Validation of EPIC for Two Watersheds in Southwest Iowa

S.W. Chung[1], P.W. Gassman[2,*], L.A. Kramer[3], J.R. Williams[4], and R. Gu[1]

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Center for Agricultural and Rural Development
Iowa State University
Ames, IA 50011-1070

[1]Dept. of Civil and Construction Engineering.; Town Engineering Building; Iowa State University; Ames, Iowa

[2,*]Center for Agricultural and Rural Development; Dept. of Economics; Iowa State University; Ames, Iowa (pwgassma@iastate.edu)

[3]U.S. Department of Agriculture; Agricultural Research Service; National Soil Tilth Laboratory; Deep Loess Research Station; Council Bluffs, Iowa

[4]The Texas Agricultural Experiment Station, Blackland Research Center, Temple, Texas.

ABSTRACT

<p>The Erosion Productivity Impact Calculator (EPIC) model was validated using long-term data collected for two southwest Iowa watersheds in the Deep Loess Soil Region, which have been cropped in continuous corn (*Zea Mays L.*) under two different tillage systems (conventional tillage and ridge-till). The annual hydrologic balance was calibrated for both watersheds during 1988-94 by adjusting the runoff curve numbers and residue effects on soil evaporation. Model validation was performed for 1976-87, using both summary statistics (means or medians) and parametric and nonparametric statistical tests. The errors between the 12-year predicted and observed means or medians were less than 10 percent for nearly all of the hydrologic and environmental indicators, with the major exception of a nearly 44 percent overprediction of the N surface runoff loss for Watershed 2. The predicted N leaching rates, N losses in surface runoff, and sediment loss for the two watersheds clearly showed that EPIC was able to simulate the long-term impacts of tillage and residue cover on these processes. However, the results also revealed weaknesses in the model's ability to replicate year-to-year variability, with r^2 values generally below 50 percent and relatively weak goodness-of-fit statistics for some processes. This was due in part to simulating the watersheds in a homogeneous manner, which ignored complexities such as slope variation. Overall, the results show that EPIC was able to replicate the long-term relative differences between the two tillage systems and that the model is a useful tool for simulating different tillage systems in the region.

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IN SOUTHWEST IOWA

Agricultural decision makers are encountering increasingly complex challenges in ensuring a stable and cost-efficient food supply. These challenges are multifaceted, often requiring that management and policy alternatives be considered both for potential economic and environmental impacts. For instance, an agricultural policy change that results in crop production shifts can also trigger questions concerning the corresponding water quality and soil erosion effects. Field and monitoring studies provide essential data and critical answers for many of these types of questions. However, field studies are prohibitively costly to perform across all possible landscape, weather, management, and cropping system combinations, especially for large agricultural regions. Also, monitoring of water quality, soil erosion, and/or other environmental indicators only captures baseline conditions, and will not project future impacts that result from current policy decisions.

For these reasons, applications of integrated modeling systems are increasing to provide economic and environmental outcomes in response to alternative management systems and/or agricultural policies. Integrated modeling systems range from farm-level (Foltz et al. 1993; Taylor et al. 1992; Wossink et al. 1992), to watershed (Bouzaher et al. 1990; Lakshminarayan et al. 1991), and ultimately to regional (Bernardo et al. 1993; Bouzaher et al. 1995; Lakshminarayan et al. 1996) applications. In each of these systems, functions and/or models are incorporated to predict environmental indicators for different combinations of landscape, soil, management, and climate conditions.

The Erosion Productivity Impact Calculator (EPIC) model (Williams 1990, Williams 1995) has been adapted within several integrated modeling systems, because of its flexibility in handling a wide array of crop rotations, management systems, and environmental conditions. Originally, EPIC was designed to simulate the impacts of erosion on soil productivity (Williams et al. 1984). Current versions of EPIC can also produce indicators such as nutrient loss from fertilizer and animal manure applications (Edwards et al. 1994; Phillips et al. 1993), climate change impacts on crop yield and soil erosion (Favis-Mortlock 1991; Stockle et al. 1992;

Williams et al. 1996), losses from field applications of pesticides (Williams et al. 1992), and soil carbonsequestration as a function of cropping and management systems (Mitchell et al. 1998).[1]

The flexibility of EPIC has led to its adoption within the Resource and Agricultural Policy Systems (RAPS), an integrated modeling system designed to project shifts in production practices (crop rotations, tillage levels, and conservation practices) and evaluate the resulting environmental impacts, in response to agricultural policies implemented for the North Central United States (Babcock et al. 1997). The focus of the EPIC applications within RAPS is to provide nitrogen loss and soil erosion (both wind and water) indicators in response to variations in crop rotation, tillage, soil, fertilizer applications, and environmental conditions. Although EPIC has proven to be a robust tool within RAPS, there is an ongoing need to test the model with as much site-specific data as possible to further improve its prediction capabilities. To date, limited validation studies of EPIC with field data have been performed in the RAPS study region; thus, testing of EPIC with site-specific data has been incorporated as a component within RAPS.

The goal of this study is to test EPIC version 5300 (EPIC5300) using long-term data sets collected by the U.S. Department of Agriculture–Agricultural Research Service (USDA-ARS) at two field-sized watersheds, denoted as Watersheds 2 and 3, located in southwestern Iowa near Treynor (Kramer et al. 1989; Kramer and Hjelmfelt 1989; Kramer et al. 1990). These watersheds are representative of the 2.2 million ha Deep Loess Soil Major Land Resource Area (MLRA 107) that covers much of western Iowa and northwestern Missouri. Water balance, sediment, and nutrient loss data have been collected from both watersheds, which have been cropped with continuous corn (*Zea Mays L.*) and managed with contrasting tillage systems (conventional versus ridge tillage) for more than two decades.

The effect of conservation tillage systems relative to conventional tillage systems on water balance, nutrient transport, soil loss, and crop yield can range from slight to substantial (Singh and Kanwar 1995; Phillips et. al 1980; Christensen and Norris 1983; Steiner 1989). At Treynor, Kramer et. al (1989) reported reduced surface runoff, increased seepage flow, and increased leached nitrogen for the Watershed 3 ridge-till system relative to the conventional tillage system used for Watershed 2. Kramer and Hjelmfelt (1989) also found that the ridge-till system greatly reduced soil erosion during storms of high erosion potential compared to the conventional tillage system.

