Sny Magill Watershed Modeling Project: Final Report

Ali Saleh, Philip W. Gassman, and Catherine L. Kling

Staff Report 01-SR 95
October 2008 (Revised)

Center for Agricultural and Rural Development
Iowa State University
Ames, Iowa 50011-1070
www.card.iastate.edu

Ali Saleh is a research scientist, Texas Institute for Applied Environmental Research (TIAER), Tarleton State University, Stephenville, Texas. Philip W. Gassman is an assistant scientist, Resource and Environmental Policy Division, Center for Agricultural and Rural Development, and Catherine L. Kling is division head, Resource and Environmental Policy Division, Center for Agricultural and Rural Development (CARD), and a professor of economics, Department of Economics, Iowa State University.

For questions or comments about the contents of this paper, please contact Philip Gassman, 477 Heady Hall, Iowa State University, Ames, IA 50011-1070; Phone: 515-294-6313; Fax: 515-294-6336; E-mail: pwgassma@iastate.edu.

Contents

Tables

Figures

Abstract

Improved assessment of flow, sediment, and nutrient losses from watersheds with computer simulation models is needed in order to identify and control nonpoint source pollution. One model, currently under consideration by the U.S. Environmental Protection Agency for watershed assessments, is the Soil Water and Assessment Tool (SWAT). We describe an application of SWAT for the Sny Magill Creek Watershed (SMCW), which covers 7,100 hectares in northeastern Iowa. The goal of this application was to further evaluate the suitability of using SWAT for Iowa conditions.

Model output was compared to sediment and nutrient measurements collected at various stream sites within the watershed for validation. The model was generally able to predict flow, sediment, and nutrient losses, considering the limited quantity of available monitoring data. Thus, this study supports the hypothesis that SWAT could be used to estimate rapidly, accurately, and inexpensively the factors important for water quality assessments, such as flow, sediment, and nutrient losses at the watershed level. The SWAT model also provided useful insights regarding the importance of accurate data inputs (rainfall, for example), weaknesses in some of the data collecting methodologies (such as the frequency of the organic-N and -P measurements), and the impacts of best management practices (BMPs) (terraces, for example) on water quality.

Key words: BMP, land use, modeling, nutrient management, water quality, watershed.

SNY MAGILL WATERSHED MODELING PROJECT: FINAL REPORT

Introduction

The Iowa Department of Natural Resources Geological Survey Bureau (IDNR-GSB) initiated a 10-year U.S. Environmental Protection Agency (USEPA) 319 water quality monitoring program in 1991 to monitor and assess anticipated improvements in surface water quality in response to implementation of best management practices (BMPs) in the Sny Magill Creek Watershed (SMCW), which covers 9,126 hectares (ha) (22,567 acres [ac]) of Clayton County in northeast Iowa. This initiative was conducted in conjunction with other water quality projects, including two U.S. Department of Agriculture (USDA) land treatment projects: the Sny Magill Hydrologic Unit Area (HUA) Project and the North Cedar Creek Water Quality Special Project. A paired watershed approach was used to compare the surface water quality of the SMCW to the 8,920 ha (22,032 ac) Bloody Run Creek Watershed, which is the control watershed located immediately to the north. The four key monitoring components included in the Sny Magill 319 project were (1) flow and sediment measurements taken at USGS stream gages, (2) an annual habitat assessment along the stream corridors, (3) an annual fisheries survey, and (4) weekly monitoring of chemical and physical water quality variables.

The SMCW Modeling Project was performed to test the Soil and Water Assessment Tool (SWAT) model version 2000 (Arnold et al. 1998; Srinivasan et al. 1998) with measured data collected over the 1991-99 period in the SMCW. Continuous time simulations can be performed with SWAT with a high level of spatial detail by dividing a watershed or river basin into grid cells or sub-watersheds. The model operates on a daily time step and is designed to evaluate management effects on water quality, sediment, and agricultural chemical yield in large, ungauged basins. Applications of SWAT have been performed for flow and/or pollutant loads for a wide varitety of watershed scales (Arnold and Allen 1996; Arnold et al. 2000; Arnold et al. 1999; Binger 1996; Kirsch 2000; Saleh et al. 2000). The model also proved very flexible in simulating multiple management scenarios for the Upper Maquoketa River Watershed (UMRW) in northeast Iowa (Keith et al. 2000; Gassman et al. 2002).

The objectives of the SMCW SWAT study were to (1) capture the impact of key management and land use changes over the 1991-99 period, and (2) compare predicted versus measured values for flow, sediment, nitrogen (N), and phosphorous (P) losses.

Data Sources

The first phase of data collection for the SMCW SWAT simulations consisted of contacting individuals who had previously worked for either Iowa State University Extension (ISUE) or the USDA Natural Resource Conservation Service (NRCS) in assisting with implementation of BMPs within the HUA and related SMCW water quality projects. Table 1 lists the individuals contacted, their previous and current agency affiliations, and the types of information they provided and/or the issues that were discussed. A watershed tour in August 2000 also provided very useful insight into current watershed land use and management practices.

The main conclusions drawn from the consultations and watershed tour are as follows:

1. Contouring and conservation tillage were already established practices in the early 1990s.
2. Very little acreage was cropped in soybeans at the start of the decade. Soybean acreage gradually increased over time, with the largest influx occurring after the 1996 farm bill.
3. Terraces and water sediment control basins were the two major types of structural BMPs installed in the watershed over the duration of the 1990s.
4. ISUE and NRCS nutrient management programs resulted in better accounting of manure nutrients by producers in the watershed.
5. Strip-cropping, contour buffer strips, and no-till are other BMPs that are used in the watershed, although not as extensively as contouring, conservation tillage, and terraces.

The other main sources of data obtained for the SMCW SWAT modeling were Geographical Information System (GIS) data layers, surface water monitoring data, precipitation data provided by IDNR-GSB, and estimates of current Conservation

TABLE 1. Contacted SMCW water quality project participants, 1991-99

Name	Previous Agency Affiliation	Current Agency Affiliation	Information Provided/Issues Discussed
Susan Brown	ISUE	ISUE	Producer survey results
Dave Brummel	NRCS	NRCS	BMPs; land use changes
Eric Palas	ISUE	NRCS	BMPs; land use; other management
Nick Rolling	ISUE	-[a]	Nutrient management; tillage; contouring
Jeff Tisl	NRCS	IDNR	BMPS; land use changes

[a]Farm operator.

Reserve Program (CRP) acreage and livestock production. Survey data collected by ISUE during the course of the HUA project also provided important fertilizer use information and further insights into livestock production, land use, and other management practices.

SWAT Input Data and Management Assumptions

Data inputs needed for executing SWAT include climate, soil, topographic, crop rotations and other land use, tillage system, and fertilizer rates. Some of the data must be loaded in the form of GIS maps while other data is input in ASCII format via multiple input files. Key data inputs used in the SWAT SMCW simulation are described below.

Climate, Soil, and Topographic Data

SWAT can be executed with historical climate data, generated climate data using an internal weather generator, or a combination of historical and generated inputs. Daily climate data required for SWAT are precipitation (millimeters, mm), maximum temperature (degrees Celsius, °C), minimum temperature (°C), solar radiation (mega joules per cubic meter, MJ/m^3), relative humidity (percentage, %), and windspeed (meter per second, m/s). Historical precipitation and temperature data provided by Seigley (2000) were input into SWAT for the SMCW simulation; the remaining climate inputs were generated internally in the model. Maximum and minimum temperature data measured at Prairie du Chien, Wisconsin, were input over the entire 10-year simulation period. The main source of precipitation data used for the simulation was rainfall

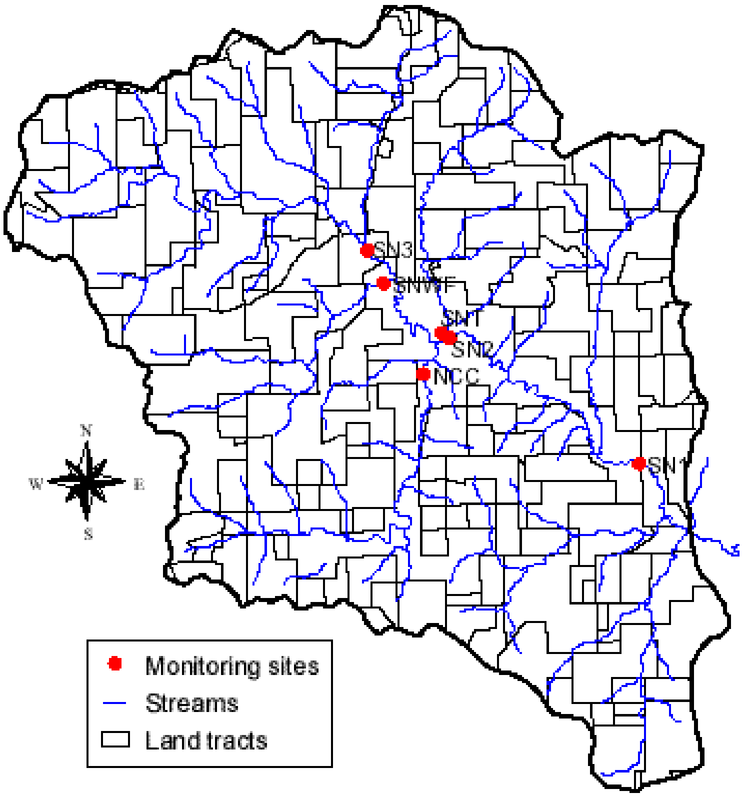

FIGURE 1. Location of the monitoring sites, including SN1, on the SMCW stream system

measured at a rain gauge located at the SMCW stream monitoring site SN1 (Figure 1). Precipitation measured at Prairie du Chien also had to be used during some periods due to gaps in rainfall recorded at site SN1.

Comparisons of daily precipitation data between Prairie du Chien and site SN1 revealed that large differences could occur between the two sites, despite the relative proximity of Prairie du Chien to the watershed. For example, considerable differences in daily rainfall amounts between the two sites are clearly observable for an eight-month period in 1992 (Figure 2). These differences underscore the need for inputting the most accurate precipitation data available into SWAT, especially when attempting to compare model output with in-stream monitoring data.

Digital Elevation Model (DEM) data was supplied by IDNR-GSB (2000) at a scale of 1:24,000 to develop the topographic GIS map (Figure 3) required for the simulation. Stream flow paths and sub-basin boundaries used in the SWAT analysis were determined

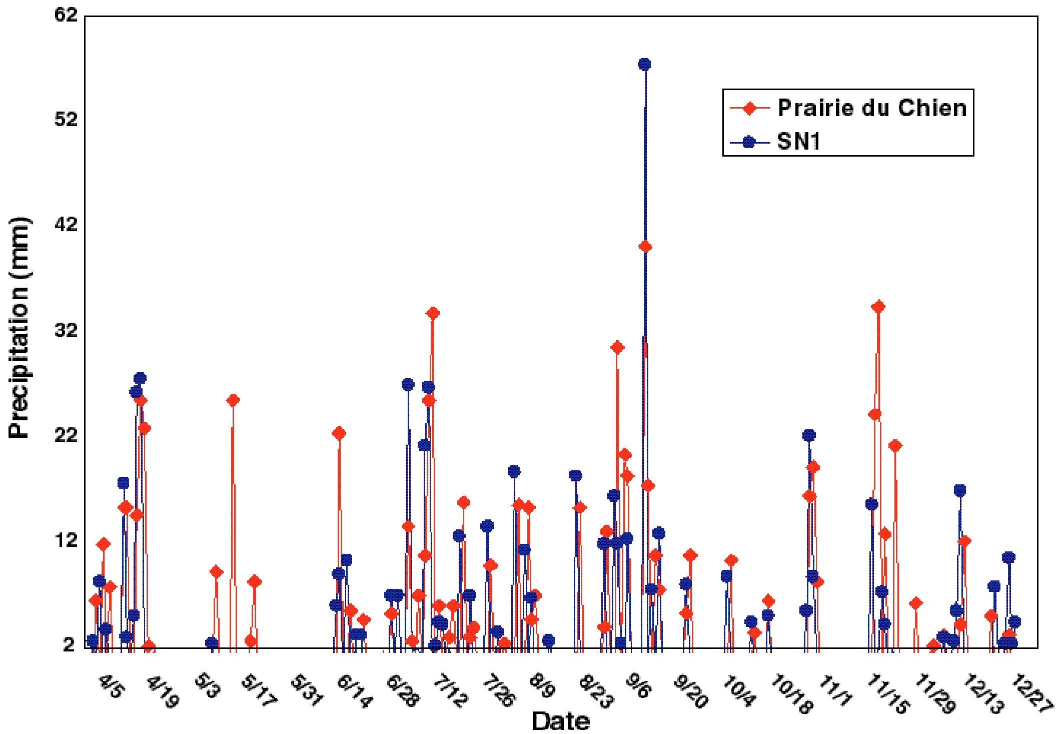

FIGURE 2. Precipitation measured at Prairie du Chien, WI, and site SN1 in the SMCW over eight months in 1992

by processing the DEM data with tools available in the SWAT ARCVIEW interface. The SWAT simulation was limited to the portion of the watershed that drains to site SN1 (Figure 4), which covers 7,152 ha (17,666 ac) or approximately 78 percent of the total SMCW area. The six sub-basins configured for the analysis and major stream channels are shown in Figure 4.

