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Abstract: The Water Erosion Prediction Project (WEPP) model and the Agricultural Non-Point-Source Pollution Model (AGNPS) were used in conjunction with a geographic information system (GIS) database to predict runoff and sediment discharges for Rock Creek watershed, an agricultural watershed in Ohio, USA. Observed and predicted values were compared for selected storm events in 1988 and 1990. The statistical evaluation of the WEPP and AGNPS models showed that WEPP predicted average runoff, peak runoff and sediment yield better than AGNPS. WEPP and AGNPS overpredicted peak runoff rates compared to observed data by 15.5% and 26.5%, respectively. The t-test showed that there was no significant statistical difference between measured and predicted runoff and sediment data for both models (at $\propto = 0.05$ level). The average root mean square error between observed and predicted average runoff was 11.5 $m^3 s^{-1}$ and 14 $m^3 s^{-1}$ for WEPP and AGNPS, respectively. While AGNPS underestimated average sediment discharge by 17%, WEPP overestimated average sediment load by 37%. With careful parameterization, the study demonstrated that WEPP and AGNPS could be used to simulate runoff and sediment in agricultural watersheds.

Key Words: Modeling, WEPP, AGNPS, Surface runoff, Soil erosion.

Coğrafi Bilgi Sistemleri Yardımıyla Erozyon ve Yüzey Akış Tahmininde Kullanılan WEPP ve AGNPS Modellerinin Karşılaştırılması

Özet: WEPP ve AGNPS modelleri, coğrafi bilgi sistemi ile birlikte, Ohio-USA'da yer alan Rock Creek tarımsal havzasındaki yüzey akış ile birlikte erozyonun tahmin edilmesinde kullanılmıştır. Bilgisayar simülasyonu, 1988 ve 1990 yılları arasında gözlenen ve tahmin edilen veriler kıyaslanarak yapılmıştır. Istatistiksel analizler WEPP modelinin ortalama yüzey akış, pik akış ve sediment miktarını AGNPS modeline göre daha iyi tahmin ettiğini göstermiştir. WEPP ve AGNPS modelleri pik yüzey akışı sırasıyla % 15.5 ve 26.5 oranında fazla tahmin etmiştir. Yapılan t-testi, ölçülen ve model tarafından tahmin edilen yüzey akış ve sediment verileri arasında ($\propto = 0.05$ seviyesinde) istatistiksel bir fark olmadığını göstermiştir. Ortalama yüzey akış tahmininde WEPP ve AGNPS modellerinin hata kareler ortaması sırasıyla 11.5 $m^3 s^{-1}$ ve 14 $m^3 s^{-1}$ olarak bulunmuştur. AGNPS modeli erozyonu % 17 oranında daha az tahmin ederken WEPP modeli sedimenti % 36 oranında fazla tahmin etmiştir. Bu çalışma model girdilerinin dikkatli bir şekilde belirlenmesi koşuluyla, WEPP ve AGNPS modellerinin tarımsal havzalardaki yüzey akış ve sediment tayininde kullanılabilinecegini göstermiştir.

Anahtar Sözcükler: Modelleme, Wepp, Agnps, Yüzey akış, Toprak erozyonu.

Introduction

Nonpoint source pollutant modeling is the most widely used and effective tool for soil conservation planning and design due to the difficulty in monitoring the influence of each specific management practice in a diverse ecosystem. In order to simulate complex interactions of hydrologic processes and to determine sediment and runoff from agricultural watershed, many water quality computer simulation models have been developed (Maidment, 1991). These can be classified as lumped or distributed parameter models. A lumped model is expressed by ordinary differential equations taking no account of the spatial variability of processes and watershed charcteristics. A distributed parameter model acts directly on the spatially distributed data and is very suitable for modeling hydrologic transport processes affecting water quality. Hydrological modeling linked with GIS helps decision makers by allowing them to do their work more quickly and efficiently (Goodchild, 1992).

The objective of this study was to evaluate the WEPP and AGNPS watershed model predictions of runoff and sediment yields relative to measured data on the Rock Creek watershed outlet considering different watershed size resolutions.

