Calibrating WEPP Model Parameters for Erosion Prediction on Construction Sites

A. D. Moore, R. A. McLaughlin, H. Mitasova, D. E. Line

Abstract. *Soil erosion on construction sites can be many times greater than on agricultural fields, yet there has been little modeling done for construction conditions. The objective of our study was to calibrate management and soil parameters in the agriculturally based model Water Erosion Prediction Project (WEPP) for construction and post-construction site conditions. Data from a 4 ha watershed at various stages of construction in Wake County, North Carolina, were used to compare model results with measured runoff volume and sediment yields. Model simulations were performed in GeoWEPP, a geospatial interface designed for WEPP that operates within ArcView GIS. Model parameters were adjusted from WEPP default parameters as supported by the literature and site observations. Predicted values were regressed against field data for Nash-Sutcliffe model efficiency (NSE), with NSE > 0.50 regarded as satisfactory performance. We were able to generate runoff and sediment yields comparable to observed values by replacing soil surface properties with subsoil properties, in conjunction with the cutslope management parameter file in WEPP. We found a similar agreement between predicted and observed values for stabilized conditions by increasing critical shear stress from 0.3 to 10 Pa for the soil input layer. In addition, changes to the model source code to reduce the lower limit of effective hydraulic conductivity (Kef) for impermeable surfaces resulted in improved runoff NSE, but consequently increased sediment yield on areas with higher Kef values. WEPP has great potential for modeling applications on construction sites; however, more validation studies are needed to confirm and expand upon our findings.*

Keywords. *Calibration, Construction, Erosion, GeoWEPP, GIS, Runoff, Sediment, Watershed, WEPP.*

Since the passage of the Soil Conservation Act in 1935, agriculture has been the primary focus of erosion control in the U.S. Various incentives and efforts in education have reduced erosion from U.S. croplands and Conservation Reserve Program land by 32% between 1982 and 1997 (USDA-NRCS, 1997). This trend is a result of a strong financial incentive to prevent the loss of nutrient-rich topsoil. Unfortunately, there are other sources of sediment pollution that are overlooked that also contribute large amounts of sediment to neighboring streams, such as exposed soil surfaces on construction sites. Wolman and Schick (1967) demonstrated that construction areas contributed more sediment on an area basis than agricultural fields. The U.S. Environmental Protection Agency (USEPA, 1976) documented the magnitude of impact to be greater for forested areas disturbed by construction sites than by farmland. Toy and Hadley (1987) also noted that land disturbance from mining, residential, commercial, and highway construction accelerated erosion by two or more orders of magnitude. By 1980, construction activities had disturbed an estimated 1.7% of land in the U.S. (Toy and Hadley, 1987). Several studies have illustrated the harmful impacts of sediment from land-disturbing activities on riffle and pool macroinvertebrates, resulting in population reductions and imbalances (Barton, 1977; Taylor and Roff, 1986; Hogg and Norris, 1991). Other negative impacts include sedimentation reduction of water reservoir capacity, damage of vegetation, and increased runoff. Gregory et al. (2006) found that equipment traffic resulted in infiltration rate reductions of up to 99% on construction sites compared to predevelopment rates.

Erosion prediction models can provide estimates of sediment losses from disturbed sites to predict (and prevent) heavy sediment loading. With the large number of models available, it is important to carefully select the erosion prediction model that best meets the needs of a contractor/developer in the case of construction activity. The Universal Soil Loss Equation (USLE) was the first widely accepted erosion prediction model, and quite possibly the most recognized model (Wischmeier and Smith, 1965). The USLE is a simple empirical model supported by statistically significant relationships, and is therefore limited to the areas and conditions that it was derived from. For this reason, USLE is a poor choice for the highly variable conditions that exist on construction sites. The more commonly used Revised Soil Loss Equation (RUSLE) was created from the USLE model in order to include improved versions of the determining factors (crop, rainfall, erodibility, slope length, and support practice) and was upgraded further as RUSLE2 to include process-based equations within the empirical structure (Renard et al., 1997). Although an improvement of the USLE, these empirical models are still extremely limited in their applications, as mentioned previously.

Submitted for review in May 2006 as manuscript number SW 6473; approved for publication by the Soil & Water Division of ASABE in January 2007.

The authors are **Amber D. Moore,** Research Affiliate, USDA-ARS, Prosser, Washington; and **Richard A. McLaughlin, ASABE Member,** Associate Professor, Department of Soil Science, **Helena Mitasova,** Associate Adjunct Professor, Department of Marine, Earth and Atmospheric Sciences, and **Daniel E. Line, ASABE Member Engineer,** Extension Specialist, Department of Biological and Agricultural Engineering, North Carolina State University, Raleigh, North Carolina. **Corresponding author:** Amber D. Moore, USDA-ARS, 24106 Bunn Rd., Prosser, WA 99350; phone: 509-786-9362; fax: 509-786-9277; e-mail: amoore@pars.ars.usda.gov.

The most suitable erosion prediction model for construction sites would be a process-based model, which maintains both empirical and physical relationships within a physically based structure. The Water Erosion Prediction Project (WEPP) model is a process-based erosion prediction model that was originally developed as a replacement for the USLE model to provide users with a model that: (1) can be applied to a variety of situations, (2) can predict erosion losses from both single storm events and long-term averages, (3) can estimate erosion and deposition on both hillslopes and watersheds, (4) can estimate deposition in small impoundments, and (5) is user-friendly (Flanagan et al., 2001). The greatest disadvantage in using WEPP for construction sites is that it was developed for agricultural landscapes instead of construction sites. Romkens et al. (1975) noted the challenge of applying erosion prediction models to land-disturbing conditions. He observed that models consist of equations that are based on relationships determined from the surface soil layer, which is generally coarser in texture and has a lower bulk density than the exposed subsoils on construction sites. In contrast to construction sites, agricultural surfaces are partially protected from soil loss by raindrop impacts. In addition, root systems serve as an anchor, holding the soil in place when soil moisture reaches and exceeds the saturation point. Erosion output for agricultural erosion prediction models is typically expressed as soil loss, since the greatest concern of farmers is generally the conservation of topsoil. In contrast, sediment pollution in neighboring streams is a greater concern on construction sites than soil loss.

There has been a significant effort to develop WEPP parameters for agricultural fields (Liebenow et al., 1990; McIsaac et al., 1992; Zhang et al., 1995a, 1995b) and rangelands (Nearing et al., 1989; Wilcox et al., 1992; Simanton et al., 1991; Savabi et al., 1995). In contrast, there has been extremely limited work toward calibrating WEPP parameters for construction sites (Lindley et al., 1998; Laflen et al., 2001). Some options for disturbed areas have recently been added to the management and soil input parameters in the WEPP model. However, they were derived from cleared areas in forested regions and most likely do not represent construction site conditions in urban areas.