Two sets of soil information are required for a SWAT simulation: a soil map GIS layer and associated soil layer (attribute) data for each soil included in the soil map. Soil layer data used in SWAT includes layer thickness (mm), sand (%), silt (%), clay (%), bulk density (megagram per cubic meter, Mg/m^3), organic carbon (%), available water capacity (%), and saturated hydraulic conductivity (millimeters per hour, mm/hr). The soil map used for the SMCW simulation (Figure 5), developed at a scale of 1:15,860 with an accuracy of within 50 meters, was obtained from the IDNR-GSB (2000);

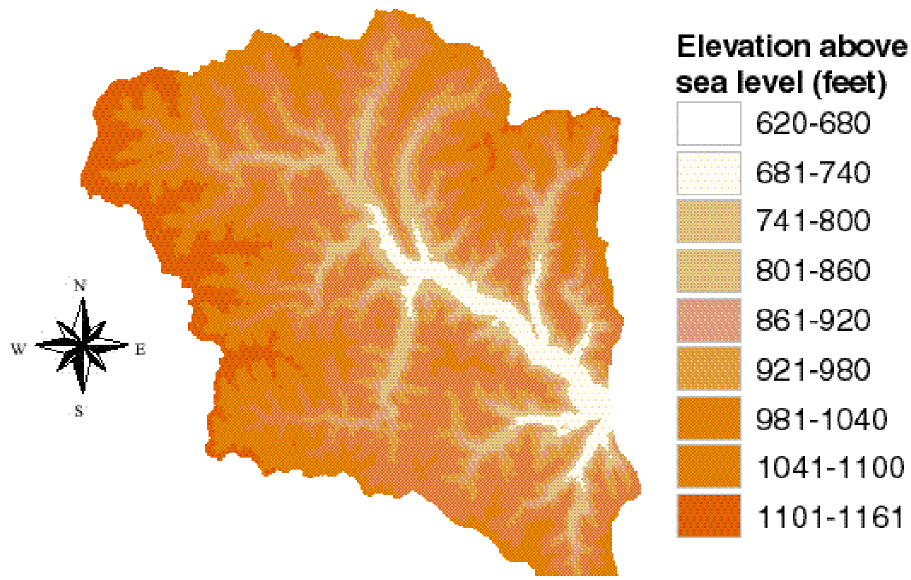

FIGURE 3. SMCW topographic map used for the SWAT simulation

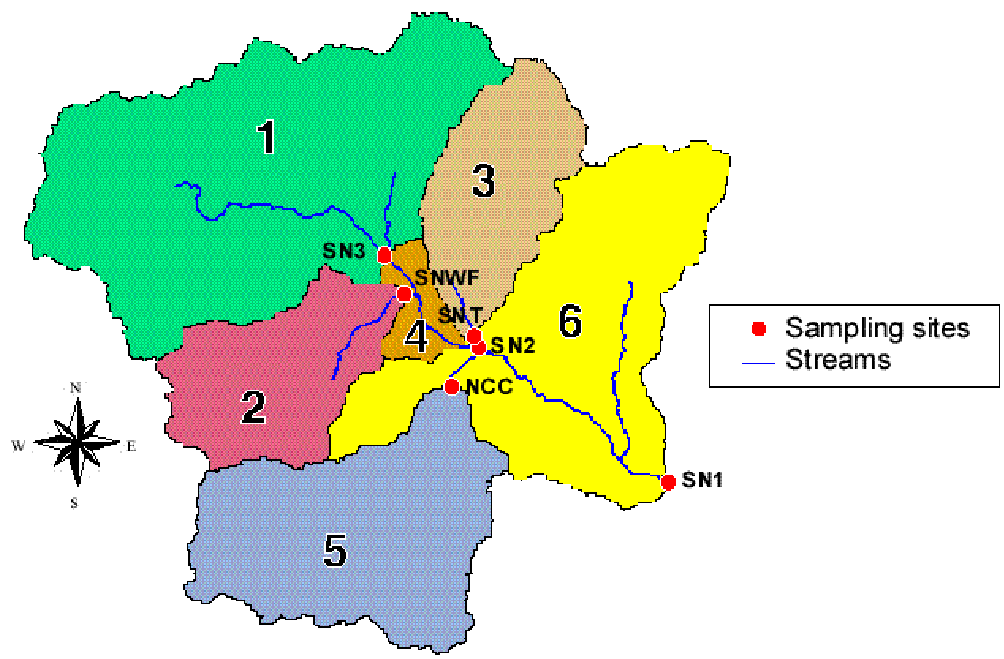

FIGURE 4. Overlay of sub-basins on main stream channels and sampling sites

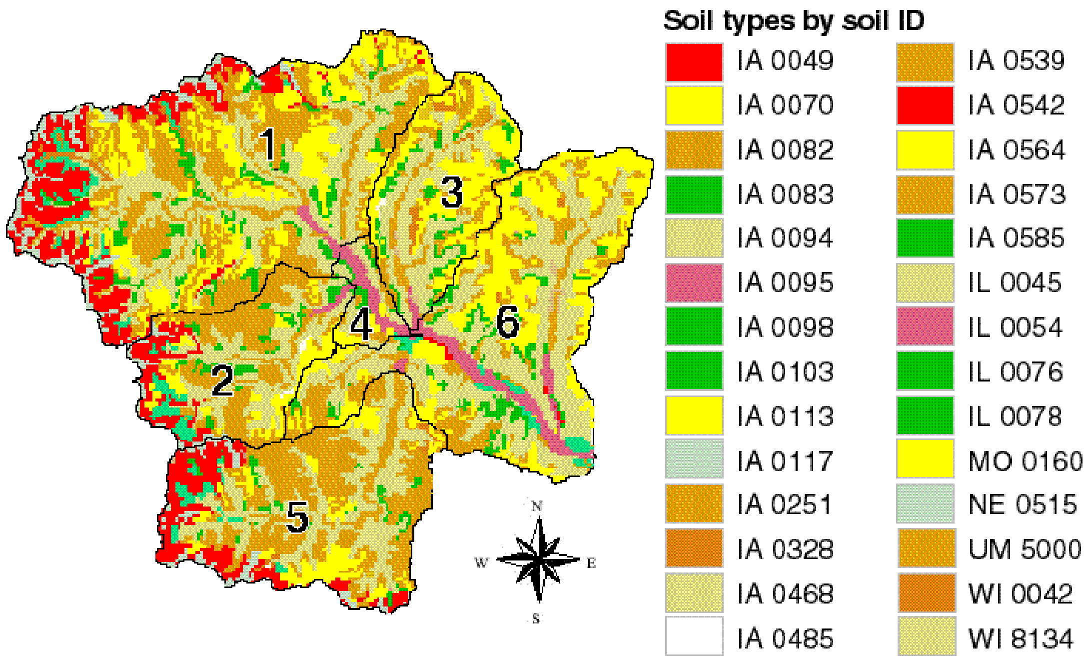

FIGURE 5. SMCW soil map

corresponding soil layer data was also supplied by IDNR-GSB. Table 2 lists selected properties of dominant soils simulated in SWAT for the portion of the SMCW that drains to site SN1.

Land Use Assumptions

An initial step in the development of the management assumptions for the SWAT simulations was the establishment of SMCW general land use patterns. IDNR-GSB constructed a digitized data layer of 1992 land use (Figure 6) based on aerial photographs taken of the SMCW (Seigley et al. 1994). The land use categories shown in Figure 1 include cover crop, forest, permanent pasture, row crop, strip crop, urban, and water. Further delineations of crops grown on terraced land are also shown as terraced cover crops, terraced row crops, and terraced strip crops. Seigley et al. (1994) further summarized the 1992 land use into four broad categories (Table 3). Later reports such as Lombardo et al. (2000) assume the exact same distribution of land use in the SMCW (Table 1), indicating that no major shifts in land use occurred later in the decade.

TABLE 2. Major soils simulated in SWAT for the portion of the SMCW that drains to site SN1

Soil Name	Area (ha)	Watershed Coverage (%)	Sand (%)	Silt (%)	Clay (%)	Bulk Density (g/cm^3)
Fayette	3124.1	44.2	9.6	65.8	24.6	1.3
Dubuque	690.4	9.8	11.3	67.7	21.0	1.3
Nordness	2069.1	29.0	26.3	52.7	21.0	1.3
Orion	33.0	0.5	14.2	71.8	14.0	1.3
Dorchester	158.9	2.2	11.4	68.1	20.5	1.3
Downs	752.4	10.6	10.2	66.2	23.6	1.3
Frankville	114.0	1.6	11.2	67.3	21.5	1.3
Other soils	134.2	2.1	-	-	-	-

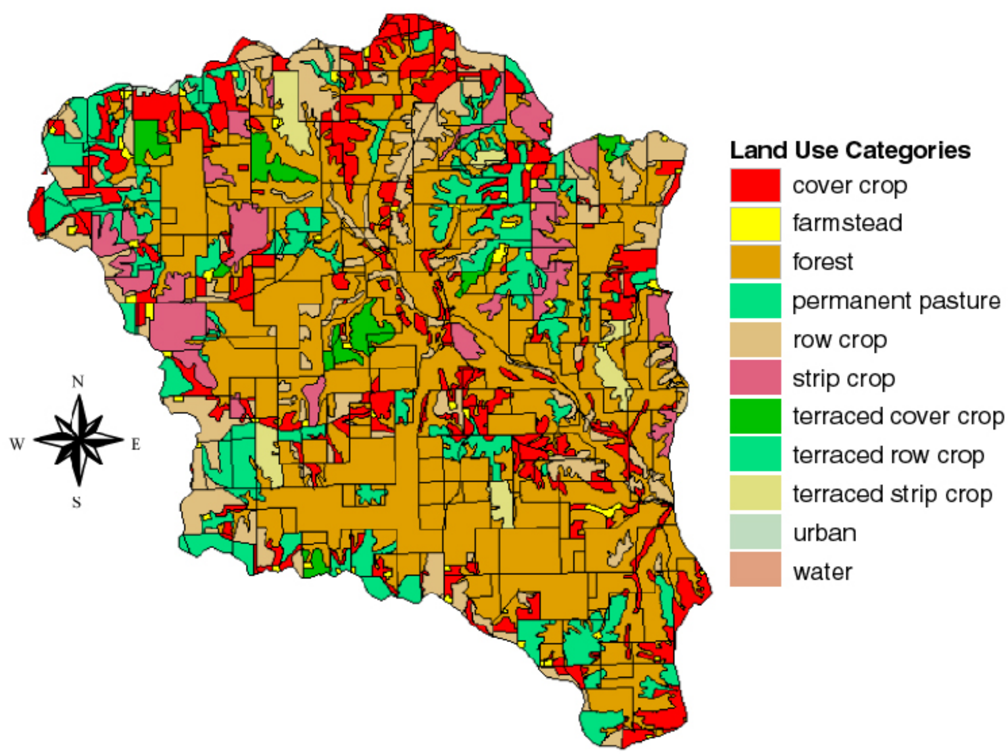

FIGURE 6. SMCW 1992 land use categories digitized by IDNR-GSB

Table 3 also shows alternative SMCW land use patterns reported in Clayton SWCD (1994) and Tisl (1998). Tisl (2001) commented that the land use percentages listed in these two sources are derived from estimates made in support of the HUA project initiated in 1990. These land use estimates were made before the development of the 1992 digitized land use data and are thus less reliable. However, these less accurate numbers were still used for internal reporting purposes over the duration of the HUA and related projects.

We assumed that the 1992 land use data compiled by IDNR-GSB was representative of initial SMCW land use conditions. We also assumed that there were no major land use shifts between these general categories for the remainder of the decade, following Lombardo et al. (2000). Figure 7 shows the land use categories for the portion of the watershed that drains to SN1 for the six sub-basins in the SWAT simulation.

Land Use Differences between 1990-94 and 1995-99

The management files constructed for the SWAT simulation captured changes that occurred in the SMCW between 1990-94 and 1995-99. The key differences accounted for in the management assumptions between the two time periods reflect the following trends for the second half of the decade: (1) an influx of soybeans, (2) greater participation in CRP, and (3) increased installation of terraces. These trends were simulated by incorporating shifts in land use and expansion of terracing directly into the management files.

TABLE 3. Area of major land use categories within SMCW, reported by various sources

Land Use Category	Seigley et al. (1994)	Lombardo et al. (2000)	Clayton SWCD (1994)	Tisl, J. (1998)
		acres (% of total land area)		
Forest/woodland[a]	11,034 (48.9)	11,034 (48.9)	3,250 (18)	5,305 (23)
Pasture[b]	5,400 (23.9)	5,400 (23.9)	7,240 (37)	7,295 (32)
Cropland	5,842 (25.9)	5,842 (25.9)	8,215 (42)	9,555 (42)
Other	291 (1.3)	291 (1.3)	585 (3)	625 (3)
Totals	22,567 (100)	22,567 (100)	19,560[c] (100)	22,780 (100)

[a]Includes forested pasture.
[b]Includes cover crops.
[c] Does not include the 3,220 acres in the North Cedar Creek sub-watershed.

