Geographical information system erosion assessment at a military training site

R.L. Gaffer, D.C. Flanagan, M.L. Denight, and B.A. Engel

Abstract: US military training facilities often experience significant environmental damage from soil erosion. Much of this erosion occurs on roads and trails created by repeated military vehicle traffic during training operations. If the roads are located on steep slopes or in areas of concentrated runoff, soil loss can be accelerated. A geographical information system software package and a modified Universal Soil Loss Equation (USLE) were used to estimate erosion potential at Camp Atterbury located in south-central Indiana. Geospatial interface to the Water Erosion Prediction Project model (GeoWEPP) was also used to estimate soil loss for the camp. Each erosion estimate was overlain with the roads and trails map. Estimated erosion levels on the camp's trafficways with the USLE and GeoWEPP methods were then evaluated with on-site inspections of erosion conditions at Camp Atterbury. A significant correlation was found between predicted and observed erosion for both the modified USLE and GeoWEPP methods. The statistical significance for the USLE and GeoWEPP procedures allows their use in estimating erosion potential for unimproved roads and trails with confidence.

Key words: geographical information system (GIS)—soil erosion prediction—Universal Soil Loss Equation—Water Erosion Prediction Project—water erosion

US military training facilities experience significant erosion on their roads and trails, many of which are created by vehicles deviating from planned roadways during training exercises. Impacts from erosion can be quite costly. Estimated costs for in–stream and off–stream impacts due to sedimentation in the United States exceed $11.6 billion annually (Herzog et al. 2000). Soil erosion often results in sediment–laden streams. Additional impacts can include eutrophication, reduced water quality, fugitive dust, reduced vegetation and ground cover, reduced soil nutrients, altered infiltration patterns, and poor quality wildlife habitats (Grace 2002; Gatewood 2002).

Negative impacts resulting from soil erosion can be minimized; however, in order to most efficiently control or remediate critical regions, the areas with the highest erosion potential must be identified. Often, the most practical and easiest way to do this is with the use of an erosion prediction model. Although the validity of some soil erosion models has been well documented (Tiwari et al. 2000), they have not often been tested for conditions that exist on military training facilities.

Many military facilities have uninhabited lands that are often forested. Forested lands actually have little erosion if left unaltered (Grace 2002) due to increased surface cover from trees and forest litter. Heavy military traffic destroys this residue as well as loosening the road surface, and subsequently forest roads can become major sources of sediment (Binkley and Brown 1993), accounting for as much as 90% of all erosion losses on forested lands (Anderson et al. 1976; McClelland et al. 1999; Megahan 1972). Unvegetated slopes may have accelerated soil losses compared to losses on vegetated slopes (Grace 2002).

Military training roads are sometimes graveled, which has numerous advantages including reducing the amount of exposed surface soil, providing a firmer road surface that resists rutting, and reducing the water flow velocity, thereby reducing its erosive force (Kochenderfer and Helvey 1987). Reducing overland flow momentum decreases the flow shear forces and thus reduces total erosion, and this is most often accomplished by diverting the flow to the surrounding forest floor or by installing drainage dips in the forest road (Egan 1999).

On-site assessment of erosion potential is often not practical for an entire watershed or military facility. Additionally, erosion conditions may not be visible or evident due to vegetation, current weather patterns, or other extenuating circumstances. Equations and/or computer models allow a land manager to readily identify areas of high erosion potential. Numerous soil erosion prediction tools have been developed, including the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978), the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997), and the Water Erosion Prediction Project model (WEPP) (Flanagan and Nearing 1995).

Various studies have been conducted to test models for soil loss from forestlands and roads. For example, Elliot et al. (1999) used the Forest Service Water Erosion Prediction Project model to predict erosion in forested areas. Rhee et al. (2004) conducted a study to assess the accuracy of erosion modeling on forest roads with WEPP using various levels of input: high, intermediate, and low for both the road traveled-way geometry and buffer geometry. They concluded that high levels of detailed input are required to accurately predict sediment delivered to streams. However, for estimated detached sediment, the low levels of detail predicted similar results as inputs with high levels of detail.

Recent improvements have been made to the WEPP prediction system that make it easier to simulate spatial soil erosion losses across a small watershed area (Renschler et al. 2002; Flanagan et al. 2004). Geospatial interface to the Water Erosion Prediction Project model (GeoWEPP) (Renschler et al. 2002; Renschler 2003) is an ArcView extension that is used to set-up and run WEPP model simulations for small watersheds and to display the spatial erosion output results. This system allows for easier and faster applications of the WEPP model, especially for an

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Table 1
Soil series within Camp Atterbury in Indiana.

Soil series	Family level classification	Surface texture	Slopes
Berks	Loamy-skeletal, mixed, mesic, Typic Dystrochrept	Silt loam	6% to 70%
Cincinnati	Fine-silty, mixed, mesic, Typic Fragiudalf	Silt loam	6% to 12%
Crosby	Fine, mixed, mesic, Aeric Ochraqualf	Silt loam	1% to 5%
Dubois	Fine-silty, mixed, mesic, Aeric Fragiaqualf	Silt loam	0% to 2%
Hennepin	Fine-loamy, mixed, mesic, Typic Eutrochrept	Loam	18% to 40%
Hickory	Fine-loamy, mixed, mesic, Typic Hapludalf	Silt loam	12% to 17%
Miami	Fine-loamy, mixed, mesic, Typic Hapludalf	Silt loam	6% to 15%
Rensselaer	Fine-loamy, mixed, mesic, Typic Argiaquoll	Loam	0% to 2%
Sawmill	Fine-silty, mixed, superactive, mesic Cumulic Endoaquolls	Silty clay loam	0% to 3%
Stendal	Fine-silty, mixed, acid, mesic, Aeric Fluvaquent	Silt loam	0% to 2%

experienced geographical information system (GIS) user (Flanagan et al. 2004).

