# Water Quality Modeling for the Raccoon River Watershed Using SWAT

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## Abstract

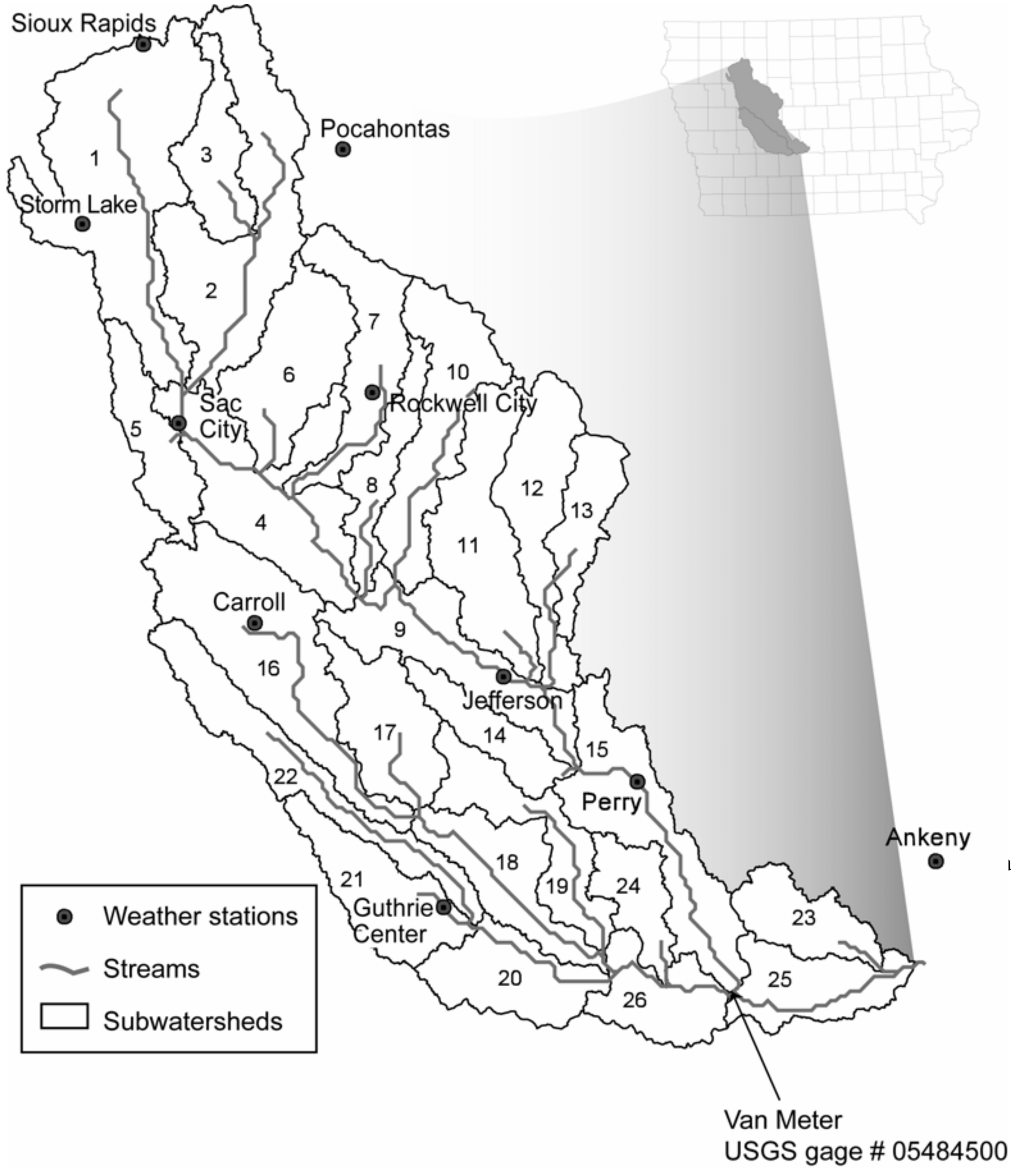
The Raccoon River Watershed (RRW) in West-Central Iowa has been recognized as exporting some of the highest nitrate-nitrogen loadings in the United States and is a major source of sediment and other nutrient loadings. An integrated modeling framework has been constructed for the RRW that consists of the Soil and Water Assessment Tool (SWAT) model, the interactive SWAT (i_SWAT) software package, Load Estimator (LOADEST) computer program, and other supporting software and databases. The simulation framework includes detailed land use and management data such as different crop rotations and an array of nutrient and tillage management schemes, derived from the U.S. Department of Agriculture's National Resources Inventory databases and other sources. This paper presents the calibration and validation of SWAT for the streamflow, sediment losses, and nutrient loadings in the watershed and an assessment of land use and management practice shifts in controlling pollution. Streamflow, sediment yield, and nitrate loadings were calibrated for the 1981-1992 period and validated for the 1993-2003 period. Limited field data on organic nitrogen, organic phosphorus, and mineral phosphorus allowed model validation for the 2001-2003 period. Model predictions generally performed very well on both an annual and monthly basis during the calibration and validation periods, as indicated by coefficient of determination ($R^2$) and Nash-Sutcliffe simulation efficiency (E) values that exceeded 0.7 in most cases. A set of land use change scenarios based on taking cropland out of production indicated a significant benefit in reducing sediment yield at the watershed outlet. A second scenario set found that relatively small reductions in nutrient applications resulted in significant reductions in nitrate loadings at the watershed outlet, without affecting crop yields significantly.