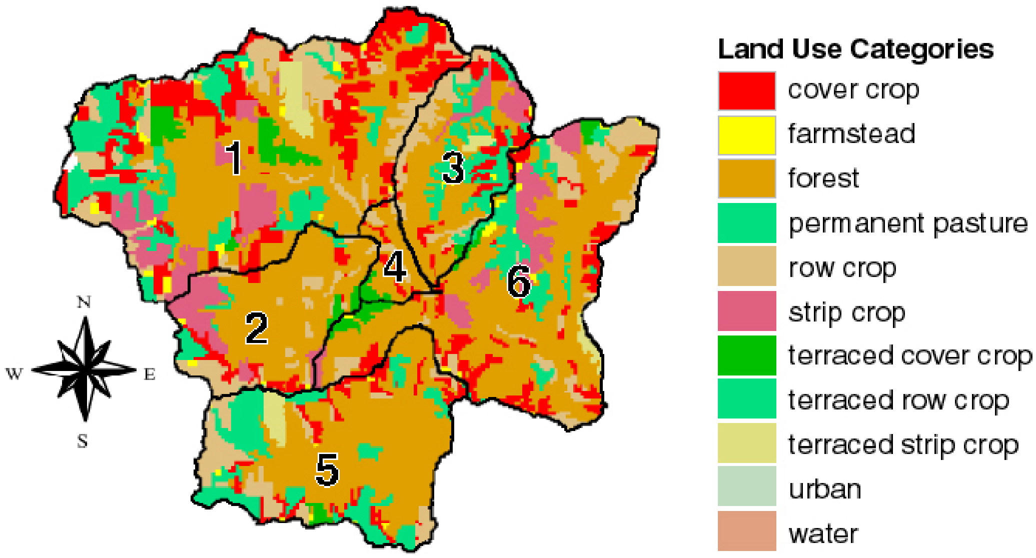

FIGURE 7. Overlay of the six SWAT sub-basins on land use for the portion of the SMCW that drains to site SN1

Specific crop rotations and other land use simulated for sub-areas in each SWAT sub-basin are listed in Appendix A. These sub-areas are called Hydrologic Response Units (HRUs) and are assumed to have homogeneous land use and soil characteristics, and to have been planted in continuous corn (CCCCC), corn-corn-oats(alfalfa)[1]-alfalfa-alfalfa (CCOAA), and oats(alfalfa)-alfalfa-alfalfa-corn-corn (OAACC) in 1990-94, respectively. Cropping patterns that shift from one rotation to another beginning in 1995 are depicted with a "/" in Appendix A (e.g., CC/SC.), and row crop areas that were assumed planted to corn for the entire ten years are designated as "cont. corn."

The increase in soybeans was accounted for by shifts in cropland, cropped previously in 1990-94 in either continuous corn (CCCCC) or in a five-year rotation (CCOAA or OAACC), into a soybean-corn (SC) rotation during 1995-99 (Table 4 and Appendix A). Exact levels of SMCW soybean acres in any given year are unknown; we assumed for the SWAT simulation that about 1,750 acres of cropland were planted in soybeans in alternating years starting in 1995.

Palas (2000) identified land tracts enrolled in the CRP within each SWAT sub-basin using aerial photographs of the SMCW. The total CRP area was estimated to be about

TABLE 4. Soybean-corn and CRP acres for 1995-99 replacing 1990-94 rotations, and total terraced acres for 1990-94 and 1995-99

	Soybean-Corn Acres		CRP Acres		Total Terraced Acres[b]	
Subbasin	**from CCCCC[a]**	**from CCOAA or OAACC**	**from CCCCC[a]**	**from CCOAA or OAACC[a]**	**1990-94**	**1995-99**
1	357	314	0	314	737	1,886
2	92	35	0	44	376	747
3	177	51	165	72	379	710
4	0	0	19	18	39	39
5	299	61	32	0	711	1,085
6	237	125	104	83	782	1,044
Total	1,162	586	320	531	3,024	5,511

[a]Soybean-corn for 1995-99 and CRP acres were assumed converted from either continuous corn (CC) or a five-year rotation (CCOAA or OAACC) previously simulated for 1990-94.
[b]Total terraced acres for 1990-94 and 1995-99 are based on the total areas that had been terraced by 1992 and 1997, respectively.

850 acres for the portion of the SMCW draining to SN1, based on Palas's CRP mapping. In comparison, Tisl (1998) reported that about 1,400 acres were enrolled in the CRP across the entire SMCW. Most of the CRP enrollments occurred after 1995 and thus we assumed that no CRP was present in the first half of the decade. We again inferred that the simulated CRP fields were converted from CCCCC, CCOAA, and OAACC fields that were simulated for 1990-94 (Table 4).

Terraces were the key structural BMPs installed in the SMCW over the duration of the 1990s via the HUA and related water quality projects. Installations of terraces occurred in every year between 1991 and 1998. However, simulating annual additions of new terraces for the SMCW in SWAT was not feasible. Thus, the cumulative amounts of area that were terraced by 1992 and 1997 were chosen to represent the 1990-94 and 1995-99 periods in the SWAT simulation because both years were the respective midpoint of the corresponding time period. The total areas that were assumed terraced for 1990-94 and 1995-99 were 3,024 and 5,511 acres (Table 4). Individual HRUs that were assumed terraced are indicated with a "yes" in the appropriate columns in Appendix A.

Conservation Practice P Factors

Simulation of conservation practices in SWAT requires entering a P factor for each practice, as described by Wischmeier and Smith (1978) for the USDA Universal Soil Loss Equation (USLE). Contouring, strip-cropping, and terracing P factors presented by Wischmeier and Smith are listed in Table 5 as a function of slope range. Alternative “northeast Iowa” P factor values used by the NRCS are shown by slope range and appropriate slope in Table 6. Contouring and strip-cropping P factors are roughly equivalent between Tables 5 and 6 but the Table 5 terrace P factors are considerably lower than those listed in Table 6. The key difference between the two sets of terrace P factors is that the original values given by Wischmeier and Smith reflect terrace impacts on sediment yield from a field or watershed, while the Table 5 values represent terrace impacts only on downslope movement of sediment within a field (Gibney 2000).

The P factors chosen for the SWAT terrace simulations (Table 7) were based on the Table 5 values because sediment yield was estimated for each HRU using the Modified USLE (MUSLE) equation (Williams and Berndt 1977), rather than simply simulating downslope sediment movement. We assumed any HRU that was terraced in 1990-94 (Seigley et al. 1994) was terraced for the entire 1990-99 time period (Appendix A). We accounted for expanded terracing in 1995-99 by simulating a shift in P factors for those HRUs that were indicated as terraced starting in 1995 (Appendix A). Modifications to the SWAT source code were required in order to accommodate the shifts in P factors that were simulated at mid-decade. We also assumed that all terraced fields were tile-drained to the depth of 1.2 m.

Designated 1992 row crop and cover crop HRUs not terraced in 1990-94 and/or 1995-99, were considered managed with contouring (Appendix A). Similarly, we designated HRUs defined as strip cropped in 1992 as managed with strip-cropping in 1990-94 and/or 1995-99 if terraces were not installed (Appendix A). The P factors used for contouring and strip-cropping in SWAT are shown by sub-basin in Table 7.

TABLE 5. Original P-factor values for contouring, strip-cropping, and terraces

Slope ranges	Contouring	Strip-cropping[a]	Terraces[b]
1 to 2	0.6	0.3	0.12
3 to 5	0.5	0.25	0.1
6 to 8	0.5	0.25	0.1
9 to 12	0.6	0.3	0.12
13 to 16	0.7	0.35	0.14
17 to 20	0.8	0.4	0.16
21 to 25	0.9	0.45	0.18

Source: Wischmeier and Smith (1978).
[a]Strip-cropping P-values based on the following four-year rotation: row crop, small grain with meadow (alfalfa) seeded into it, and two years of meadow.
[b]Based on expected sediment yield for terraces with graded channels and outlets.

TABLE 6. NRCS northeast Iowa P-values for contouring, strip-cropping, and terraces

Slope ranges (%)	Assumed slope (%)	Slope length (m)	Contouring	Strip Cropping	Terraces[a]
2-5 (B)	4	76.2	0.5	0.25	0.4
5-9 (C)	7	61.0	0.5	0.25	0.35
9-14 (D)	11	61.0	0.76	0.3	0.47
14-18 (E)	16	39.6	0.82	0.35	0.36
18-25 (F)	20	30.5	0.88	0.4	-[b]

Source: Palas (2000).
[a]Designed to estimate downslope sediment movement rather than sediment yield.
[b]Not applicable.

TABLE 7. Conservation P-factors assumed for the SWAT simulation by sub-basin

Sub-basin	Average Slope (%)	Contouring	Strip-cropping	Terraces
1	6.4	0.5	0.25	0.1
2	9.3	0.6	0.3	0.12
3	9.7	0.6	0.3	0.12
4	3.2	0.5	0.25	0.1
5	7.3	0.5	0.25	0.1
6	3.9	0.5	0.25	0.1

Runoff Curve Numbers

Partitioning of precipitation between surface runoff and infiltration is calculated in SWAT using the USDA Soil Conservation Service (SCS) runoff curve number technique (Mockus 1972). Standard runoff curve numbers (CN2) used in the technique were tabulated by Mockus (1969) for different hydrologic soil-crop cover complexes (Table 8) and antecedent moisture condition 2 (average moisture conditions for the preceding five-day period). The majority of soils in the SMCW were classified in the B or C hydrologic groups. The appropriate curve numbers listed in Table 8 were used for the different combinations of soil hydrologic group, crop, and conservation practice that were simulated in SWAT.

Tillage Simulation Assumptions

Conservation tillage was assumed for the majority of cropping systems simulated in SWAT for the SMCW. Table 9 shows tillage and other implement passes simulated as a function of cropping sequence.

TABLE 8. Standard curve number values used in SCS runoff curve number technique

Crop/Management	Hydrologic Group[a]			
	A	B	C[b]	D
Row crop/contoured or strip cropped	65	75	82	86
Row crop/contoured & terraced	62	71	78	81
Alfalfa/contoured or strip cropped	55	69	78	83
Alfalfa/contoured or terraced	51	67	76	80
Oats/contoured or strip cropped	61	73	81	84
Oats/contoured or terraced	59	70	78	81
Pasture	39	61	74	80
Forest	25	55	70	77

Source: Mockus (1969).
[a]Good hydrologic condition was assumed for row crop, alfalfa, oats, and pasture; poor hydrologic condition was assumed for forest.
[b]The curve number values listed for hydrologic group C were assumed for all soil and land use combinations for the SWAT simulation.

TABLE 9. Tillage and other implement passes simulated in SWAT by cropping sequence

Cropping Sequence	Crop Rotations[a]	Implement Pass	Simulation Date
Corn after corn	CC, CCOAA, OAACC	Harvest corn	October 18
		Chisel plow	November 2
		Anhydrous ammonia application	April 10
		Field cultivator	May 1
		Plant corn	May 3
Soybean after corn	SC	Harvest corn	October 18
		Chisel plow	November 2
		Field cultivator	May 10
		Plant soybean	May 20
Corn after soybean	SC	Harvest soybean	October 2
		Anhydrous ammonia application	April 10
		Field cultivator	April 30
		Plant corn	May 1
Corn after alfalfa	CCOAA, OAACC	Third alfalfa cutting	August 28
		Moldboard plow	October 1
		Tandem disk	April 10
		Anhydrous ammonia application	April 10
		Field cultivator	April 30
		Plant corn	May 1
Oats after corn	CCOAA, OAACC	Harvest corn	October 18
		Chisel plow	November 2
		Tandem disk	April 5
		Spike harrow	April 8
		Plant oats and alfalfa[b]	April 11
		Culti-packer	April 15
Alfalfa after oats	CCOAA, OAACC	Harvest oats	July 25
		Alfalfa cutting after oats harvest	September 1
		First alfalfa cutting	May 27
		Second alfalfa cutting	July 4
Alfalfa after alfalfa	CCOAA, OAACC	Third alfalfa cutting (prev. year)	August 28
		First alfalfa cutting	May 27
		Second alfalfa cutting	July 4

[a]CC = continuous corn; CCOAA = corn-corn-oats-alfalfa-alfalfa; OAACC = oats-alfalfa-alfalfa-corn-corn; SC = soybean-corn.
[b]Alfalfa is typically interseeded with oats; only one alfalfa cutting is made in the first year.

The majority of the implement-cropping sequence combinations are categorized as mulch till, which is defined as a tillage system that leaves at least 30 percent residue cover at planting (CTIC 1996). The two exceptions are the tillage systems for corn following alfalfa and oats following corn; in both cases, we simulated conventional tillage that more closely mirrors typical practice in the region.

Fertilizer and Manure Application Assumptions

In the simulation, we assumed Commercial N fertilizer was applied only to corn in the crop rotations; all N fertilizer applications were anhydrous ammonia, injected at a depth of 178.1 mm (7 in). Table 10 shows application rates as a function of cropping sequence; these were based on 1994 survey results (ISUE 1994), except for corn following soybeans, which was based on expert opinion (Palas 2000). Four commercial phosphate fertilizer applications of 22.4 kg/ha (20 lb/ac) were also assumed for alfalfa over the three years of oats(alfalfa)-alfalfa-alfalfa of the CCOAA and OAACC rotations. Land-applied livestock manure is a significant source of N and P in the SMCW. However, it was difficult to determine the total manure generated and which fields the manure was applied to because of incomplete livestock production data. Appendix B describes the process of determining the manure loads and manure applications rates for each sub-basin, and the HRUs that the manure was applied to in each sub-basin.

TABLE 10. Nitrogen fertilizer rates simulated for corn by cropping sequence and crop rotation

		N Fertilizer Application Rate		
Crop Sequence	**Crop Rotation**	**kg/ha**	**lb/ac**	**Date**
Corn after corn	CC	155[a]	138[a]	April 10
Corn after alfalfa	CCOAA, OAACC	78	70	April 10
Corn after corn	CCOAA, OAACC	134	120	April 10
Corn after soybean	SC	112	100	April 10

[a]These rates were reduced to 54 kg/ha (50 lb/ac) when manure was applied to continuous corn.