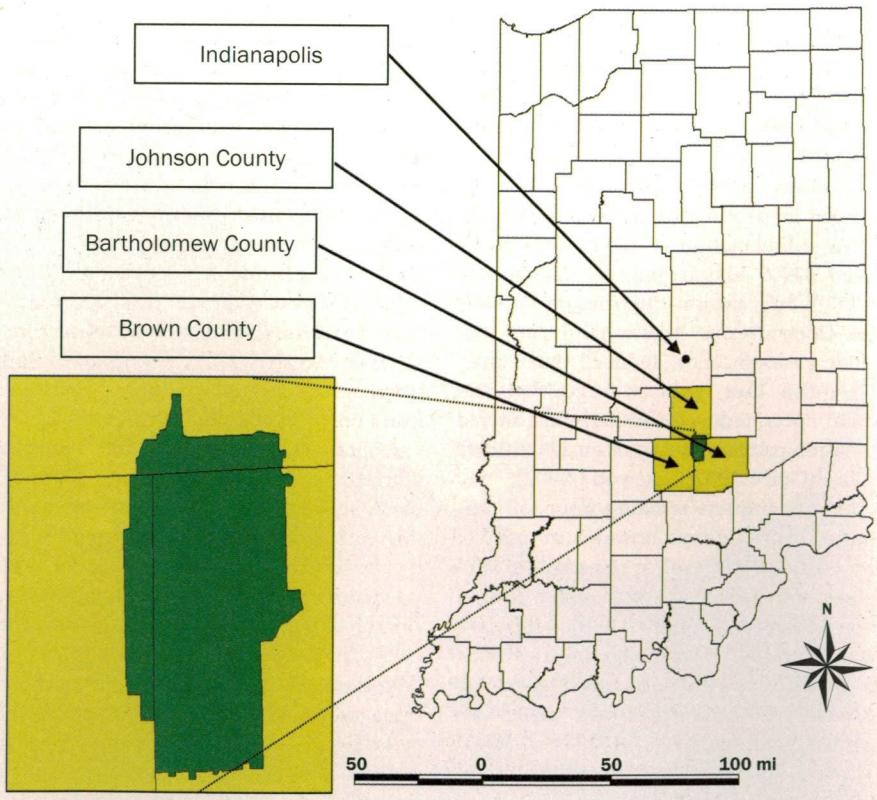
The USLE is an empirical equation developed from more than 10,000 plot–years of data (Wischmeier and Smith 1978) and designed to compute long–term average annual soil losses from sheet and rill erosion for mainly agricultural applications. Advantages of the USLE include the simplicity of the model and that the data required is typically readily available. However, the USLE does not account for all erosion processes, especially deposition, which limits its usefulness in applications requiring sediment yield estimates. Regardless, the USLE remains the most widely used method for quickly obtaining erosion estimates (Yu 1999). The overall aim of this study was to develop and assess a user–friendly computer system that would estimate erosion potential for roads and trails at a military training facility. The results of model predictions and on–site erosion evaluations for roads and trails at such a facility are presented.

Materials and Methods

Erosion potential for roads and trails at a military training facility was estimated using a modified version of the USLE (Wischmeier and Smith 1978) in a GIS. Data for each component of the USLE was acquired in the GIS software and applied in each grid cell over the entire site. The GeoWEPP (Renschler et al. 2002; Renschler 2003) ArcView extension with WEPP (Flanagan and Nearing 1995) version 2004.7 was also used as an alternative method to estimate site–wide erosion potential. The spatial soil loss prediction data were then overlain in the GIS with the roads and trails of the site. Seventy five points on these roads and trails were then randomly selected, and conditions at these locations were observed so that comparisons could be made with erosion predictions.

Study Site Description. Camp Atterbury, located approximately 35 mi (56 km) south of Indianapolis, near Edinburgh, Indiana, served as the study site. The majority of the facility is within Bartholomew County. A small portion of the base along the northern edge is located in Johnson County, and a small portion along the western edge is located in Brown County, as shown in figure 1. This camp is an Army National Guard (ARNG) base that is the home for many ARNG and United States Army Reserve units, which train and mobilize there. Also located at the camp is an Air National Guard station. The camp covers more than 13,000 ha (32,000 ac) and includes more than 50 live firing ranges that vary from small arms to artillery. During peak training times, it is quite common to have 2,000 or more troops training simultaneously at the base.

Figure 1
Camp Atterbury location in the state of Indiana.



There are four general soil classifications at Camp Atterbury, as obtained from the general soil map produced by the USDA Soil Conservation Service (1990). These soils are of the Pekin-Chetwynd-Bartle, Hickory-Cincinnati-Rossmoyne, Crosby-Miami-Rensselaer, and Stonelick-Chagrin associations. From these 4 general classes, 10 soil series were located within the facility (table 1).

Estimating Erosion Potential with a Modified Universal Soil Loss Equation. The potential erosion levels were estimated over the entire facility, using a modified version of the USLE (equation 1) in a GIS software package. This was accomplished by breaking it into smaller steps to obtain each factor. Once each variable was obtained, equation 1 was applied to grid cells in a Digital Elevation Model (DEM) of the entire camp area, resulting in estimates of erosion potential sitewide. The USLE is:

$$A = R \times K \times LS \times C \times P, \qquad (1)$$

where A is defined as the average annual soil loss (t ha^{-1} y^{-1}), R is the rainfall–runoff erosivity factor (MJ cm ha^{-1} h^{-1}), K is the soil erodibility factor (t ha h MJ^{-1} ha^{-1} cm^{-1}), L is the slope length factor (dimensionless), S is the slope steepness factor (dimensionless), C is the cover management factor (dimensionless), and P is the conservation practice factor (dimensionless) (Wischmeier and Smith 1978; USDA SEA 1981).

The rainfall–runoff erosivity factor, R, is a constant based on geographic location and climate. The R factor is calculated from the annual summation of rainfall energy in every storm, times its maximum thirty minute intensity (Wischmeier and Smith 1978). An R factor of 298 MJ cm ha^{-1} h^{-1} was used in this study for Camp Atterbury, as taken from an R factor map in Haan et al. (1994).

The soil erodibility factor, K, was obtained from the State Soil Geographic Database (STATSGO) available through the USDA Natural Resources Conservation Service (NRCS) and the Soil Survey Geographic (SSURGO) database, also available through NRCS. Only Bartholomew County data were available in SSURGO format at the time of this study; therefore, the K factor for portions of the camp in Brown and Johnson Counties were completed with the use of STATSGO data. K ranged from 0.03 to 0.72 t ha h MJ^{-1} ha^{-1} cm^{-1}.

The slope length factor, L, is a ratio of soil loss from a field slope length to soil loss from a 22.1 m (72.5 ft) length under identical conditions. The slope length was estimated using flow accumulation calculated from the DEM. The slope steepness factor, S, is a ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions. The slope length and steepness were derived from a 30-m (100-ft) resolution GIS digital elevation map obtained from the US Geological Survey (USGS).

The length and slope factors were computed using equation 2 (Moore and Burch 1986):

$$LS = \left(\frac{\text{FlowAccumulation} \times \text{CellSize}}{22.13}\right)^{0.4} \times \left(\frac{\sin\Theta}{0.0896}\right)^{1.3}, \qquad (2)$$

where LS is the length-slope factor, FlowAccumulation is the resultant GIS map with cell values for the number of cells flowing into that cell, CellSize is the length of each cell as set by the user (units in length are defined by the user), and Theta (Θ) is the slope angle in degrees. LS values ranged from 0.00 to 28.04. Cells where flow originated had a flow accumulation value of zero. The maximum flow length was not constrained, thereby accounting for concentrated flow that occurs on roads and trails common to military training areas.