Another limitation of the WEPP model is the manual partitioning of complex landscapes into homogeneous hillslope segments. This is challenging for construction sites, where topography, soil, and even management can vary significantly. It is necessary to account for these variations in order to accurately predict erosion and deposition rates. To support efficient modeling in areas with spatially variable topography, Renschler (2003) developed GeoWEPP, a geospatial interface for WEPP that operates within ArcView GIS. GeoWEPP maps illustrate expected soil loss and deposition on individual raster cells, providing the user with the ability to pinpoint erosion-prone areas within the watershed. Since the development of the interface, several studies have reported on the application of GeoWEPP for analysis of the WEPP model equations, as well as simulating a variety of land management scenarios for decision making. Covert et al. (2005) applied GeoWEPP to harvested and prescribed-burn timber forests, finding that the WEPP hydrologic equations reasonably modeled several years of monitored runoff and sediment data. Renschler and Lee (2005) compared a variety of field border and grassway best management practice scenarios by altering land management inputs into the GeoWEPP model.

The purpose of our study was to isolate and/or develop WEPP input parameter files to be used with WEPP and GeoWEPP software for the accurate prediction of runoff volumes and sediment yields exiting construction sites.

Methods and Materials

Site Description

Construction site parameters were calibrated by comparing runoff and sediment data to WEPP model outputs for a small 4.2 ha watershed undergoing construction activities. The watershed was located at 35.818° N and 78.856° W on a 160 ha development site for the Carpenter Village residential community in Cary, North Carolina (fig. 1). Approximate elevation of the watershed was 107 m above sea level. A sediment trap was installed at the watershed outlet, as required by North Carolina erosion and sediment control standards, and was monitored for determination of sediment trapping efficiency (Line and White, 2001). Detailed dimensions of the sediment trap were provided by Line and White (2001). Site and sampling information for both construction and post-construction conditions at the Carpenter watershed is listed in table 1.

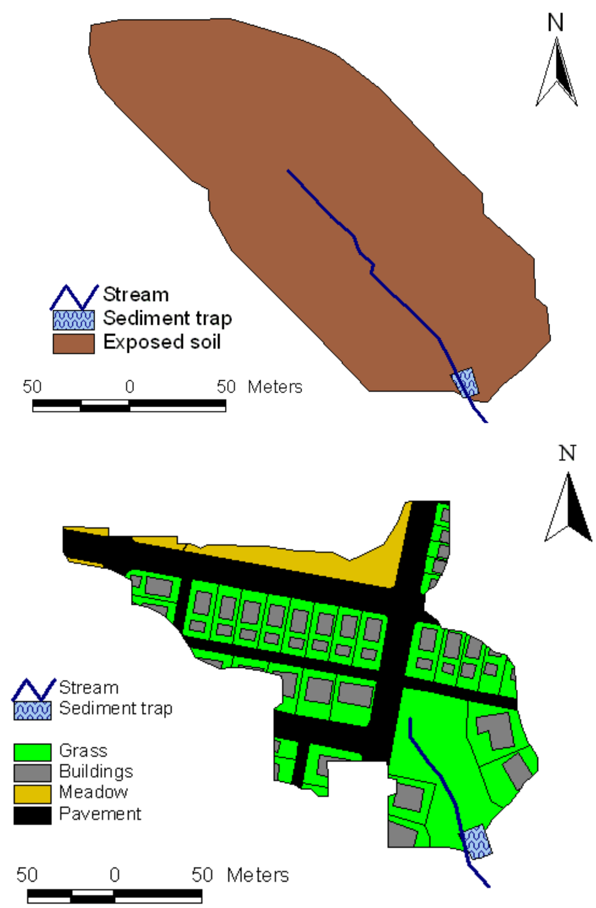

Figure 1. Management maps of the Carpenter watershed during (top) construction and (bottom) site stabilization. Watershed boundaries before and after construction were altered as a result of clearing and grading changes at the site.

Table 1. Site and sampling characteristics of the Carpenter watershed.

	Construction	Post-construction[a]
Area (ha)	4.2	2.5
Average slope	3%	3%
Range of slope	0% to 8%	0% to 9%
Soil Series[b]	15% Worsham 24% White Store 61% Creedmoor	45% impermeable 15% Worsham 12% White Store 28% Creedmoor
Management	100% bare soil	4% impermeable 47% stabilized surfaces 7% tall grass
Storm events monitored	37	39
Sampling period	10 Dec. 1997 to 13 Dec. 1998	13 Dec. 1998 to 25 Apr. 2000

[a] Watershed characteristics were altered due to changes in topography that occurred during grading.
[b] Because of the WEPP input structure, it is necessary to include impermeable surfaces in soils and management layers.

Watershed Monitoring

Watershed monitoring at Carpenter was described in detail by Line and White (2001). Briefly, a rectangular weir with end contractions and a width of 0.91 m was placed downstream of the sediment trap at the watershed outlet. Flow measurements were taken 0.3 m upstream of the weir at 5 min intervals. Continuous measurement of water depth over the weir was made by an automated sampler and converted to flow using the following equation (Grant, 1991):

$$Q = 3.330 \times (3.0 - 0.2H) \times H^{1.5} \quad (1)$$

where Q is the flow rate (cfs), and H is the depth of water (ft) over the weir crest.

The sampler was programmed to begin sampling when water depth exceeded 0.1 cm above the weir, and samples were collected for every 38 to 57 m^3 of runoff passing through the weir. Samples collected from each storm were combined into one composite sample for TSS measurement. Precipitation depth was measured for over 95% of the events at 15 min intervals with a tipping-bucket rain gauge on site. Precipitation data for the missed storm events were collected from the Raleigh-Durham International Airport weather station, located approximately 10 km from the site (SCONC, 2004).

Sediment Yield Estimation

The following is a brief description of the sediment yield information presented by Line and White (2001). The sediment load exiting the trap for individual storms was calculated from flows and sample sediment concentrations, and the sediment retained was estimated from deposition depth and sampling within the trap (table 2). Measurement of sediment trap deposition consisted of periodically surveying sediment deposition depth and computing the change in volume of deposited sediment. Between two and four samples from the deposited sediment were collected on 13 November 1998, 16 February 1999, and 3 September 2000 and analyzed for bulk density to convert volume of sediment into mass. During the depth survey periods, sediment yield was the total sediment exiting the trap plus the total deposited.

Table 2. Sediment trapping efficiency for the sediment trap at the Carpenter watershed between sampling events.[a]

Construction Phase	Sampling Date	Sediment Load (kg)	Trapping Efficiency (%)	Peak Storm Intensity (in./h)
Clearing and grading	23 July 1998	39000	77	1.30
	25 Aug. 1998	53000	49	2.03
	14 Oct. 1998	41000	71	0.68
Stabilization	8 Jan. 1999	3000	23	0.77
	16 Feb. 1999	7000	69	0.30
	12 May 1999	3000	18	0.88
	3 Sept. 1999	5000	47	1.03
	3 Mar. 2000	12000	18	0.77

[a] Adapted from Line and White (2001).