In-Stream Monitoring Data

Flow, sediment, NO_3-N, and P monitoring data were provided by Seigley (2000). Portions and/or summaries of these data are also reported in several publications (Table 11). Stage-discharge relationships at site SN1 were developed by continuously recording stream stage and making monthly stream discharge change measurements. Stream flow at site SN1 was measured on a daily basis. Local observers at site SN1 also collected suspended sediment samples each day during normal flow and with an automatic sampler at predetermined intervals during rain events. IDNR-GSB and U.S. National Park Service-Effigy Mounds National Monument personnel monitored NO_3-N at all six SMCW sites (Figure 1). Sites SN2 and SNT were sampled monthly while all other sites were sampled weekly. Organic-N and total-P were monitored at site SN1 on a weekly basis. Seigley et al. (1994, 1996) provide further details regarding in-stream monitoring procedures.

Results and Discussion

The SWAT simulation was executed for a total of 10 years in order to incorporate full simulation of five-year rotations for 1990-94 and 1995-99. However, the results of the SWAT simulation are shown for two shorter periods: 1992-94 and 1995-98. The 1992-94 timeframe served as a calibration period for the modeling exercise while the 1995-98 period was used for validation of the simulation. Comparisons of SWAT output with measured data were performed primarily for site SN1 (Figure 1), except for two sets of predicted and measured nitrate (NO_3-N) concentration comparisons that were made for

TABLE 11. List of reports that contain portions and/or summaries of the SMCW in-stream monitoring data

Water Year	Sampling Sites	Reference
1992-93	SN3, SNWF, SNT, SN2, NCC, SN1	Seigley et al. 1994
1994	SN3, SNWF, SNT, SN2, NCC, SN1	Seigley et al. 1996
1995	SN1	May et al. 1996
1996	SN1	May et al. 1997
1997	SN1	May et al. 1998
1998	SN1	May et al. 1999

all six monitoring sites shown in Figure 1. We assumed that BMP development (i.e., terraces) held constant within 1990-94 and 1995-99 as previously described, but annual implementation of BMPs were, in fact, dynamic over virtually the entire decade.

Daily flow and sediment comparisons between SWAT output and measured data at site SN1 are also reported for water year 1994 (October 1993 to September 1994), to provide further insight into SWAT's ability to replicate measurements in the SMCW.

SWAT Calibration

SWAT calibration was not required in order to achieve reasonable flow estimates of the annual average flows recorded at site SN1. The simulation included daily flow and NO_3-N inputs that were known for one spring;[2] similar data was not available for any other springs in the watershed. A minor calibration of the N loss estimates at site SN1 was performed by setting the average groundwater NO_3-N concentration at 2 mg/l in each of the sub-basins at the start of the simulation.

Flow Comparisons

Comparisons of the annual average measured and predicted daily flows for both the calibration (1992-94) and validation (1995-98) periods are shown in Figure 8 and Appendix C. The simulated flow was about 11 and 16 percent lower than measured levels during the calibration and validation periods, indicating that SWAT accurately tracked flows throughout the 10-year simulation period. The average annual flow was generally about 30 percent lower during the validation period relative to the calibration period. This is attributed mainly to the higher flow that occurred during 1993 (roughly double the normal flow) because of precipitation inputs that were 25 percent higher than the historical average for the watershed.

Sediment Comparisons

The predicted annual average sediment loads (metric ton or mt) were 14 and 32 percent lower than the corresponding measured values for 1992-94 and 1995-98 (Figure 9). The 1996 sediment load was underpredicted by almost 80 percent (Appendix C), which greatly impacted the 1995-98 results. The average annual sediment concentrations

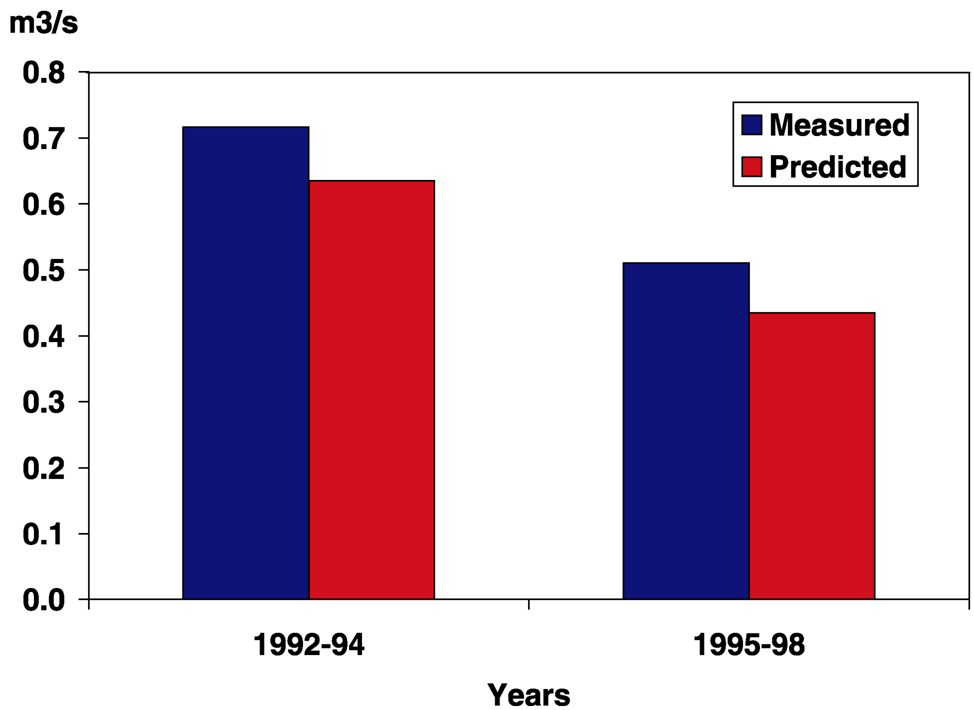

FIGURE 8. Annual average measured and predicted flow for the SWAT calibration (1992-94) and validation (1995-98) periods

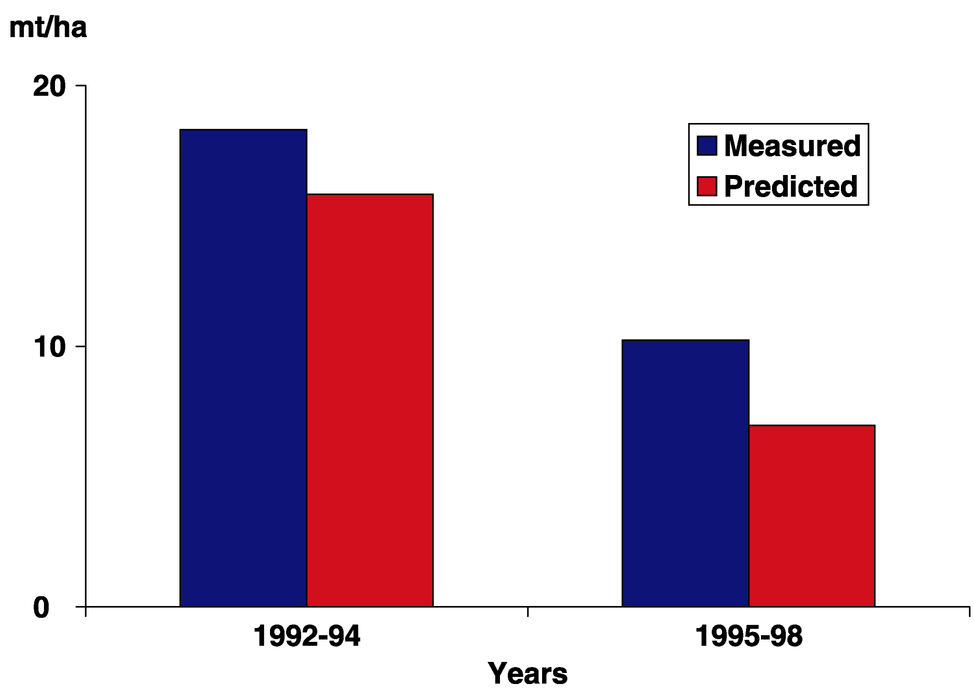

FIGURE 9. Daily average measured and predicted sediment loads for the SWAT calibration (1992-94) and validation (1995-98) periods

were overpredicted by 11 percent for 1992-94 and were underpredicted by 1 percent for 1995-98 (Figure 10 and Appendix C). Large overpredictions of 64 and 43 percent occurred for the 1994 and 1995 sediment concentration simulations (Appendix C). Sediment load reductions approaching 50 percent are indicated by the relative magnitudes of the annual average measured sediment loads shown for the calibration and validation periods (Figure 9 and Appendix C). This apparent sediment load decline is partially skewed because of the unusually high sediment losses that occurred in 1993 (Appendix C). However, the increased levels of terracing clearly impacted sediment yield, as confirmed by the decline in both the measured and the predicted sediment yield concentrations that occurred between 1992-94 and 1995-98 (Figure 9 and Appendix C).

Nutrient Comparisons

Simulated and measured daily average NO_3-N concentrations (mg/l) for all six sites are shown in Figures 11 and 12 for the calibration and validation periods. Concentrations at the watershed outlet (site SN1) were overpredicted by 33 and 38 percent for the calibration and validation periods (Figures 11 and 12; Appendix C). The predicted annual average NO_3-N concentrations were closer to the measured values for the other sampling sites in 1992-94, except for site SN2 for which the NO_3-N concentrations were again overpredicted. Besides site SN1, the least accurate simulation for 1995-98 was for site SNT, which was underpredicted by SWAT by about 30 percent. It is important to note that the measured NO_3-N concentrations were actually obtained in weekly and monthly intervals; each day included in the given week or month was thus assumed to have the same measured concentration. This could result in mismatches with the concentrations predicted by SWAT, which are simulated dynamically on a daily basis. Slightly higher levels of NO_3-N were measured at all the sites in the validation period relative to the calibration period, including site SN1 at the watershed outlet (Figures 11 and 12; Appendix C). This may be a function of the increased levels of terraces and tile drainage; greater infiltration can result from terracing that in turn leads to higher NO_3-N losses via the tile drains (Keith et al. 2001). The model predications do not reflect these slight NO_3-N increases at all the sites. However, the SWAT output does accurately reflect the

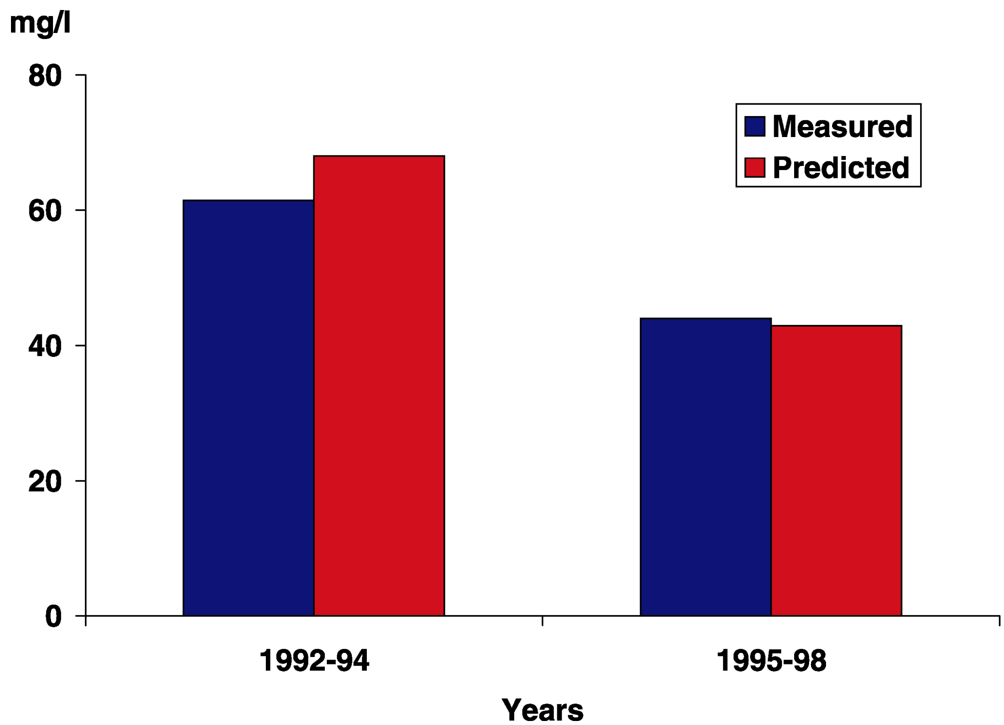

FIGURE 10. Daily average measured and predicted sediment concentrations for the SWAT calibration (1992-94) and validation (1995-98) periods

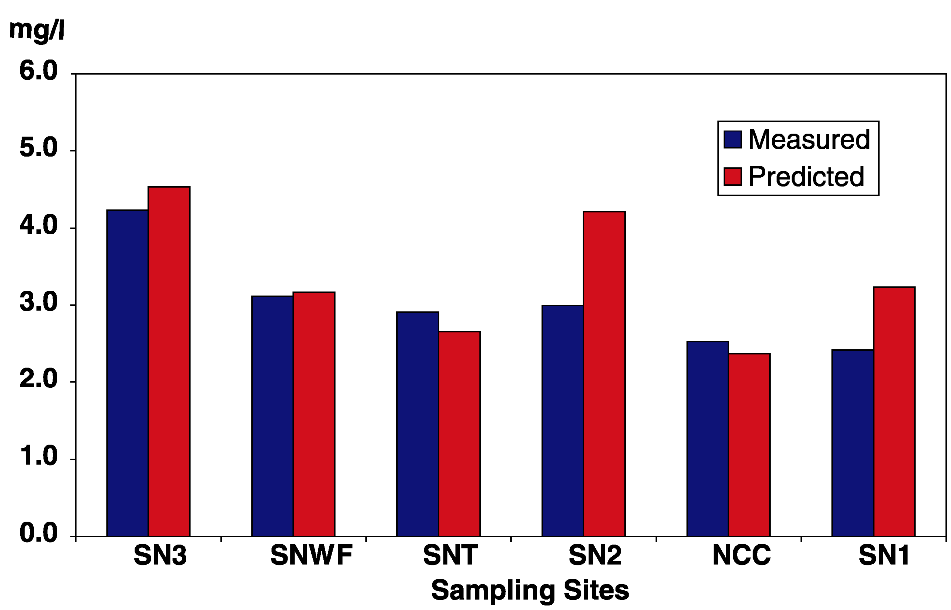

FIGURE 11. Comparisons of daily average measured and predicted NO_3-N concentrations for the SWAT calibration period (1992-94) for all six SMCW sampling sites