The USLE support practice factor, P, refers to support practices such as terracing, strip cropping, or contouring, and it is a ratio of the soil loss with a practice to the soil loss with none. For this study, no support practices were used, so P was always set equal to 1.

The cover management factor, C, is the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow (Wischmeier and Smith 1978). To illustrate the significant erosion that may be prevented from disturbed bare soils on the roads at Camp Atterbury, erosion potential with the existing land use cover and without cover ($C = 1$) were computed and compared. The land use cover was acquired from the Earth Remote Observation Systems (EROS) dataset from the USGS. The C factor values used for each land use class in the land use cover data are shown in table 2. Calculation of erosion estimates with the USLE cover factor required multiplication of the erosion potential with the land use cover map with C factors based on the EROS dataset. This produced an additional GIS map of potential erosion estimates based on existing land use.

Table 2
Land use cover factors.

Land use	C factor
Water	0.00
Low-density residential	0.03
High-density residential	0.03
Deciduous forest	0.02
Evergreen forest	0.02
Mixed forest	0.02
Pasture/grasses	0.05
Row crops	0.18
Woody wetlands	0.00
Herbaceous wetlands	0.00
Class 3 road	0.25
Class 4 road	0.50

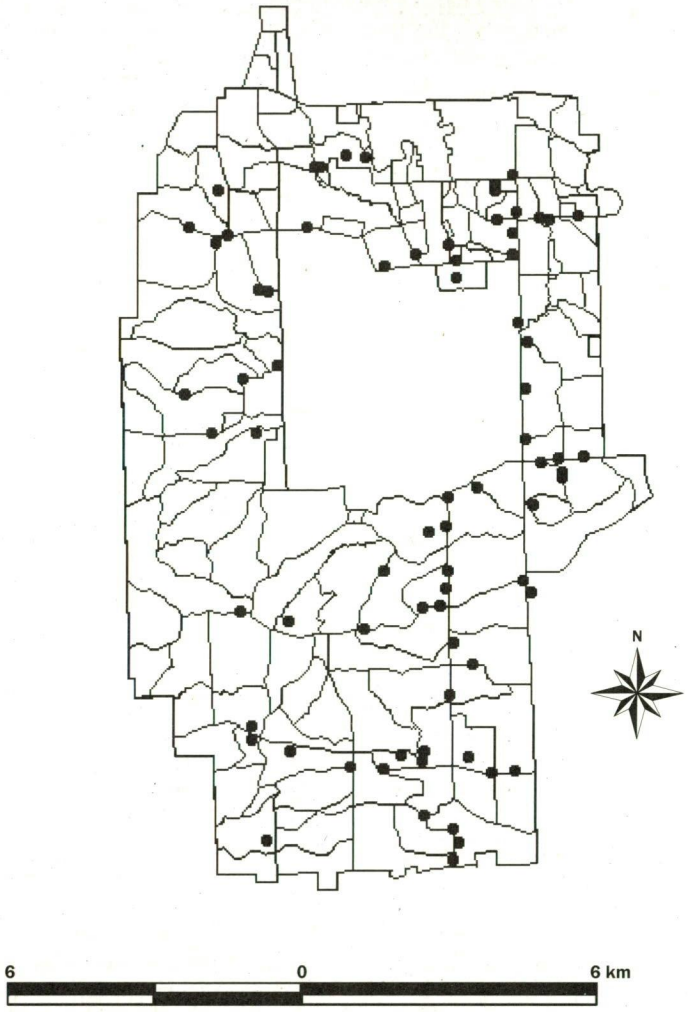
The presence of gravel on roads can reduce erosion (Wu 2001; Egan 1999). In order to estimate the erosion potential on the graveled roads at Camp Atterbury, a C factor of 0.25 was assigned for class 3 roads (also referred to as improved roads), and for class 4 roads (also referred to as semi-improved roads) a C factor of 0.50 was applied (Wu 2001).

Geospatial Interface to the Water Erosion Prediction Project Erosion Estimation. GeoWEPP was applied to Camp Atterbury with input data used in the modified USLE estimates with one exception. The STATSGO soil map was used, instead of a combination of SSURGO and STATSGO data, due to incompatibility of the combined soil data with GeoWEPP software. The GeoWEPP erosion estimates were calculated using 30-yr model simulations with generated climate from the climate generation program, CLIGEN version 4.3 (Nicks et al. 1995).

As with the USLE application procedure, GeoWEPP was used to predict soil erosion with and without vegetative cover. The estimation of erosion for no cover was performed by setting all land uses to continuous clean till fallow, which is similar to setting a C value equal to 1 in the USLE.

GeoWEPP utilizes the TOPAZ (Garbrecht and Martz 1997) software to delineate channels in the DEM where runoff is predicted to concentrate. By selecting a point on one of these channels, the software automatically determines the land area that drains to that location. In order to ensure GeoWEPP results covered all of Camp Atterbury, the DEM, land use, and soil maps were made with 500-m (1,600-ft) buffers around their boundaries.

Figure 2
Erosion observation sample locations at Camp Atterbury.



Road Classes. Five classes of roads were defined by Ayers et al. (2005): class 1—primary, all weather, hard surface (e.g., freeway, state highway); class 2—secondary, all weather, hard surface (e.g., local thoroughfare, county road); class 3—light duty, all weather, hard or improved surface (e.g., residential street, rural road, or graveled road); class 4—fair or dry weather, unimproved surface (e.g., improved road with no maintenance, unimproved dirt road; twin tracks; no tracks, but easily discerned vegetation change); class 5—difficult to see (better seen across canyon than when driving), old fire break, or cow or motorcycle path.

Class 1, 2, and 3 roads were not considered at the camp since they are paved and nonerodible. However, the runoff from these roads can cause increased erosion downslope. Unpaved roads at Camp Atterbury were divided into two categories: gravel and dirt. The gravel roads were often divided into subcategories according to their condition, improved and semi-improved. Sitewide erosion estimates from the USLE and GeoWEPP were overlain with a map of the existing roads and trails to obtain erosion estimates on the road and trail locations. Best-case and worst-case scenarios (with existing cover and bare tilled fallow) of erosion estimates allowed calculation of potential erosion reduction.