Materials and Methods

The study was conducted for the Rock Creek watershed located in Seneca County, Ohio, USA. The total watershed area is about 95 km^2; it is a subwatershed of the Sandusky River watershed and discharges into Lake Erie. The watershed has till plain soils with undulating or flat topography, and about 80% of the land is under agricultural production. Sediment loads and stream flow were measured at the watershed outlet by the Water Quality Laboratory at Heidelberg College at Tiffen, Ohio.

WEPP Model

The WEPP watershed model, a process-based and distributed parameter computer simulation model, was developed to predict erosion effects from agricultural management practices and to accommodate spatial and temporal variability in topography, soil properties, and land use conditions within small agricultural watersheds of less than 260 ha (Ascough et al., 1994). The erosion component of the WEPP model uses a steady-state sediment continuity equation as the basis for the erosion computions. WEPP considers only Hortonian flow or flow that occurs when the rainfall rate exceeds the infiltration rate. The model uses two methods of computing the peak discharge: a semi-analytical solution of the kinematic wave model and an approximation of the kinematic wave model. The first method is used when WEPP is run in single event mode while the second is used when WEPP is run in continuous simulation mode (Ascough et al., 1994; Flanagan and Livingston, 1995).

AGNPS Model

AGNPS was developed to analyze and provide estimates of runoff water quality, and specifically to evaluate sediments and nutrients in runoff from agricultural watersheds (20,000 ha or larger) for a specific storm event (Maidment, 1991). The basic model components include hydrology, erosion, sediment transport, and chemical transport. In the hydrology component, runoff volume is calculated by the Soil Conservation Service (SCS) curve number procedure. Erosion is computed from the Modified Universal Soil Loss Equation (MUSLE) (Maidment, 1993; Young et al., 1994). An intriguing aspect of the model is the grid-cell method used for representing spatially distributed physical and simulated data. Runoff and sediment are routed from the headwaters of the watershed to its outlet through cells in a stepwise manner so that flow at any point between cells may be examined. A weakness of the grid-cell method is that square units are used to represent the irregular shaped boundaries of the physical data. Approximation of the physical characteristics of the watershed through the cell representation leads to input errors. The AGNPS model, unlike many watershed models, is an event-oriented model (Young et al., 1989).

Procedures

In order to run the AGNPS and WEPP watershed models, the methodology developed by Young et al. (1989) and Gowda (1996) were used, respectively. The WEPP and AGNPS models were applied to the Rock Creek watershed by creating subwatersheds or cell sizes (grids), respectively, whose areas were 50, 100, and 150 ha. A GIS database consisting of soil type, slope, landuse and management practice was developed for each basic unit using ARC/INFO. In the application of WEPP to Rock Creek watershed, a classification technique involving Hydrological Response Units (HRUs) and Transformed Hydrological Response Units (THRUs) was used.

In order to make a logical comparison, both models were run for selected storm events. The digital elevation model (DEM) of the Rock Creek watershed was used to get the boundaries of each subwatershed or grid. The drainage network layer used for developing the DEM was obtained from the United States Environmental Protection Agency (USEPA). A soil layer for the Rock Creek watershed was extracted from the State Soil Geographic Database (STATSGO), a digital soil database in ARC/INFO format. All required soil input data for the AGNPS and WEPP models were derived from the Map Unit Use File (MUUF), an NRCS (Natural Resources Conservation Service, 1994) soils database. The agricultural management practice and landuse data sets for the Rock Creek watershed were obtained from previous studies conducted by Gowda (1996) and Van Deventer et al. (1994). While creating the climate file of the WEPP model, a stochastic weather generator called CLIGEN was used. However, while running the AGNPS model, the only required climate data (rainfall) were obtained directly from a local weather station near the basin. In the determination of the SCS curve number for AGNPS model, land use, tillage, and soil GIS layers were combined in ARC/INFO format using the INTERSECT overlay command; the calculated area weighted curve numbers were assigned to all of the cell units for 50, 100, and 150 ha resolution. The slope and flow direction was extracted from the DEM using the ARC/INFO functions.