The objectives of this research are to confirm that EPIC5300 can replicate the impacts of the two different tillage systems by (1) calibrating the model using observed water balance data for 1988 to 1994; and (2) validating the simulated water balance, nutrient loss, and crop yields using measured data for

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[1] The expanded use of EPIC for applications other than erosion impacts on soil productivity has resulted in the model name being changed to Environmental Policy Integrated Climate (Mitchell et al. 1996).

1976 through 1978. Estimates of soil erosion are also reported; however, these could not be compared directly with measured data. Summary statistics and graphical comparisons are the primary tools used to assess model validity; parametric and nonparametric statistical tests are also used within the validation step.

Materials and Methods

Watershed Description

Watersheds 2 and 3 cover 34.4 and 43.3 ha over rolling topography defined by gently sloping ridges, steep side slopes, and alluvial valleys with incised channels that normally end at an active gully head, typical of the deep loess soil in MLRA 107 (Kramer et al. 1990). The cropped portions of the watersheds cover the ridges, side-slopes, and toe-slopes. Bromegrass was maintained on the major drainageways of the alluvial valleys. Slopes usually range from 2 to 4 percent on the ridges and valleys and 12 to 16 percent on the side slopes. An average slope of about 8.4 percent was estimated for both watersheds, using first-order soil survey maps. The major soil types are well-drained Typic Hapludolls, Typic Udorthents, and Cumulic Hapludolls (Marshall-Monona-Ida and Napier series), classified as fine-silty, mixed, mesics. The surface soils consist of silt loam and silty clay loam textures that are very prone to erosion, requiring suitable conservation practices to prevent serious erosion.

The regional geology is characterized by a thick layer of loess overlying glacial till that together overlay bedrock. The loess thickness ranges from 3 m in the valleys to 27 m on the ridges. Seepage flow continuously discharges into the valley gully channels from a saturated zone located at the loess-till interface. Stream flow at each watershed outlet, consisting of the perennial seepage flow and surface runoff during storm events, was continuously recorded with instrumented broad-crested V-notch weirs. Precipitation was measured with three Universal recording rain gauges placed on each of the watershed boundaries.

Watershed 2, cropped with continuous corn, has been managed consistently with conventional tillage on the approximate contour from 1964 through the study period. The conventional tillage system consisted of moldboard plowing or heavy tandem disking around mid-April to incorporate corn stalk residues, followed by shallower tandem disking or field cultivation about two weeks later to complete seedbed preparation. One or two cultivations were performed during the growing season for weed control. An average annual equivalent mineral nitrogen (N) application rate of 185 kg/ha was applied to Watershed 2 during 1976-94, the period used for the simulation study.

Watershed 3 was originally managed as bromegrass pasture from 1964 to 1971 and was converted in 1972 to a continuous corn ridge-till plant system consisting of an early May planting with a 4-row Buffalo till planter in the corn residue on the approximate contour. One or two cultivations with a 4-row Buffalo

cultivator were performed to control weeds and to construct ridges along the corn rows. Ridge heights of between 15 and 20 cm were maintained for the cropped portions of the watershed. The average annual N application rate at Watershed 3 was 169 kg/ha during 1976-94 (1972-75 data were assumed to represent a land use transition and were considered nonrepresentative of the ridge-till system).

Simulation Methodology and Input Data

The EPIC model can be subdivided into nine separate components: weather, hydrology, erosion, nutrients, soil temperature, plant growth, plant environment control, tillage, and budgets (Williams 1990). It is a field-scale model, designed to simulate drainage areas of up to 100 ha (Williams et al. 1996) that are characterized by homogeneous weather, soil, landscape, crop rotation, and management system parameters. It operates on a continuous basis using a daily time step and can perform long-term simulations of hundreds of years. More detailed discussions of EPIC are given in Williams (1990,1995).

The average slope of 8.4 percent was assumed for both watersheds to satisfy the requirement of homogeneity. The dominant soil type, Monona, was also assumed to represent both watersheds for the EPIC simulations. Up to 20 soil layer parameters can be input into EPIC; required values include layer depth, bulk density, wilting point, field capacity, percentage sand, percentage silt, pH, and percentage organic carbon. Table 1 lists the layer data for the 1.8 m Monona soil profile. These data were primarily obtained from the USDA (USDA 1991). Bulk density inputs for the upper 20 cm are mean values measured by Kramer and Grossman (1992) during the spring season between 1979 and 1991 (no measurements were made in 1988-89). The surface layer pH values (top 20 cm) were based on measurements made in Watersheds 2 and 3 in 1989 and 1995 (Kramer 1995). These low pH values resulted from little or no liming inputs over several years. The pH values for the remainder of the profile were obtained from Monona soil data included in the EPIC soil database (Mitchell et al. 1996).

EPIC is driven by observed and/or simulated daily climatic inputs that include total precipitation, maximum and minimum air temperature, total solar radiation, average relative humidity, and average wind speed. Measured precipitation and temperature values were input for the 19-year simulation period. The remaining climatic inputs were generated using monthly weather statistics for Oakland, Iowa, located approximately 25 km northeast of the watersheds, the nearest climatic station available in the EPIC weather generator parameter database. The average annual precipitation levels were 824 and 802 mm at Watersheds 2 and 3 between 1976 and 1994, reflecting the variability in rainfall patterns and amounts that occur within the 3 km between the two watersheds.

Table 1. Properties by layer for the Monona soil.

