EVALUATION OF WEPP RUNOFF AND SOIL LOSS PREDICTIONS USING NATURAL RUNOFF PLOT DATA

X. C. Zhang, M. A. Nearing, L. M. Risse, K. C. McGregor

ABSTRACT. *Model testing and evaluation are critical to the acceptance of any new prediction tool. This study was conducted to evaluate the overall performance of the Water Erosion Prediction Project (WEPP) hillslope model in predicting runoff and soil loss under cropped conditions. Natural runoff plot data, including 4,124 selected events, 556 plot years, and 34 cropping scenarios, from eight locations were selected. The average length of record for the cropping scenarios was about nine years. Several common crops and tillage systems were included. The WEPP input files for soil, slope, climate, and crop management were compiled based on measured data. The coefficient of determination (r^2) between model-predicted and measured-runoff volumes for optimized Green and Ampt hydraulic conductivity (K_b) was 0.77 for selected events, 0.76 for annual values, and 0.87 for average annual values; the r^2 between predicted and measured soil losses (excluding fallow and corn plots at Bethany, Mo.) was 0.36, 0.60, and 0.85, respectively. Similar predictions of runoff and soil loss were also obtained with WEPP internally estimated K_b values. Runoff and soil loss were slightly overpredicted for small storms and for years with low runoff and soil loss rates, and were underpredicted for large storms and for years with high runoff and soil loss rates. However, average runoff and soil loss rates for different cropping and management systems were adequately predicted. The accuracy and reliability of the predictions were shown to improve from an event to annual to average annual basis. Results of this study show that the WEPP model is a useful tool for predicting runoff and soil loss rates under cropped conditions.*

Keywords. *Model validation, Soil erosion, Soil conservation, Erosion modeling, Runoff prediction.*

Soil erosion is a major factor causing land degradation and environmental quality deterioration. It is often triggered and accelerated by inappropriate land use and poor management. To effectively control soil erosion and wisely manage land resources, erosion mechanisms must be well understood and the effectiveness of management practices must be assessed. Erosion prediction models offer us a powerful way to make informed land management decisions. Thus, development of up-to-date prediction technology is of great importance in preserving land productivity and environmental quality.

The Water Erosion Prediction Project (WEPP) was initiated to develop a new generation prediction technology to serve as an improved tool for soil and water conservation planning and assessment. This study is an assessment of WEPP for applications on individual hillslopes. The WEPP model is a physically based, continuous simulation model composed of many submodels, including a climate generator and components that simulate hydrology, plant growth, residue decomposition, irrigation, and erosion. Detailed descriptions of all these components are beyond the scope of this article, but can be found in Flanagan and Nearing (1995). The following presents a brief introduction to the principle mathematical relationships in the infiltration and erosion routines.

In WEPP, infiltration rate (f, mm h^{-1}) is calculated using the Green and Ampt equation (1911) for unsteady rainfall as presented by Chu (1978):

$$f = K_e(1 + N_s/F) \tag{1}$$

where

K_e = effective hydraulic conductivity (mm h^{-1})

F = cumulative infiltration depth (mm)

N_s = effective matric potential (mm) that is computed by:

$$N_s = (\eta_e - \theta_i)\psi \tag{2}$$

where

η_e = effective porosity (cm^3 cm^{-3})

θ_i = initial soil water content (cm^3 cm^{-3})

ψ = average wetting front capillary potential (mm)

Wetting front capillary potential is estimated from soil properties (Rawls et al., 1989). K_e under row cropped conditions is predicted by (Zhang et al., 1995a):

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$$K_e = K_b \times TA(1 - SC_{ef}) + (0.0534 + 0.01179 \times K_b)P \times SC_{ef} \qquad (3)$$

where

K_b = maximum hydraulic conductivity under freshly tilled and noncrusted conditions (mm h^{-1}) and is estimated from basic soil properties (Risse et al., 1995a)

TA = dimensionless tillage and crusting adjustment factor that decreases exponentially with cumulative rainfall energy (Risse et al., 1995b)

SC_{ef} = effective surface cover in decimal form

P = storm precipitation amount (mm)

K_e under meadow conditions is estimated by multiplying K_e from equation 3 by a factor of 1.81 (Zhang et al., 1995b).

Upland erosion has been separated into interrill and rill erosion processes. Interrill detachment rate per unit interrill area (D_i, kg s^{-1} m^{-2}) is computed in the WEPP model by (Flanagan and Nearing, 1995):

$$D_i = K_i \times I \times I_e \times S_f \times SDR \qquad (4)$$

where

K_i = adjusted interrill soil erodibility (kg s m^{-4})

I = rainfall intensity (m s^{-1})

I_e = interrill runoff rate (m s^{-1})

S_f = slope factor (Elliot et al., 1989)

SDR = interrill sediment delivery ratio

Rill detachment capacity (D_c, kg s^{-1} m^{-2}) is calculated when flow shear stress (τ_f, Pa) exceeds critical shear stress of soil (τ_c, Pa) as documented by Flanagan and Nearing (1995):

$$D_c = K_r(\tau_f - \tau_c) \qquad (5)$$

where K_r is the baseline rill erodibility (s m^{-1}). Rill detachment rate (D_r, kg s^{-1} m^{-2}) is computed by (Foster, 1982):

$$D_r = D_c(1 - G/T_c) \qquad (6)$$

where G is the sediment load (kg s^{-1} m^{-1}) and T_c is the sediment transport capacity (kg s^{-1} m^{-1}). Net deposition in rills is computed separately when sediment load is greater than transport capacity. The erodibility parameters of K_i, K_r, and τ_c are internally adjusted daily in the WEPP model. The adjustment factors are designed to account for canopy cover, residue cover, incorporated residue, live and dead roots, surface roughness, and soil consolidation.

Thorough testing and evaluation of the WEPP model are critical to its acceptance and successful implementation. Before it can be widely accepted, substantial validation and testing must be accomplished to evaluate the reliability and accuracy of model predictions. The objective of this study was to evaluate overall model performance in predicting storm, annual, and average annual runoff and soil loss rates under cropped conditions using measured natural runoff plot data collected from eight different locations.