On-site Road Erosion Evaluations. The erosion potential maps were divided into three categories: low, moderate, and high. Low erosion potential was assumed for 0 to 9 t ha^{-1} y^{-1} (0 to 4 tn ac^{-1} yr^{-1}) predicted soil losses, moderate erosion potential for >9 to 24.2 t ha^{-1} y^{-1} (4 to 10 tn ac^{-1} yr^{-1}) predicted erosion, and high erosion potential for modeled losses greater than 24.2 t ha^{-1} y^{-1}.

Qualitative estimates of erosion were made at 75 randomly selected locations on unimproved roads and trails at Camp Atterbury (figure 2). Roads in areas with active training at the time of the field sampling were excluded. Coordinates of each location were identified with a global positioning system (GPS). Factors used to estimate the erosion severity were presence of gullies and rills, vegetation, slope, and gravel road conditions, and these were documented with photographs and on paper forms (Gaffer 2005). Each factor was scored according to the location's conditions regarding potential erosion: low (1), moderate (2), or high (3). This method was based on work by Bracmort (2004) who evaluated performance of various soil conservation management practices.

Vegetation scores were assigned by counting the number of anchored vegetation at 0.3 m (1.0 ft) intervals in a 6 m (20 ft) span across the road. For traffic ways that were at least 6 m wide, a tape measure was placed perpendicular to the direction of travel with 3 m (10 ft) on either side of the center. For roads less than 6 m wide, the transect was angled so that it spanned 6 m across the road. A low value was scored if the number of anchored vegetation marks ranged between 15 and 20. Moderate scores were assigned for vegetation marks from 10 to 14, and a high score was assigned for less than 10 marks. Gravel road evaluations were treated similarly to vegetation (Egan 1999; Wu 2001). A transect was placed across the road, and gravel pieces greater than 2 cm (0.8 in) were counted as gravel cover.

Rills and gullies were documented with their approximate dimensions, length, width, and depth. In the on-site survey for this study, if no rills or gullies were present, a score of 1 (low) was assigned. For roads with only rills present, a score of 2 (moderate) was assigned, and where one or more gullies were present the score was 3 (high).

Slope gradient at a point was determined with a clinometer. Low scores were assigned for slopes of 2% or less, moderate scores for slopes between >2% to 6%, and high scores for slopes >6%. Example survey sheets for each of the assessment factors and more details on the procedure used for the onsite evaluations can be found in Gaffer (2005).

The overall observed erosion score was obtained for each sample by averaging the

Figure 3
Class 4 road at Camp Atterbury with high erosion.

three (vegetation/gravel, rills/gullies, and slope) scores and rounding to the nearest integer. A final score of 1 (low), 2 (moderate), or 3 (high) was then assigned to each location sampled. This score was compared to the predicted score for the same location from the site-wide erosion predictions.

Two additional analyses were performed to further investigate the contribution of rills and gullies to erosion potential. The observed score was changed to match the score of rills and gullies, regardless of the vegetation or slope scores, and the observed score was also calculated with the gully score given twice the weight of that given to vegetation or slope (equation 3). Both of these observation scores were then compared with estimated erosion potential and subjected to the same statistical analyses as the original method:

$$\text{ObservedScore} = (0.25 \times \text{VegetationScore}) + (0.50 \times \text{GullyScore}) + (0.25 \times \text{SlopeScore}). \quad (3)$$

Typical conditions of one of the road sites that was sampled can be seen in figure 3. The field observations were conducted over three days (March 15, 16, and 24, 2005). When beginning to acquire data at each location, the time, date, and coordinates were documented and photographs were taken. The time to complete each sample location varied depending on road condition and location, and average observation time was approximately 10 min.

Statistical Analysis. Spearman's rank correlation (Neter et al. 1996) was computed for the evaluation sample points, and the value of rho (ρ) obtained was compared to the critical value of ρ for a dataset with 75 samples and alpha (α) equal to 0.05 (a confidence level of 95%). The null hypothesis (H_0) stated that there was no rank order correlation between predicted and observed erosion rates. If the value obtained for ρ is greater than the critical value of ρ, H_0 is rejected, and a rank order relationship exists between predicted and observed erosion at Camp Atterbury.

Results and Discussion

Camp Atterbury Sitewide Erosion with Modified Universal Soil Loss Equation Approach. Erosion potential maps were generated for the study site based upon the modified USLE technique described previously. The first erosion potential map created did not consider vegetative cover and therefore represents the erosion potential for instances in which there is disturbed bare soil (figure 4a), while the second map includes the cover factor (figure 4b). These maps clearly illustrate that the erosion potential greatly decreased with the addition of the cover factor. More than 11,000 ha (27,000 ac), or 88% of Camp Atterbury, was in the high erosion potential category without a cover factor. The moderate erosion potential category represented 8%, or just over 1,000 ha (2,500 ac), while the low erosion potential category had the smallest area, representing 4% of the camp, or just slightly less than 500 ha (1,200 ac). The erosion potential area percentages with the C factor included were 5%, 16%, and 79% for the high, moderate, and low erosion classes, respectively.

Geospatial Interface to the Water Erosion Prediction Project Analysis. The maps for the GeoWEPP analyses are shown in figure 5. Visual comparisons of these maps to those in figure 4 show that the modified USLE and GeoWEPP procedures yielded similar results. However, GeoWEPP provided additional information on sediment depositional areas that could not be predicted with the modified USLE technique.

Estimated areal erosion levels using GeoWEPP for a tilled fallow condition (figure 5a) were 85.8%, 0.7%, 2.0%, and 11.5% for high, moderate, low, and deposition categories, respectively. After applying the actual land uses indicated by the EROS dataset, these values became 15.5%, 4.3%, 22.2%, and 57.9% for the high, moderate, low, and deposition categories, corresponding to areas of 1,900, 530, 2,800, and 7,300 ha (4,700, 1,310, 6,900, and 18,000 ac), respectively.

Erosion on Roads and Trails. Once potential erosion levels were obtained for the entire facility, lengths of gravel and dirt roads and trails in each category were obtained. Tables 3 and 4 show the percentage of each type of road and trail in each estimated erosion potential category for the modified USLE and GeoWEPP methods. Table 3 was acquired from the tilled fallow erosion estimates (figures 4a and 5a). Table 4 provides results for when the appropriate land use and cover based upon the EROS dataset were used in the simulations (figures 4b and 5b).

These results indicate that by having adequate vegetative cover, erosion can potentially be greatly reduced. Comparison of the "dirt" road and trail segment length results show potential erosion reductions from 81.2% of the segment lengths in the high erosion level to 6.5% for the modified USLE method (tables 3 and 4). This corresponds to lengths of approximately 160 km and 12.9 km (99 mi and 8.0 mi) of road, respectively.

Figure 4
Modified USLE estimated erosion potential with (a) no cover tilled fallow, C factor of 1.0, and (b) C factor set as a function of land use from EROS dataset (table 1).