Model Description

WEPP (Water Erosion Prediction Project) is a distributed parameter, one-dimensional, process-based erosion model that is used to predict sediment yield and runoff volume during storm events by simulating the detachment, transport, and deposition of sediment on rectangular hillslopes during runoff events (Flanagan and Nearing, 1995). Model runs were simulated using the flowpath method in GeoWEPP ArcX 2004.3, which is an ESRI-ArcView extension that directly links Geographic Information Systems (GIS) to the WEPP model (Renschler, 2003). GeoWEPP uses a digital elevation model (DEM) supplied by the user to create channels and subwatersheds. In the flowpath method, the WEPP model equations are applied to all possible flowpaths, using the slope profile of the path as the representative slope. Sediment loss and runoff volume are calculated for each flowpath, and then averaged at the flowpath discharge point into the channel (Cochrane and Flanagan, 1999). Climate, management, and soil parameter inputs were adjusted in WEPP version 2004.70. The WEPP source was modified to decrease the minimum limit of effective hydraulic conductivity (K_{ef}) from 0.07 to 3.6×10^{-8} mm h^{-1} to completely inhibit infiltration beneath impermeable areas in our simulations (D. Flanagan, personal communication, 13 Feb. 2006). Both the original and the altered WEPP executable code were used in our modeling efforts.

Model Inputs

Data layers for GeoWEPP were constructed and modified using ArcView GIS 3.2a and GRASS 5.0. The DEMs were computed using a spline module in GRASS (Neteler and Mitasova, 2004) to interpolate 2 ft (0.6 m) interval contour maps to a 5 m resolution grid for the construction phase. The 5 m DEM for the post-construction phase was interpolated from LIDAR data with a one point per 3 m density, again using the spline algorithm. Soil maps scaled at 1:24,000 were downloaded from the USDA-NRCS Soil Survey Geographic (SSURGO) database (USDA-NRCS, 2000). The management maps for the Carpenter watershed post-construction simulation was derived from aerial photos of the site. Aerial photos were not taken during construction; therefore, the management for the Carpenter watershed was assumed to be entirely bare soil for the construction simulation. Soil, management, and DEM grids were exported to the ASCII format required by the GeoWEPP program.

Calibration

Soil and management parameters were calibrated using sediment yield and runoff volume measurements for storm events from the watershed outlet. For the calibration step, we used WEPP default parameter files whenever possible to gain a better understanding of the current WEPP parameter files for construction site conditions. Our method was to fit the data to model output based on adjustments supported by previous research, suggestions from the WEPP manual (Alberts et al., 1995), and personal observations. Predicted values were regressed against measured field data for Nash-Sutcliffe model efficiency (NSE), which is defined as the variance of prediction from a 1:1 line (Nash and Sutcliffe, 1970). NSE is calculated as follows:

$$\mathrm{NSE} = 1 - \frac{(Y_{\mathrm{obs}} - Y_{\mathrm{pred}})^2}{\sum (Y_{\mathrm{obs}} - Y_{\mathrm{mean}})^2} \qquad (2)$$

where

Y_{obs} = measured sediment yield (tonne) or runoff volume (m^3) for each storm event

Y_{pred} = model-predicted sediment yield or runoff volume for each storm event

Y_{mean} = mean measured sediment yield or runoff volume over all storm events.

The NSE ranges from $-\infty$ to one, with a value of one representing a perfect fit between predicted and measured data. An NSE of zero indicates that the mean measured value is as good an overall predictor as the model, and a negative efficiency indicates that the measured mean is a better predictor than the model (Zhang et al., 1995a, 1995b). Quinton (1997) suggested that NSE values greater than 0.5 indicate satisfactory model performance. Therefore, we generally considered parameters used for model runs with NSE values greater than 0.5 to be satisfactory for construction site conditions, with NSE values greater than zero but less than 0.5 to be adequate, and NSE values less than zero to be poor.

Soil Parameters

Surface soil properties and parameters that were used for WEPP model simulations are listed in table 3. The clay loam cutslope (CLCS) soil parameter file was selected from the WEPP soil database for construction conditions, because all three of the soil series on the Carpenter watershed have fine-textured subsoils according to the USDA-NRCS soil series database (USDA-NRCS, 2006). The term “cutslope” generally refers to graded areas on construction sites. The Worsham (Typic Endoaquult), White Store (Oxyaquic Vertic Hapludalf), and Creedmoor (Aquic Hapludult) soil series parameter files, which were mapped on the site by USDA-NRCS, were also selected for calibration. Because the Appling, Cecil, and White Store soil series were not included in the WEPP soil database, new profiles were created using NRCS soil series descriptions for texture information and suggestions from the WEPP manual for soil erosion factors, including critical shear stress and erodibility (Flanagan and Livingston, 1995; Alberts et al., 1995). The three soil series parameter files were also altered to account for the removal of topsoil during clearing by removing the soil surface (A horizon). Effective hydraulic conductivity (K_{ef}) was adjusted manually as a function of hydrologic soil group and sand percentage using recommendations from the WEPP manual (Flanagan and Livingston, 1995; Alberts et al., 1995). Effective hydraulic conductivity is a variable in the Green-Ampt infiltration model and is based on saturated hydraulic conductivity. Predetermined values for critical shear stress (τ), interrill erodibility (K_i), and rill erodibility (K_r), as a function of soil texture, were also used from the WEPP manual (Flanagan and Livingston, 1995; Alberts et al., 1995).

The impermeable-surfaces soil parameter file was created using suggestions from Laflen et al. (2001) to represent non-soil surfaces such as roads and rooftop surfaces. The critical shear stress value, rill, and interrill erodibility values were modified to prevent soil detachment from these surfaces in the model (table 3). The lower limits of effective hydraulic conductivity (K_{ef}) were reduced to 3.6×10^{-8} mm h^{-1} in the model source code to completely prevent infiltration of water into the soil layer beneath these surfaces.

The soil input parameter files for the post-construction phase were selected based on results from calibration of the construction phase, with the assumption that physical soil properties had not significantly changed between grading and stabilization. The site was stabilized with a combination of grass seed and either erosion mats or straw tacked with tar. To simulate a recently stabilized surface, critical shear stress values for erosion mats were used to replace critical shear stress values for each soil series. Since the critical shear stress of the mats and the straw mulch combination used at the site is not known, we applied critical shear stress values for erosion mat products (τ = 74 Pa) that had been used in previous WEPP model testing for initial modeling efforts (Laflen et al., 2001).

Management Parameters

WEPP management parameters that were identified as highly sensitive by Nearing et al. (1990) are listed in table 4. The WEPP cutslope management file was used for imperme–

Table 3. Surface soil properties and WEPP input soil parameters for the Carpenter watershed.