Model Evaluation

The WEPP and AGNPS watershed model responses were compared to each other and to the observed data at the outlet of the watershed. The t-statistic was used for testing agreement between measurements and model predictions. In addition, five statistical procedures were used for the model evaluation. These were (1) the observed and predicted means and their standard deviations, (2) coefficient of determination (r^2), (3) the slope and intercept of a least square regression between the predicted and observed values, (4) root mean square error (RMSE), and (5) an index of agreement (d). The RMSE is an index of the actual error produced by the model and is calculated as

$$RMSE = \left(\sum_{i=1}^{N} \frac{1}{N} (P_i - O_i)^2 \right)^{0.5}$$

where N is the number of cases, P_i is the predicted value, and O_i is the corresponding observed value. The d can be used to reflect the degree to which the predicted variation accurately estimates the observed variation and is calculated as

$$d = 1 - \frac{\sum_{i=1}^{N} (P_i - O_i)^2}{\sum_{i=1}^{N} (|P_i'| + |O_i'|)^2} \qquad (2)$$

where and $P_i' = P_i - \bar{P}$ and $O_i' = O_i - \bar{O}$.

Results and Discussion

The prediction results of the WEPP and AGNPS computer models for event simulation are shown in Figures 1 through 6. The results of t-test and linear regression analysis are presented in Tables 1, 2 and 3. The average measured runoff, sediment load and peak runoff for the selected events were 17.95 $m^3 s^{-1}$, 911.61 t and 24.4 m^3 s^{-1}, respectively, at the outlet of the watershed. The t-statistic showed that there was no statistically significant difference between model predictions and observed data at $\propto$ = 0.05 level. In addition, $p > \propto = 0.05$ was observed for all components as shown in Tables 1, 2 and 3. Hence, the results obtained from model analysis revealed that both models could be used to simulate runoff and sediment in agricultural watersheds.

Flow

Figures 1 and 2 show the comparison of predicted and observed mean runoff amounts for WEPP and AGNPS respectively. AGNPS underestimated mean runoff amounts by 17.5% whereas WEPP overestimated them by 19.22%. When we evaluate the watershed resolutions on average runoff amount, we see that there were significant differences between predicted runoff amounts for 50, 100 and 150 ha for both models. From Table 1, the statistical evaluation of predicted runoff amounts (for 50, 100, and 150 ha resolutions) against observed data gave an RMSE of 13.30, 13.0 15.56 and r^2 and d values of 0.95, 0.93, 0.89 and 0.96, 0.95, 0.94, respectively, for AGNPS. However, WEPP gave an RMSE of 8, 9.5,

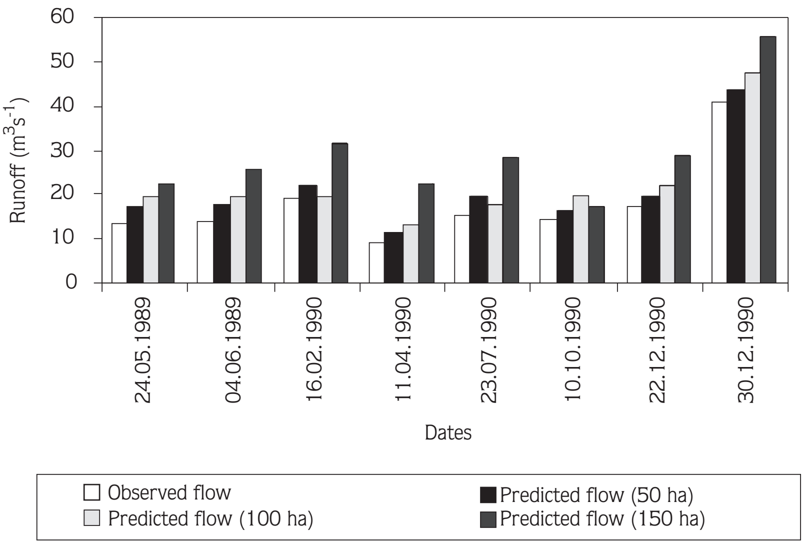

Figure 1. Comparison of predicted and observed average runoff rates at the outlet of the Rock Creek watershed using WEPP.