MATERIALS AND METHODS

General information on data sets used in this study is tabulated in table 1. Eight sites located in the eastern United States were selected to have a broad range of climatic and physiographical conditions. Several common tillage systems such as conventional-till, conservation-till, and no-till were included. In general, moldboard plow, disking, harrowing, and field or row cultivation were employed in the conventional tillage system. Chisel plow rather than moldboard plow was used as the primary tillage in the conservation tillage system to leave more residue on the soil surfaces. For the no-till system, none of the above tillage operations were used and the soil surfaces were not severely disturbed. Crops, planted either continuously or in rotation, included corn, soybeans, cotton, oats, potatoes, wheat, and several species of perennial crops. Data from 556 plot-years with 34 cropping scenarios were selected, of which 13 treatments were not replicated. Average length of record for the cropping scenarios was approximately nine years. To minimize random error, replicate means rather than each individual value were used in comparisons. A series of storms, which accounted for more than 70% of total runoff, was selected for each cropping system in making event by event comparisons. Storm events were screened based on data quality. Events were excluded when there were apparent errors in the data, such as events for which measured runoff was greater than rainfall or large differences in runoff and soil loss among replicates existed. Events for which a single storm occurred over multiple days or several storms fell within one day were not included to avoid errors caused by regrouping storms on a daily basis. Winter events that had average daily

Table 1. Site, cropping and management, data period, numbers of replicates, and selected events used in this study

Site	Crop Management Systems*	Replicates	Years	Events Used
Holly Springs, Miss.	1. Fallow	2	1961-68	208
	2. Conv. corn, spring TP	2	1961-68	163
	3. Bermuda-corn-bermuda	2	1962-68	127
	4. Conv. soybean 70-73 and 78-80, conv. corn for silage 74-77	2	1970-80	406
	5. No-till soybean 70-73, conv. corn 74-77, reduced-till soybean 78-80	2	1970-80	406
	6. No-till corn and soybean rotation 70-73, no-till corn 74-77, no-till soybean 78-80	2	1970-80	405
	7. No-till corn and soybean rotation 70-73, no-till corn for silage 74-77	2	1970-76	267
Madison, S.D.	1. Fallow	3	1962-70	59
	2. Conv. corn, spring TP	3	1962-70	48
	3. Cons. corn, no TP	3	1962-70	50
	4. Continuous oats, no TP	3	1962-64	15
Morris, Minn.	1. Fallow	3	1962-71	67
	2. Conv. corn, fall TP	3	1962-71	67
	3. Bromegrass-corn-oats	3	1962-71	41
Presque Isle, Me.	1. Fallow	3	1961-65	65
	2. Continuous potato	3	1961-65	64
	3. Potato-oats-meadow	3	1961-65	46
Watkinsville, Ga.	1. Fallow	2	1961-67	147
	2. Conv. corn, spring TP	2	1961-67	97
	3. Conv. cotton, spring TP	2	1961-67	112
	4. Corn-bermuda-bermuda	2	1961-67	83
Bethany, Mo.	1. Fallow	1	1931-40	109
	2. Conv. corn, spring TP	1	1931-40	112
	3. Alfalfa	1	1931-40	83
	4. Bromegrass	1	1931-40	79
Geneva, N.Y.	1. Fallow	1	1937-46	97
	2. Summer fallow, winter rye	1	1937-46	77
	3. Conv. soybean, spring TP	1	1937-46	45
	4. Red clover	1	1937-41	19
	5. Brome grass	1	1937-46	30
Guthrie, Okla.	1. Fallow	1	1942-56	170
	2. Conv. cotton, spring TP	1	1942-56	140
	3. Bermudagrass	1	1942-56	96
	4. Wheat-clover-cotton	1	1942-56	124

* Conv. = conventional till; TP = turn-plow; cons. = conservation till.

Table 2. Basic soil properties of top 200-mm soil layer at each location

Site	Soil	Texture Class*	Optimized K_b† (mm h^{-1})	Estimated K_b† (mm h^{-1})	Sand (%)	Clay (%)	Organic Matter (%)
Holly Springs	Providence	sil	0.5	1.9	2.0	19.8	0.81
Madison	Egan	sicl	1.6	1.0	7.0	32.2	3.70
Morris	Barnes	1	17.7	7.4	39.4	23.2	3.37
Presque Isle	Caribou	grsil	4.7	7.6	38.8	13.7	3.76
Watkinsville	Cecil	scl	19.8	22.8	66.5	19.6	0.89
Bethany	Shelby	sil	3.5	4.6	27.8	29.0	3.03
Geneva	Ontario	1	5.1	9.4	44.2	14.9	4.50
Guthrie	Stephensville	fsl	18.2	21.9	73.2	7.9	1.60

* Sil = silt loam; sicl = silty clay loam; 1 = loam; grsil = gravel silt loam; scl = sandy clay loam; fsl = fine sandy loam.

† From Risse et al. (1995b).

temperatures below 0°C were also excluded. In addition, several of the largest storms that had no measured runoff (approximately 10% of total selected events) were included into event files to partially offset the occurrences of the events that had measured runoff but no predicted runoff. The average number of selected events per cropping system was 121.

Soil information is presented in table 2. Several common texture groups were included. The WEPP soil input files were compiled using measured data. Soil erodibilities were estimated with the WEPP prediction equations given in the WEPP user manual (Flanagan and Nearing, 1995). Other parameters, such as sand and clay contents, and organic matter were obtained either from site specific data or by averaging all the information available from various sources for the soil. The soil profiles in this study were greater than 1.5 m. The WEPP internally estimated K_b as well as optimized K_b (Risse et al., 1995a, b) were used to compare model predictions. Optimized K_b was obtained when sum of square error of measured minus predicted runoff volumes for the selected events from fallow plots (table 1) reached its minimum using equations 1 and 2 and $K_e = K_b \times TA$. Internal adjustment of hydraulic conductivity to environmental conditions was allowed during simulation.

The WEPP management input file for each cropping system was built based on experimental data from site records. Tillage operations in the WEPP operation database were selected to represent each tillage practice. Initial conditions in the input file were estimated by averaging model output for the cropping system if measured data for initial conditions were not available. Plant growth parameter values of crop biomass-energy ratio and optimum yield were varied in a trial and error manner to obtain reasonable surface residue mass predictions for each crop and on each location according to measured data. When measured data did not exist, an average production level for the site was assumed. Calibration of crop growth parameters was conducted to reduce the effects of crop production differences between different climatic regions and crop varieties on runoff and soil loss predictions.

Values for amounts of rainfall, rainfall duration, time to peak intensity, and ratio of mean to peak intensity were calculated from rainfall breakpoint data for each storm at all the sites. Measured daily values of maximum and minimum temperatures and rainfall were input into the CLIGEN model to generate the remainder of the weather parameters in the WEPP climate input files (Nicks et al., 1993). Plots were all standard USLE natural runoff plots. Slope length of all plots was approximately 22 m. Plot width was approximately 4 m, except for the Geneva and Guthrie sites where a width of 1.8 m was used. Slope steepness on the plots was nearly uniform at all sites, ranging from 0.05 to 0.08 m m^{-1}.

The WEPP model (version 95.1) was run in a continuous simulation mode. Model predicted event, annual, and average annual runoff volumes and soil loss rates with both estimated and optimized K_b values were compared to measured data. In addition, a program was written to adjust predicted runoff volume to equate with measured runoff for each selected storm event by altering only the effective hydraulic conductivity (K_e in eq. 1) within the WEPP model. Event soil losses predicted with equalized runoff volumes also were compared to measured data. This was to reduce the effects of runoff prediction error on soil loss estimation.