Property	Soil Layer								
	1	2	3	4	5	6	7	8	9
Depth	.01	0.05	0.20	0.35	0.50	0.85	1.10	1.55	1.80
BD (Mg/m^3)	1.08[†]	1.08	1.25	1.38	1.26	1.28	1.35	1.41	1.44
	(0.87)[‡]	(0.87)							
WP (m/m)[§]	0.13	0.13	0.13	0.13	0.12	0.12	0.11	0.11	0.12
FC (m/m)[§]	0.25	0.25	0.25	0.26	0.26	0.26	0.28	0.27	0.28
Sand (%)	4.3	4.3	4.1	3.7	5.1	5.4	6.1	6.3	6.4
Silt (%)	68.7	68.7	68.3	68.9	70.2	70.3	73.0	71.4	73.5
Soil pH	5.5	5.5	5.5	7.3	7.4	7.6	8.0	8.0	8.0
Org. C (%)	1.97	1.97	1.21	0.68	0.38	0.30	0.24	0.17	0.16

[†]   Bulk density for Watershed 2 under conventional tillage system.
[‡]   Bulk Density for Watershed 3 under ridge tillage system.
[§]   WP and FC denote wilting point and field capacity.

Simulation of tillage, planting, fertilizer, and harvest passes were performed on the dates recorded for each year. A single date was assumed for operations that spanned several days. The simulated amounts and forms of N fertilizer were varied annually according to records for both watersheds. Total amounts of N applied ranged from 166 to 237 kg/ha and 160 to 190 kg/ha for Watersheds 2 and 3 during the 1976 to 1987 validation period (N applications were also simulated during the calibration period). For Watershed 2, 90 percent of the applied N was simulated as anhydrous ammonia injected 20 cm deep and the remaining portion was surface-applied. The majority of N used on Watershed 3 was assumed to be surface-applied; simulation of anhydrous ammonia was also performed for a portion of the total N application during 1976-78.

Tillage passes simulated in EPIC directly affect soil bulk density and residue cover levels. The simulated residue cover levels for Watersheds 2 and 3 averaged approximately 10 and 60 percent on an annual basis.   Simulated erosion levels were greatly impacted by these residue levels, consistent with observations for the two watersheds. However, the impact of tillage on the hydrologic balance had to be indirectly simulated by adjusting the curve numbers. Simulation of constructed ridges for Watershed 3 was not feasible in EPIC so a no-till planter was assumed to represent the Buffalo till planter.

Calibration process. The EPIC calibration process focused primarily on the infiltration and runoff partition at the soil surface and the effects of soil residue on the soil evaporation portion of evapotranspiration (ET). The 1988-94 time frame was chosen as the calibration period because it included the driest (just over 400 mm in 1988) and wettest (over 1,300 mm in 1993) years in the entire 19-year precipitation record, allowing the remaining 12-year period (1976-87) to be used for validation. Calibration of nutrient losses and crop yield were not performed because (1) data were not available for

some of these indicators over all of the calibration period, and (2) these indicators are a direct function of the hydrologic balance.

Comparisons between EPIC output and measured seepage flows was difficult, because leaching was only simulated to a 1.8 m depth in EPIC. An approximate comparison approach was used, in which the combined EPIC leaching and lateral subsurface flow output were assumed to be equal to the measured seepage flows in the gully channels. However, correlation analyses performed for 1976-94 between the measured annual precipitation and seepage flows showed r^2 values of 0.15 and 0.50 for Watersheds 2 and 3. This indicates that a lag-time longer than one year exists before much of the infiltrated precipitation discharges from the gullies, especially for Watershed 2. Thus, comparing measured seepage flows with EPIC predictions has limited meaning on an annual basis.

The USDA Soil Conservation Service (SCS) runoff curve number method (Mockus 1972) is used to partition precipitation between infiltration and runoff volume in EPIC, with modifications incorporated for slope and soil profile water distribution effects as described by Williams (1995). The effect of frozen soil on surface runoff is also simulated. Standard runoff curve numbers (CN2) have been tabulated for different hydrologic soil-cover complexes and antecedent moisture condition 2 (average moisture conditions for the preceding five-day period) as given in Mockus (1969). These CN2 values represent conventional tillage practices and need to be reduced to reflect the impacts of conservation tillage (Rawls et al. 1980; Rawls and Richardson 1983). Thus, a key calibration step for the EPIC simulations was the adjustment of the curve number for Watershed 3 to reflect the effects of surface residue and ridges, as described in the calibration results section.

Adjustment of residue impacts on the soil evaporation portion of ET was also performed in the calibration phase. "Measured ET" was inferred for both watersheds by using an annual water balance equation in which ET was set equal to precipitation minus surface runoff and seepage flow, assuming steady state soil water storage changes (dS/dt = 0) from year to year. Field measurements of surface runoff and seepage flow during 1976-94 indicate that less ET occurred from Watershed 3 relative to Watershed 2, implying that the greater residue cover on Watershed 3 led to more infiltration and seepage flow, and conversely less ET. Phillips et al. (1980) reported a similar response for a four-year study in central Kentucky, where ET rates under conventionally-tilled continuous corn averaged 85 mm per year (20%) more than that for no-tilled continuous corn.

EPIC computes soil water evaporation and plant transpiration separately by an approach similar to that of Ritchie (1972). The depth distributed estimate of soil water evaporation may be reduced according to the following equation if soil water is limited in a layer:

$$SEV_l^* = {}_l \exp \left[parm \ (12) \frac{SW_l - FC_l}{FC_l \ WP_l} \right] SW_l < FC_l, \tag{1}$$

where SEV_l is the potential soil evaporation for layer l (mm), SEV^* is the adjusted soil water evaporation (mm), SW is the soil water content for layer l (mm), FC is the field

$$SEV_l^* = SEV_l, \ SW_l \geq FC_l, \tag{2}$$

capacity (mm), and WP is the wilting point (mm). Parm (12) is a parameter that governs the rate of soil evaporation from upper 0.2 m of soil as a function of residue cover. The effect of the Watershed 3 residue cover on soil water evaporation was simulated by adjusting parm (12), as discussed in the calibration results section.

A final calibration step was the selection of the minimum C factor values for simulating water erosion with the Universal Soil Loss Equation (USLE) option (Wischmeier and Smith 1978) in EPIC. The C-factor measures the combined crop and residue cover effects upon soil erosion for a given management system, relative to the corresponding soil loss that would occur for the same landscape under conditions of clean-tilled continuous fallow (Wischmeier and Smith 1978).   For this study, C-factors of 0.2 for Watershed 2 and 0.023 for Watershed 3 were chosen on the basis of model documentation and NRCS guidelines (NRCS 1990) rather than actual calibration.