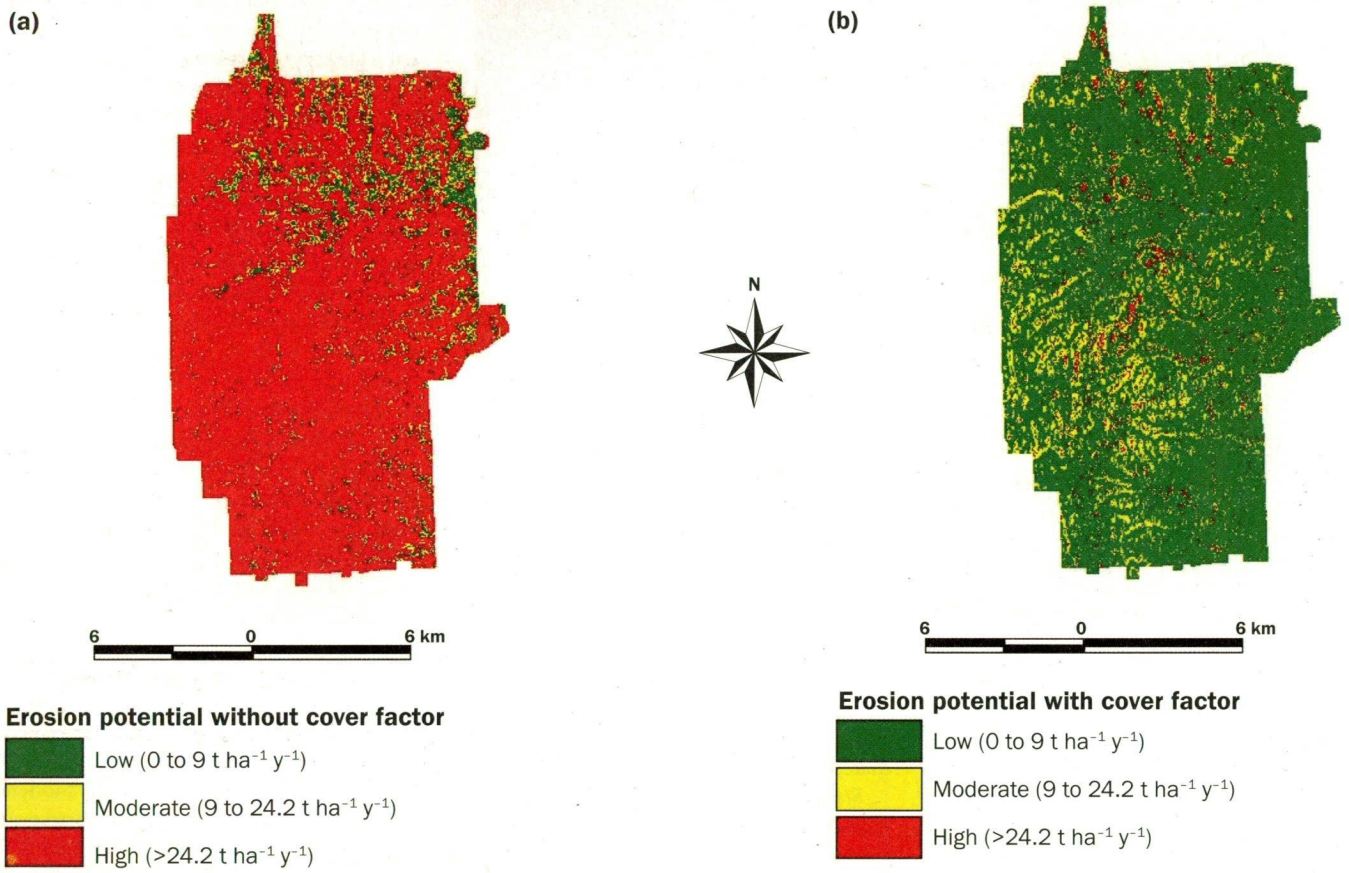


Table 3
Percent of road and trail lengths with estimated erosion potential in low, moderate, high, and deposition categories when simulating continuous tilled fallow management (no cover).

		Percent of road in category			
Road type	**Erosion level**	**Deposition**	**Low**	**Moderate**	**High**
Modified USLE estimated gravel		NA	7.0%	10.3%	82.7%
Modified USLE estimated dirt		NA	6.8%	12.0%	81.2%
GeoWEPP estimated gravel		5.6%	1.2%	0.3%	92.9%
GeoWEPP estimated dirt		10.7%	2.9%	0.9%	85.6%

Table 4
Percent of road and trail lengths with estimated erosion potential when existing EROS dataset land use is applied in low, moderate, high, and deposition categories.

		Percent of road in category			
Road type	**Erosion level**	**Deposition**	**Low**	**Moderate**	**High**
Modified USLE estimated gravel		NA	83.2%	11.3%	5.5%
Modified USLE estimated dirt		NA	82.1%	11.4%	6.5%
GeoWEPP estimated gravel		51.5%	24.9%	2.1%	21.5%
GeoWEPP estimated dirt		60.1%	14.5%	2.5%	22.9%

When a cover factor is considered, the road and trail lengths in the high categories decrease, with a corresponding increase in the low and deposition categories (table 5). Negative values here indicate an increase in the length of roads and trails in these erosion level categories.

Erosion Potential Evaluation. Seventy–five randomly selected locations (figure 2) on roads and trails at Camp Atterbury were used to evaluate the modified USLE and GeoWEPP erosion potential estimates. Two areas that were not sampled at the camp were in the central and southeastern portions of the facility; these are the impact and air to ground firing ranges, and they were unsafe to access. Table 6 contains the observed sample distributions by road and trail type, with gravel roads separated into improved (class 3) and semi-improved (class 4) classes. Table 7 shows the results of predicted versus observed erosion with the modified USLE procedure and the GeoWEPP estimated soil loss.

Figure 5
GeoWEPP estimated erosion potential (a) for no cover tilled fallow and (b) for land use and vegetation from EROS dataset.