A soil loss ratio (the "C-factor") is used in other erosion prediction models such as USLE and RUSLE to represent cover and management effect on soil loss rate. It is defined as the ratio of soil loss under cropped conditions to that under clean-tilled, continuous fallow conditions (Wischmeier and Smith, 1978). To evaluate model response to cover and management effect, soil loss ratios were calculated by dividing soil loss from cropped plots by that from companion fallow plots using both measured and predicted soil loss data. Data were not included for the case where the companion fallow plots did not exist. Due to high variability of measured event and annual soil loss rates, these soil loss values were not used to compute soil loss ratios. Only the measured and predicted average annual soil losses and total soil losses from the selected events (table 1) were used.

RESULTS AND DISCUSSION

RUNOFF

Measured and predicted runoff values for each selected event are plotted in figure 1a for the case of optimized K_b and in figure 1b for the case of estimated K_b. The r^2, slope, and intercept of the regression were 0.77, 0.89, and 1.19 for optimized K_b and 0.67, 0.72, and 0.65 for estimated K_b. The results indicate that the model tended to slightly overpredict runoff for small runoff events (positive intercepts) with both K_b values, while it underpredicted runoff for large runoff events, particularly with estimated K_b. These trends are also shown in figures 2a and 2b. The "straight cutoff lines" in figure 2 are upper bounds of underpredictions. These lines reflect zero predicted runoff by the model as opposed to measured runoff. Of 491 selected events that had no measured runoff, the WEPP model predicted runoff on 38% for optimized K_b and 28% for estimated K_b. For the events with measured runoff > 0 and < 5 mm, the model overpredicted total runoff by 76% with optimized and 36% with estimated K_b. For the events with measured runoff ≥ 5 mm, the model underpredicted total runoff by 8 and 28%, respectively. The model performed better in predicting runoff for large events with optimized K_b than with estimated K_b. The poorer performance for large events with estimated K_b might be partially attributed to the uncertainties associated with parameter estimation, because this type of bias was apparently reduced when optimized K_b was used. Overall, WEPP predicted average event runoff reasonably well with either optimized or estimated K_b. Measured and predicted

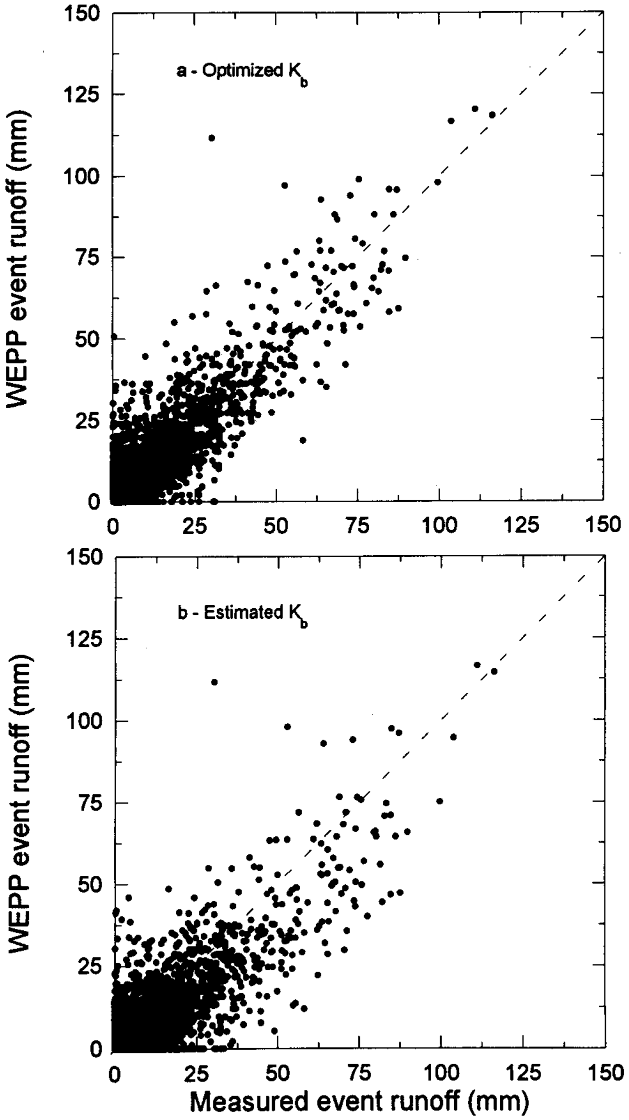

Figure 1–WEPP-predicted event runoff with (a) optimized K_b and (b) estimated K_b vs. measured event runoff. 1:1 lines are shown.

average runoff values per event were very close, with the average error per event being –0.2 mm for optimized K_b and 1.8 mm for estimated K_b (table 3). The average magnitude of errors was within 5 mm per event in both cases. The size distribution of the runoff events was also adequately represented. The standard deviation was 13.2 mm for the measured event runoff and 13.5 mm for the predicted event runoff with optimized K_b. The similarity in the standard deviation reveals that the range and distribution of the predicted event runoff volumes resemble those of measured values.

Yearly runoff volumes under different cropping systems and surface conditions were predicted well. The model overpredicted annual runoff by approximately 14 mm per year when optimized K_b was used, while it underpredicted runoff by about 26 mm per year when estimated K_b was used (table 3). The average magnitude of errors per year was 60 mm for optimized K_b and 76 mm for estimated K_b. Considering the large runoff variations among cropping systems and between years, these results seem acceptable.

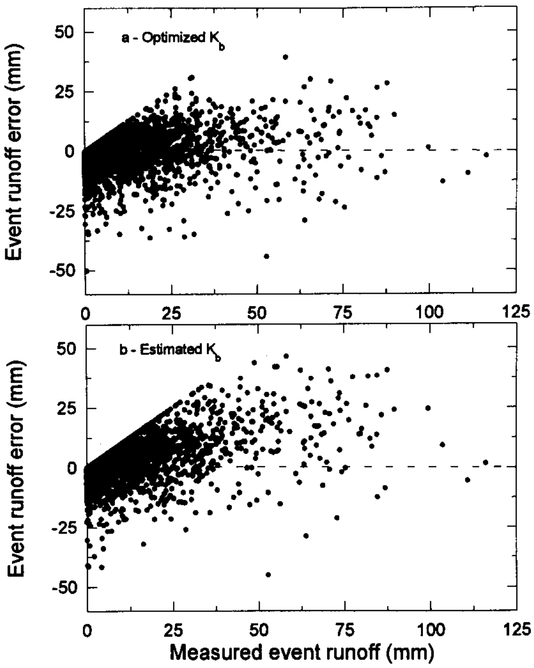

Figure 2–Plots of measured event runoff vs. event runoff error (measured minus predicted) for (a) optimized K_b and (b) estimated K_b.