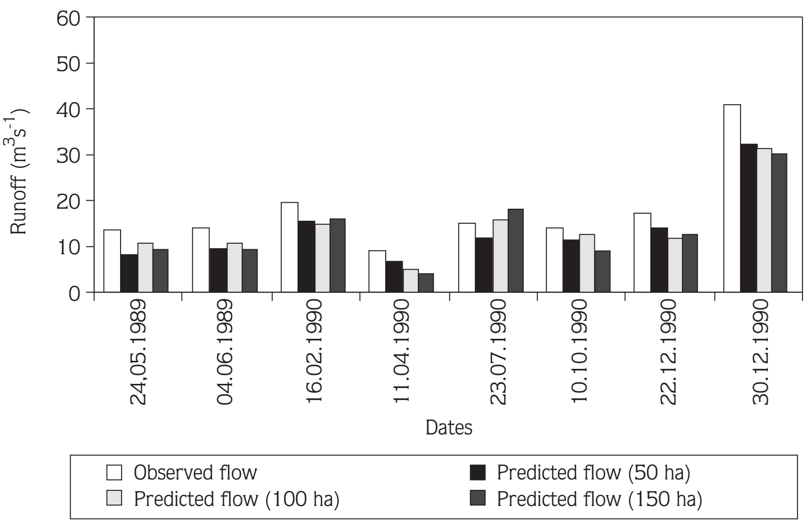

Figure 2. Comparison of predicted and observed average runoff rates at the outlet of the Rock Creek watershed using AGNPS.

Table 1. Statistical comparison of observed (O) and predicted (P) average flow (AF) rates for the Rock Creek watershed.

Statistical parameters		WEPP Model			AGNPS Model		
		AF (50 ha)	AF (100 ha)	AF (150 ha)	AF (50 ha)	AF (100 ha)	AF (150 ha)
O	Mean	17.95	17.95	17.95	17.95	17.95	17.95
	Std. Dev	9.7	9.7	9.7	9.7	9.7	9.7
P	Mean	20.51	20.47	23.22	13.64	14.19	16.58
	Std. Dev	9.96	10.79	11.25	7.98	7.63	8.12
RMSE		8.0	9.5	17.30	13.30	13.0	15.56
Intercept		2.24	0.95	3.23	-1.02	0.54	-0.46
Slope		1.01	1.08	1.11	0.81	0.76	0.78
r^2		0.95	0.91	0.87	0.95	0.93	0.89
d		0.97	0.96	0.84	0.96	0.95	0.94
t-statistic		-0.52	-0.49	-1.01	0.97	0.86	0.98
p-value* (∝ = 0.05)		0.61	0.63	0.33	0.35	0.40	0.35

* probability at 0.05 significance level.

17.30 and r^2 and d values of 0.95, 0.91, 0.87 and 0.97, 0.96, and 0.84, respectively. A comparison of predicted mean runoff rates for different scales (50, 100 and 150 ha) against observed data shows that AGNPS underpredicted the average runoff rate for these three resolutions while WEPP overestimated it. It can be seen that the magnitude and timing of the predicted flow tended to represent observed data (Figures 1 and 2). This good performance is comparable and better than other watershed models. For example, in a study carried out with the Soil and Water Assessment Tool (SWAT) model on the Seco Creek watershed central Texas by Srinivasan and Arnold (1995) reported an r^2 of 0.86 for average flow rates. Gowda (1996) reported an r^2 of 0.85 for mean flow rates on the Rock Creek watershed Ohio by using the Agricultural Drainage And Pesticide Transport (ADAPT) model.