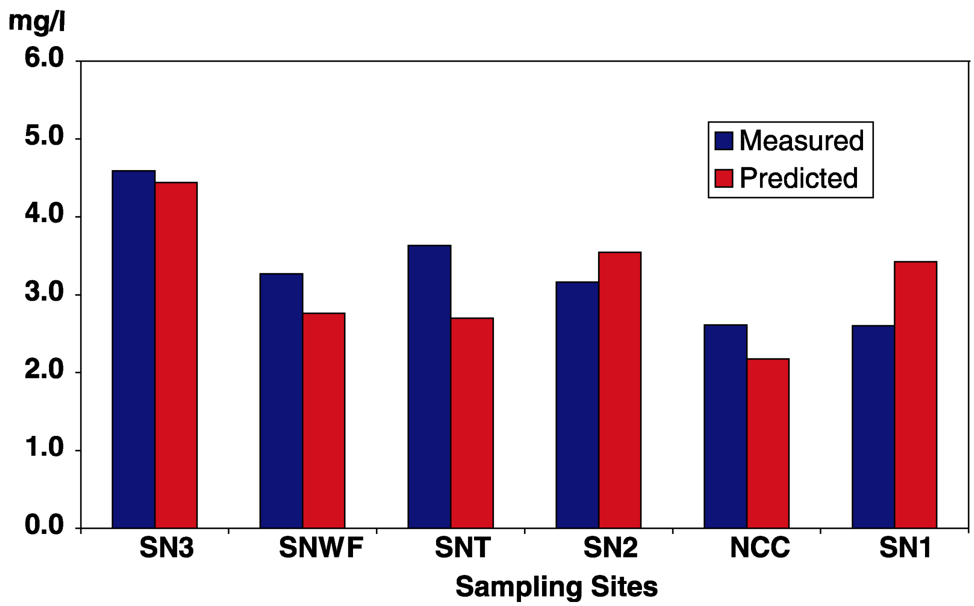

FIGURE 12. Daily average measured and predicted NO_3-N concentrations for the SWAT validation period (1995-98) for all six SMCW sampling sites

magnitudes of the NO_3-N concentrations that were measured at the different sites during the two periods.

Measured and predicted daily average organic-N and total-P[3] concentrations (mg/l) are presented for the calibration and validation periods in Figures 13 and 14 and in Appendix C. The predicted annual average organic-N level for 1992-94 was 21 percent below the corresponding measured value. Individual years during the three-year period were underpredicated or overpredicted by 26 to 42 percent (Appendix C). The predicted annual average organic-N level was almost 50 percent lower than the average annual measured level for 1995-98. This was because of underpredictions by factors of 2 to 6 during 1995-97 (Appendix C). The average annual total-P predications were overpredicted by 36 and 25 percent for 1992-94 and 1995-98 (Figure 14 and Appendix C). Predictions for individual years were considerably more accurate than were those for organic-N during the validation period (Appendix C).

Some error that occurred for individual years may be due to the sampling frequency of the organic-N concentrations and the organic-P and soluble-P components of the total-P concentrations, which were measured on a weekly basis. In contrast, SWAT again

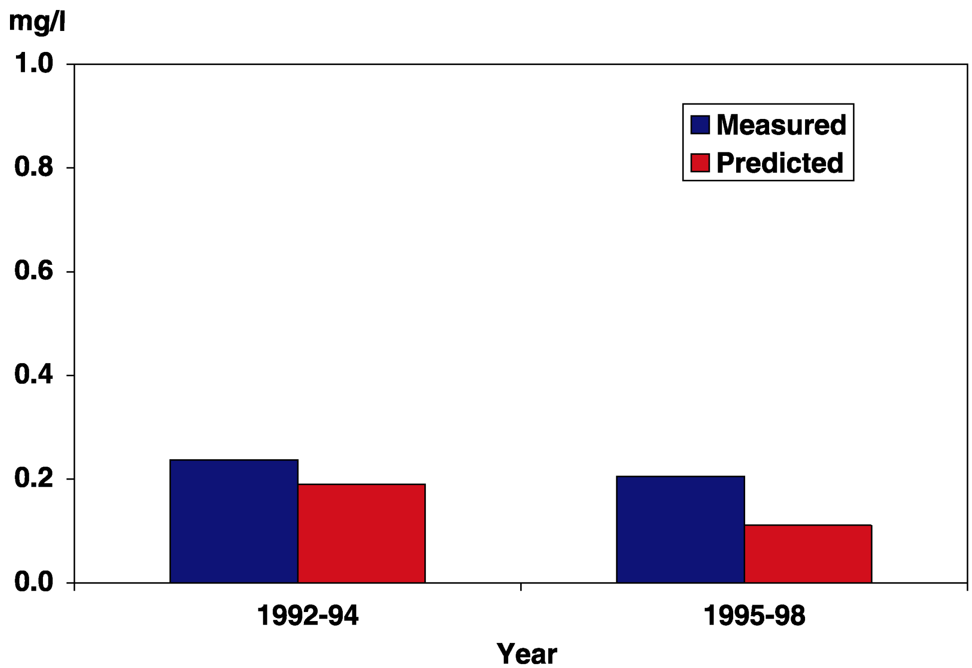

FIGURE 13. Daily average measured and predicted organic-N concentrations for the SWAT calibration (1992-94) and validation (1995-98) periods

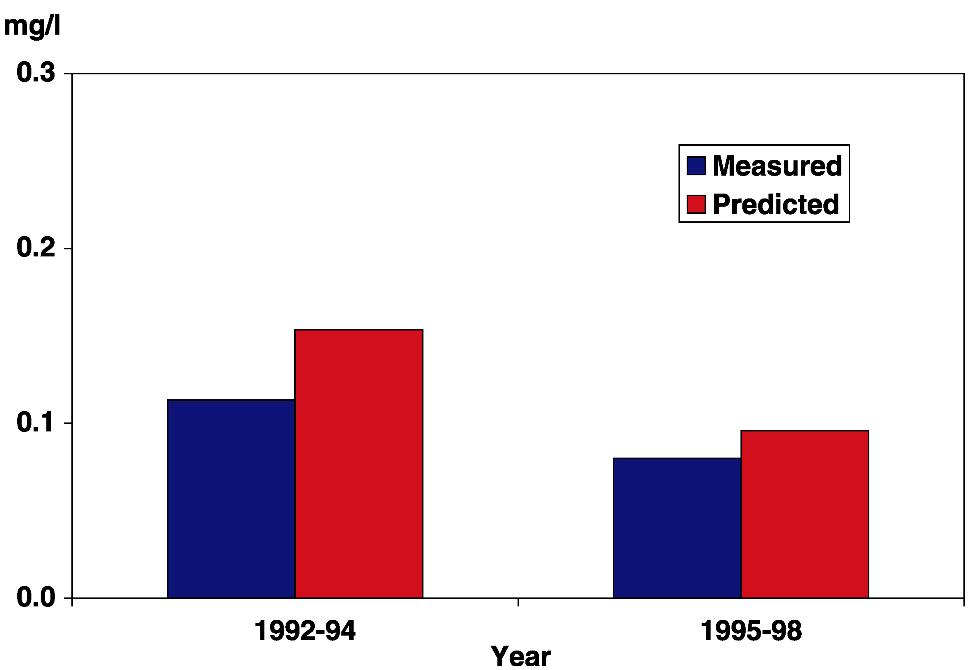

FIGURE 14. Daily average measured and predicted organic-P concentrations for the SWAT calibration (1992-94) and validation (1995-98) periods

simulated the organic-N, organic-P, and soluble-P movement on a daily basis. Overall, the general magnitude of the average annual organic-N and total-P estimates were in the range of what was measured at site SN1.

Definite declines in losses of both organic-N and total-P were predicted by SWAT for the validation period relative to the calibration period (Figures 13 and 14; Appendix C). This was in direct response to the increased installation of terraces that occcured during the second half of the decade.

Daily Comparisons

Comparisons between predicted and observed daily flow and sediment values were also performed for the 1994 water year to further assess SWAT's ability to replicate measurements made at site SN1. The comparisons were limited to flow and sediment because the nutrient measurements were conducted at intervals of one week or one month and thus could not be directly compared to the daily SWAT estimates.

Figure 15 shows the comparison between the SWAT daily flow estimates and measured daily flows for the 1994 water year. The model accurately tracked most of the peak flow events that occurred during the year, although the measured peaks were generally overpredicted by SWAT. In contrast, the majority of the low-flow periods were underpredicted by the model, which is the main reason the flow was underpredicted for the 1994 calendar year (Appendix C). A coefficient of determination (R^2) value of 0.76 was calculated for the daily flow estimates (Figure 16), indicating that the model accurately replicated the daily measured flow trends that occurred during the 1994 water year.

The predicted versus the measured sediment loads for the 1994 water year are plotted in Figure 17. The sediment load trends were again accurately tracked by SWAT, as reflected in the R^2 value of 0.68 calculated for the sediment load predications (Figure 18). However, the majority of the sediment load peaks were underpredicted by the model by a factor of 2 or more (Figure 17). The underpredictions of the peak sediment events result in an overall underprediction of the total sediment load for the 1994 calendar year (Appendix C).

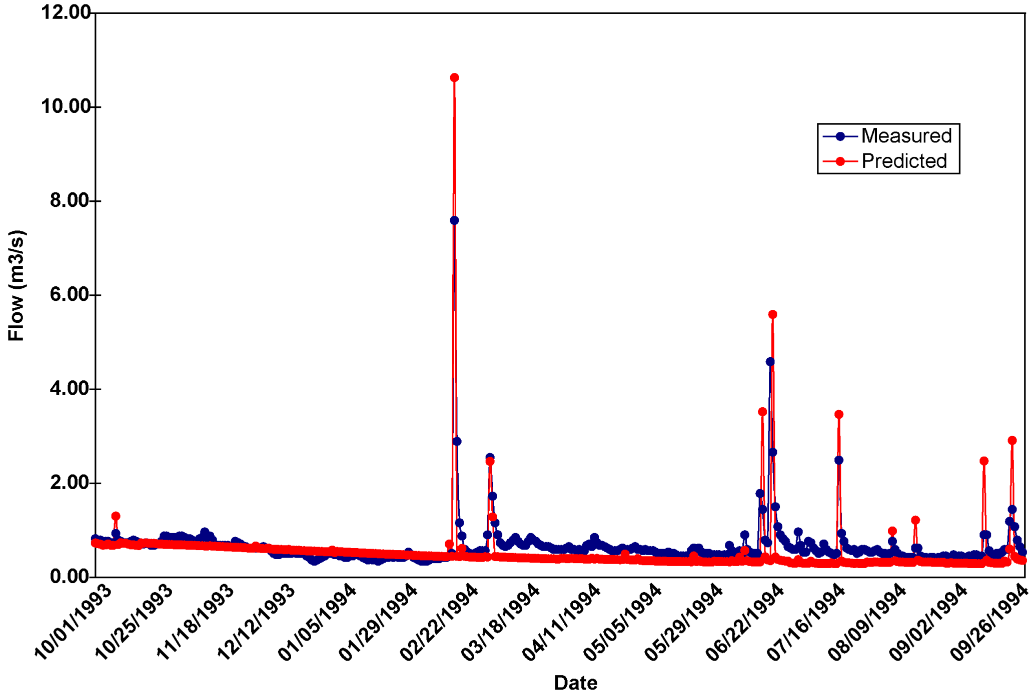

FIGURE 15. Predicted versus measured daily flows for water year 1994 (October 1993 to September 1994)

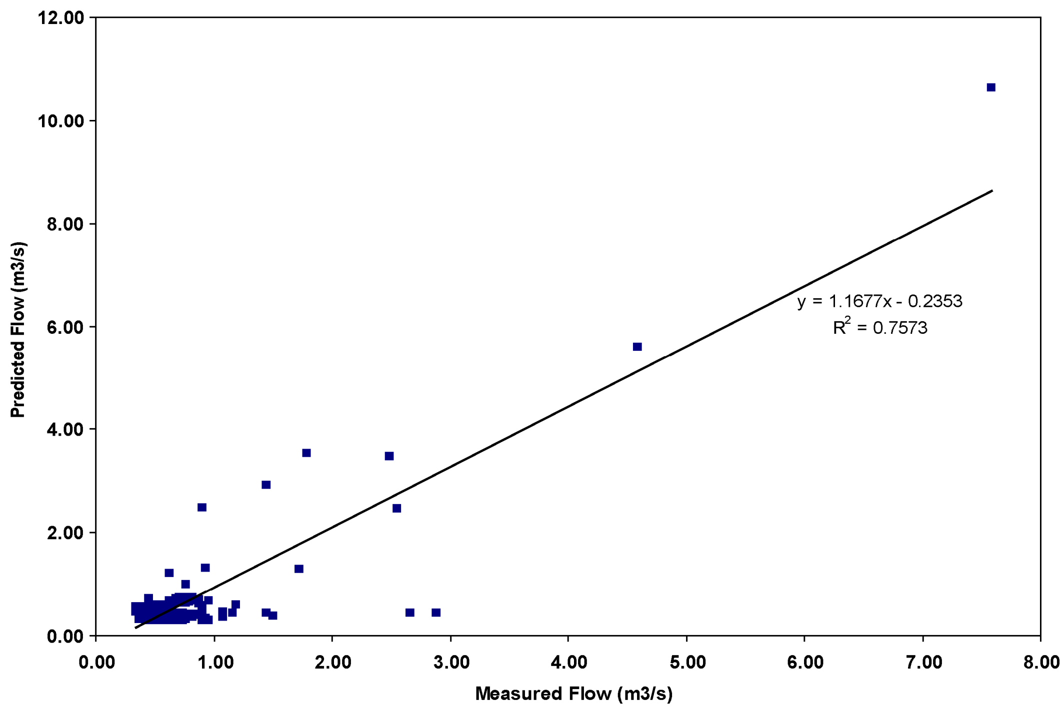

FIGURE 16. Coefficient of determination (R^2) for predicted daily flows relative to measured daily flows for water year 1994 (October 1993 to September 1994)