Annual runoff predictions also showed a tendency to overpredict runoff for the years with small runoff volumes and underpredict runoff for the years with large runoff volumes (figs. 3a and 3b). With optimized K_b, 70 to 90% of the years with annual runoff less than 50 mm were overpredicted, while less than 30% of the years when runoff was greater than 400 mm were overpredicted. No consistent bias was shown for annual runoff between 50 and 400 mm (fig. 4). As compared to event runoff prediction, model performance in annual runoff prediction was slightly improved with optimized K_b, but was somewhat regressed with estimated K_b (table 3).

Measured and predicted average annual runoff volumes are shown in figure 5. Model performance in predicting long-term average runoff was improved compared to annual runoff for both K_b values. This was expected as average annual values tend to lump cyclical effects as well as the effects of random errors. The WEPP model did not show a discernible bias in predicting average annual runoff with optimized K_b (fig. 5a), since the slope of the

Table 3. Mean, standard deviation, and linear regression results for event, annual, and average annual runoff depths predicted by WEPP with both optimized and estimated K_b values*

	Optimized K_b			Estimated K_b		
Parameter	Event	Annual (mm)	Avg. Annual (mm)	Event	Annual (mm)	Avg. Annual (mm)
			Runoff			
Avg. measured	8.8±13.2	166.7±172.5	170.7±153.4	8.8±13.2	166.7±172.5	170.7±153.4
Avg. predicted	9.0±13.5	181.0±181.1	192.9±167.2	6.9±11.6	140.5±131.6	151.5±118.9
Avg. error	–0.2± 6.7	-14.3± 90.2	-22.2± 60.1	1.8± 7.6	26.2±110.1	19.2± 86.2
Avg. absolute error†	4.3± 5.1	60.3± 68.6	47.3± 43.1	4.9± 6.1	76.3± 83.6	64.4± 60.4
			Regression Results			
Intercept	1.19	28.55	19.30	0.65	42.54	41.80
Slope	0.89	0.91	1.02	0.72	0.59	0.64
r^2	0.77	0.76	0.87	0.67	0.59	0.69

* Sample size is 4,124 for event, 310 for annual, and 34 for average annual.

† Average of absolute differences between measured and predicted runoff.

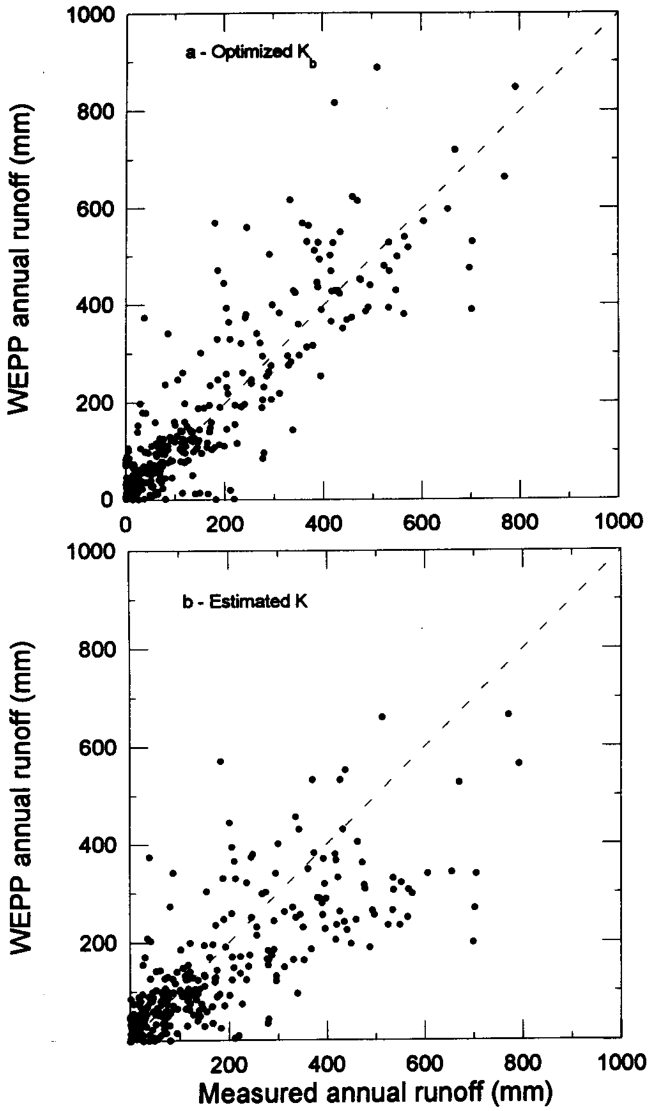

Figure 3–WEPP-predicted annual runoff with (a) optimized K_b and (b) estimated K_b vs. measured annual runoff. 1:1 lines are shown.

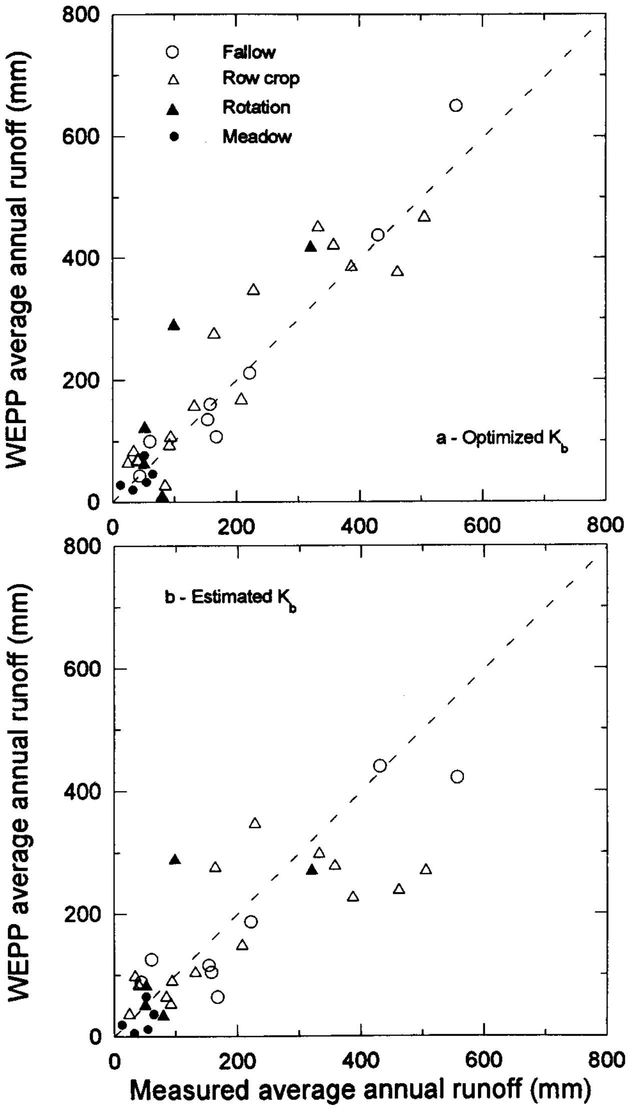

Figure 5–WEPP-predicted average annual runoff with (a) optimized K_b and (b) estimated K_b vs. measured runoff. 1:1 lines are shown.