Soil Parameter File	Soil Texture[a]	Hydrologic Soil Class	Interrill Erodibility, K_i (kg sec m^{-4})	Rill Erodibility, K_r (sec m^{-1})	Crit. Shear Stress, τ (Pa)	Hydraulic Cond., K_{ef} (mm h^{-1})	Sand (%)	Clay (%)	CEC (meq 100 g^{-1})	Rock (%)
CLCS[b]	CL	--[c]	1.50×10^6	1.00×10^{-3}	1.0	2.0	30	30	26	20
Impermeable surfaces	SL	--[c]	1.00×10^3	1.00×10^{-4}	100	0.1	10	70	25	90
Creedmoor	SL	C	4.88×10^6	9.21×10^{-3}	2.8	12.6	68	12	4.5	3
Creedmoor subsoil	CL	C	4.31×10^6	4.80×10^{-3}	4.7	0.3	43	27	5.5	2
White Store	FSL	D	4.88×10^6	9.20×10^{-3}	2.8	0.3	60	10	10	3
White Store subsoil	CL	D	4.31×10^6	4.80×10^{-3}	4.7	0.3	30	40	30	2
Worsham	FSL	D	6.02×10^6	9.56×10^{-3}	2.7	9.8	55	16	5.8	5
Worsham subsoil	C	D	2.15×10^6	8.90×10^{-3}	2.9	0.3	41	42	8.5	6

[a] SL = sandy loam, L = loam, CL = clay loam, FSL = fine sandy loam, C = clay.
[b] CLCS = clay loam cutslope parameter file.
[c] Not applicable.

Table 4. Selected WEPP management parameters for the Carpenter watershed.

Plant Growth and Harvest Parameters[a]	Cutslope	Bare Soil[b]	Continuous Grass
Maximum Darcy Weisbach friction factor for living plant	1	0	12
Days since last tillage	0	200	200
Days since last harvest	0	2000	92
Initial canopy cover (%)	0	0	50
Initial interrill cover (%)	0	0	50
Initial residue cropping system	Fallow	Fallow	Perennial
Initial ridge height after last tillage (cm)	0.6	0	2
Initial rill cover (%)	0	0	50
Initial roughness after last tillage (cm)	0.6	0.1	2
Initial total dead root mass (kg m^{-2})	0	0	0.2

[a] Agricultural conditions in the management parameters were manipulated to reflect construction site conditions.
[b] Experimental parameter file not included in the WEPP software.

able roads and rooftops to represent a surface that is essentially absent of vegetation. As recommended by Laflen et al. (2001), the cutslope management file was used in combination with the impermeable soil file to represent the extremely low permeability and erodibility values of impermeable surfaces. Our experimental bare soil management file was also combined with the impermeable soil file for comparison with the cutslope management file.

The WEPP cutslope management file and the experimental bare soil management file were tested to represent the exposed soil surface during the construction phase. For the post-construction phase, the WEPP continuous grass management file was tested, assuming full vegetative grass cover on the site. The WEPP continuous grass management file is representative of perennial grass that is not mowed or harvested. Because the grass seeded at the site was mowed regularly, we compared the WEPP continuous grass file with an altered version that was cut on a weekly basis from May until September through model simulations (data not shown). We found that the WEPP model was not sensitive to the addition mowing; therefore, we decided to use the WEPP continuous grass file instead of creating a new management file. In addition to the continuous grass file, the bare soil management file was tested in conjunction with the erosion mat soil parameter files in order to provide minimal management interaction for these newly stabilized surfaces (rill and interrill cover = 0%) (table 4).

Results and Discussion

The NSE values for sediment yield and runoff from the Carpenter watershed were determined separately for construction and post-construction conditions. Soil and management parameters listed in tables 3 and 4 were tested and adapted as necessary, as described below. Soil and management parameters were continually changed until the NSE values for both sediment and runoff volume were greater than 0.50. Changes were performed based on suggestions from the literature, suggestions from WEPP model experts, site observations, and basic intuition. Justification for parameter selection is described in greater detail in the preceding Calibration section.

Construction Phase

Simulation of construction conditions began with the WEPP clay loam cutslope (CLCS) soil parameter file, which consistently underpredicted runoff volume and overpredicted sediment yield (runs 8 and 9, table 5). The effective hydraulic conductivity (2.0 mm h^{-1}) was used for all three mapped soil types, which had calculated hydraulic conductivity values ranging from 0.3 to 12.6 mm h^{-1} (table 3). The rock content for the CLCS parameter file was also much higher (20%) than is typical for the Worsham, White Store, and Creedmoor soils (table 3). Applying WEPP soil parameters separated by soil series improved model efficiencies for both sediment and runoff when compared to CLCS, but still underpredicted runoff volume (runs 8 and 10, table 5). This was a result of overestimating hydraulic conductivity, which was calculated to be as high as 12.6 mm h^{-1} using the recommended equations from the WEPP manual (Alberts et al., 1995). The overestimation of hydraulic conductivity was related to the higher sand content associated with surface soil horizons, in comparison to the lower subsoil horizons (table 3).

Applying individual WEPP soil series without the A horizon to represent the three different soils at the site further improved the NSE from 0.33 to 0.78 for runoff volume and from −0.07 to 0.66 for sediment yield when combined with the bare soil management parameter file (runs 11 and 13, table 5). This improvement is related to a reduction in soil infiltration, ranging in effective hydraulic conductivity from 0.3 to 1.9 mm h^{-1} (table 3). These results suggest that GeoWEPP has potential as an effective model for predicting runoff volumes and sediment yields from construction sites when the

Table 5. NSE coefficients for WEPP-predicted output and measured values for the construction phase.

Run	Land Cover	Soil Series			NSE		% Error[a]	
					Runoff	Sediment Yield	Runoff	Sediment Yield
	Exposed soil	Creedmoor	White Store	Worsham				
8[b]	Cutslope	CLCS[c]	CLCS	CLCS	0.01	−0.04	−62	109
9	Bare soil[d]	CLCS	CLCS	CLCS	0.26	−1.62	−62	82
10	Cutslope	Creedmoor	White Store	Worsham	0.34	0.44	−58	20
11	Bare soil	Creedmoor	White Store	Worsham	0.33	0.53	−58	−18
12	Cutslope	Creedmoor subsoil[d]	White Store subsoil[d]	Worsham subsoil[d]	0.78	−0.07	−6	49
13[e]	Bare soil	Creedmoor subsoil	White Store subsoil	Worsham subsoil	0.78	0.66	−5	2

[a] % Error = [(predicted − measured) / measured] × 100. Negative values represent an underprediction of runoff or sediment; positive values represent an overprediction.
[b] Starting parameters.
[c] CLCS = clay loam cutslope soil parameter file.
[d] Experimental soil and management parameters.
[e] Row is shaded to indicate optimal WEPP parameters for modeling runoff and sediment yield on a landscape during cutting and grading.