**Keywords:** calibration, management practices, Raccoon River Watershed, SWAT.

## INTRODUCTION

Excess nitrogen, phosphorus, and sediment loadings have resulted in water quality degradation within the Upper Mississippi River and its tributaries. This is particularly true for watersheds draining in portions of Iowa, which are generally greatly impacted by agricultural nonpoint source pollution. Kalkoff et al. (2000) report that nitrogen and phosphorus levels measured in several large eastern Iowa watersheds, which drain to the Mississippi River, were among the highest found in the Corn Belt region and in the entire United States as part of the U.S. Geological Survey (USGS) National Water-Quality Assessment Program. Schilling and Libra (2000) state that annual export of nitrate from surface waters in Iowa was estimated to be about 25% of the nitrate that the Mississippi River delivers to the Gulf of Mexico, despite Iowa occupying less than 5% of its drainage area. The nitrate load discharged from the mouth of the Mississippi River has been implicated as the primary cause of the seasonal oxygen-depleted hypoxic zone that occurs in the Gulf of Mexico, which has covered upwards of 20,000 $km^2$ in recent years (Rabalais et al., 2002).

The Raccoon River Watershed (RWW) is located in an intensive agricultural production region in West-Central Iowa (Figure 1) and is impacted by sediment, phosphorus, and nitrogen pollution (Lutz, 2004). Primary RRW nutrient input sources include widespread use of fertilizers, livestock manure applications, legume fixation, and mineralization of soil nitrogen. Nitrate pollution is a particularly acute problem in the RWW; nitrate is transported primarily through groundwater discharge via baseflow and tile drainage. Schilling and Zhang (2004) report that nitrate export from the RWW is among the highest in the interior United States. The watershed's high concentrations of nitrates have exceeded the federal maximum contaminant level standard of 10 mg/L with enough frequency since the late 1980s to warrant the installation and operation of the world's largest nitrate removal facility by Des Moines Water Works. Sections of the Raccoon River have also been listed in Iowa's Federal Clean Water Act 303(d) list of impaired waters because of the elevated nitrate levels.




ıtions.

**Figure 1. Raccoon River Watershed and delineated 10-digit subwatersheds with climate stations**

Several studies have been performed in the RWW to quantify nitrate concentration patterns and corresponding streamflow relationships. Schilling and Lutz (2004) examined a 28-year record (1972-2000) of streamflow and nitrate concentrations measured in the Raccoon River and reported evidence of strong seasonal patterns in annual nitrate concentrations, with higher concentrations occurring in the spring and fall. No long-term trends in nitrate concentrations were noted during the entire period. Schilling and Zhang (2004) described nitrate loading patterns in the Raccoon River and found that nitrate losses in baseflow comprised nearly two-thirds of the total nitrate load over the same 28-year monitoring period. They also found that seasonal patterns of nitrate loads were similar to nitrate concentration patterns, with baseflow contributions to nitrate loads greatest in the spring and later fall, when baseflow contributed more than 80% of the total nitrate export.