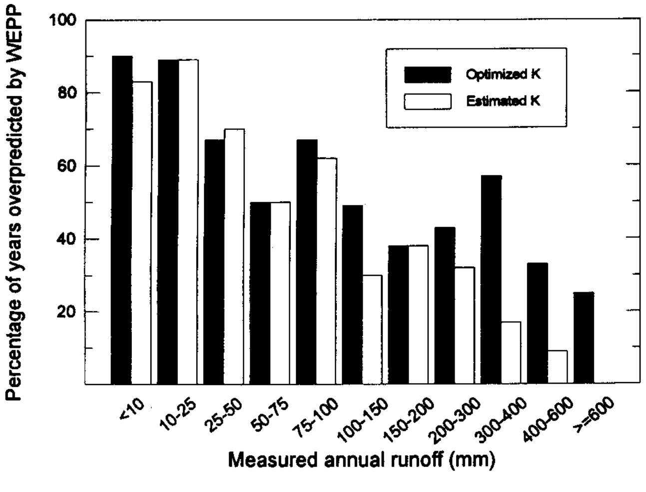

Figure 4–Relationship between the percentages of years overpredicted by WEPP and measured annual runoff depths.

regression line was nearly unity and the intercept was small (table 3). Although the model predicted average annual runoff better than either event or annual runoff with estimated K_b, it still had the tendency of underpredicting runoff on the occasions when runoff volume was relatively large (fig. 5b). This trend has also been observed under fallow conditions in other studies (Risse et al., 1995b).

SOIL LOSS

Predictions of event, annual, and average annual soil losses were made with both optimized and estimated K_b values. The model performed poorly for the fallow and continuous corn at the Bethany site. The measured total soil loss of the selected events was 148.5 kg for fallow and 95.2 kg for conventional corn, while the predicted total soil loss with optimized K_b was 58.1 and 22.4 kg, respectively. Similar results also were obtained when predicted runoff values were adjusted to equal measured values for each selected event. Statistical analyses were done both with and without these two cropping systems to obtain a better picture on model performance (table 4). On an event basis,

Table 4. Mean, standard deviation, and linear regression results for event, annual, and average annual soil losses predicted by WEPP with both optimized and estimated K_b values

	Optimized K_b*			Estimated K_b		
Parameter	Event	Annual ($kg\ m^{-2}$)	Avg. Annual ($kg\ m^{-2}$)	Event	Annual ($kg\ m^{-2}$)	Avg. Annual ($kg\ m^{-2}$)
With All Cropping Systems						
Soil loss						
Avg. measured	0.18±0.79	2.99±5.96	3.05±4.71	0.18±0.79	2.99±5.96	3.05±4.71
Avg. predicted	0.15±0.50	2.64±3.87	2.86±3.45	0.13±0.44	2.27±3.32	2.46±2.89
Avg. error	0.03±0.62	0.35±4.22	0.19±2.81	0.05±0.60	0.73±4.19	0.60±2.83
Avg. absolute error†	0.16±0.60	2.07±3.70	1.59±2.33	0.15±0.58	1.92±3.79	1.45±2.50
Regression results						
Intercept	0.08	1.27	1.06	0.06	1.05	0.91
Slope	0.39	0.46	0.59	0.37	0.41	0.51
r^2	0.38	0.50	0.65	0.43	0.54	0.68
Without Fallow and Corn Cropping Systems at Bethany, Mo.						
Soil loss						
Avg. measured	0.13±0.66	2.18±4.70	2.32±3.69	0.13±0.66	2.18±4.70	2.32±3.69
Avg. predicted	0.14±0.47	2.49±3.78	2.74±3.48	0.12±0.42	2.11±3.18	2.33±2.88
Avg. error	–0.01±0.53	–0.31±2.97	–0.42±1.43	0.01±0.51	0.06±2.91	–0.01±1.44
Avg. absolute error†	0.13±0.52	1.57±2.57	1.07±1.01	0.11±0.49	1.34±2.59	0.89±1.13
Regression results						
Intercept	0.08	1.13	0.72	0.07	0.95	0.64
Slope	0.43	0.62	0.87	0.4	0.54	0.73
r^2	0.36	0.6	0.85	0.4	0.63	0.87

* Sample size is 4,124 for event, 310 for annual, and 34 for average annual with all cropping systems; and is 3,903; 290; and 32, respectively, without Bethany fallow and corn treatments.

† Average of absolute differences between measured and predicted runoff.

the model underpredicted average soil loss, with the average error of 0.03 kg m^{-2} per event for optimized K_b and of 0.05 kg m^{-2} per event for estimated K_b. With both optimized and estimated K_b values, the model apparently overpredicted soil loss for small runoff events (positive intercepts) and underpredicted soil loss for large runoff events (slope being less than 0.4). This trend can be clearly seen in figures 6a and 6b where residuals (differences between measured and predicted) are plotted with event soil loss rates. The model showed a consistent bias in event predictions for the cases of both optimized K_b and adjusted runoff in which predicted and measured event runoff volumes were equalized. The bias in runoff prediction may be partially responsible for the bias in soil loss prediction for optimized K_b, but this carry-over effect should not be a factor when adjusted runoff values were used. The underprediction for large storms was also reported by Kramer and Alberts (1995). One possible source for this discrepancy might be due to the short slope length used in this study. Rill erosion is often limited on short slopes due to low runoff shear of the concentrated flow, and hence a greater proportion of erosion is from interrill areas. On the other hand, this observation might indicate a bias in conceptualizing erosion processes in the model, such as the inadequate representation of gravitational erosion by flow shear (e.g., head cutting and side wall slumping) in rill erosion processes, or errors in mathematical representations of erosion mechanisms, such as the assumption of linearity in equations 5 and 6.

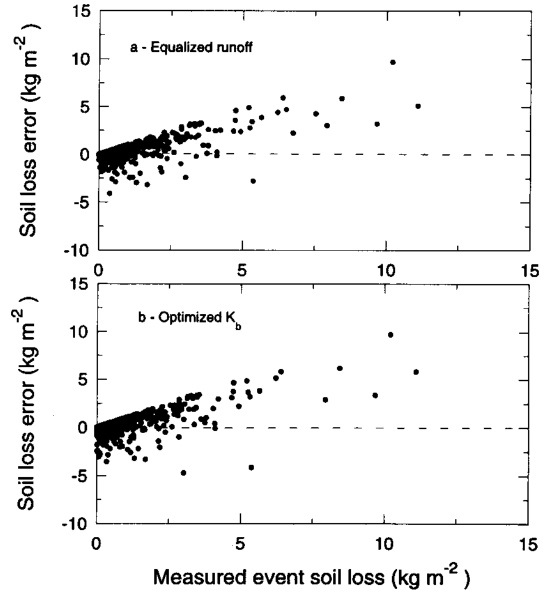

Figure 6–Plots of measured event soil loss vs. soil loss error for (a) equalized runoff and (b) optimized K_b.