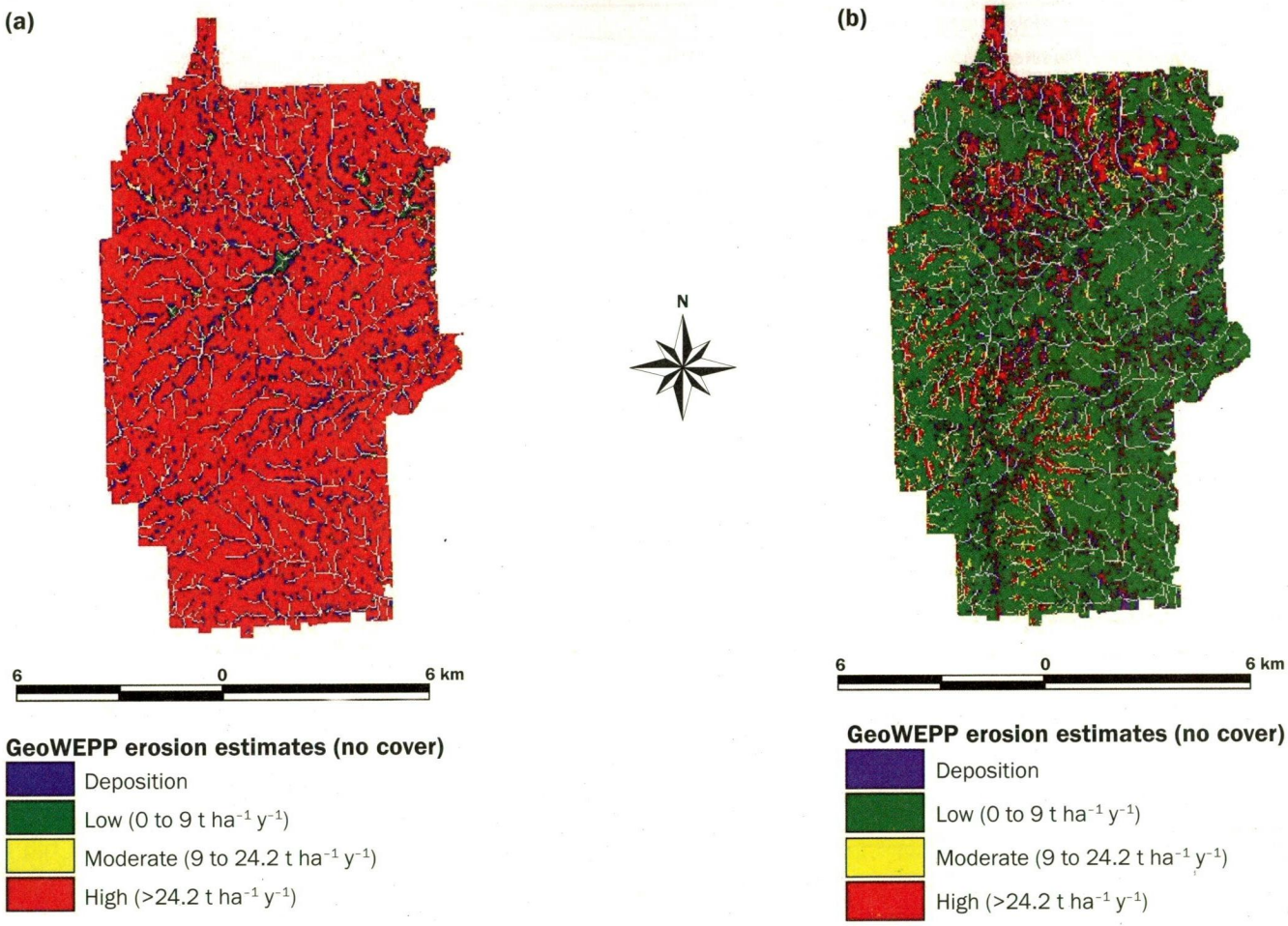


Table 5
Percent reduction in road and trail length erosion potential at Camp Atterbury after EROS dataset land use (cover factor) has been considered.

		Percent reduction in road and trail length erosion potential			
Road type	**Erosion level**	**Deposition**	**Low**	**Moderate**	**High**
Modified USLE estimated gravel		NA	-76.2%	-1.0%	77.2%
Modified USLE estimated dirt		NA	-75.3%	0.6%	74.6%
GeoWEPP estimated gravel		-44.8%	-22.7%	8.2%	59.3%
GeoWEPP estimated dirt		-46.5%	-11.1%	13.9%	43.7%

Table 6
Observed sample distribution by road and trail type.

	Sample distribution by road type		
Road type	**Dirt**	**Improved**	**Semi-improved**
Number of samples	42	18	15

Table 7 indicates that 51% of the sample points were correctly predicted (38/75) with the modified USLE method. Twenty-nine locations were over predicted (39%), while eight sites were under predicted (11%). Table 7 shows that many of the GeoWEPP predictions did not correctly match the on-site observations. Eighteen locations correctly matched the predictions made using GeoWEPP (24%), forty-two sites were over predicted (56%), and fifteen were under predicted (20%). It should be noted that GeoWEPP also predicts soil deposition. Any of the observed erosion locations that were estimated by GeoWEPP as areas of deposition were placed in the low erosion category.

Spearman's rank correlation was computed for the sample points estimated with the modified USLE. The rho (ρ) value obtained was 0.50, while the critical value of ρ for a dataset with 75 samples and alpha

Table 7
Modified USLE and GeoWEPP method predicted and observed erosion correlation matrix for roads and trails at Camp Atterbury.

	Predicted erosion potential					
	Modified USLE			GeoWEPP		
Observed erosion	Low	Moderate	High	Low	Moderate	High
Low	8	3	7	4	3	11
Moderate	7	19	19	11	6	28
High	0	1	11	2	2	8

Table 8
Modified USLE and GeoWEPP method predicted and observed erosion correlation matrix for roads and trails at Camp Atterbury using observed rills and gullies scores only.

	Predicted erosion potential					
	Modified USLE			GeoWEPP		
Observed erosion	Low	Moderate	High	Low	Moderate	High
Low	8	3	6	6	8	3
Moderate	7	17	19	7	3	33
High	0	3	12	4	0	11

Table 9
Modified USLE and GeoWEPP method predicted and observed erosion correlation matrix for roads and trails at Camp Atterbury using equation 3 for observed scoring.

	Predicted erosion potential					
	Modified USLE			GeoWEPP		
Observed erosion	Low	Moderate	High	Low	Moderate	High
Low	7	3	7	3	6	8
Moderate	8	18	20	13	5	28
High	0	2	10	1	0	11

(α) equal to 0.05 is 0.19. Because the value obtained for ρ exceeded the critical value, the null hypothesis was rejected (Neter et al. 1996), and we concluded with 95% confidence that there was significant correlation between modified USLE predicted erosion and on-site observed erosion potential. The value obtained for ρ using the GeoWEPP methods was 0.35, also indicating a significant correlation between the GeoWEPP predicted and the observed erosion.