The focus of this study was to assess the ability of the Soil and Water Assessment Tool (SWAT) version 2000 (Arnold et al., 1998; Arnold and Fohrer, 2005) to simulate stream flow and associated movement of nitrogen, phosphorus, and sediment in the RWW. No previous studies have been found in the literature regarding an in-depth simulation study of the RWW. Developing reliable simulation tools could provide very useful insight into the movement and potential mitigation of nonpoint source pollution in the watershed, which is especially important considering the pervasive high nitrate loadings in the watershed. The results could also provide useful insight into the application of SWAT and comparable tools for other similarly impacted agricultural watersheds in Iowa and the midwestern United States. Thus, the objectives of this study were to (1) calibrate and validate the SWAT model for stream flow, sediment, and nutrients for the entire watershed; and (2) evaluate the effects of alternative management practices in controlling pollution.

## Materials and Methods

### SWAT Model

SWAT is a hydrologic and water quality model developed by the U.S. Department of Agriculture's Agricultural Research Service (USDA-ARS). It is a long-term continuous watershed scale simulation model that operates on a daily time step and is designed to assess the impact of different management practices on water, sediment, and agricultural chemical yields. The model is physically based, computationally efficient, and capable of simulating a high level of spatial detail. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management. In SWAT, a watershed is divided into multiple subwatersheds, which are further subdivided into unique soil/land use characteristics called hydrologic response units (HRUs). The water balance of each HRU is represented by four storage volumes: snow, soil profile, shallow aquifer, and deep aquifer. Flow generation, sediment yield, and pollutant loadings are summed across all HRUs in a subwatershed, and the resulting loads are then routed through channels, ponds, and/or reservoirs to the watershed outlet.

Surface runoff from daily rainfall is estimated with the modified Soil Conservation Service curve number method (Mishra and Singh, 2003), which estimates the amount of runoff based on local land use, soil type, and antecedent moisture condition. The Green-Ampt method (Green and Ampt, 1911) of estimating infiltration is an alternative option for estimating surface runoff and infiltration that requires sub-daily weather data. Melted snow is treated the same as rainfall for estimating runoff and percolation. Channel routing is simulated using either the variable-storage method or the Muskingum method; both methods are variations of the kinematic wave model (Chow et al., 1988). Three methods of estimating potential evapotranspiration are available: Priestley-Taylor (Priestley and Taylor, 1972), Hargreaves (Hargreaves and Samani, 1985), and Penman-Monteith (Allen et al., 1989).

Erosion and sediment yield are estimated for each HRU with the Modified Universal Soil Loss Equation (Williams, 1995). The channel sediment routing equation uses a modification of Bagnold's sediment transport equation (Bagnold, 1977) that estimates the transport concentration capacity as a function of velocity. The model either deposits excess sediment or re-entrains sediment through channel erosion depending on the sediment load entering the channel.

SWAT simulates the complete nutrient cycle for nitrogen and phosphorus. The nitrogen cycle is simulated using five different pools; two are inorganic forms (ammonium and nitrate) while the other three are organic forms (fresh, stable, and active). Similarly, SWAT monitors six different pools of phosphorus in soil; three are inorganic forms and the rest are organic forms. Mineralization, decomposition, and immobilization are important parts in both cycles. These processes are allowed to occur only if the temperature of the soil layer is above 0ºC. Nitrate export with runoff, lateral flow, and percolation are estimated as products of the volume of water and the average concentration of nitrate in the soil layer. Organic N and organic P transport with sediment is calculated with a loading function developed by McElroy et al. (1976) and modified by Williams and Hann (1978) for application to individual runoff events. The loading function estimates daily Org N and P runoff loss based on the concentrations of constituents in the top soil layer, the sediment yield, and an enrichment ratio. The amount of soluble P removed in runoff is predicted using labile P concentration in the top 10 mm of the soil, the runoff volume and a phosphorus soil partitioning coefficient. In-stream nutrient dynamics are simulated in SWAT using the kinetic routines from the QUAL2E in-stream water quality model (Brown and Barnwell, 1987).

A detailed theoretical description of SWAT and its major components can be found in Neitsch et al. (2002). SWAT has been widely validated across the United States and in other regions of the world for a variety of applications, including hydrologic, pollutant loss, and climate change studies. An extensive set of SWAT applications is documented in Gassman et al. (2005).

## WATERSHED DESCRIPTION

The RRW (Figure 1) encompasses approximately 9,397 $km^2$ of prime agricultural land in West-Central Iowa. Land use in the RRW is dominated by agriculture and is composed of cropland (75.3%), grassland (16.3%), forest (4.4%), and urban space (4.0%). The watershed is a part of the Des Moines lobe of the Wisconsin Glacier, which is a swampy prairie pothole region.