Slope lengths of 81.4 and 79.4 m were used for Watersheds 2 and 3. These lengths were derived from 0.6 m contour interval topographic maps for a previous application of the USLE to the watersheds (USDA-ARS unpublished data). These slope lengths represent the cropped portions of the watersheds that include the upland ridges and sideslope areas. The EPIC USLE simulations provided estimates of sediment loss to the bottom of these slopes, using the assumed average gradient of 8.4 percent for each watershed. These USLE estimates could not be directly compared with the measured soil erosion levels at the gully headcuts because sediment movement from the steeper side-slopes through the valley waterways to the gully headcuts must be estimated by applying sediment delivery theory. However, the USLE estimates do provide an indication of the model's ability to replicate tillage and residue impacts on erosion.

Model Evaluation Methods

Summary statistics and goodness-of-fit measures were selected to evaluate the model performance, following suggestions given by Loague and Green (1991) and Zacharias et al. (1996) for normally and nonnormally distributed parameters. The summary statistics for the normally distributed variables include long-term means, standard deviations, percentage error, and the coefficient of determination (r^2). The median and median absolute deviation (MAD) were used for the nonnormally distributed variables instead of the mean and standard deviation. The MAD is expressed as:

$$MAD = 1.4826 \times median \left\{|x_i - x_m| : i = 1, 2, ..., n\right\}$$ (3)

where x_i is the ith observation, x_m is the sample median, and n is the sample size. These summary statistics, along with graphical illustrations, were the primary means of comparison between model output and field measurements.

Goodness-of-fit measures were used to further assess the difference between the predicted and observed values (residual errors analysis). Statistical tests were performed with SAS (SAS 1989) to assess whether the measured data (annual totals from 1976 through 1994) were normally or nonnormally distributed and thus determine the appropriate statistical measures. All the hydrologic variables were identified as being normally distributed at a significance level of $\forall = 0.1$. However, the tests indicated that nitrate losses via leaching and runoff, soil erosion, and crop yield were distributed in a nonnormal fashion.

Goodness-of-fit tests selected for evaluating the normally distributed indicators include the normalized root mean square error (RMSE), modeling efficiency (EF), and coefficient of residual mass (CRM):

$$RMSE = \frac{100}{\bar{o}} \sqrt{\frac{\sum_{i=1}^{n}\left(P_i - o_i\right)}{n}},$$ (4)

$$EF = \frac{\sum_{i=1}^{n}\left(o_i - \bar{O}\right)^2 - \sum_{i=1}^{n}\left(P_i - o_i\right)^2}{\sum_{i=1}^{n}\left(o_i - \bar{O}\right)^2}$$ (5)

$$CRM = \frac{\sum\limits_{i=l}^{n} O_i - \sum\limits_{i=l}^{n} P_i}{\sum\limits_{i=l}^{n} O_i} \tag{6}$$

where O_i and P_i are the observed and predicted values at each comparison point i, n is the number of observed and predicted values that are being compared, and $\varnothing$ is the mean of the observed values.   In contrast, the normalized median absolute error (MdAE) and robust modeling efficiency (REF) are used to evaluate the goodness-of-fit of the nonnormally distributed variables:

$$MdAE = median \left(|O_i - P_i| : i = 1, 2, ..., n \right) \left(\frac{100}{O_m} \right) \tag{7}$$

$$REF = median \left[\frac{median \left(|O_i - O_m| : i = 1, 2, ..., n \right) - median \left(|O_i - P_i| : i = 1, 2, ..., n \right)}{median \left(|O_i - O_m| : i = 1, 2, ..., n \right)} \right] \tag{8}$$

where O_i, P_i, and n are the same as previously defined and O_m is the median of the observed values.

The RMSE and MdAE are basically the overall difference in the sum of squares normalized to the number of observations. The desired value is zero for the RMSE, MdAE, and CRM, and one for the EF and REF. Negative values can result for the EF, CRM, and REF measures. Negative values for the CRM indicate model overprediction while positive CRM values point to a trend in underpredicting the observed data. Negative EF and REF values suggest that it is better to use the observed mean than the model predictions.

Explicit standards for model evaluation using these statistics are not established, partly because judging model results is highly dependent on the purpose of the model application. Clouse and Heatwole (1996) further state that "no guidelines for rating model performance based on these statistics have been established, therefore they are primarily useful in assessing which modeling scenarios are predicted better than other scenarios."   They simply evaluated the goodness-of-fit statistics in how close they were to the optimum values. A similar approach was used by Penell et al. (1990) who compared output from several pesticide leaching models. However, Ramanarayan et al. (1997) took a different approach by setting definitive criterion for several statistics including 0.5 for r.

For this study, the following criteria were chosen to assess if the model results were satisfactory: RMSE and MdAE < 50%, EF and REF > 0.3, and -0.2 < CRM < +0.2. Standards of < 20% for the percentage error and >0.5 for r^2 were also set, which have optimum values of zero and one. These standards provide a useful guideline to indicate when the model predictions are deviating greatly from the observed values.

Results and Discussion

Model Calibration

To simulate the differences between these two tillage systems, the CN2 and parm (12) values were calibrated in EPIC using annual surface runoff, seepage flow, and ET levels observed from 1988 to 1994. The CN2 and parm (12) values were adjusted until the percentage error between the observed and simulated average values was less than 5 percent. The calibration process for Watershed 2 resulted in a CN2 value of 74, a slight reduction from the standard value of 75 (Mockus 1969). The Watershed 2 calibration also resulted in a parm(12) value of 4.0, a slight increase over the EPIC default value of 2.5.

The Watershed 3 calibration resulted in a curve number of 61, which is a reduction of about 19 percent from the standard value of 75. Rawls et al. (1980) analyzed surface runoff data from small watershed and plot areas managed under different tillage systems to determine appropriate CN2 adjustments for different residue coverage levels. They showed a maximum CN2 reduction of 10 percent would occur for conservation tillage systems leaving greater than 60 percent residue cover. Rawls (1997) confirmed that an even greater CN2 reduction could be expected with ridge tillage, due to the "mini-terracing" effects of the ridges. A parm (12) value of 14 was selected from the Watershed 3 ET calibration, reflecting the effect of greater residue cover on ET.