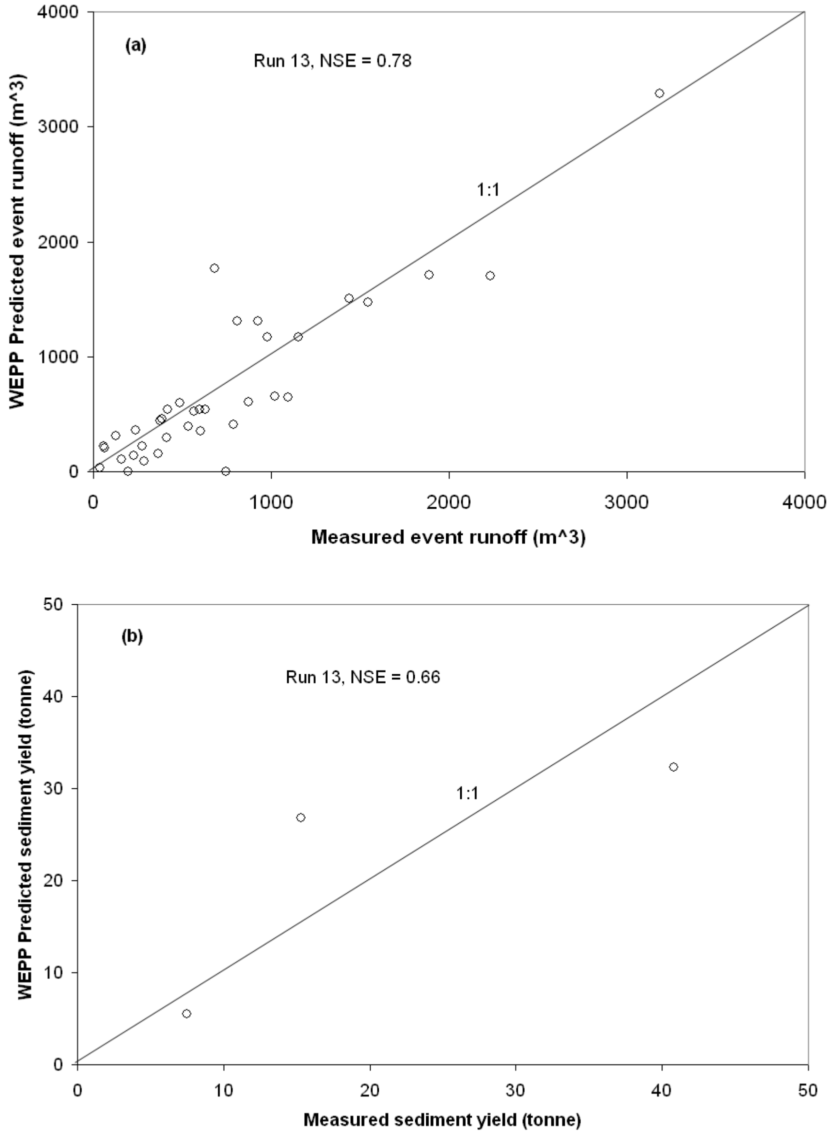

Figure 2. Observed and WEPP-predicted (a) runoff volumes and (b) sediment yields for the Carpenter watershed, applying WEPP soil parameter files for individual soil series without the A horizon along with the bare soil management parameters. The three data points in fig. 2b represent the three sediment depth survey events at the site.

appropriate soil and management parameters are used (fig. 2). It is common for subsoils to become the surface soil during the grading operations on a construction site.

Applying the WEPP cutslope management parameters provided a satisfactory runoff efficiency coefficient (NSE = 0.78) when combined with the soil series parameters for subsoil (run 12, table 5); however, the sediment efficiency coefficient was poor (NSE = −0.07). Our experimental bare soil management provided the same runoff NSE as the cutslope management, but with a satisfactory sediment yield efficiency coefficient (NSE = 0.66). Applying the bare soil management parameters provided a smaller difference in soil loss between the total predicted and the total measured sediment load than the cutslope management, with an overprediction 49% when the cutslope management was applied and an overprediction of only 2% for bare soil (runs 11 and 12, table 5). The bare soil management parameters included an initial 200 days since the last tillage event, compared to zero days for the WEPP cutslope management (table 4). The WEPP model calculates sealing and crusting as a function of cumulative days since last soil disturbance (Alberts et al., 1995), which likely explains why the bare soil management was more representative of compacted construction site soils as opposed to a freshly tilled soil.

The Carpenter watershed was delineated accurately in comparison to actual inspections at the site. We decreased the critical source area (CSA) in GeoWEPP, which represents the threshold drainage area necessary for a channel formation, from 5 ha to 1 ha in the model in order to extend the stream into the watershed, as had been visually observed at the site. The model produced expected patterns of minimal soil loss on gradual slopes near the watershed boundary and greater soil loss on steeper slopes leading into the stream (fig. 3).

Temporary Stabilization

We initially selected the WEPP continuous grass file to represent the combination of seed along with the ground

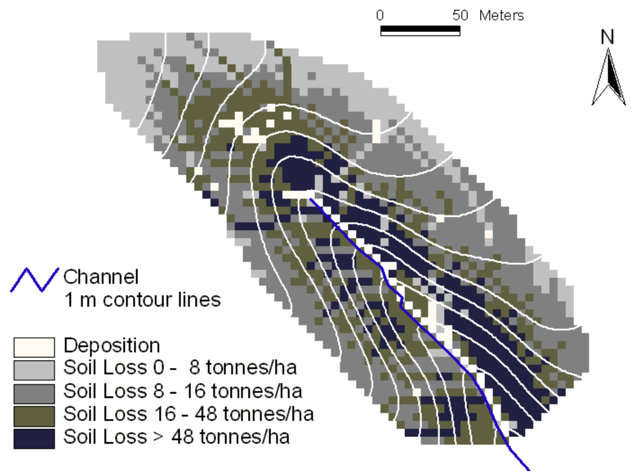

Figure 3. GeoWEPP-generated annual soil loss map for the Carpenter watershed, applying WEPP individual soil series parameters without the A horizon along with the bare soil management parameters.

covers on the soil, assuming that the properties of the germinating grass combined with the ground covers would be similar to that of established grass. As previously mentioned, the continuous grass cover was not mowed, but because grass cutting had no effect on sediment yield or runoff in the model, adjustments were not made to the parameter file. The WEPP continuous grass file was a satisfactory management parameter file for predicting runoff volume (NSE = 0.57) but poor for sediment yield (NSE = −0.29) (run 14, table 6). The underprediction of sediment yield was most likely an effect of the 50% ground coverage assumed in the model, which inhibited soil detachment. It is likely that the actual coverage was significantly less than 50%, as the grass usually takes several months to become established and there are often areas of poor stand establishment.

Because the model underpredicted sediment yield when we used grass cover as the management parameter file, we decided to experiment with the method suggested by Laflen et al. (2001) to account for the properties of the erosion mats. We applied the bare soil management parameters in conjunction with a critical shear stress value for erosion control mats (τ = 74 Pa) (run 15, table 6). Because erosion mat manufacturers publish information on critical shear stress instead of values for WEPP management coefficients, we had to make management adjustments in the soil component where critical shear value stress is entered. The result was a good runoff efficiency coefficient (NSE = 0.81) but only adequate sediment yield efficiency coefficient (NSE = 0.44) (run 15, table 6).