The Raccoon River and its tributaries drain all or parts of 17 of Iowa's 99 counties before emptying into the Des Moines River in the city of Des Moines. It is the primary source of drinking water for more than 370,000 residents in Des Moines and other Central Iowa communities. The primary sources of nitrates in the RRW are high organic matter soils and extensive nonpoint-source agricultural activities. Cropland production areas are also the primary sources of sediment losses and other nutrient loadings to the Raccoon River.

## INPUT DATA

Basic input data required for a SWAT simulation include topography, weather, land use, soil, and management data. Topography data are used to delineate a watershed into multiple subwatersheds and also to calculate watershed/subwatersheds parameters such as slope and slope length. Topography data were obtained in the form of Digital Elevation Model at 90 m resolution from the U.S. Environmental Protection Agency's Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) modeling package version 3.1 (http://www.epa.gov/waterscience/BASINS/). Daily climatic data include precipitation, maximum and minimum air temperature, solar radiation, wind speed, and relative humidity for each subwatershed. These climatic inputs can be entered from historical records and/or generated internally in the model using monthly climate statistics that are based on long-term weather records. In this study, daily precipitation and temperature data were collected from National Climatic Data Center (http://www.ncdc.noaa.gov) for 10 weather stations located in and around the watershed (Figure 1). Missing data in the precipitation and temperature records, as well as daily solar radiation, wind speed, and relative humidity inputs, were generated internally in SWAT.

Land use, soil, and management data are used in the model to delineate subwatersheds further into HRUs. The primary source of these data is the USDA 1997 National Resources Inventory (NRI) database (Nusser and Goebel, 1997; http://www.nrcs.usda.gov/technical/NRI). The NRI is a statistically based survey database that contains information for the entire United States, such as landscape features, soil type, cropping histories, tile drainage, and conservation practices for roughly 800,000 nonfederal land "points." Each point represents an area, generally ranging from a few hundred to several thousand hectares in size, which is assumed to consist of homogeneous land use, soil, and other characteristics. These points are spatially referenced at the state, major land resource area, county, and 8-digit watershed levels. These data were apportioned to HRUs within the 26 subwatersheds based on guidance provided by the 2002 Iowa Department of Natural Resources land use data (IDNR-IGS, 2004) and ISPAID (Iowa Soil Properties and Interpretations Database) soil data, as described for a similar process discussed by Kling et al. (2005). Crop rotations are derived from cropping histories reported in the NRI. The soil layer data was obtained from a soil database that contains soil properties consistent with those described by Baumer et al. (1994) and includes ID codes that allow linkage to NRI points. The 1997 NRI survey does not include information about tile drainage. Thus, tile drainage distribution data were obtained by linking the survey points to the 1992

NRI survey. It was assumed that tile drains were installed on about 51% of the entire cropland area, based on the 1992 NRI data. The information on tillage implements simulated for different levels of tillage (conventional, reduced, mulch, and no-till) were obtained from data reported in the USDA 1990-95 Cropping Practices Survey (CPS) data (which can be accessed at http://usda.mannlib.cornell.edu/usda/ess_entry.html).

Nutrient inputs to cropland were simulated in the form of fertilizer and manure applications. Explicit fertilizer application rate data is not available for the RRW. Thus, a nitrogen application rate of 145.6 kg $ha^{-1}$ (130 lb $ac^{-1}$) was assumed applied to corn regardless of rotation sequence. This rate is consistent with a suggested "average application rate range of 120 to 140 lb $ac^{-1}$ for the RRW" as quoted in Woolson (2003), and is also consistent with 2003 Iowa statewide survey and sales average application rates (see http://extension.agron.iastate.edu/soils/pdfs/Nuse/NBackch5.PDF). The nitrogen was applied in either a single amount or in a split application, based on weighted random draws of surveyed nitrogen application practices in the CPS. The corn phosphorus fertilizer application rates were based on values reported in the CPS, which ranged between 28 and 67.2 kg/ha. No fertilizer applications were assumed applied to soybeans.