Table 2 shows the summary statistics of observed and simulated hydrologic variables after calibration. The percentage errors between the simulated and observed mean surface runoff, seepage flow and ET levels were all less than 5 percent. Most of the variability between years was also captured by EPIC (average $r^2 = 0.75$). However, the weak r^2 for the Watershed 2 seepage flow underscores the problem of comparing EPIC output with the measured seepage flow, due to the previously discussed lag-time issue. This comparison difficulty is further confirmed by the much greater seepage flow standard deviations predicted by EPIC, as compared to the observed values. The large discrepancy between the simulated and observed ET standard deviations indicates that the steady-state assumption for soil water storage is valid over the long term but does not hold on an annual basis. Apparently, excess soil moisture is stored in the unsaturated and saturated zones below the root zone during wetter periods and then discharged during drier periods, which violates the assumption of dS/dt = 0 on an annual basis.

Table 2. Observed and Simulated Hydrologic Indicator Summary Statistics, based on the annual values for the 1988-94 calibration period.

Watershed	Hydrologic Indicator	Observed		Simulated		% error[†]	r^2
		Mean	Std. Dev.	Mean	Std. Dev.		
		-------------------------mm-------------------------					
2	Precipitation	790.0	283.3	790.0	283.3	-[‡]	-
	Surface runoff	51.7	66.9	53.2	40.3	+2.8	0.92
	Seepage flow	155.2	123.1	148.9	200.5	-4.2	0.42
	ET	583.1	200.9	581.2	39.8	-0.3	0.76
3	Precipitation	784.1	274.3	784.1	274.3	-	-
	Surface runoff	32.5	48.8	32.0	31.4	-1.7	0.83
	Seepage flow	210.3	125.5	214.0	213.9	+1.8	0.74
	ET	541.3	159.4	538.1	36.1	-0.6	0.83

[†] % error=[(simulated mean – observed mean)/observed mean] *100.
[‡] Not applicable.

Model Validation

The calibrated model was validated against a second set of observed data for 1976-87 that included annual surface runoff, seepage flow, ET, nitrate-nitrogen (NO_3-N) losses via leaching and runoff, and crop yield. Short- and long-term predictions for each indicator were validated by comparing both annual and 12-year average estimates with field data.

Water Balance. The summary statistics of observed and simulated 12-year average hydrologic variables are compared in Table 3. The statistics indicate that predicted mean surface runoff, seepage flow, and ET are in good agreement with observed values for both watersheds. The percentage error of each estimated indicator is within 5 percent of the corresponding observed level, except for the Watershed 2 mean seepage flow. Data analysis of Watershed 2 has revealed that the seepage flow component of the overall runoff has increased during the later part of the study period, and there is no clear explanation so far. Thus, a calibration performed for 1988-94 can be expected to result in overprediction of the seepage flow in earlier years. The large difference between the simulated and observed ET standard deviation values again reveals the weakness of the steady-state soil water storage assumption. The r^2 values are generally satisfactory, with the weakest explanatory power for the Watershed 2 seepage flow and Watershed 3 ET levels.

Table 3. Observed and Simulated Hydrologic Indicator Summary Statistics, based on the annual values for the 1976-87 validation period.

Watershed	Hydrologic Indicator	Observed Mean	Observed Std. Dev.	Simulated Mean	Simulated Std. Dev.	% error[†]	r[2]
		--------------------------mm--------------------------					
2	Precipitation	843.6	178.2	843.6	178.2	-[‡]	-
	Surface runoff	74.4	39.3	76.0	39.3	+2.1	0.62
	Seepage flow	141.6	57.4	155.7	82.8	+10.0	0.37
	ET	627.6	144.9	612.0	35.4	-2.5	0.69
3	Precipitation	812.5	143.5	812.5	143.5	-	-
	Surface runoff	40.0	23.7	40.1	21.7	+0.2	0.59
	Seepage flow	218.8	82.2	211.7	93.1	-3.2	0.48
	ET	553.7	100.2	560.9	35.9	+1.3	0.44

[†] % error=[(simulated mean – observed mean)/observed mean] *100.
[‡] Not applicable.

Annual time series of observed precipitation, runoff, and seepage flow, and simulated surface runoff and seepage flows are plotted in Figure 1. In most years, EPIC reliably tracked the annual level of observed surface runoff for both watersheds. The model's ability to track seepage flow was not as consistent, especially for Watershed 2. This conforms to expectations because water movement was not simulated through the deeper loess to the gully discharge points. The seepage flow comparisons reveal trends of overprediction during wetter years and underprediction during the driest years. This may be due in part to the simple storage routing technique in EPIC to simulate percolation and lateral subsurface flow, which does not allow for more complex water movement such as the effect of matric potential on the upward movement of soil water (Warner et al. 1995).   However, it is also clearly a function of the inability to simulate the water flow throughout the complete system, thus missing dynamics such as water storage during wetter periods that is subsequently discharged during drier years.