To increase sediment yield in the WEPP output, we experimented with reducing the critical shear stress values from 74 Pa to 10 Pa to decrease the length of time required for soil detachment to begin. Typical shear stress values for bare surface soils typically range from 0 to 7 Pa (Elliot et al., 1989). Therefore, we selected a critical shear stress value greater than that found on soil surfaces to simulate the decrease in soil detachment expected from erosion control covers. Sprague et al. (2001) recommended a permissible shear stress between 4 and 10 Pa for erosion control netting, and Chen and Cotton (1988) recommended 7.2 Pa for woven paper netting. Reducing the critical shear stress to 10 Pa increased the sediment yield NSE to 0.98, while reducing the NSE value slightly to 0.69 for the runoff volume (run 17, table 6; fig. 4).

Despite the fact that we were within the satisfactory range for NSE for both runoff volume and sediment yield, we were interested in experimenting with K_{ef} values lower than 0.1 mm h^{-1} for pavement surfaces. Because the WEPP model requires an input value greater than zero for K_{ef}, we had to experiment with extremely low values to achieve the desired results. The source code for WEPP version 2004.70 was modified to reduce the lower limit of K_{ef} from 0.07 to 3.6×10^{-8} mm h^{-1} (D. Flanagan, personal communication, 13 Feb. 2006). We lowered the K_{ef} for pavement from 0.1 to

Table 6. NSE coefficients for WEPP-predicted output and measured values for the stabilization phase.

Run	Management				Soil Series			NSE		% Error[a]	
								Runoff	Sediment Yield	Runoff	Sediment Yield
	Tall grass	Impermeable surfaces and buildings	Stabilized area	Impermeable surfaces and buildings	Creedmoor	White Store	Worsham				
14[b]	Tall prairie grass	Bare soil[c]	Grass	Impermeable surfaces[d]	Creedmoor subsoil[c]	White Store subsoil[c]	Worsham subsoil[c]	0.57	−0.29	−69	−61
15	Tall prairie grass	Bare soil	Bare soil	Impermeable surfaces	Creedmoor subsoil (τ = 74 Pa)	White Store subsoil (τ = 74 Pa)	Worsham subsoil (τ = 74 Pa)	0.81	0.44	−38	−41
16	Tall prairie grass	Bare soil	Bare soil	Impermeable surfaces	Creedmoor subsoil (τ = 10 Pa)	White Store subsoil (τ = 10 Pa)	Worsham subsoil (τ = 10 Pa)	0.69	0.98	−48	12
17[e]	Tall prairie grass	Bare soil	Bare soil	Impermeable surfaces (K_{ef} = 0.0001 mm h^{-1})	Creedmoor subsoil (τ = 10 Pa)	White Store subsoil (τ = 10 Pa)	Worsham subsoil (τ = 10 Pa)	0.89	0.75	−24	54

[a] % Error = [(predicted − measured) / measured] × 100. Negative values represent an underprediction of runoff or sediment; positive values represent an overprediction.
[b] Starting parameters.
[c] Experimental soil and management parameters.
[d] Impermeable surface parameter file created by Laflen et al. (2001), but not currently available with WEPP software.
[e] Row is shaded to indicate optimal WEPP parameters for modeling runoff and sediment yield on a stabilized landscape.

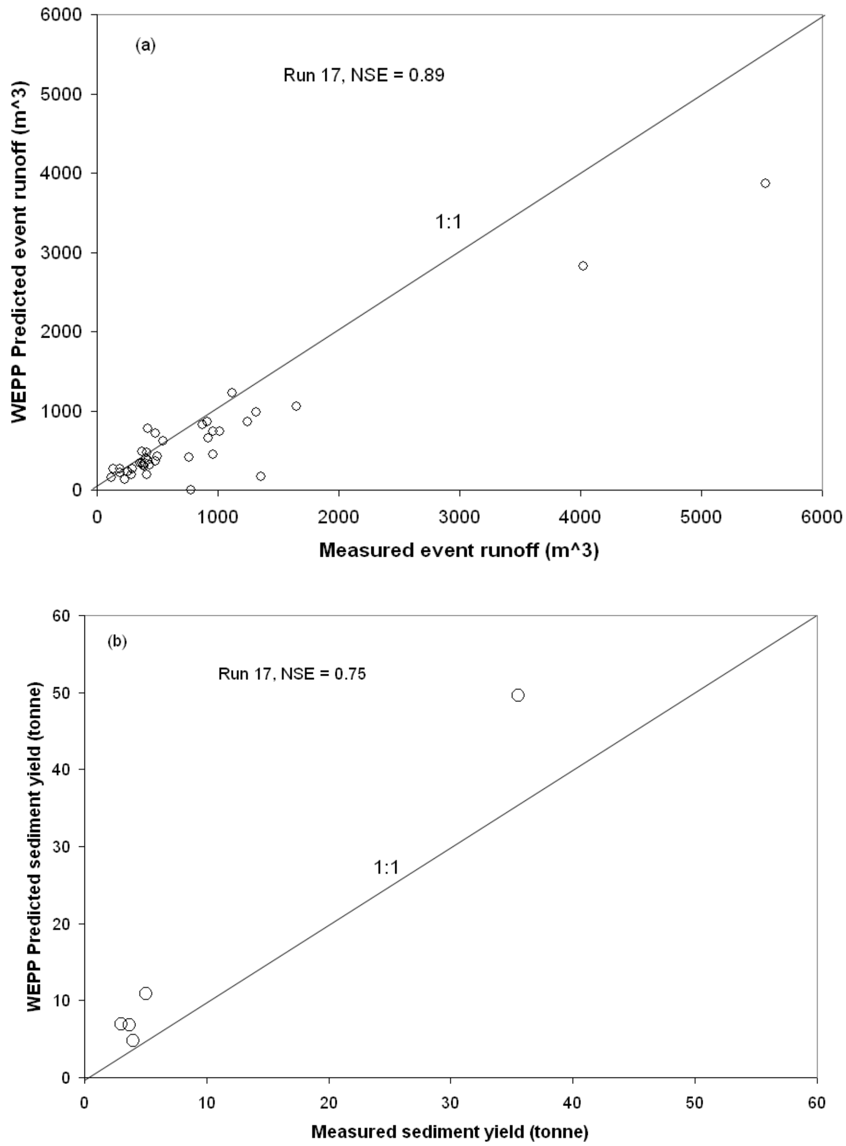

Figure 4. Observed and WEPP-predicted (a) runoff and (b) sediment yield for the Carpenter watershed for the post-construction phase (τ = 10 Pa).