Due to the high variation of soil loss rate, WEPP did not predict event soil loss as well as it predicted event runoff. In analyzing 1,700 plot years of soil loss data on 208 natural runoff plots, Risse et al. (1993) reported the average difference in measured annual soil loss between the replicates was 32 ± 35%, with absolute differences ranging from 0 to 7.23 kg m^{-2}. One may expect a larger difference if the comparison was made on an event basis. This observation clearly shows the highly variable nature of soil loss rate and the difficulties in making event predictions.

Measured and predicted total soil losses of the selected events for all cropping systems are plotted in figures 7a, 7b, and 7c for equalized runoff, optimized K_b, and estimated K_b, respectively. As mentioned earlier, WEPP did rather poorly in predicting soil loss for the fallow and conventional corn at the Bethany site. It is difficult to offer a satisfactory explanation here. By analyzing the measured soil loss data, we found soil loss from a few large storms accounted for a considerable amount of total soil loss on the site. As discussed above, WEPP underpredicted soil loss for the events with high erosion rates. This would have resulted in underpredictions of total soil loss. To reduce the influence caused by extreme values, these two cropping systems were not used in the regression analyses. The coefficients of determination were 0.85 for the cases of equalized runoff and optimized K_b, and 0.92 for estimated K_b. The slopes of the regression lines were 0.85, 0.92, and 0.74, respectively. In general, the model produced a more reliable soil loss prediction of event-total for a cropping system than of each individual event.

The WEPP model performed well in predicting annual soil loss for the years with soil loss rates between 0.5 and 10 kg m^{-2}, whereas it tended to overpredict soil loss for the years with lower soil loss rates, and underpredict soil loss for the years with higher soil loss rates (figs. 8a and 8b). Approximately 65 to 95% of the years with soil loss less than 0.5 kg m^{-2} were overpredicted, whereas less than 10% of the years when soil loss rate was greater than 10 kg m^{-2} were overpredicted (fig. 9). This trend was also observed by Ghidey et al. (1995). With all the treatments, the model tended to underestimate annual soil loss for both optimized and estimated K_b values. The average errors for all cropping systems were 0.35 kg m^{-2} per year with optimized K_b and 0.73 kg m^{-2} with estimated K_b. If the fallow and continuous corn at the Bethany site were excluded, the goodness of fit was significantly improved (table 4). This resulted in an overprediction of soil loss for

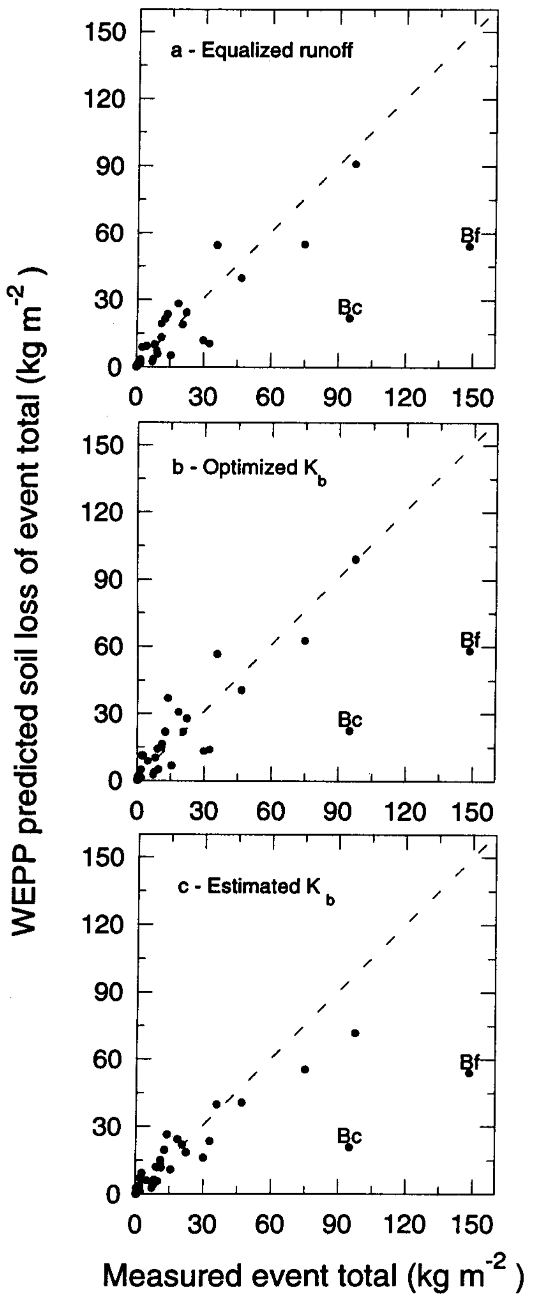

Figure 7–Predicted vs. measured total soil loss of the selected events with (a) equalized runoff, (b) optimized K_b, and (c) estimated K_b. Data points of Bethany fallow and corn are labeled by Bf and Bc, respectively. 1:1 lines are shown.

optimized K_b with the average error of – 0.31 kg m^{-2} and a slight underprediction for estimated K_b with the average error being near zero.

The model predicted average annual soil loss well for all cropping systems except for the fallow and conventional corn at the Bethany site (figs. 10a and 10b). With all the cropping systems, the model appeared to underestimate average annual soil loss with both optimized and estimated K_b values as indicated by the positive average errors (table 4). However, with the exclusion of these two cropping systems from the Bethany site, the model performance was substantially improved. The slope of regression increased from 0.59 to 0.87 for optimized K_b