The goodness-of-fit measures for the predicted hydrologic outputs are summarized in Table 4. Based on the previously established criterion, the goodness-of-fit statistics are all satisfactory except the EF seepage flow of 0.26 for Watershed 3, which was slightly below the cutoff of 0.3. The negative CRM value of –0.1 for the Watershed 2 seepage flow indicates that the model tended to slightly overpredict this variable. Otherwise, little systematic model over- or underprediction occurred.
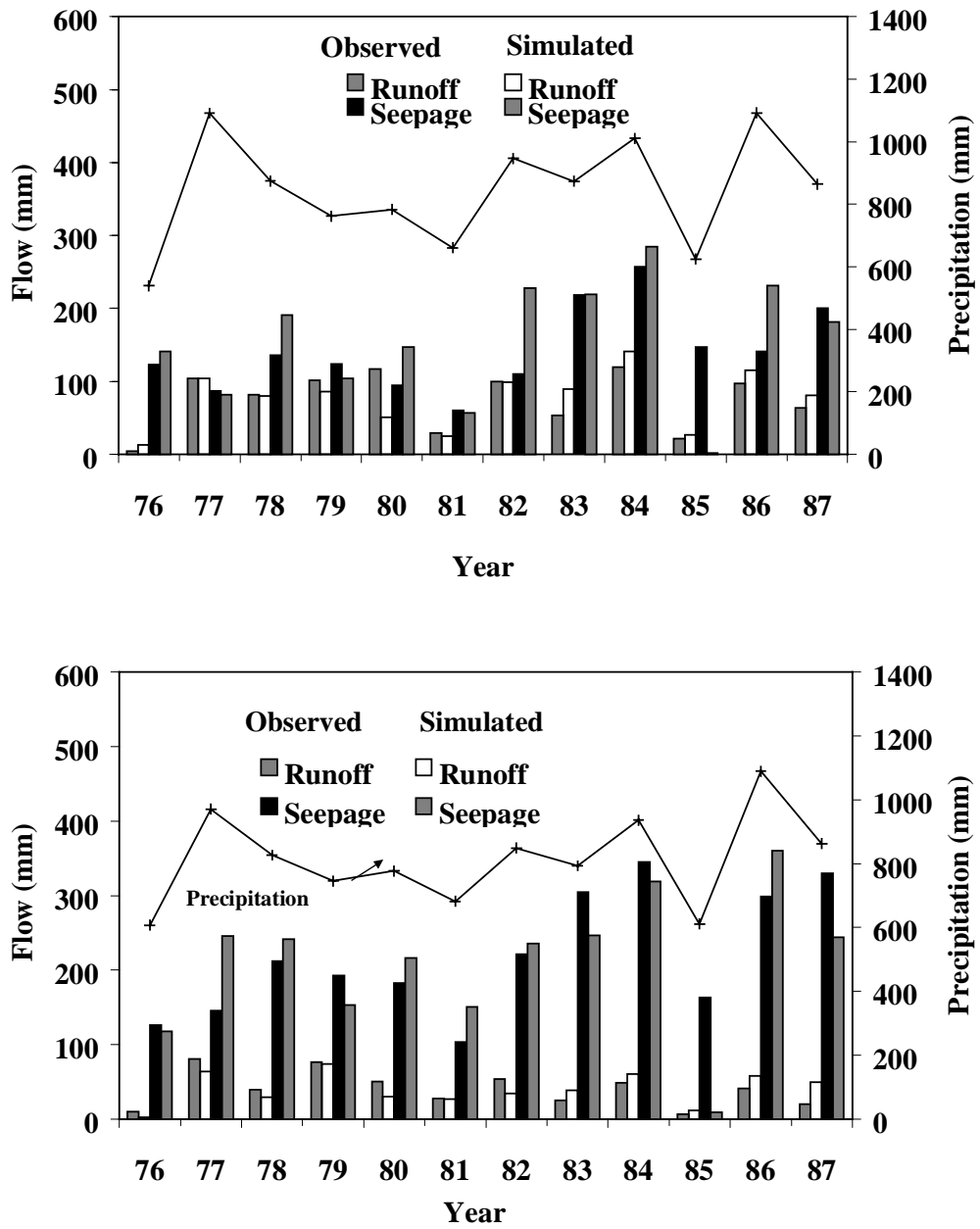
Figure 1. Annual Precipitation and Observed and Simulated Annual Surface Runoff and Seepage Flows for (a) Watershed 2 and (b) Watershed 3 during the Validation Period.
Source: S.W. Chung, P.W. Gassman, L.A. Kramer, J.R. Williams, and R. Gu

Table 4. Parametric model evaluation statistics for the simulated hydrologic indicators, based on the annual values for the 1976-1987 validation period.

Hydrologic Indicator	Watershed 2 RMSE[†] (0.0)[#]	EF[‡] (1.0)	CRM[§] (0.0)	Watershed 3 RMSE (0.0)	EF (1.0)	CRM (0.0)
Surface runoff	32.5	0.59	-0.02	34.5	0.56	0.00
Seepage flow	46.0	0.40	-0.10	30.9	0.26[¶]	0.03
ET	18.3	0.32	0.04	14.0	0.35	0.00

[†] Normalized root mean square error (%).
[‡] Modeling efficiency.
[§] Coefficient of residual mass.
[#] Optimal value.
[¶] Underlined value is outside of target criteria.

Nitrogen Losses, Crop Yield, and Soil Losses. Observed and simulated 12-year median, MAD, percentage error, and r^2 values are listed in Table 5 by watershed for N loss and crop yield indicators. Median and MAD values are also shown for the soil erosion estimates, but percentage error and r^2 calculations were not performed because the soil erosion estimates could not be compared with the measured data. The predicted 12-year medians are in close agreement with the measured values for the N loss and crop yield variables. However, the Watershed 2 surface runoff N loss was overpredicted by about 44 percent. The r^2 values are generally weak; only the Watershed 3 N leaching indicator explained greater than 50 percent of the annual variability.

Median erosion rates of 58.8 and 3.6 mg/ha were predicted for Watersheds 2 and 3 (Table 5), which clearly reflect the effect of the different tillage systems used for each watershed. As expected, these simulated erosion rates were higher than those measured at the headcuts, due to the sediment deposition that could occur in the grassed waterways between the bottom of the slopes and the gullies. Based on these median estimates, approximately 20 and 30 percentage of the predicted sediment loss would actually be transported to the Watershed 2 and 3 gully headcuts. The implied sediment delivery ratio (SDR) for Watershed 2 compares favorably with average SDR estimates over 1969-84 of 18 to 24 percentage made with both the USLE and a photogrammetric technique by Spomer and Mahurin (1987) for adjacent USDA Watershed 1, which is cropped and managed like Watershed 2. No further assessment can be made of the USLE estimates for either Watershed 2 or 3.

Table 5.   Observed and simulated environmental indicator summary statistics, based on the annual values for the 1976-1987 validation period.