The reasons for the over-predicted sample points were attributed to two factors. The USLE does not estimate classical or ephemeral gully erosion. Therefore, it is normally necessary to limit slope lengths to approximately 150 m (490 ft) when computing the *LS* factor in the USLE. However, that was not done in this study, as the intent was to over predict rather than under predict the erosion potential, for any case where estimated erosion potential did not match the observed erosion potential. This provided a built in safety factor for use of the erosion estimates as a management tool. The calculated results from the modified USLE are long-term average annual erosion soil loss rates. Many of the roads at Camp Atterbury were recently created or recently maintained (graded), and thus they may not have been subjected to a sequence of erosive storm events that would cause formation of rills and gullies. The GeoWEPP method also over predicted a large portion of the evaluation sites, and similar reasons as described for the modified USLE were likely responsible.

Further examination of incorrectly predicted points was made to determine if there were consistent reasons for them. This analysis examined the *LS* factor, slope obtained in the GIS software, observed slope, vegetation score, and gully score. For the 29 points that were over predicted by the modified USLE approach, no consistent reasons were found. However, for the 8 points that were under predicted by the modified USLE method, a very consistent reason was that the GIS software estimated slopes were significantly lower than the slopes observed during on-site evaluation. The errors in the predicted slope were attributed to the DEM data. The software uses an elevation value from one cell (30 × 30 m [100 × 100 ft]) and compares it to the surrounding cell values to acquire the slope. It does not account for elevation changes that may occur within a cell. This error could be minimized by having more accurate input data (e.g., a DEM of finer resolution). A finer resolution DEM would better capture local variability of the ground surface and therefore allow better estimation of slopes.

Additional investigation of the observed erosion data was made by assigning evaluation scores based only on the score for rills and gullies, which is shown in table 8. The calculated value of ρ for assigning observed erosion scores according to the presence of rills and gullies was 0.47 for the modified USLE method, indicating a significant correlation between predicted and observed erosion potential when the observed erosion is based solely on the presence of rills and gullies. The value of ρ for the GeoWEPP method was 0.31. This was also significant (critical ρ was 0.19). As shown in table 8, 49% of the locations were correctly predicted by the modified USLE process (37/75), 37% of the locations were over predicted (28/75), and 13% of the locations were under predicted (10/75). The locations that were under predicted again had significantly lower slopes for GIS predicted slopes compared to the observed slopes. For GeoWEPP (table 8), the values for correctly predicted, over predicted, and under predicted were 27% (20/75), 59% (44/75), and 14% (11/75), respectively.

A third analysis was conducted by assigning the observed rills and gully score with twice the weight as that of the observed vegetation and slope scores (equation 3), and these results are shown in table 9. Although the number of correctly predicted, over predicted, and under predicted locations did not change from scores that were computed for the rill and gully score for the modified USLE process, they did change greatly for the GeoWEPP process. Again, there was

no consistent reason for the over predicted locations, but the under predicted locations all had significantly lower slopes in the GIS software than the observed slopes in the modified USLE method. The calculated value of ρ for this case was 0.48, indicating a significant correlation between predicted and observed erosion estimates when on-site road erosion estimates were made by weighting the rill and gully score. The GeoWEPP method produced a ρ value of 0.38 for the weighted gully score correlation.

These results indicate that the modified USLE method as described was reliable for identifying roads and trails that have the potential for erosion problems. The predicted erosion estimates matched the qualitative observed erosion for more than 50% of the locations sampled. For the predictions that were incorrect, 29 out of 37 were predicted in a more severe erosion condition than observed (over prediction), which is more desirable than predicting erosion potential less than observed (under prediction) for many applications. Typically, the over predicted cases were by only a single category. The 8 locations with under predictions were a result of poor DEM slope data.

The results obtained using the modified USLE and GeoWEPP indicate that these models are a reliable means of estimating soil erosion hazard along military training area unimproved roads and trails. The land managers at military training facilities could use the models to identify roads and trails that should be improved, revegetated or closed so that erosion is reduced. In this particular instance, the results for the USLE better matched the observed results. GeoWEPP is best applied to field and small watershed scales, and its use is not necessarily the most efficient or practical means for estimating erosion on a site as large as Camp Atterbury. However, there are advantages for using GeoWEPP, including identification of depositional regions, because sediment deposition over time may also cause significant concerns.

The military requires an easy means to estimate soil erosion. The generalized categories obtained with the modified USLE procedure were sufficient to accomplish this. Along with the military, many future users may only require such categorized estimations of erosion levels. In these cases, the modified USLE as applied in this study may be optimal for such applications. If detailed descriptions for soil loss and deposition as well as runoff flow and infiltration are required, applying GeoWEPP with a few minor improvements would be a better alternative.

The results from applying GeoWEPP, and the inconsistencies between its results and those from the modified USLE were surprising. There is a clear potential for error, however, between utilizing either the modified USLE or GeoWEPP technologies that provide long-term average annual soil loss predictions and comparing them to single point-in-time field observations at road and trail sites. Further work in this area is needed to identify the factor(s) that led to the variability between GeoWEPP, the modified USLE procedure, and the on-site observations.

Summary and Conclusions

Military facilities often experience negative environmental impacts from soil erosion caused by the repeated use of graveled and unimproved roads and trails by military vehicles. Erosion potential was estimated for Camp Atterbury using an application of a modified USLE and GeoWEPP in GIS software, for both tilled fallow (no cover) and existing EROS land use. The estimated erosion on the roads and trails at the facility was extracted, and potential erosion reduction due to closure and revegetation of these areas was also calculated.

Seventy-five points on roads and trails were randomly sampled for evaluating the erosion potential for Camp Atterbury. Data were collected for each location to identify the erosion category according to the conditions for vegetation, slope, and presence of rills and gullies. The observed erosion results were compared to the modified USLE and GeoWEPP predicted results at those locations. Of the 75 points, 38 were correctly predicted for the modified USLE approach. There were 29 points that were predicted by the modified USLE to have a higher erosion potential than the observed erosion. This is not unexpected because the data inputs were conservative in order to minimize under prediction of erosion. A total of 8 points were predicted with less severe erosion potential than observed. The GeoWEPP method predicted 18 locations correctly, 42 locations were over predicted, and 15 locations were under predicted. Additional analyses were conducted by assigning observed scores according to the rill and gully score and also by weighting the rill and gully score. The modified USLE and GeoWEPP performed similarly to the analyses described previously for these modifications in observed erosion scores. Spearman's rank correlation showed with 95% confidence that a significant correlation exists between predicted and observed erosion potential for both the modified USLE and GeoWEPP methods for all cases evaluated.

The results indicate that the modified USLE and GeoWEPP are reliable means of estimating the severity of soil erosion along military training area unimproved roads and trails and for other locations with similar conditions. The land managers at military training facilities could use the models to identify roads and trails that should be improved, revegetated or closed to address erosion problems. This approach might also be used by land managers for planning road and trail maintenance or developing plans to locate new roads and trails to minimize potential erosion problems.