0.0001 mm h^{-1}. This change improved runoff NSE to 0.89, yet also caused a noticeable overprediction of sediment yield (run 17, table 6). We initially believed that this was a direct result of increased runoff, but noticed the same overprediction of sediment yield occurred when using K_{ef} values greater than 1 mm h^{-1}. The error could be attributed to an imbalance between the user input K (K_{input}) and the internally computed K (K_{calc}) (D. Flanagan, personal communication, 24 Feb. 2006). In the new code provided by Flanagan, an internally calculated value could be as low as 3.6 × 10^{-8} mm h^{-1}. This change would affect the K_{input}/K_{calc} ratio, which could potentially increase soil loss and runoff.

Minimal soil loss was predicted by GeoWEPP from roads and buildings, as was expected (fig. 5). Figure 5 suggests that sediment-laden runoff is channeling across one of the roads to get to the watershed outlet. This may or may not be a realistic prediction, because of the storm drains described earlier. Manually altering the DEM to include raster cells of lower value where pipes are located would likely correct flowpath locations as well as the watershed delineation. Soil loss was distributed evenly between 4 and 12 tonnes ha^{-1} for

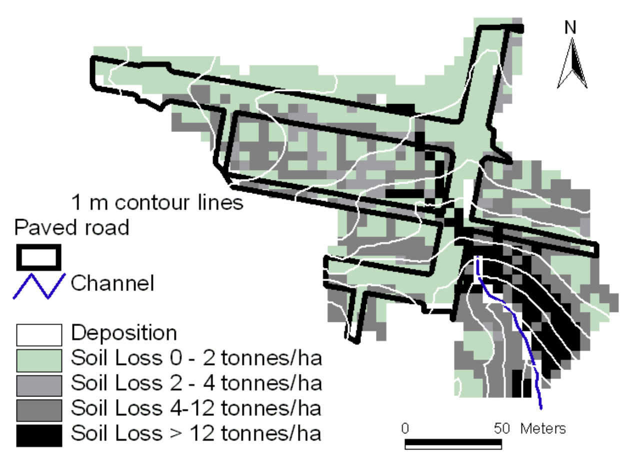

Figure 5. GeoWEPP generated annual soil loss map for the Carpenter watershed, applying optimal parameters for the post-construction phase.

most of the residential properties, but soil loss rates were much greater on steeper slopes near the watershed outlet.

Table 7. Recommended WEPP soil and management parameters for construction and post-construction phases.

Conditions Typically Found on Construction Sites	Suggested WEPP Soil Parameters	Suggested WEPP Management Parameters
Impermeable surfaces (pavement, buildings, roads).	Create an impermeable surfaces parameter for impermeable surfaces, applying parameters suggested by Laflen et al. (2001) in table 3. K_{ef} should be decreased from 0.1 to 0.0001 mm h^{-1}.	WEPP cutslope
Soil surfaces exposed for construction.	WEPP individual soil series with A horizon removed and critical shear stress, erodibility, and hydraulic conductivity adjusted using WEPP user manual.	Create a bare soil parameter for exposed soil surfaces by supplementing WEPP cutslope with the addition of bare soil inputs listed in table 4.
Areas recently stabilized with erosion mats or straw and tackifier.	Same as above for exposed soil surfaces, except τ = 10 Pa for each soil series on all graded areas.	Bare soil (table 4)
Lawn grass	WEPP individual soil series	WEPP continuous grass for lawn grass, addition of harvest/cutting parameters not necessary. No apparent effect on runoff or sediment yield.
Meadow	WEPP individual soil series	WEPP tall grass for meadows, addition of harvest/cutting parameters not necessary. No apparent effect on runoff or sediment yield.

This was observed at the site, with noticeable areas of exposed soil and rills forming on these slopes.

Modeling and Calibration Observations

This study allowed us to make observations about general issues related to model calibration and erosion prediction modeling. It is often the case that models must group inputs into distinct subgroups to simplify the user interface or data needed to run the model. For example, the WEPP inputs are grouped by soil, management, slope, and climate. However, parameters like hydraulic conductivity and critical shear stress are influenced by both soil and management, rather than a single factor. Therefore, the values selected for hydraulic conductivity and critical shear stress, which are added exclusively as soil parameters to WEPP, will change depending on the management inputs used. One solution would be to develop an interface that allows users to access and modify inputs internally calculated by the model.

Parameter Recommendations and Comments for Construction Sites

Table 7 lists a summary of the recommended WEPP parameters based on our findings for the construction and post-construction phases. For soil series not installed in WEPP, we would recommend using soil series data from USDA-NRCS (2006).

Conclusion

In this study, we were successful in developing and applying input parameter files to predict sediment yield and runoff volume with the WEPP model for construction site and stabilization conditions on a 4 ha watershed. Test parameters were selected based on previous research of WEPP application on construction sites, suggestions from the WEPP manual, model observations, and personal communication with WEPP developers. Successful parameter inputs were indicated when NSE values were greater than 0.50. For construction site conditions, replacing surface horizon soil characteristics with subsurface horizon characteristics resulted in an effective runoff efficiency coefficient (NSE = 0.78) and sediment yield efficiency coefficient (NSE = 0.66). After site stabilization at the same watershed, increasing critical shear stress to 10 Pa resulted in satisfactory predictions of runoff volume (NSE = 0.89) and sediment yield (NSE = 0.75) when compared to actual runoff and sediment loss at the site.

For future work, we would recommend monitoring sediment yield and runoff volume from construction sites located on soil types, climates, topographies, and watershed sizes different from ours to validate and add to our parameter suggestions. Finally, we would recommend verifying our post-construction results with the known critical shear stress values of various erosion control products.

Acknowledgements

We would to like acknowledge Dennis Flanagan, Chris Renschler, Jamie Stansell, Rob Austin, and the review committee at ASABE for their invaluable support and advice on this project.

References

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

Barton, B. A. 1977. Short-term effects of highway construction on the limnology of a small stream southern Ontario. *Freshwater Biol.* 7(2): 99-108.

Chen, Y. H., and G. K. Cotton. 1988. Design of roadside channels with flexible linings. Hydraulic Engineering Circular No. 15, Report No. FHWA-IP-87-7. Washington, D. C.: Federal Highway Administration.

Cochrane, T. A., and D. C. Flanagan. 1999. Assessing water erosion in small watersheds using WEPP with GIS and digital elevation models. *J. Soil Water Cons.* 54(4): 678-685.

Covert, S. A., P. R. Robichaud, W. J. Elliot, and T. E. Link. 2005. Evaluation of runoff prediction from WEPP-based erosion models for harvested and burned forest watersheds. *Trans. ASAE* 48(3): 1091-1100.

Elliot, W. J., A. M. Liebenow, J. M. Laflen, and K. D. Kohl. 1989. A compendium of soil erodibility data from WEPP cropland soil field erodibility experiments, 1987 and 1988. NSERL Report No. 3. Columbus, Ohio: Ohio State University and USDA Agricultural Research Service.

Flanagan, D. C., and S. J. Livingston. 1995. *WEPP User Summary.* NSERL Report No. 11. West Lafayette, Ind.: USDA-ARS National Soil Erosion Research Laboratory.