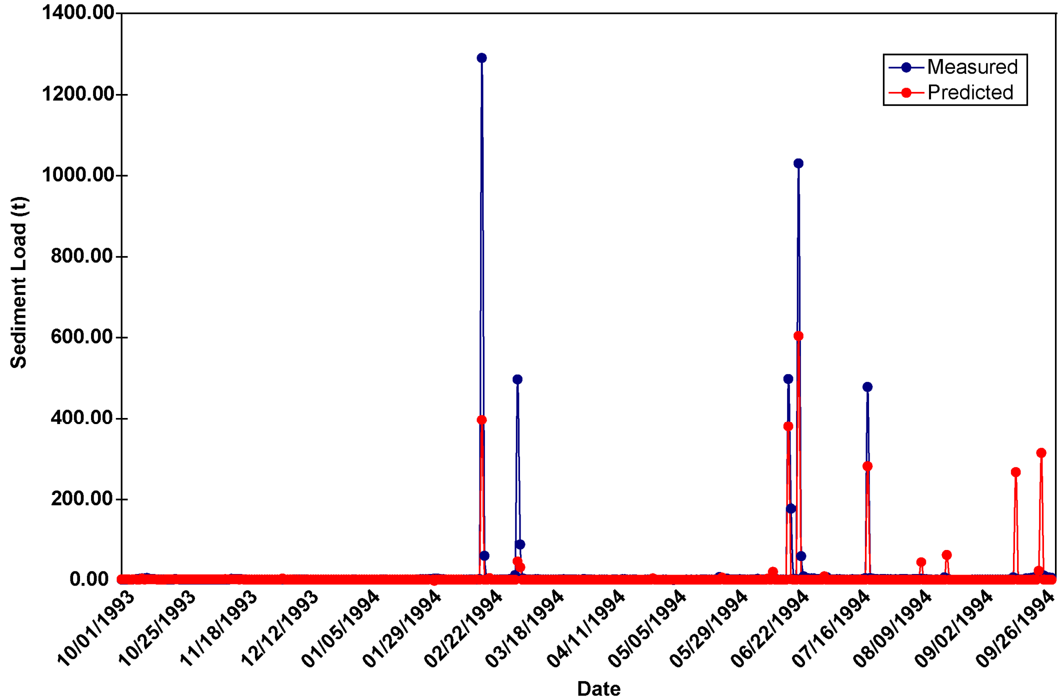

FIGURE 17. Predicted versus measured daily sediment loads for water year 1994 (October 1993 to September 1994)

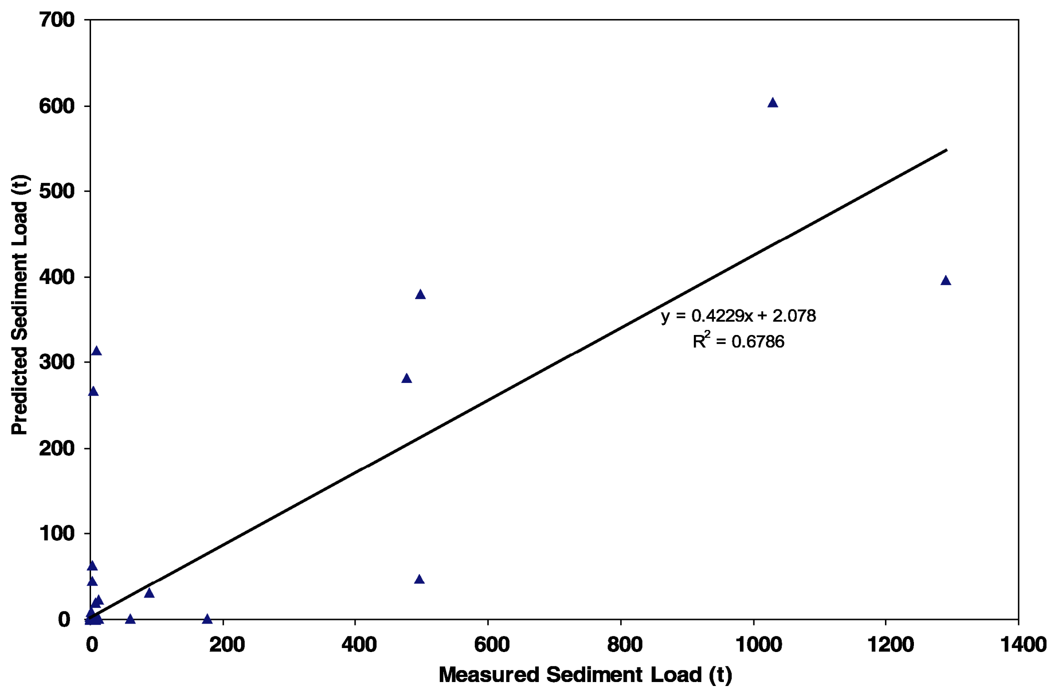

FIGURE 18. Coefficient of determination (R^2) for predicted sediment loads relative to measured sediment loads for water year 1994 (October 1993 to September 1994)

The time series of predicted versus measured sediment concentrations and the associated R^2 results are plotted in Figures 19 and 20. The weak R^2 value of 0.30 (Figure 20) indicates that SWAT did not accurately track the daily measured sediment concentrations for this period. However, the annual average sediment concentration for the 1994 calendar year was only 6 percent greater than the corresponding measured total. It is important to note that some of the peak predicted sediment concentrations occurred for relatively small sediment load losses, for example, in October and December of 1993 (Figures 17 and 19). This underscores that the sediment loads are a more reliable indicator of sediment loss for the SMCW simulations.

Conclusions

The results of this study show that the SWAT model was generally able to predict flow, sediment, and nutrient losses, especially considering limitations regarding some of the available input and monitoring data. The average annual flow and sediment concentration estimates were within 1 to 16 percent of the corresponding measured

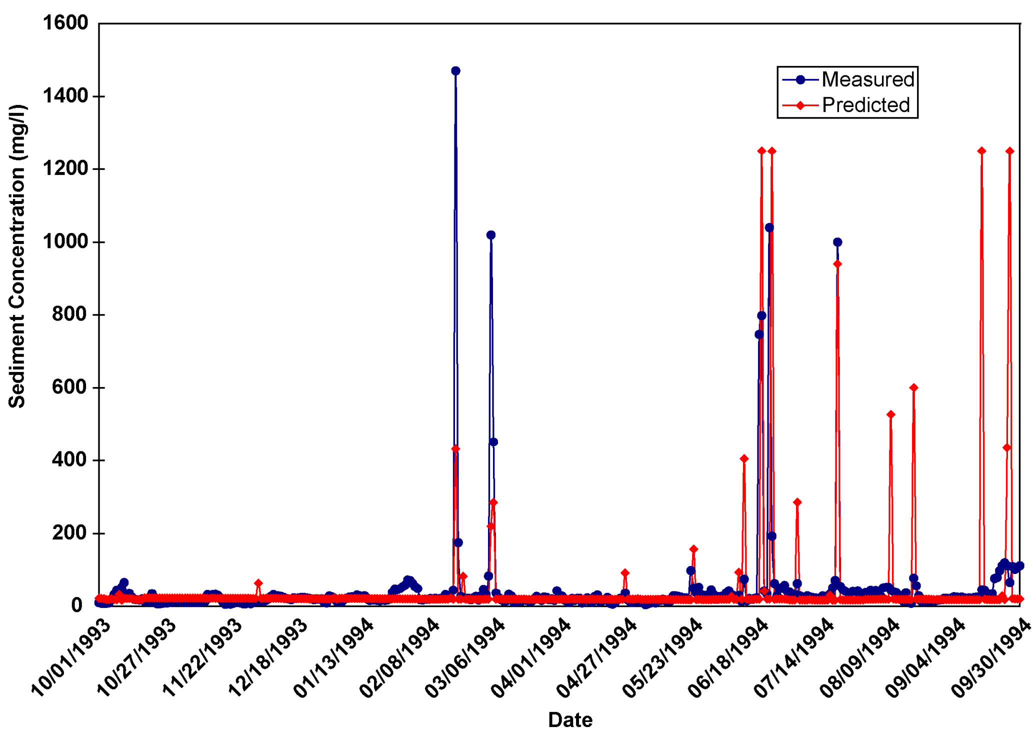

FIGURE 19. Predicted versus measured daily sediment concentrations for water year 1994 (October 1993 to September 1994)

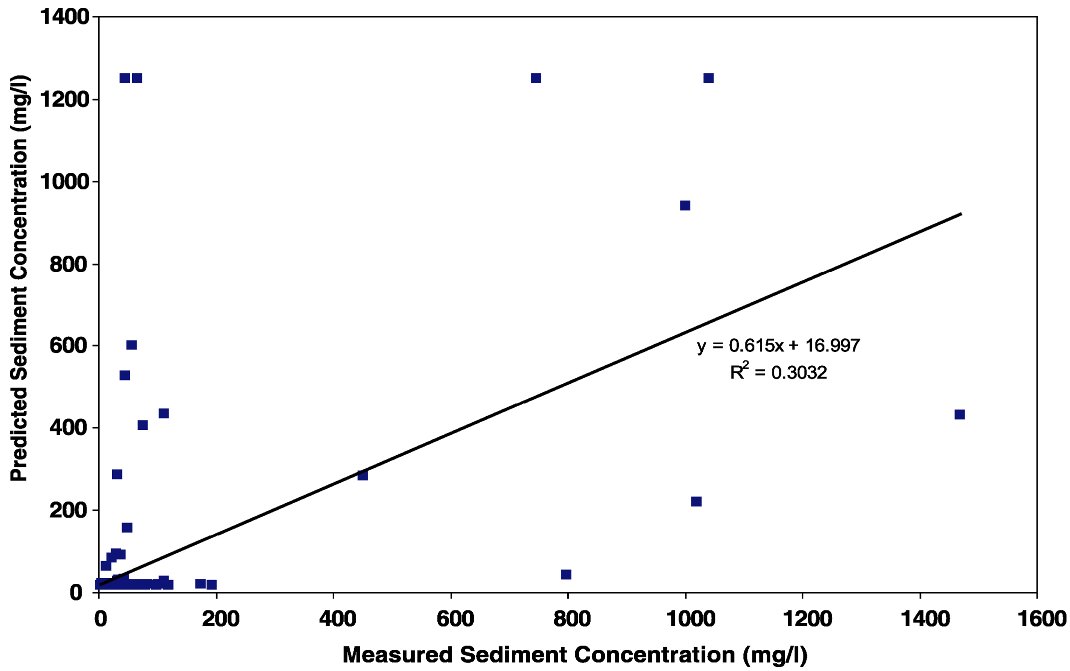

FIGURE 20. Coefficient of determination (R^2) for predicted sediment concentrations for water year 1994 (October 1993 to September 1994)

values for the two simulation periods. The predicted average annual sediment and nutrient loads were less acccurate, but the magnitudes of the estimated losses generally were similar to those measured. The daily flow values predicted for the 1994 water year accurately tracked the corresponding observed values, as evidenced by the time series comparison and the R^2 value of 0.76. A relatively strong R^2 value of 0.68 also resulted for the sediment load predictions, but the peak sediment load events were greatly underpredicted by SWAT. The model was not able to accurately track the sediment load concentrations, largely because of sediment concentrations that occurred for small sediment loss events. The results reported here indicate that predicted sediment loads rather than sediment concentrations should be used to assess the sediment loss impacts of different simulated conditions in SWAT.

This study supports the hypothesis that SWAT could be used to estimate rapidly, accurately, and inexpensively the factors such as flow, sediment, and nutrient losses that are important parameters in evaluating water quality at the watershed level. The SWAT modeling also provided useful insights regarding the following issues: (1) the importance of accurate data inputs such as rainfall; (2) weaknesses in some of the data collecting methodologies, such as the frequency of the nutrient measurements; and (3) the impacts of BMPs, such as terraces, on water quality. Because of the high cost, time constraints, and uncontrollable conditions (e.g., problems with weather patterns) associated with field studies, models such as SWAT can be used as an alternative to evaluate the impact of various factors, such as management and weather, on water quality at field and watershed scale. However, further modeling will be needed with a more refined SWAT model to better capture the temporal and spatial patterns of conservation practices in the watershed, and to verify the accuracy of the model predictions relative to the final complete set of monitoring data collected in the watershed (through September 2001).

Endnotes

1. Alfalfa is assumed interseeded with oats when the oats are planted. An initial cutting of alfalfa is performed about one month after the oats harvest (Table 7). Forage yield from the first cutting is typically low. Yields of the cuttings in each of the two subsequent years (Table 7) are usually much higher.