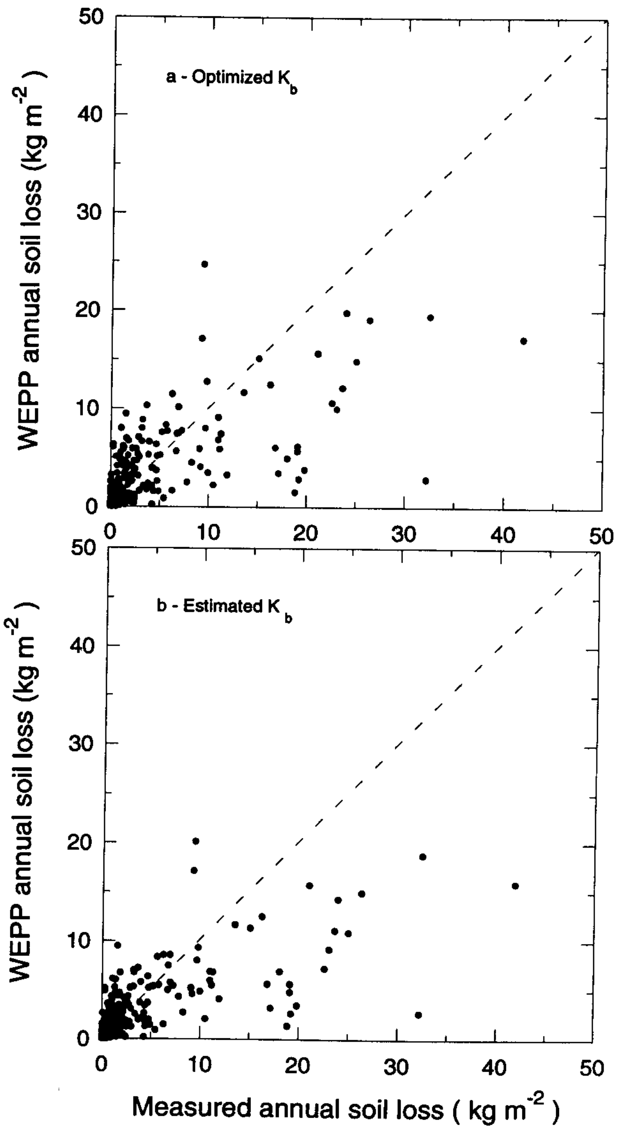

Figure 8–Predicted vs. measured annual soil loss with (a) optimized K_b and (b) estimated K_b. 1:1 lines are shown.

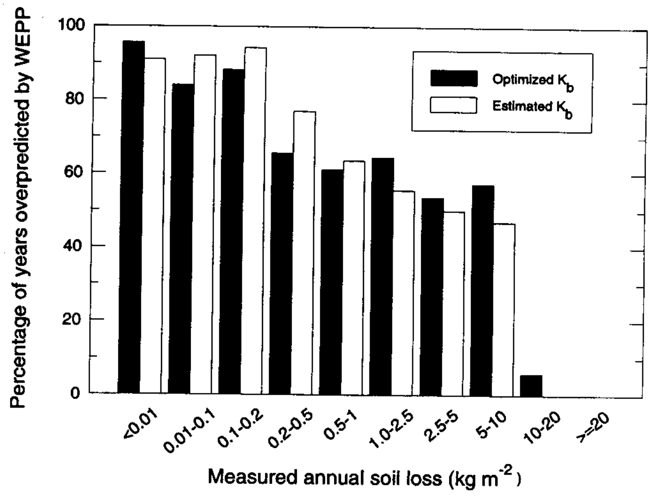

Figure 9–Effect of measured annual soil loss rates on the percentage of years overpredicted by WEPP.

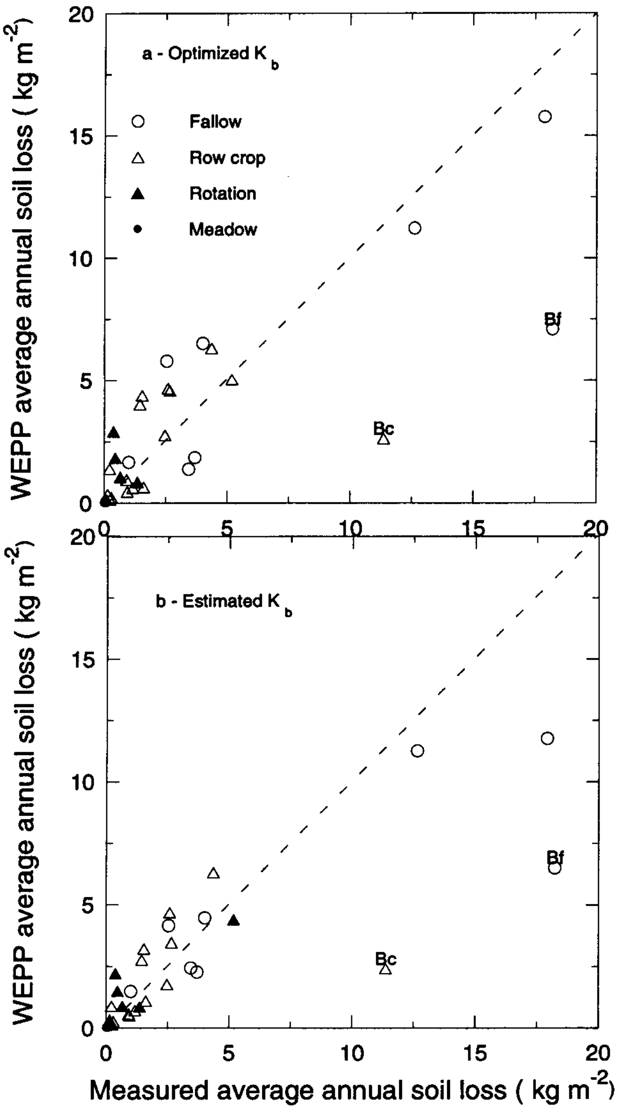

Figure 10–WEPP-predicted vs. measured average annual soil loss with (a) optimized K_b and (b) estimated K_b. Data points from Bethany fallow and corn are labeled by Bf and Bc, respectively. 1:1 lines are shown.

and from 0.51 to 0.73 for estimated K_b. The r^2 increased from 0.65 to 0.85 for optimized K_b and from 0.68 to 0.87 for estimated K_b. In general, the model has a tendency of overestimating soil loss at lower soil loss rates and underestimating soil loss at higher soil loss rates on either an event, annual, or average annual basis, but its performance was shown to improve from an event to annual to average annual basis. Although the size of samples may have some effect on the statistical results, the trend appeared to be clear and reasonable. This is because long-term averages tended to reduce cyclical effects as well as unexplained random variations.

RESPONSE TO CROPPING AND MANAGEMENT

Soil loss ratios computed with event totals are shown in figure 11a for equalized runoff and in figure 11b for optimized K_b. Unlike the total soil loss of the selected events, average annual soil loss represented the total soil losses from rainfall runoff as well as snow melt runoff. The model tended to slightly overpredict soil loss ratios under these two conditions particularly for conventional-till systems, but it adequately reflected the general trend and the relative differences between cropping systems. Because runoff-prediction errors were eliminated for the case of equalized runoff, predicted soil loss ratio under this condition represented a more intrinsic response of the model to the cover and management effect. Thus, the better results with equalized runoff indicate that the model adequately represents cropping and management effects.