Watershed	Environmental Indicator	Observed		Simulated		% error[‡]	r^2
		Median	MAD[†]	Median	MAD		
2	NO$_3$-N leached (kg/ha)	8.0	5.9	7.3	6.8	-8.8	0.35
	NO$_3$-N runoff (kg/ha)	1.6	0.8	2.3	1.2	+43.8	0.42
	Soil erosion (Mg/ha)	11.7[§]	15.3[§]	58.8[#]	37.8[#]	-[¶]	-
	Crop yield (Mg/ha)	7.4	2.1	7.7	0.5	+4.1	0.30
3	NO$_3$-N leached (kg/ha)	32.2	25.3	33.7	36.8	+4.7	0.69
	NO$_3$-N runoff (kg/ha)	2.7	1.8	2.7	1.4	0.0	0.36
	Soil erosion (mg/ha)	1.1[§]	1.4[§]	3.6[#]	1.5[#]	-	-
	Crop yield (Mg/ha)	7.9	0.5	7.8	0.8	-1.3	0.29

[†]   Median absolute deviation.
[‡]   % error = [(simulated median – observed median)/observed median] * 100.
[§]   The observed soil erosion was measured at the gulley headcut.
[#]   The simulated soil erosion was at the base of the sideslopes.
[¶]   Not applicable.

The calibrated model captured the effects of ridge tillage, predicting less soil erosion and greater N leaching for Watershed 3 relative to Watershed 2. However, the median predicted crop yields were essentially identical rather than reflecting the 0.5 t/ha difference harvested over the period. Yields harvested from the USDA Watersheds 1 and 4 are similar to those measured for Watershed 3. However, a greater coefficient of variation has been observed for the Watershed 2 yields for unexplained reasons. Thus it is possible that specific soil or other conditions exist in Watershed 2 that affect crop yields but were not accounted for in our parameterization of EPIC.

Graphical time series comparisons between the predicted and measured annual levels of N loss in leaching and surface runoff are shown in Figures 2 and 3. The predicted surface runoff N losses for Watershed 2 followed the observed annual variations reasonably well, although general overprediction is obvious. Less consistent tracking by EPIC is shown for the Watershed 3 surface runoff N losses, particularly at the start and finish of the simulation period. The model's ability to capture the N leaching trends (Figure 2) was mixed for both watersheds, in part due to the issues of the water movement lag-time previously discussed.
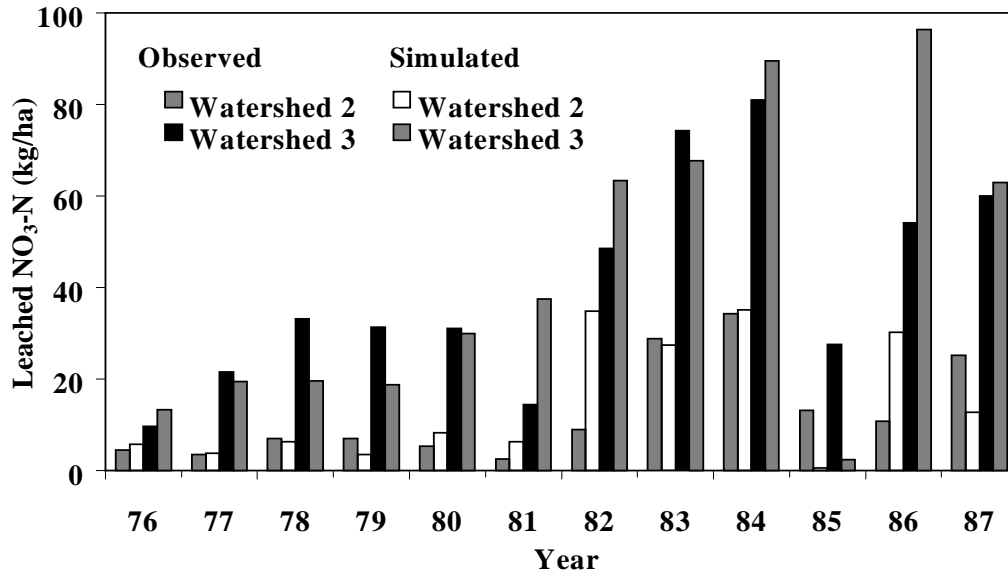
Figure 2. Observed and Simulated Annual Leached NO$_3$-N for Watersheds 2 and 3 During the Validation Period.
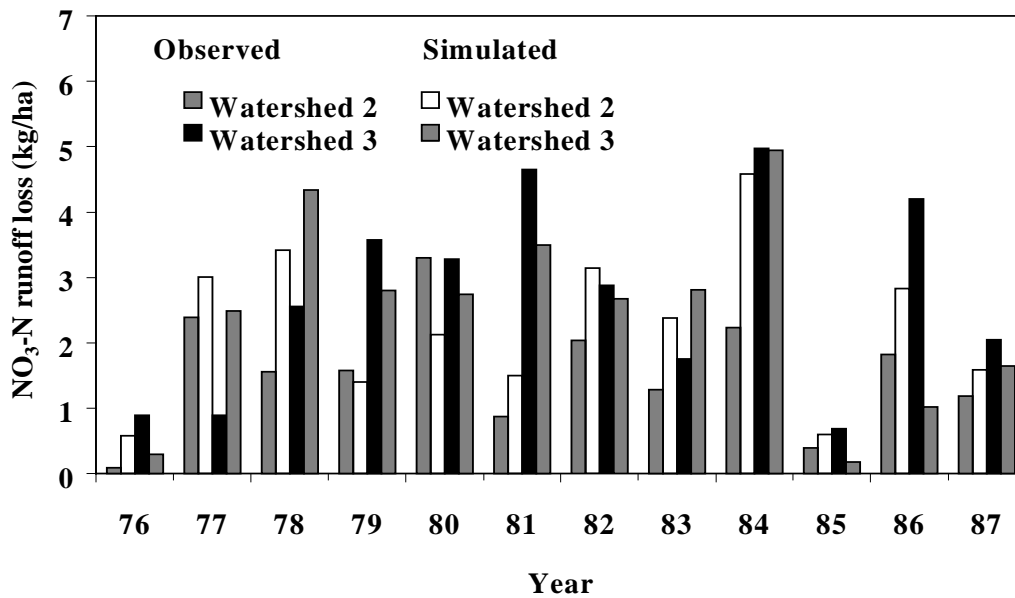Source: S.W. Chung, P.W. Gassman, L.A. Kramer, J.R. Williams, and R. Gu

Figure 3. Observed and Simulated Annual N)$_3$-N Loss Via Surface Runoff for Watersheds 2 and 3 During the Validation Period.
Source: S.W. Chung, P.W. Gassman, L.A. Kramer, J.R. Williams, and R. Gu

The crop yield results (Figure 4) clearly show that EPIC missed the measured yield variability for both watersheds. Kiniry et al. (1995), Touré et al. (1994), and Moulin and Beckie (1993) also found similar results with EPIC; i.e., generally good agreement between long-term and predicted yields but inaccurate reflection of year-to-year yield variability.