The choice of appropriate manure application rates for the RRW is even more uncertain than those regarding fertilizer application rates. The total manure mass and application rates assumed for the study are listed in Table 1 and are based on data obtained from the USDA Natural Resources Conservation Service (Personal communication, R. Kellogg, 2004, USDA-NRCS, Beltsville, MD), which are based on manure use computed for a national assessment of Comprehensive Nutrient Management Plans (USDA-NRCS, 2003). These assumed manure application rates result in about 10% of the simulated cropland receiving manure and reflect assumptions that much of the manure will be applied at higher-than-agronomic rates. It was also assumed that manured cropland received fertilizer during years that corn was planted, at the same rate as the HRUs planted to corn that did not receive manure. These generally high nutrient application rates reflect conditions of little or no manure nutrient crediting, such as described by Gassman et al. (2002) for a watershed in Northeast Iowa and to a lesser extent by Shepard (1999) for two watersheds in Wisconsin. Actual manure management across the RRW likely reflects a broader spectrum of nutrient crediting, which would include cropland that only receives manure applied at appropriate agronomic rates. Two alternative scenarios for the HRUs that receive manure have been included in this study (described in the Alternative Management Scenarios subsection), to provide further insight into the impacts of the manure management applications.

**Table 1. Assumed manure application rates, and cropland areas the manure was applied to, by 8-digit watershed**

| 8-digit watershed (HCU) ID | Crop | Area ($km^2$) | Nitrogen application rate (kg/ha) | Phosphorus application rate (kg/ha) |
|---|---|---|---|---|
| 7100006 | Corn | 310 | 314.9 | 125.4 |
| 7100006 | Corn | 303 | 173.8 | 78.0 |
| 7100006 | Soybean | 14 | 390.0 | 187.4 |
| 7100006 | Pasture | 12 | 151.8 | 59.9 |
| 7100007 | corn | 31 | 53.3 | 23.6 |
| 7100007 | corn | 37 | 162.6 | 69.9 |

## CONFIGURATION OF SWAT FOR BASELINE SCENARIO

The RRW was subdivided into 26 subwatersheds (Figure 1) using the automatic delineation tool of the SWAT ArcView interface (AVSWAT), in order to perform the SWAT simulation. The watershed was delineated in such a way that the boundaries of the simulated subwatersheds coincided with the boundaries of the 10-digit hydrologic cataloging unit (HCU) watersheds (http://www.ncgc.nrcs.usda.gov/products/datasets/watershed/history.html).

The subwatersheds were then further subdivided into multiple HRUs by aggregating NRI points that possess common soil type, land use, and management characteristics. The smallest spatial unit that the NRI data is considered to be statistically reliable for is the USGS 8-digit level of watershed. Thus, the HRUs were first created for the two 8-digit watersheds (07100006 and 07100007) that comprise the RRW. Common soil types were aggregated at the 8-digit level by means of a statistically based soil clustering process that was performed for NRI-linked soils for most of the United States (Sanabria and Goss, 1997). For land use, all of the points within a given category such as forest, urban, pasture, and

Conservation Reserve Program (CRP) were clustered together, except for the cultivated cropland. For the cultivated cropland, the NRI points were first aggregated into several crop rotation land use clusters based on the NRI cropping histories. The final step of developing HRUs required aggregation across NRI points according to the management characteristics such as tile drainage (yes or no), conservation practices (terracing, contouring, and/or strip cropping), and type of tillage (conventional, reduced, mulch, or no-till). A total of 321 HRUs were created between two 8-digit watersheds. These HRUs were then allocated to 26 subwatersheds using land use distribution information from land use data available for year 2002 (IDNR-IGS, 2004).

SWAT needs one set of climate data for each subwatershed. AVSWAT2000 was used to automatically assign weather stations from a set of 10 weather stations located in and around the watershed to each of the delineated 26 subwatersheds based on the proximity of the weather station to the centroid of the subwatershed. Additional simulation options that were used for the RRW study included the modified curve number method to calculate surface runoff, the Muskingum method for channel routing process, and the Hargreaves method for estimating potential evapotranspiration.

## SWAT CALIBRATION AND VALIDATION

Calibration and validation of water quality models are typically performed with data collected at the outlet of a watershed. The watershed outlet for this study is assumed to be a sampling site located at Van Meter (Figure 1); approximately 95% of the entire watershed drains to this location. An extensive amount of measured data has been collected at this location, especially for flow, sediment, and nitrate. Daily USGS streamflow data (http://nwis.waterdata.usgs.gov/usa/nwis/discharge) were obtained for station # 05484500 at Van Meter for the 1981-2003 period. Water quality data including sediment, nitrate, organic N, organic P, and mineral P for the Raccoon River at Van Meter were obtained from the Des Moines River Water Quality Network as described by Lutz (2004). These samples are collected on a weekly or biweekly basis and are analyzed by the Analytical Services Laboratory at Iowa State University. Sediment and nitrate data are available for the entire 1981-2003 period, but organic N, organic P, and mineral P data are available only from May 2000 to December 2003.