Flanagan, D. C., and M. A. Nearing, eds. 1995. *USDA Water Erosion Prediction Project: Hillslope Profile and Watershed Model Documentation.* NSERL Report No. 10. West Lafayette, Ind.: USDA-ARS National Soil Erosion Research Laboratory.

Flanagan, D. C., J. C. Ascough, M. A. Nearing, and J. M. Laflen. 2001. The Water Erosion Prediction Project (WEPP) model. In *Landscape Erosion and Evolution Modeling*, 145-199. New York, N.Y.: Kluwer Academic/Plenum.

Grant, D. M. 1991. *Isco Open Channel Flow Measurement Handbook.* Lincoln, Neb.: Isco, Inc.

Gregory, J. H., M. D. Dukes, P. H. Jones, and G. L. Miller. 2006. Effect of urban soil compaction on infiltration rate. *J. Soil Water Cons.* 61(3): 117-124.

Hogg, I. D., and R. H. Norris. 1991. Effects of runoff from land clearing and urban development on the distribution and abundance of macroinvertebrates in pool areas of a river. *Australian J. Mar. Freshwater Res.* 42(5): 507-518.

Laflen, J. M., D. C. Flanagan, and B. A. Engel. 2001. Application of WEPP to construction sites. In *Symp. Proc. Soil Erosion Research for the 21st Century*, 135-138. J. C. Ascough and D. C. Flanagan, eds. St. Joseph, Mich.: ASAE.

Liebenow, A. M., W. J. Elliot, J. M. Laflen, and K. D. Kohl. 1990. Interrill erodibility: Collection and analysis of data from cropland soils. *Trans. ASAE* 33(6): 1882-1888.

Lindley, M. R., B. J. Barfield, J. C. Ascough II, B. N. Wilson, and E. W. Stevens. 1998. The surface impoundment element for WEPP. *Trans. ASAE* 41(3): 555-564.

Line, D. E., and N. M. White. 2001. Efficiencies of temporary sediment traps on two North Carolina construction sites. *Trans. ASAE* 44(5): 1207-1215.

McIsaac, G. F., J. K. Mitchell, J. W. Hummel, and W. J. Elliot. 1992. An evaluation of unit stream power theory for estimating soil detachment and sediment discharge from tilled soils. *Trans. ASAE* 35(2): 535-544.

Nash, J. E., and J. V. Sutcliffe. 1970. River flow forecasting through conceptual models: Part I. A discussion of principles. *J. Hydrol.* 10(3): 282-290.

Nearing, M. A., D. I. Page, J. R. Simanton, and L. J. Lane. 1989. Determining erodibility parameters from rangeland field data for a process-based erosion model. *Trans. ASAE* 32(3): 919-924.

Nearing, M. A., L. Deer-Ascough, and J. M. Laflen. 1990. Sensitivity analysis of the WEPP hillslope profile erosion model. *Trans. ASAE* 33(3): 839-849.

Neteler, M., and H. Mitasova. 2004. *Open Source GIS: A GRASS GIS Approach.* Boston, Mass.: Kluwer Academic Press.

Quinton, J. N. 1997. Reducing predictive uncertainty in model simulations: A comparison of two methods using the European Soil Erosion Model (EUROSEM). *Catena* 30(2-3): 101-117.

Renard, K. G., G. R. Foster, G. A. Weesies, D. K. McCool, and D. C. Yoder. 1997. *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation*. Agriculture Handbook No. 703. Washington, D.C.: USDA.

Renschler, C. S. 2003. Designing geo-spatial interfaces to scale process models: The GeoWEPP approach. *Hydrol. Process.* 17(5): 1005-1017.

Renschler, C. S., and T. Lee. 2005. Spatially distributed assessment of short- and long-term impacts of multiple best management practices in agricultural watersheds. *J. Soil Water Cons.* 60(6): 446-456.

Romkens, M. J. M., D. W. Nelson, and C. B. Roth. 1975. Soil erosion on selected high clay subsoils. *J. Soil Water Cons.* 30(4): 173-176.

Savabi, M. R., W. J. Rawls, and R. W. Knight. 1995. Water erosion prediction project (WEPP) rangeland hydrology component evaluation on a Texas range site. *J. Range Mgmt.* 48(6): 535-541.

SCONC. 2004. State Climate Office of North Carolina. Raleigh, N.C.: North Carolina State University. Available at: www.nc-climate.ncsu.edu/.

Simanton, J. R., M. A. Weltz, and H. D. Larsen. 1991. Rangeland experiments to parameterize the water erosion prediction project model: Vegetation canopy cover effects. *J. Range Mgmt.* 44(3): 276-282.

Sprague, J., S. Allen, and J. Nelson. 2001. RECP Laboratory performance testing overview. In *Hot Topics in Geosynthetics II*, 115-129. Folsom, Pa.: Geosynthetic Research Institute.

Taylor, B. C., and J. C. Roff. 1986. Long-term effects of highway construction on the ecology of a southern Ontario stream. *Environ. Pollution Ser. A* 40(4): 317-344.

Toy, T. J, and R. F. Hadley. 1987. *Geomorphology and Reclamation of Disturbed Lands.* San Diego, Cal.: Academic Press.

USEPA. 1976. Loading functions for assessments of water pollution from nonpoint sources. EPA-600/2-76-151. Washington D.C.: U.S. Environmental Protection Agency.

USDA-NRCS. 1997. *A Geography of Hope.* Washington, D.C.: USDA Natural Resources Conservation Service.

USDA-NRCS. 2000. Soil Survey Geographic (SSURGO) data. Washington, D.C.: USDA Natural Resources Conservation Service. Available at: www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/.

USDA-NRCS. 2006. Official Soil Series Descriptions (OSD) with series extent mapping capabilities. Washington, D.C.: USDA Natural Resources Conservation Service, Soil Survey Division. Available at: http://soils.usda.gov/technical/classification/osd/index.html.

Wilcox, B. P., M. Sbaa, W. H. Blackburn, and J. H. Milligan. 1992. Runoff prediction from sagebrush rangelands using water erosion prediction project (WEPP) technology. *J. Range Mgmt.* 45(5): 470-474.

Wischmeier, W. H., and D. D. Smith. 1965. Predicting rainfall erosion losses from cropland east of the Rocky Mountains. Agric. Handbook 282. Washington D.C.: USDA Agricultural Research Service.

Wolman, M. G., and A. P. Schick. 1967. Effects of construction on fluvial sediment, urban and suburban areas of Maryland. *Water Resources Res.* 3(2): 451-464.

Zhang, X. C., M. A. Nearing, and L. M. Risse. 1995a. Estimation of Green-Ampt conductivity parameters: Part I. Row crops. *Trans. ASAE* 38(4): 1069-1077.

Zhang, X. C., M. A. Nearing, and L. M. Risse. 1995b. Estimation of Green-Ampt conductivity parameters: Part II. Perennial crops. *Trans. ASAE* 38(4): 1079-1087.