The observed versus predicted peak runoff rates are plotted in Figures 3 and 4 for the WEPP and AGNPS models, respectively. Table 2 shows that WEPP simulates peak runoff better than AGNPS for small scales (50 ha resolution). However, AGNPS gives better predictions for

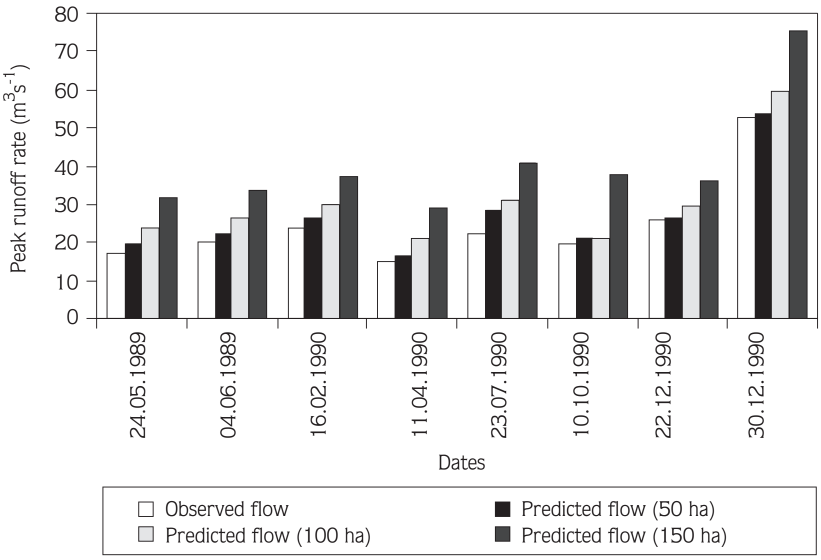

Figure 3. Comparison of predicted and observed peak runoff rates at the outlet of the Rock Creek watershed using WEPP.

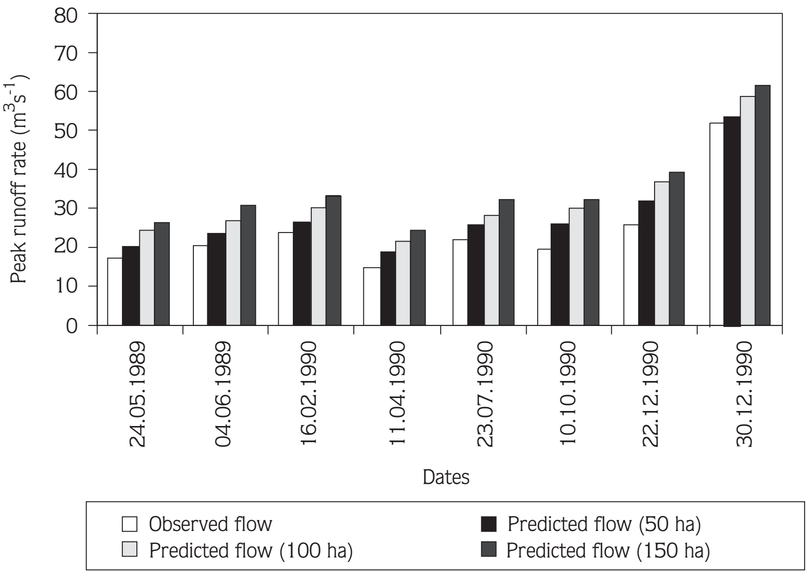

Figure 4. Comparison of predicted and observed peak runoff rates at the outlet of the Rock Creek watershed using AGNPS.

larger scales. Both models overpredicted peak runoff rates for 50, 100, and 150 ha size resolutions. When we compare the predicted peak runoff rates with those from other watershed models, it is found that both models with an average r^2 of 0.95 between observed and predicted peak flow rates were better than others. An r^2 of 0.86 between predicted and observed data using Watershed Storm Hydrograph Multiple Options (WASHMO) model on the Rock Creek watershed was reported by Wu et al. (1992). The errors in the average and peak runoff rate predictions against observed data might be due to inadequate information on magnitude and timing of rainfall, error in input data, incorrect estimation of parameter values and a combination of errors.

Sediment

Figures 5 and 6 illustrate the comparison of predicted sediment discharge and observed data at the outlet of the watershed. Simulation results showed that both models were sensitive to the accuracy of flow predictions and the size of the watershed. The AGNPS sediment discharge prediction had an RMSE of 935.2, 941.8, and 1509.3 t for 50, 100 and 150 ha resolutions, respectively. On the

Table 2. Statistical comparison of observed (O) and predicted (P) peak flow (PF) rates for the Rock Creek watershed.