2. Data for one spring located within the drainage area of sampling site SN3 was provided by Seigley (2000). The flow, ranging from 0.09 to 0.13 m^3/s, and associated measured NO_3-N concentration of 4.2 mg/l were input to the SWAT simulation.

3. The total-P concentration includes both the organic-P and soluble-P (PO_4-P) fractions.

Appendix A

Table A.1. Characteristics of Hydrologic Response Units (HRUs) by SWAT sub-basin

Sub-basin	1992 IDNR-GSB Land Use Category For Each HRU	Assumed Rotation (And Length) For Each HRU	HRU Area (Ha)	HRU Area Relative To Sub-basin Area (%)	Terraced 1990-94	Terraced 1995-99	Contoured 1990-94	Contoured 1995-99	Strip-cropped 1990-94	Strip-cropped 1995-99
1	Cover crop	OAACC (5 yr)	321	13.1	no	no	yes	yes	no	no
	Cover crop	OAACC/CRP (10 yr)	64	2.6	no	no	yes	no	no	no
	Cover crop	OAACC/SC (10 yr)	127	5.2	no	yes	yes	no	no	no
	Cover crop	OAACC (5 yr)	91	3.7	yes	yes	no	no	no	no
	Pasture	bromegrass	225	9.2	no	no	no	no	no	no
	Forest		825	33.7	no	no	no	no	no	no
	Row crop	cont. corn (1 yr)	237	9.7	no	yes	yes	no	no	no
	Row crop	CCCCC/SC (10 yr)	100	4.1	no	yes	yes	no	no	no
	Row crop	cont. corn (1 yr)	105	4.3	yes	yes	no	no	no	no
	Row crop	CCCCC/SC (10 yr)	44	1.8	yes	yes	no	no	no	no
	Strip crop	CCOAA (5 yrs)	142	5.8	no	no	no	no	yes	yes
	Strip crop	CCOAA/CRP (10 yr)	64	2.6	no	no	no	no	yes	no
	Strip crop	CCOAA (5 yr)	59	2.4	yes	yes	no	no	no	no
	Other		44	1.8	no	no	no	no	no	no
2	Cover crop	OAACC (5 yr)	40	5.2	no	yes	yes	no	no	no
	Cover crop	OAACC/SC (10 yr)	14	1.8	no	yes	yes	no	no	no
	Cover crop	OAACC (5 yr)	22	2.8	yes	yes	no	no	no	no
	Pasture	bromegrass	16	2.1	no	no	no	no	no	no
	Forest		452	58.2	no	no	no	no	no	no
	Row crop	cont. corn (1 yr)	67	8.6	no	yes	yes	no	no	no
	Row crop	CCCCC/SC (10 yr)	29	3.7	no	yes	yes	no	no	no
	Row crop	cont. corn (1 yr)	19	2.4	yes	yes	no	no	no	no
	Row crop	CCCCC/SC (10 yr)	9	1.1	yes	yes	no	no	no	no
	Strip crop	CCOAA (1 yr)	85	11	yes	yes	no	no	no	no
	Strip crop	CCOAA/CRP (10 yr)	18	2.3	yes	yes	no	no	no	no

Table A.1. Continued

Sub-basin	1992 IDNR-GSB landuse category for each HRU	Assumed Rotation (And Length) For Each HRU	HRU area (ha)	HRU area relative to sub-basin area (%)	Terraced 1990-94	Terraced 1995-99	Contoured 1990-94	Contoured 1995-99	Strip-cropped 1990-94	Strip-cropped 1995-99
	Other		6	0.8	no	no	no	no	no	no
	Cover crop	OAACC/SC (10 yr)	321	2.9	no	no	yes	no	no	no
	Pasture	bromegrass	64	5.3	no	no	yes	no	no	no
3	Cover crop	OAACC (5 yr)	70	9.8	no	yes	yes	no	no	no
	Cover crop	OAACC/SC (10 yr)	21	2.9	no	no	yes	yes	no	no
	Pasture	bromegrass	38	5.3	no	no	no	no	no	no
	Forest		267	37.6	no	no	no	no	no	no
	Row crop	cont. corn (1 yr)	35	5	no	yes	no	no	no	no
	Row crop	CCCCC/CRP	31	4.4	no	no	yes	no	no	no
	Row crop	CCCC/SC (10 yr)	29	4.1	no	yes	yes	no	no	no
	Row crop	cont. corn (1 yr)	64	9	yes	yes	no	no	no	no
	Row crop	CCCCC/CRP	35	5	yes	yes	no	no	no	no
	Row crop	CCCCC/SC (10 yr)	43	6	yes	yes	no	no	no	no
	Strip crop	CCOAA	28	4	no	no	no	no	yes	yes
	Strip crop	CCOAA/CRP	29	4.1	no	no	no	no	yes	no
	Strip crop	CCOAA	11	1.6	yes	yes	no	no	no	no
	Other		9	1.2	no	no	no	no	no	no
4	Cover crop	OAACC (5 yr)	10	6.2	no	no	yes	yes	no	no
	Cover crop	OAACC/CRP	7	4.7	no	no	yes	no	no	no
	Cover crop	OAACC (5 yr)	16	10.2	yes	yes	no	no	no	no
	Forest		100	64.3	no	no	no	no	no	no
	Row crop	cont. corn (1 yr)	8	5.2	no	no	yes	yes	no	no
	Row crop	CCCCC/CRP	8	5.0	no	no	yes	no	no	no
	Row crop	CCCCC/SC (10 yr)	7	4.4	no	no	yes	yes	no	no

Table A.1. Continued

Sub-basin	1992 IDNR-GSB landuse category for each HRU	Assumed Rotation (And Length) For Each HRU	HRU area (ha)	HRU area relative to sub-basin area (%)	Terraced 1990-94	Terraced 1995-99	Contoured 1990-94	Contoured 1995-99	Strip-cropped 1990-94	Strip-cropped 1995-99
5	Cover crop	OAACC (5 yr)	73	5.6	no	no	yes	yes	no	no
	Cover crop	OAACC/SC (10 yr)	25	1.9	no	no	yes	yes	no	no
	Cover crop	OAACC (5 yr)	14	1.1	yes	yes	no	no	no	no
	Pasture	bromegrass	21	1.6	no	no	no	no	no	no
	Forest		723	55.5	no	no	no	no	no	no
	Row crop	cont. corn (1 yr)	102	7.8	no	yes	yes	no	no	no
	Row crop	CCCCC/CRP	13	1.0	no	no	yes	no	no	no
	Row crop	CCCCC/SC (10 yr)	50	3.8	no	yes	yes	no	no	no
	Row crop	cont. corn (1 yr)	166	12.7	yes	yes	no	no	no	no
	Row crop	CCCCC/SC (10 yr)	72	5.5	yes	yes	no	no	no	no
	Strip crop	CCOAA	36	2.8	yes	yes	no	no	no	no
	Other		9	0.7	no	no	no	no	no	no
6	Cover crop	OAACC (5 yr)	116	6.9	no	no	yes	yes	no	no
	Cover crop	OAACC/CRP	34	2.0	no	no	yes	no	no	no
	Cover crop	OAACC/SC (10 yr)	51	3.0	no	yes	yes	no	no	no
	Cover crop	OAACC (5 yr)	44	2.6	yes	yes	no	no	no	no
	Pasture	bromegrass	32	1.9	no	no	no	no	no	no
	Forest		881	52.3	no	no	no	no	no	no
	Row crop	cont. corn (1 yr)	103	6.1	no	no	yes	yes	no	no
	Row crop	CCCCC/CRP	42	2.5	no	no	yes	no	no	no
	Row crop	CCCCC/SC (10 yr)	62	3.7	no	no	yes	yes	no	no
	Row crop	cont. corn (1 yr)	79	4.7	yes	yes	no	no	no	no
	Row crop	CCCCC/SC (10 yr)	34	2.0	yes	yes	no	no	no	no
	Strip crop	CCOAA	24	1.4	no	no	no	no	yes	yes
	Strip crop	CCOAA	160	9.5	yes	yes	no	no	no	no
	Other		24	1.4	no	no	no	no	no	no

Appendix B

Determination of Manure Production Levels and Application Rates

The first step we took in determining SMCW manure nutrient amounts was to estimate the total livestock inventories at the start and end of the 1990s. The only livestock inventory data available for the initial part of the decade was 1992 ISUE survey results (Table B.1). A total of 34 responses were received from the survey (a response rate of 74 percent), and 34 producers reported raising one or more types of livestock. It is not known where in the SMCW the surveyed producers were located, what percentage of the other producers who did not respond to the survey also raised livestock (and what type of livestock they raised), and whether surveys were sent to all producers in the watershed at that time. An initial inventory of livestock production for the late 1990s was performed in 2000, in an attempt to determine how many SMCW producers were still raising livestock after the 1990s. In contrast to the ISUE information, this inventory did include location of the livestock operations that allowed identification of livestock production levels by SWAT sub-basin.

A comparison between the two surveys shows implied declines in the inventory livestock numbers of roughly 50 percent relative to the 1992 ISUE survey. The inventory indicated that 30 operations in the SMCW have livestock, with 19 of those located above sampling site SN1. However, 1999 ISUE survey results (Brown 2000) report that 60 out of 91 responding producers still had livestock. Thus, it is likely that the true number of livestock operations is underreported in the inventory.

TABLE B.1. Livestock production levels from 1992 survey of the SMCW

Livestock/ Production Method	Producers Responding	Herd Size Ranges	Mean Herd Sizes
Swine[a]			
Farrow-to-finish	13	100–1800	1012
Feeder-to-finish	3	20–800	357
Feeder pigs	4	10–2400	930
Beef			
Stock cows[b]	19	7-100	42
Feedlot steers/heifers[a]	10	12-550	81
Replacement heifers	10	1-20	9
Dairy			
Milking herd	10	31-73	53
Replacement heifers	10	5-60	30

Source: ISUE (1992).
[a]Number of animals marketed in 1991.
[b]Average size of herd.

We compared agricultural census data (USDA 1997) for Clayton County dairy, swine, and beef cattle for 1992 and 1997 production levels as an additional check on total herd size estimates for the start and end of the decade. Consistent production declines of 16-17 percent are reported for all three livestock types in Clayton County in 1997 compared to 1992. These trends, if assumed representative for the SMCW, indicate that the decline in livestock numbers is not as great as that suggested by the 2000 inventory.

The final sets of livestock production levels assumed for the 1990-94 and 1995-99 time periods represented a compromise between the different sets of available information. Table B.2 shows three different sets of SMCW estimated livestock inventories by SWAT sub-basin, one for 1992 and two for 2000. The "2000" scenario is the herd sizes and distributions found in the 2000 inventory. Herd size distributions between sub-basins for the "1992" and "alternate 2000" scenarios were based on the distributions mapped in the 2000 inventory. Additional assumptions for the 1992 scenario were as follows:

1. The total SMCW herd sizes for each category of livestock were the mean multiplied by the number of operations as given in Table 11;
2. All beef stock cows were grazed on pasture at a stocking density of 3 cows/ha (1.2 cows/ac);
3. The remaining beef cattle (feedlot steers, heifers, and replacement heifers) were located in the drainage area above site SN1; and
4. The percentage of total swine and dairy cows (as derived from the values in Table B.1) were located in the SN1 watershed in a proportion roughly equal to the SN1 watershed area divided by the entire SMCW watershed area.

We used the 1992 scenario as a representative of livestock production for the 1990-94 SWAT simulation period. The alternate 2000 scenario simply assumes a 17 percent decline in livestock numbers (based on the agricultural census trends from Clayton County) relative to the 1992 scenario and was considered the most accurate reflection of livestock production levels for the 1995-99 SWAT simulation period. The model holds constant across 1995-99 the beef cow pasture stocking densities simulated for 1990-94.

The model bases manure amounts produced and ultimately land-applied for the 1990-94 and 1995-99 on algorithms developed for mixed livestock farms simulated for the UMRW (partially described in Osei et al. 2000b). For the SMCW, we assumed that each sub-basin contained a single livestock farm consisting of the Table B.1 herd distributions listed for the 1992 scenario (for 1990-94) and the alternate 2000 scenario (for 1995-99). The initial step in the process required the estimation of the total annual manure, manure N, and manure P levels generated per animal for each combination of livestock species and production system (Table B.3). We then calculated the same manure, manure N, and manure P levels for the total herds in each sub-basin, including the determination of the dominant livestock species, i.e., dominant as based on the total manure amount produced. Manure application rates simulated within each sub-basin (Table B.4) were based on rates used in the UMRW simulations for manure applied to corn, as described by Osei et al. (2000a). However, "hybrid manure characteristics" were used to depict the N and P levels in the applied

TABLE B.2. Three estimates of total swine, dairy, and feeder cattle inventories by sub-basin in 1992 and 2000 at site SN1

SWAT Sub-basin	Livestock Type	1992[a]	2000[b]	Alternate 2000[c]
1	Open lot swine	4,627	2,756	3,840
	Cattle feeder	900	130	747
2	Open lot swine	2,686	1,600	2,229
	Dairy cows	170	90	141
	Dairy replacement heifers	102	60	85
3	Open lot swine	2,014	1,200	1,672
	Dairy cows	313	166	260
	Dairy replacement heifers	188	100	156
5	Open lot swine	1,645	980	1,365
	Swine confinement	326	125	271
	Dairy cows	47	25	39
	Dairy replacement heifers	28	15	23
6	Open lot swine	2,182	1,300	1,811
	Swine confinement	1,303	500	1,081

Note: Estimates are for the SMCW drainage area above sampling site SN1.
[a]Derived from ISUE (1992) and spatial distributions mapped in the 2000 inventory; these livestock production numbers were assumed for the 1990-94 SWAT simulation period.
[b]2000 inventory.
[c]This scenario assumes a 17 percent decline in livestock production numbers between the start and end.