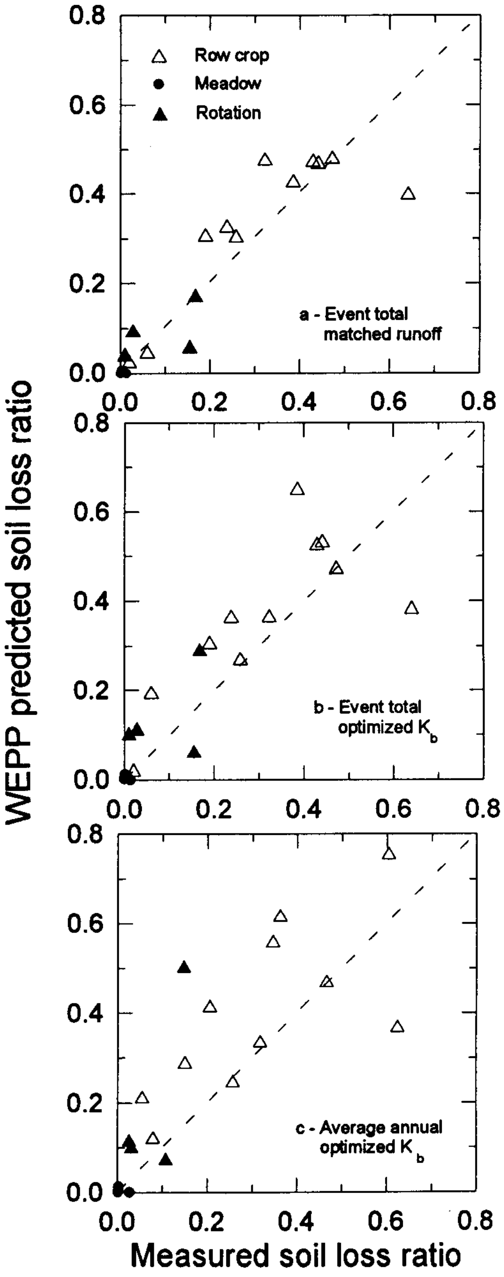

Figure 11–WEPP-calculated vs. measured soil loss ratio using (a) event total and matched runoff, (b) event total and optimized K_b, and (c) average annual and optimized K_b. 1:1 lines are shown.

Measured and predicted soil loss ratios using average annual soil loss rates are plotted in figure 11c for optimized K_b. Again, WEPP tended to overpredict soil loss ratio as compared to the measured values. Similar results were also obtained with estimated K_b (not presented). Similar soil loss ratios predicted with both optimized and estimated K_b values suggest that to a certain degree, estimated K_b is capable of reflecting relative differences in cropping systems. The larger variation of soil loss ratios calculated with average annual soil loss values compared to event totals might be because only high quality events (table 1) were used in calculating the soil loss ratio. The screening procedure used in event selection would have reduced the errors caused by regrouping storm events on a daily basis. In addition, WEPP might predict some soil loss for the events in which there were actually no measured values. This could adversely affect the relationship.

CONCLUSIONS

The WEPP model predicted runoff reasonably well on either event, annual, or average annual basis with optimized K_b when applied to 34 different cropping systems at eight locations. The model showed a tendency of slightly underestimating runoff for large runoff events and for the years with large runoff volumes. The WEPP model internally estimated K_b produced reasonable runoff predictions as compared to measured runoff as well as predicted runoff with optimized K_b.

The WEPP model tended to overpredict soil loss for small events or in the years with low erosion rates, and to underpredict soil loss for large events or for the years with high erosion rates on both event and annual basis. However, means of event and annual soil loss were predicted well. The accuracy and reliability of prediction were shown to improve from an event to annual to average annual basis due to high variability of soil loss rates. The WEPP model performed well in predicting both event totals and average annual values for most cropping systems for the data set in this study. This indicates that the WEPP model is more reliable in predicting longer term averages.

The WEPP model tended to slightly overpredict soil loss ratios for cropping practices in most cropping systems, especially for conventionally tilled annual crops. Nonetheless, the general trend and the relative differences in cropping systems in terms of soil loss reduction were well represented.

Due to the limited nature of the data set, caution for other locations and cropping systems should be taken when extrapolating the results of this study. An additional effort has begun to expand the database by including more locations and cropping systems. In addition, the functionality of the WEPP model should be applied to a broader range of conditions, including steeper slopes, different slope shapes, and various support practices such as strip cropping, contouring, and terracing.

REFERENCES

Chu, S. T. 1978. Infiltration during unsteady rain. *Water Resources Research* 14(3):461-466.

Elliot, W. J., A. M. Liebenow, J. M. Laflen and K. D. Kohl, eds. 1989. A compendium of soil erodibility data from WEPP cropland soil field erodibility experiments 1987 and 1988. NSERL Report No. 3. West Lafayette, Ind.: USDA-ARS-NSERL.

Flanagan, D. C. and M. A. Nearing, eds. 1995. USDA-water erosion prediction project: Technical documentation. NSERL Report No. 10. West Lafayette, Ind.: USDA-ARS-NSERL.

Foster, G. R. 1982. Modeling the erosion process. In *Hydrologic Modeling of Small Watersheds*, ed. C. T. Haan, 297-360. St. Joseph, Mich.: ASAE.

Ghidey, F., E. E. Alberts and L. Kramer. 1995. Comparison of runoff and soil loss predictions from the WEPP hillslope model to measured values for eight cropping and management treatments. ASAE Paper No. 95-2385. St. Joseph, Mich.: ASAE.

Green, W. H. and G. A. Ampt. 1911. Studies on soil physics: 1. Flow of air and water through soils. *J. Agric. Sci.* 4:1-24.

Kramer, L. A. and E. E. Alberts. 1995. Validation of WEPP 95.1 daily erosion simulation. ASAE Paper No. 95-2385. St. Joseph, Mich.: ASAE.

Nicks, A. D., L. J. Lane, G. A. Gander and C. Manetsch. 1993. Regional analysis of precipitation and temperature trends using gridded climate station data. In *Advances in Hydro-Sciences and Engineering*, vol. I, ed. S. Y. Wang, 497-502. In *Proc. of the First Int. Conf. on Hydro-Science and Engineering*. Washington, D.C., 7-11 June, 1993. Mississippi State: Center of Hydroscience and Engineering, Univ of Mississippi.

Rawls, W. J., J. J. Stone and D. L. Brakensiek. 1989. Infiltration. In *USDA-Water Erosion Prediction Project: Hillslope Profile Model Documentation*, eds. L. J. Lane and M. A. Nearing. 4.1-4.12. NSERL Report No. 2. West Lafayette, Ind.: USDA-ARS-NSERL.

Risse, L. M., B. Y. Liu and M. A. Nearing. 1995a. Using curve number to determine baseline values of Green-Ampt effective hydraulic conductivity. *Water Resources Bull.* 31(1):147-158.

Risse, L. M., M. A. Nearing and X. C. Zhang. 1995b. Variability in Green-Ampt effective hydraulic conductivity under fallow conditions. *J. Hydrol.* 169(1):1-24.

Risse, L. M., M. A. Nearing, A. D. Nicks and J. M. Laflen. 1993. Error assessment in the universal soil loss equation. *Soil Sci. Soc. Am. J.* 57(3):825-833.

Wischmeier, W. H. and D. D. Smith. 1978. *Predicting Rainfall Erosion Losses: A Guide for Conservation Planning*. USDA Agric. Handbook. 537. Washington, D.C.: GPO.

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

————. 1995b. Estimation of Green-Ampt conductivity parameters: Part II. Perennial crops. *Transactions of the ASAE* 38(4):1079-1087.