Grab samples of water quality data were extrapolated into continuous monthly data using the USGS Load Estimator (LOADEST) regression model (Runkel et al., 2004). LOADEST estimates constituent loads in streams and rivers by developing a regression model, given a time series of streamflow, constituent concentration, and additional data inputs. LOADEST is based on two previous models: LOADEST2 (Crawford, 1996) and ESTIMATOR (Cohn et al., 1989). The model is well documented in scientific publications and is accepted as a valid means of calculating annual solute load from a limited number of water quality measurements. However, the load estimation process of the model is complicated by retransformation bias, data censoring, and non-normality. Similar uncertainties are also inherent in other approaches. For example, Ferguson (1986) reported that the rating curve estimates of instantaneous load are biased and may underestimate the true load by as much as 50%.

SWAT was executed for a total simulation period of 23 years, which includes 1981-1992 as a calibration period and 1993-2003 as a validation period. Parameter adjustment was performed only during the calibration period; the validation process was performed by simply executing the model for the different time period using the previously calibrated input parameters.

The calibration process was initiated by calibrating the water balance and streamflow for average annual conditions. Once the water balance and annual streamflow were considered correctly calibrated, the monthly calibration process was performed. Baseflow is an important component of the streamflow and had to be calibrated before the model was fully calibrated for stream flow and other components. An automated digital filter technique (Arnold and Allen, 1999) was used to separate baseflow from the measured streamflow. This approach estimated the baseflow to be about 58% of the streamflow on an average annual basis for the 1981-2003 period. A similar ratio of 54.2% was found for the 1972-2000 period by Schilling and Zhang (2004) using an automated hydrograph separation program developed by Sloto and Crouse (1996). The streamflow calibration process was then completed by varying several SWAT hydrologic calibration parameters within their acceptable ranges (Table 2), to match the model predicted baseflow fraction, average annual streamflow, and monthly streamflow time series with corresponding measured values. These parameters include the curve number (CN2), soil available water capacity (SOL_AWC), evaporation compensation coefficient (ESCO), groundwater delay (GW_DELAY), groundwater recession coefficient (GW_ALPHA), surface runoff lag coefficient (SURLAG), and snow parameters.

The streamflow calibration (1981-92) and validation (1993-2003) periods were also used for assessing the accuracy of the SWAT sediment and nitrate predictions. However, only limited measured data for organic N, organic P, and mineral P were available for May 2000 to December 2003, which precluded any formal validation being performed for those constituents. Sediment yield calibration was performed following completion of the flow calibration process. There are two sources of sediment in a SWAT simulation: loadings from the HRUs and channel degradation/deposition. Model parameters such as the linear (SPCON) and exponential (SPEXP) components of the sediment transport equation, and channel cover factor (CH_COV) were adjusted within their acceptable ranges to match simulated sediment loadings with the measured loadings (Table 2). Several model parameters were also adjusted during the nutrient transport calibration process (Table 2). These included the initial soil nutrient concentrations, biological mixing efficiency (BIOMIX), nitrogen percolation coefficient (NPERCO), phosphorus percolation coefficient (PPERCO), phosphorus soil partitioning coefficient (PHOSKD), and residue decomposition factor (RSDCO). The model predictions were evaluated for both the calibration and validation periods using two statistical measures: coefficient of determination ($R^2$) and Nash-Sutcliffe simulation efficiency (E). The $R^2$ value is an indicator of strength of relationship between the measured and simulated values. The E value measures how well the simulated values agree with the measured values. The model prediction is considered unacceptable if the $R^2$ values are close to zero and the E values are less than or close to zero. If the values equal one, the model predictions are considered perfect. Generally, $R^2$ and E values greater than 0.5 are considered acceptable; however, explicit standards have not been specified for assessing model predictions using these statistics.