TABLE B.3. Annual manure, manure N, and manure P production levels per animal for SMCW livestock type–production systems combinations

Livestock Types/ Production System	Total Manure	Total Nitrogen	Total Phosphorous
		kg/year (lb/year)	
Beef/pasture	15,002 (33,080)	87.9 (193.9)	23.8 (52.5)
Dairy cows/tie stall	18,625 (41,069)	97.5 (214.9)	20.4 (44.9)
Dairy heifers/tie stall	9,816 (21,644)	51.4 (113.3)	10.7 (23.7)
Feeder cattle/open lot	16,152 (35,615)	94.7 (208.8)	25.6 (56.5)
Swine/open lot	915 (2,017)	5.7 (12.5)	2 (4.3)
Swine/confinement	792 (1,747)	4.9 (10.8)	1.7 (3.7)

TABLE B.4. Dominant livestock type and associated manure application rate by SWAT sub-basin

Sub-basin	Dominant Livestock Type/Production System	Manure Application Rate Kg/Ha (Lb/Ac)
1	Feeder cattle/open lot	6587 (5881)
2	Dairy cow/tie stall	6273 (5,601)
3	Dairy cow/tie stall	6273 (5,601)
4[a]	-	-
5	Swine/open lot	5870 (5,241)
6	Swine/open lot	5870 (5,241)

Note: Rates are based on the assumption that manure was applied to corn, as obtained from Rodecap (1999).
[a]No manure was assumed applied in sub-basin 4.

manure, which were based on weighted-averages of the relative manure, manure N, and manure P loads (Table B.3) contributed by each type of livestock present in each sub-basin (Table B.2).

Table B.5 shows manure applications for each HRU within each sub-basin in both 1990-94 and 1995-99. Manure was assumed always to be applied to continuous corn to simplify the data input configurations for SWAT. Nitrogen fertilizer rates were reduced to 54 kg/ha (50 lb/ac) for manured continuous corn fields, reflecting known improvement in nutrient management practices that have occurred in the SMCW. Following the assumptions used for the UMRW, in the model, 25 percent of the total manure load in each of the sub-basins was deposited on open feed lots. Surface runoff losses of N and P were directly simulated from these feedlots in the UMRW with the Agricultural Policy eXtender (APEX) model (Williams et al. 1995). However, SWAT does not currently have this capability, so N and P losses from open feedlots were not accounted for in the SMCW simulation.

TABLE B.5. Simulated manure applications of specific HRUs

Sub-basin	1992 Land Use	Rotation (Length)	HRU Area (Ha)	% of Sub-basin Area	Manure 1990-94	Manure 1995-99
1	Row crop	Cont. Corn (1 yr)	237	9.7	yes	yes
	Row crop	Cont. Corn (1 yr)	105	4.3	yes	no
	Row crop	CCCCC/SC (10 yr)	44	1.8	yes	no
2	Row crop	Cont. Corn (1 yr)	67	8.6	yes	yes
	Row crop	Cont. Corn (1 yr)	19	2.4	yes	yes
3	Row crop	Cont. Corn (1 yr)	35	5	yes	yes
	Row crop	CCCCC/SC (10 yr)	29	4.1	yes	no
	Row crop	Cont. Corn (1 yr)	64	9	yes	yes
5	Row crop	Cont. Corn (1 yr)	102	7.8	yes	yes
6	Row crop	Cont. Corn (1 yr)	79	4.7	yes	yes

Appendix C

TABLE C.1. Daily average measured and predicted values for flow, sediment, and nutrients during the calibration and validation periods and for individual years within both time periods at site SN1

Year	Measured Flow (M^3/S)	Predicted Flow (M^3/S)	Measured Sediment Concen. (Mg/L)	Predicted Sediment Concen. (Mg/L)	Measured Sediment Load (Mt)	Predicted Sediment Load (Mt)	Measured Nitrate (Mg/L)	Predicted Nitrate (Mg/L)	Measured Organic N (Mg/L)	Predicted Organic N (Mg/L)	Measured Total P (Mg/L)	Predicted Total P (Mg/L)
1992	0.47	0.53	41.05	67.43	5.44	8.23	1.87	2.96	0.23	0.17	0.12	0.15
1993	1.08	0.91	91.70	81.61	35.10	30.23	2.75	2.93	0.36	0.23	0.14	0.18
1994	0.60	0.47	49.20	52.11	14.60	8.87	2.63	3.80	0.12	0.17	0.08	0.14
1992-94[a]	0.72	0.64	60.65	67.05	18.38	15.78	2.42	3.32	0.24	0.19	0.11	0.15
1995	0.55	0.44	34.30	49.10	7.33	5.87	2.35	3.19	0.24	0.12	0.08	0.10
1996	0.47	0.33	33.10	28.10	9.21	2.10	2.46	3.74	0.23	0.04	0.07	0.04
1997	0.42	0.35	42.00	31.70	4.42	3.66	2.46	3.35	0.23	0.08	0.09	0.07
1998	0.60	0.60	63.62	62.12	20.00	16.09	2.63	3.42	0.12	0.21	0.08	0.18
1995-98[a]	0.51	0.43	43.26	42.76	10.24	6.93	2.48	3.43	0.21	0.11	0.08	0.10

[a]Daily average values over the respective calibration and time periods.

References

Arnold, J.G., and P.M. Allen. 1996. "Estimating Hydrologic Budgets for Three Illinois Watersheds." *Journal of Hydrology* 176: 57-77.

Arnold, J.G., R.S. Muttiah, R. Srinivasan, and P.M. Allen. 2000. "Regional Estimation of Base Flow and Groundwater Recharge in the Upper Mississippi River Basin." *Journal of Hydrology* 227: 21-40.

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and P.M. Allen. 1999. "Continental Scale Simulation of the Hydrologic Balance." *Journal of the American Water Resources Association* 35(5): 1037-1051.

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. "Large Area Hydrologic Modeling and Assessment Part I: Model Development." *Journal of the American Water Resources Association* 34(1): 73-89.

Binger, R.L. 1996. "Runoff Simulated from Goodwin Creek Watershed using SWAT." *Transactions of the ASAE* 39(1): 85-90.

Brown, S. 2000. "Sny Magill Watershed Hydrologic Unit Area Project Ending Survey: Crop Year 1999 Survey Results and Comparison to Prior Surveys in Crop Year 1991 and 1993." Iowa State University Extension.

Clayton County Soil and Water Conservation Department (SWCD). 1994. "Sny Magill Creek Watershed." Iowa FY95, Section 319, Project Implementation Plan, Project #7. Iowa Water Quality Project Application.

Conservation Tillage Information Center (CTIC). 1996. "Conservation Tillage: A Checklist for U.S. Farmers (plus regional considerations)." Conservation Tillage Information Center, West Lafayette, IN.

Gassman, P.W., E. Osei, A. Saleh, and L.M. Hauck. 2002. "Application of an Environmental and Economic Modeling System for Watershed Assessments."*Journal of the American Water Resources Association* 38(2): 423-38.

Gibney, D. 2000. Personal communication. U.S. Department of Agriculture, Natural Resources and Conservation Service, Elkader, IA.

Iowa Department of Natural Resources, Geological Survey Bureau (IDNR-GSB). 2000. Natural Resources Geographic Information System Library. Iowa City, IA.

Keith, G., S. Norvell, R. Jones, C. Maguire, E. Osei, A. Saleh. P. Gassman, and J. Rodecap. 2000. "CEEOT-LP Modeling for the UPPER Maquoketa Watershed, Iowa: Final report." Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, TX.

Kirsch, K.J. 2000. "Predicting Sediment and Phosphorus Loads in the Rock River Basin using SWAT." Paper presented at the 2000 American Society of Agricultural Engineers annual international meeting, Milwaukee, WI. ASAE Paper No. 002175, St. Joseph, Michigan.

Iowa State University Extension (ISUE). 1992. "Frequencies—Baseline Questionnaire (74% response rate): Sny Magill Project, A USDA Water Quality Hydrologic Unit Area."Ames, IA.

———. 1994. “Sny Magill Watershed Farm Practices Survey.” Ames, IA. http://extension.agron.iastate.edu/waterquality/sny_survey.html.

Lombardo, L.A., G.L. Grabow, K.L. Tweedy, D.E. Line, D.L. Osmond, and J. Spooner. 2000. “Sny Magill Section 319 National Monitoring Program Project.” In *2000 Summary Report: Section 319 National Monitoring Program Projects,* pp. 89-101. NCSU Water Quality Group, Biological and Agricultural Engineering Dept., North Carolina State University. http://h2osparc.wq.ncsu.edu/2000rept319/.

Osei, E., P. Gassman, and A. Saleh. 2000a. “Livestock and the Environment: A National Pilot Project: CEEOT-LP Modeling for the Upper Maquoketa River Watershed, Iowa.” Technical Report No. RR0001. Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, TX.

———. 2000b. “Livestock and the Environment: A National Pilot Project; Economic and Environmental Modeling using CEEOT.” Report No. PR0002. Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, TX.

May, J.E., J.G. Gorman, R.D. Goodrich, M.W. Bobier, and V.E. Miller. 1996. “Water Resources Data, Iowa: Water Year 1995.” U.S. Geological Survey Water-Data Report IA-95-1. U.S.Geological Survey, Iowa City, IA.

———. 1997. “Water Resources Data, Iowa: Water Year 1996.” U.S. Geological Survey Water-Data Report IA-96-1. U.S. Geological Survey, Iowa City, IA.

May, J.E., J.G. Gorman, R.D. Goodrich, and V.E. Miller. 1998. “Water Resources Data, Iowa: Water Year 1997.” Volume 1: *Surface Water—Mississippi River Basin.* U.S. Geological Survey Water-Data Report IA-97-1. U.S. Geological Survey, Iowa City, IA.

May, J.E., J.G. Gorman, R.D. Goodrich, V.E. Miller, M.J. Turco, and S.M. Linhart. 1999. “Water Resources Data, Iowa: Water Year 1998.” Volume 1: *Surface Water—Mississippi River Basin.* U.S. Geological Survey Water-Data Report IA-98-1. U.S. Geological Survey, Iowa City, IA.

Mockus, V. 1972. “Estimation of Direct Runoff from Storm Rainfall.” Section 4, “Hydrology,” in *SCS National Engineering Handbook*, p. 9.1-9.11. U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

———. 1969. “Hydrologic Soil-Cover Complexes.” Section 4, “Hydrology,” in *SCS National Engineering Handbook*, pp. 10.1-10.24. U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

Palas, E. 2000. Personal communication. U.S. Department of Agriculture, Natural Resources and Conservation Service, Elkader, Iowa.

Saleh, A., J.G. Arnold, P.W. Gassman, L.M. Hauck, W.D. Rosenthal, J.R. Williams, and A.M.S. McFarland. 2000. “Application of SWAT for the Upper North Bosque River Watershed.” *Transactions of the ASAE* 43(5): 1077-1087.

Seigley, L.S. 2000. Personal communication. Iowa Department of Natural Resources, Geological Survey Bureau, Iowa City, IA.

Seigley, L.S., M.D. Schueller, M.W. Birmingham, G. Wunder, L. Stahl, T.F. Wilton, G.R. Hallberg, R.D. Libra, and J.O. Kennedy. 1994. "Sny Magill Nonpoint Source Pollution Monitoring Project, Clayton County, Iowa: Water Years 1992 and 1993." Tech. Info. Series 31. Iowa Department of Natural Resources, Geological Survey Bureau, Iowa City, IA.

Seigley, L.S., G. Wunder, A. Gritters, T.F. Wilton, J.E. May, M.D. Schueller, M.W. Birmingham, N.A. Rolling, and J. Tisl. 1996. "Sny Magill Nonpoint Source Pollution Monitoring Project, Clayton County, Iowa: Water Year 1994." Tech. Info. Series 36. Iowa Department of Natural Resources, Geological Survey Bureau, Iowa City, IA

Srinivasan, R., T.S. Ramanarayanan, J.G. Arnold, and S.T. Bednarz. 1998. "Large Area Hydrologic Modeling and Assessment Part II: Model Application." *Journal of the American Water Resource Assoc*. 34(1): 73-89.

Tisl, J. 1998. "Sny Magill Creek Watershed Project, Clayton, County Iowa: Final Report." Report submitted to the Iowa Department of Natural Resources, Des Moines, IA.

———. 2001. Personal communication. Iowa Department of Natural Resources. Des Moines, IA.

U.S. Department of Agriculture, National Agricultural Statistics Service (USDA). 1997. "Iowa County-Level Data," Vol. 1, pt. 15, chap. 2 in *1997 Census of Agriculture,* pp. 430, 461. U.S. Washington, D.C. http://www.nass.usda.gov/census/census97/volume1/ia-15/toc297.html.

Williams, J.R., and H.D. Berndt. 1977. "Sediment Yield Prediction based on Watershed Hydrology." *Transactions of the ASAE* 20(6): 1100-1104.

Williams, J.R., C.A. Jones, P.W. Gassman, and L.M. Hauck. 1995. "Simulation of Animal Waste Management with APEX." In *Innovations and New Horizons in Livestock and Poultry Manure Management*, pp. 22-26. Austin, TX, 6-7 September.

Wischmeier, W.H., and D.D. Smith. 1978. *Predicting Rainfall Erosion Losses—A Guide to Conservation Planning.* Agriculture Handbook No. 537. Washington, D.C.: U.S. Department of Agriculture.