Statistical parameters		WEPP Model			AGNPS Model		
		PF (50 ha)	PF (100 ha)	PF (150 ha)	PF (50 ha)	PF (100 ha)	PF (150 ha)
O	Mean	24.5	24.5	24.5	24.5	24.5	24.5
	Std. Dev	11.81	11.81	11.81	11.81	11.81	11.81
P	Mean	26.56	29.68	30.89	28.4	32.68	34.74
	Std. Dev	11.73	10.79	12.70	11.04	11.71	13.28
RMSE		7.75	16	20.50	11.87	23.72	30.20
Intercept		2.55	7.71	5.64	5.67	8.74	7.76
Slope		0.97	0.89	1.80	0.93	0.96	1.20
r^2		0.98	0.95	0.90	0.98	0.96	0.94
d		0.95	0.62	0.35	0.84	0.80	0.68
t-statistic		-0.35	-0.92	-1.04	-0.68	-1.39	-1.63
p-value* (∝ = 0.05)		0.73	0.38	0.32	0.51	0.19	0.13

* probability at 0.05 significance level.

Table 3. Model performances determined by evaluating predicted sediment (PS) discharges against observed data for the Rock Creek watershed.

Statistical parameters		WEPP Model			AGNPS Model		
		PS (50 ha)	PS (100 ha)	PS (150 ha)	PS (50 ha)	PS (100 ha)	PS (150 ha)
O	Mean	911.61	911.61	911.61	911.61	911.61	911.61
	Std. Dev	592.95	592.95	592.95	592.95	592.95	592.95
P	Mean	1203.8	1202.85	1347.04	828.8	746.4	691.01
	Std. Dev	716.06	698.90	845.92	526.67	502.02	495.54
RMSE		390.72	582.48	739.41	935.20	941.80	1509.30
Intercept		11.70	51.53	106.30	31.5	179.80	215.5
Slope		1.19	1.15	1.14	0.87	0.83	0.82
r^2		0.97	0.95	0.90	0.96	0.91	0.88
d		2.15	5.19	7.26	3.56	6.95	17.56
t-statistic		0.30	0.60	0.81	-0.89	-0.90	-1.19
p-value* (∝ = 0.05)		0.77	0.56	0.43	0.39	0.38	0.26

* probability at 0.05 significance level.

other hand, the WEPP model gave an RMSE of 390.72, 582.48, and 739.41 t for the same resolutions, respectively. This implies that the sediment discharge predictions of WEPP have less error than those of AGNPS. The statistical evaluation of AGNPS-predicted sediment yield against observed data gave an r^2 of 0.96,

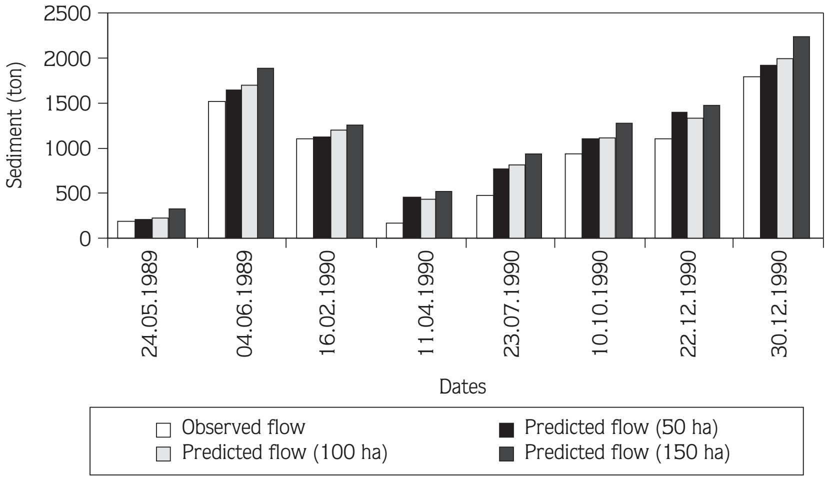

Figure 5. Comparison of predicted and observed sediment yield at the outlet of the Rock Creek watershed using WEPP.