Improved spatial data, especially elevation data with better spatial resolution, would enhance the ability of the modified USLE and GeoWEPP approaches in estimating erosion for unimproved roads and trails. The roads and trails examined in this study were unimproved and thus may not be representative of roads and trails typically found in state and national forests and on other public lands. Therefore, the erosion estimation approaches explored within this study should be evaluated further for roads and trails typical of these settings.

References

Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. Forest and water: Effects of forest management on floods, sedimentation, and water supply. General Technical Report PSW-18. San Francisco, CA: USDA Forest Service.

Ayers, P.D., A.B. Anderson, and C. Wu. 2005. Analysis of vehicle use patterns during field training exercises. Journal of Terramechanics 42(3-4):321-338.

Binkley, D., and T.C. Brown. 1993. Forest practices as nonpoint sources of pollution in North America. Water Resources Bulletin 29(5):729-740.

Bracmort, K.S. 2004. An Evaluation of Structural Best Management Practices 20 years after Installation. PhD thesis. Agricultural and Biological Engineering, Purdue University, West Lafayette, IN.

Egan, A.F. 1999. Forest roads: Where soil and water don't mix. Journal of Forestry 97(8):18-21.

Elliot, W.J., D.E. Hall, and S.R. Graves. 1999. Predicting sedimentation from forest roads. Journal of Forestry 97(8):23-29.

Flanagan, D.C., and M.A. Nearing, ed. 1995. USDA-Water Erosion Prediction Project Hillslope Profile and Watershed Model Documentation. NSERL Report Number 10. West Lafayette, IN: National Soil Erosion Research Laboratory, USDA Agricultural Research Service.

Flanagan, D.C., J.R. Frankenberger, and B.A. Engel. 2004. Web-based GIS application of the WEPP model. ASAE Paper Number 042024. St. Joseph, MI: American Society of Agricultural Engineers.

Gaffer, R.L. 2005. Predicting erosion on military training facilities using GIS. MS thesis, Dept. Agricultural and Biological Engineering, Purdue University, West Lafayette, Indiana.

Garbrecht, J., and L.W. Martz. 1997. TOPAZ: An Automated Digital Landscape Analysis Tool for Topographic Evaluation, Drainage Identification, Watershed Segmentation and Subcatchment Parameterization: Overview. ARS-NAWQL 95-1. Durant, OK: USDA Agricultural Research Service.

Gatewood, R. 2002. Environmentally friendly army tank trails. Erosion Control. http://www.forester.net/ecm_0211_environmentally.html.

Grace, J.M. III. 2002. Effectiveness of vegetation in erosion control from forest road sideslopes. Transactions of the ASAE 45(3):681-685.

Haan, C.T., B.J. Barfield, and J.C. Hayes. 1994. Design Hydrology and Sedimentology for Small Catchments. San Diego, CA: Academic Press.

Herzog, M., J. Harbor, K. McClintock, J. Law, and K. Bennett. 2000. Are green lots worth more than brown lots? An economic incentive for erosion control on residential developments. Journal of Soil and Water Conservation 55(1):43-49.

Kochenderfer, J.N., and J.D. Helvey. 1987. Using gravel to reduce soil losses from minimum-standard forest roads. Journal of Soil and Water Conservation 42(1):46-50.

McClelland, D.E., R.B. Foltz, C.M. Falter, W.D. Wilson, T. Cundy, R.L. Schuster, J. Saurbier, C. Rabe, and R. Heinemann. 1999. Relative effects on a low-volume road system of landslides resulting from episodic storms in northern Idaho. *In* Seventh International Conference on Low-Volume Roads: Vol. 2. Transportation Research Record 1652, 235-243. Washington, DC: National Research Council, Transportation Research Board.

Megahan, W.F. 1972. Logging, erosion, sedimentation: Are they dirty words? Journal of Forestry 70(5):403-407.

Moore, I.D., and G.J. Burch. 1986. Physical basis of the length-slope factor in the Universal Soil Loss Equation. Soil Science Society of America Journal 50:1294-1298.

Neter, J., M.H. Kutner, C.J. Nachtsheim, and W. Wasserman. 1996. Applied Linear Statistical Models, Fourth Edition. Chicago, IL: Irwin Publishing.

Nicks, A.D., L.J. Lane, and G.A. Gander. 1995. Weather generator. *In* USDA Water Erosion Prediction Project: Hillslope Profile and Watershed Model Documentation, ed. D.C. Flanagan and M.A. Nearing. NSERL Report 10. West Lafayette, IN: National Soil Erosion Research Laboratory, USDA Agricultural Research Service.

Renard, K.G., G.R. Foster, G.A. Weesies, K.K. McCool, and D.C. Yoder. 1997. Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). US Department of Agriculture, Agriculture Handbook No. 703. Washington, DC: US Government Printing Office.

Renschler, C.S. 2003. Designing geo-spatial interfaces to scale process models: The GeoWEPP approach. Hydrological Processes 17:1005-1017.

Renschler, C.S., D.C. Flanagan, B.A. Engel, and J.R. Frankenberger. 2002. GeoWEPP—The geo-spatial interface for the Water Erosion Prediction Project. ASAE Paper Number 022171. St. Joseph, MI: American Society of Agricultural Engineers.

Rhee, H., J.L. Fridley, and R.B. Foltz. 2004. Modeling erosion from unpaved forest roads at various levels of geometric detail using the WEPP model. Transactions of the ASAE 47(3):961-968.

Tiwari, A.K., L.M. Risse, and M.A. Nearing. 2000. Evaluation of WEPP and its comparison with USLE and RUSLE. Transactions of the ASAE 43(5):1129-1135.

USDA SCS (Soil Conservation Service). 1990. Soil Survey of Brown County and Part of Bartholomew County Indiana. Washington, DC.

USDA SEA (Science and Education Administration). 1981 Metrification of the USLE in the international system of units (SI). Supplement to Agriculture Handbook No. 537. Washington, DC: USDA.

Wischmeier, W.H., and D.D. Smith. 1978. Predicting rainfall erosion losses: A guide to conservation planning. USDA Agricultural Handbook 537. Washington, DC: US Government Printing Office.

Wu, C.-C. 2001. Surface-cover subfactor for gravel-rich surfaces. ASAE Paper Number 701P0007 presented at Soil Erosion Research for the 21st Century, Proceedings of the International Conference, Honolulu, Hawaii, January 3-5, 2001.

Yu, B. 1999. A comparison of the R factor in the Universal Soil Loss Equation and Revised Universal Soil Loss Equation. Transactions of the ASAE 42(6):1615-1620.