted to obtain data required to parameterize and test the WEPP model. In the cases of low sediment yield typical of well-managed forested watersheds, the relative variability of sediment yield tends to be high, making comparison of simulation results and observations difficult (Nearing, 2000). Often, slight differences in simulated and estimated values can lead to large PBIAS. In this study, the WEPP model correctly simulated the difference between the two study watersheds, i.e., lower annual sediment yields were associated with larger annual runoff for WS4 as compared to WS1.

Average annual precipitation, runoff, and sediment yield simulated using CLIGEN-generated climate data were 1499 mm, 588 mm, and 0.17 t ha^{-1} for WS1, and 1478 mm, 697 mm, and 0.14 t ha^{-1} for WS4. Compared with the observed average annual precipitation, the CLIGEN-generated value was slightly smaller for WS1 and slightly larger for WS4. Consequently, compared to the observed average annual runoff (table 4), the WEPP-simulated value using CLIGEN-generated climate data was slightly smaller for WS1 and slightly larger for WS4. Compared with estimated average annual sediment yields (table 4), the WEPP-simulated values using CLIGEN-generated climate data were larger for both watersheds, with an overprediction of 23% for WS1 and 75% for WS4 of the observed values. Using either observed or CLIGEN-generated climate data, the online WEPP correctly reproduced the observed differences in the hydrological conditions between WS1 and WS4, with the former having slightly higher precipitation, smaller runoff, and larger sediment yield than the latter.

Table 6 shows the frequency analysis of the extreme events from the annual maximums. For all three return periods (2, 5, and 10 years), the observed precipitation and runoff values were similar for WS1 and WS4 and the estimated sediment yield was larger for WS1 than for WS4. CLIGEN-generated precipitation was similar to the observed values for the 2-year and 5-year return periods and slightly larger than observed for the 10-year return period. Using either observed or CLIGEN-generated climate data, WEPP simulated more runoff than was

Table 6. Frequency analysis of simulated, observed, or estimated runoff and sediment yield. Note that the means and standard deviations (SD) are for the annual maximum series.

		Observed			WEPP-Simulated Using Observed Climate Data		WEPP-Simulated Using CLIGEN-Generated Climate Data		
		Precipitation (mm)	Runoff (mm)	Sediment Yield (t ha^{-1})	Runoff (mm)	Sediment Yield (t ha^{-1})	Precipitation (mm)	Runoff (mm)	Sediment Yield (t ha^{-1})
Watershed WS1									
Return period	10 years	88.4	52.7	0.011	52.8	0.084	103.4	54.0	0.120
	5 years	80.5	37.4	0.008	51.3	0.072	76.6	49.5	0.066
	2 years	63.5	24.1	0.005	33.6	0.033	60.7	37.7	0.042
Mean		64.0	28.5	0.006	34.6	0.043	65.8	37.6	0.048
SD		16.4	13.9	0.003	12.9	0.027	22.7	14.7	0.034
Watershed WS4									
Return period	10 years	90.2	55.4	0.007	56.4	0.084	103.1	57.7	0.110
	5 years	73.7	36.5	0.005	46.6	0.054	76.4	52.0	0.079
	2 years	65.0	24.9	0.003	34.5	0.034	60.5	41.0	0.036
Mean		62.6	28.1	0.003	34.8	0.035	65.5	42.3	0.044
SD		16.8	14.9	0.002	13.2	0.026	22.8	16.0	0.034

observed for the 2-year and 5-year return periods and runoff similar to that observed for the 10-year return period for both watersheds. WEPP-simulated sediment yields were about 10 times the estimated values for all three return periods. The overprediction of the extreme runoff events may be due to erroneous rainfall intensity and duration and incorrect prediction of snowmelt timing. For sediment yield, the overprediction may be attributed to the overprediction of runoff and the underestimation of watershed sediment yield for large events. Finally, WEPP-simulated runoff and sediment yield using CLIGEN-generated data was larger than runoff and sediment yield using observed climate data except for the 5-year return period for WS1.

Summary and Conclusions

Two watersheds (WS1 and WS4) with long-term monitoring records of runoff and water chemistry at the Fernow Experimental Forest near Parsons, West Virginia, were selected for testing the online WEPP GIS interface. Both watersheds have been covered with mature forest for the last two decades and are located in proximity to each other with slightly different hydrological conditions. WS1 produced smaller average annual runoff with larger mean annual precipitation and larger sediment yield with smaller runoff than WS4. For the online WEPP simulations, we used observed and CLIGEN-generated climate data. Watershed structure and topographical inputs for each watershed were generated from the USGS 30 m NED. Soil inputs were adapted from the SSURGO database to site-specific conditions. Land use and management inputs were selected from the WEPP database according to the USGS National Land Cover. The restrictive bedrock layer K_{sat} was calibrated to adequately reproduce the observed surface runoff. The midseason crop coefficient in the FAO Penman-Monteith equation was calibrated so that the simulated ET was in the range of the observed values for the region.

The performance of the online WEPP GIS interface was examined by comparing simulated and observed runoff and simulated and estimated sediment yield for daily and annual values. Overall, the simulation results accurately reflected the differences between WS1 and WS4 in their hydrological conditions. In addition, the online WEPP reasonably simulated annual runoff and overpredicted sediment yield for both watersheds. The overprediction of sediment yield was primarily due to an overprediction of channel peak flow, and thus an overprediction of channel erosion, which accounted for roughly 70% of the delivered sediment. Further work to improve channel parameterization and channel network discretization will improve understanding of the parameters and factors that influence forest hydrologic and erosion modeling using the online WEPP. The online WEPP GIS interface is a user-friendly, web-based computer package that provides a cost-effective simulation tool for scientists, researchers, and practitioners in watershed management. Future research efforts may be devoted to examining the performance of the online WEPP GIS interface under different hydrologic, land use, and management conditions.

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