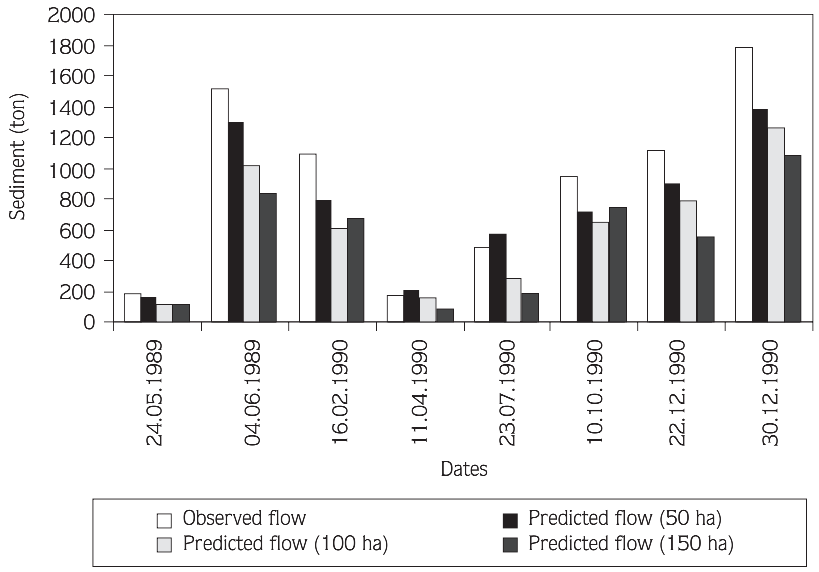

Figure 6. Comparison of predicted and observed sediment yield at the outlet of the Rock Creek watershed using AGNPS.

0.91, 0.88 for 50, 100, and 150 ha resolutions, respectively. On the other hand, the WEPP-predicted sediment yield against observed data gave an r^2 of 0.97, 0.95 and 0.90 for same resolutions, respectively. While AGNPS underestimated sediment discharge, WEPP overestimated it as shown in Figures 5 and 6. This performance of both models is comparable to the statistical results found in the literature. In a similar study using WEPP in northwest Spain, an r^2 of 0.70 for sediment discharge was reported by Soto and Diaz-Fierrors (1998). The Universal Soil Loss Equation (USLE) and MUSLE models were used to predict erosion loss in a watershed in the USA and r^2 values of 0.58 and 0.65 were found, respectively (Riesse et al., 1993; and Rapp, 1994). The USLE model parameters were determined in many basins in Turkey and it was concluded that USLE works well in Turkey (Dağdeviren, 1997; Türkseven and Ayday, 2000). Keskin and Özden (2000) tested the Land Erodibility Assessment Methodology (LEAM) in the Zir-Ankara region in Turkey and concluded that this model predicted potential erosion risk well. Errors in predicting sediment yield in AGNPS might be due to inaccurate crop management factor and SCS curve number values and also errors in the prediction of flows. Other studies were in agreement with our results. For example, studies conducted by Young et al. (1989) and Peerone and Madramootoo (1997) showed the AGNPS model was very sensitive to crop management and SCS curve number values. Errors in predicting sediment yield in WEPP may be due to the inaccurate estimation of soil parameters and especially climate data. In addition, the routing algorithm used in WEPP may lead to inaccurate sediment estimation.

Conclusions

The flow prediction of both models was better than sediment predictions. Both WEPP and AGNPS produced reasonable results when applied to the Rock Creek watershed in the USA. The WEPP model predicted average runoff, peak runoff and sediment yield with an average d of 0.92 m^3 s^{-1}, 0.64 m^3 s^{-1} and 4.86 t, respectively, whereas the AGNPS model predicted same parameters with an average d of 0.95 m^3 s^{-1}, 0.77 m^3 s^{-1}, and 9.36 t, respectively. The statistical analysis showed that both models produce the most uncertainty and errors in the prediction of peak runoff. A sensivity analysis of both models for some selected input parameters should be done in order to reduce errors in model prediction for future studies.

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