**Table 2. SWAT calibration parameters and their final values for the Raccoon River Watershed**

| SWAT calibration parameter | Final calibrated value |
|---|---|
| Streamflow Calibration | |
| Curve number (CN2) | -6.0 |
| Soil available water capacity (SOL_AWC) | -0.02 |
| Evaporation compensation coefficient (ESCO) | 0.85 |
| Revap Coefficient (REVAP) | 0.02 |
| Groundwater delay (GW_DELAY) | 60 days |
| Groundwater recession coefficient (GW_ALPHA) | 0.2 |
| Snowfall temperature (SFTMP) | 1.0ºC |
| Snowmelt base temperature (SMTMP) | -1.0ºC |
| Melt factor for snow on June 21 (SMFMX) | 2.5 Mm H2O/ºC-day |
| Melt factor for snow on December 21 (SMFMN) | 2.5 Mm H2O/ºC-day |
| Surface runoff lag coefficient (SURLAG) | 1 |
| Sediment Calibration | |
| Linear components (SPCON) | 0.0004 |
| Exponent component (SPEXP) | 2.5 |
| Channel cover factor (CH_COV) | 0.5 |
| Nutrient Calibration | |
| Initial Org N (SOL_ORGN) | 1200 mg/kg |
| Initial Org P (SOL_ORGP) | 240 mg/kg |
| Initial Min P (SOL_SOLP) | 1 mg/kg |
| Biological mixing efficiency (BIOMIX) | 0.3 |
| Nitrogen percolation coefficient (NPERCO) | 0.20 |
| Phosphorus percolation coefficient (PPERCO) | 10 |
| Phosphorus soil partitioning coefficient (PHOSKD) | 100 |
| Residue decomposition factor (RSDCO) | 0.05 |

## ALTERNATIVE MANAGEMENT SCENARIOS

The calibrated model was used to study the long-term effects of management practices including land use changes and nutrient management. SWAT was first executed for a total of 23 years (1981-2003) to establish baseline average annual values for the flow and other water quality indicators, which form the basis of comparison for scenario results. The following scenarios were then executed for the same 23-year period.

The first set of scenarios focused on taking cropland out of production; i.e., increasing the amount of CRP land in the RRW. Increasing the amount of CRP land in a watershed can be a very effective soil and water conservation practice, because cropland is usually converted into perennial grass, which results in reduced surface runoff and erosion. Five CRP scenarios were executed with SWAT runs that depicted successively increasing amounts of CRP land, which were selected as a function of the slopes of the HRUs (Table 3).

**Table 3. Slope cutoffs and corresponding amounts of converted cropland for the CRP scenarios**

| CRP Scenario | HRU slope cutoff (%) | Cropland affected (%) |
|---|---|---|
| 1 | 7 | 6 |
| 2 | 4 | 17 |
| 3 | 2 | 41 |
| 4 | 1 | 88 |
| 5 | 0 | 100 |

The second set of scenarios was performed to assess the impacts of hypothetical increases or decreases in overall nutrient applications (both fertilizer and manure) to corn in the RRW, to assess the sensitivity of different nutrient application rates on nitrogen losses to the stream system and on crop yield. The initial six scenarios reflect three successive 10% increases and in turn three successive 10% decreases in the nutrient application rates on corn, relative to the baseline application rates. Two additional scenarios were then performed that depicted a 50% increase and decrease, respectively, in the nutrient application rates as compared to the baseline.

A final set of scenarios was performed to provide further insight into how the manure application rate assumptions affected the total nutrient loadings predicted at Van Meter. Two manure application-related scenarios were performed using (1) the same rates reported in Table 1 but with no fertilizer applied to the areas that receive manure, and (2) the baseline fertilizer rates without manure applications for the cropland areas shown in Table 1.

## RESULTS AND DISCUSSION

### CALIBRATION AND VALIDATION

Figures 2 and 3 show the graphical representation of the calibration and validation results on an annual and monthly basis. Pertinent components of the average annual water balance are shown in

Table 4. SWAT predicted an average annual streamflow of 226 mm for the 1981-2003 period as compared with the measured streamflow of 224. The measured and simulated annual flow values matched well and showed a strong correlation, as reflected by the strong $R^2$ and E values (Table 5) for both annual and monthly results. The baseline hydrologic calibration yielded average annual values of 104 mm of surface runoff and 133 mm of baseflow (combined tile flow and groundwater flow). The baseflow fraction was found to be 56% of the total water yield on an average annual basis, which was consistent with the baseflow separation model estimate of 58% and the value of 54% found by Schilling and Zhang (2004). However, the tile flow portion of the overall baseflow estimate is likely underestimated and the groundwater contribution is correspondingly probably overestimated; this imbalance can be improved with a forthcoming version of SWAT as reported in Green et al. (2006).