Goodness-of-fit statistics are listed in Table 6 for the N loss and crop yield indicators. The majority of the statistics satisfy the pre-established criterion, with the main exception being N loss in surface runoff for Watershed 2. The negative value of REF for the Watershed 2 N surface runoff indicates that the model-predicted N runoff amounts are worse than simply using the measured median values.
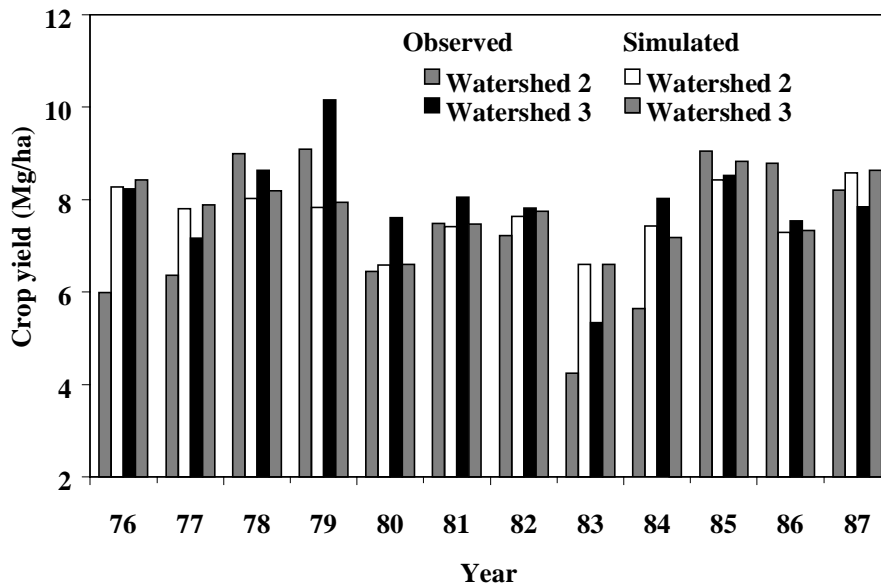

Figure 4. Observed and Simulated Annual Crop Yield for Watersheds 2 and 3 During the Validation Period. Source: S.W. Chung, P.W. Gassman, L.A. Kramer, J.R. Williams, and R. Gu

Table 6. Non-parametric model evaluation statistics for the simulated environmental indicators, based on the annual values for the 1976-87 validation period.

Environmental Indicator	Watershed 2		Watershed 3	
	MdAE[†] (0.0)[§]	REF[‡] (1.0)	MdAE (0.0)	REF (1.0)
NO_3-leached	39.45	0.21[#]	32.69	0.38
NO_3-N runoff	52.07	-0.50	25.32	0.44
Crop Yield	15.65	0.38	8.18	0.32

[†]   Normalized median absolute error.
[‡]   Robuse modeling efficiency.
[§]   Optimum value.
[#]   Underlined values are outside of target criteria.

Summary and Conclusions

Calibration of the hydrologic balance in EPIC was performed for 1988-94 for both Watersheds 2 and 3 at the USDA Deep Loess Research Station near Treynor, Iowa. The calibration process relied on adjusting the runoff curve number (CN2) for Watershed 3, to adequately reflect the impacts of ridge tillage. An alternative method of partitioning precipitation between surface runoff and precipitation is provided in EPIC, based on the theory originally proposed by Green and Ampt (1911), that might provide a more physically-based method for estimating surface runoff. EPIC could also be potentially enhanced by including the ability to more directly simulate ridge tillage in the model, rather than relying on the more empirical CN2 approach used here. Nevertheless, the CN2 adjustment procedure resulted in a successful calibration of the model.

The calibrated model captured the long-term trends (means, medians, and percentage errors) for the hydrologic and environmental indicators during the 1976-87 validation period. The large differences observed in soil erosion and nutrient leaching between the two watersheds were clearly reflected in the model output. Overprediction of N loss in surface runoff by more than 40 percent for Watershed 2 was the weakest model response. However, the corresponding estimated surface N runoff loss was greater for Watershed 3, mirroring the general observed trends between the two watersheds. Overall, the output shows that EPIC was able to replicate the long-term relative differences between the two tillage systems, which is the major emphasis in applying the model within many integrated systems including RAPS. The results also strengthen the application of EPIC within the Loess Hills region (MLRA 107), which the watersheds represent.

The r^2 and goodness-of-fit statistics, and graphical comparisons, revealed that EPIC was weaker at capturing the inter-annual variation that was observed for both watersheds. This was likely due in part to simulating the watershed in a homogeneous manner, which ignored landscape slope complexities and lag-

time in discharge of seepage flow. Despite this fact, it seems clear that EPIC will miss much of the inherent variability in crop yields and other indicators, based on the results reported here, by Touré et al. (1994), and others. Thus the model should be used cautiously for risk and other analyses that require reliance on simulated variability, especially on an event basis.

The results presented here confirm earlier studies by Rawls et al. (1980) and Rawls and Richardson (1983) that standard tabulated CN2 values (Mockus 1969) should be reduced to represent the impacts of residue cover on the partition of precipitation between surface runoff and infiltration. The large reduction (19%) required for this study is likely an extreme; reductions of 10 percent or less should be adequate for the majority of conservation tillage systems as determined previously by Rawls et al. (1980). The results also underscore the importance of ongoing model testing, for guidance in the selection of the most suitable input parameters to depict different management systems.

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