Figures 4 and 5 show the annual and monthly comparisons of measured and simulated sediment yields for both the calibration and validation periods at the watershed outlet. Statistical evaluation yielded a strong correlation between the measured and simulated values as indicated by the $R^2$ and E statistics (Table 2), except for the period of monthly calibration. Overall, the model was able to simulate sediment yield with reasonable accuracy.

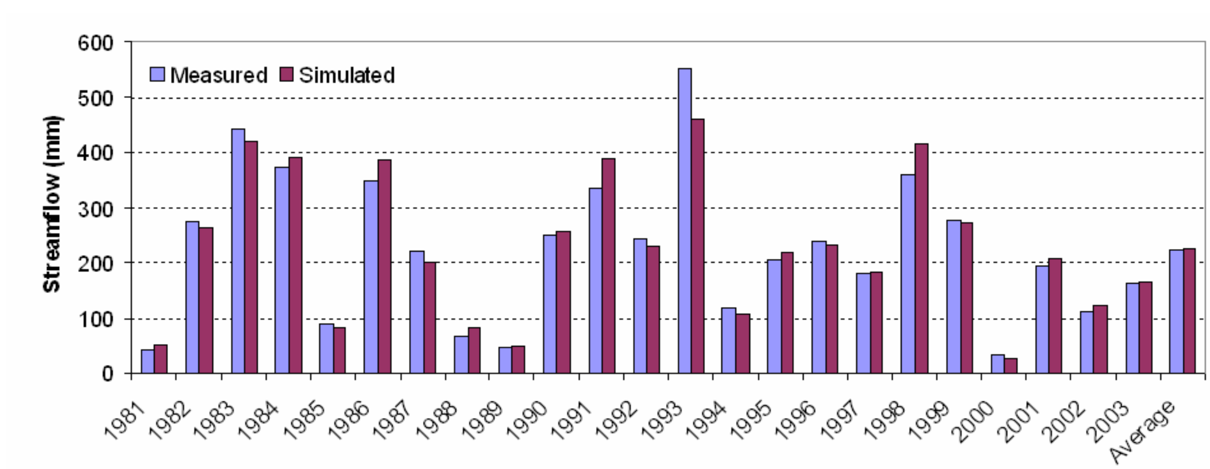



**Figure 2. Annual flow calibration and validation for the Raccoon River Watershed at Van Meter**

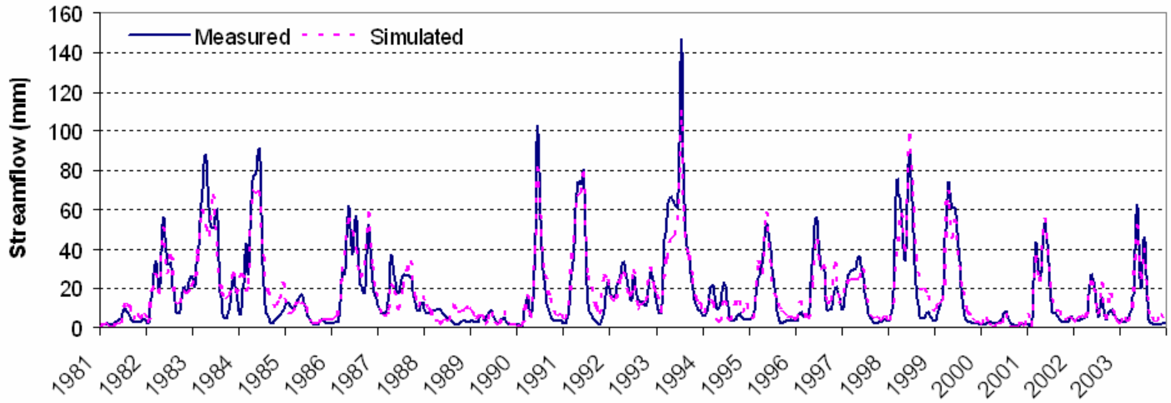



**Figure 3. Monthly flow calibration and validation for the Raccoon River Watershed at Van Meter**

**Table 4. Average annual water balance components for the Raccoon River Watershed simulation**

| Water balance component | Depth (mm) |
|---|---|
| Precipitation | 842.2 |
| Surface runoff | 105.0 |
| Groundwater (shallow aquifer) flow | 111.7 |
| Tile flow | 21.2 |
| Evapotranspiration | 599.2 |

**Table 5. $R^2$ and E values of SWAT predictions versus measured data**

| Variable | Calibration (1981-1992) | | Validation (1993-2003) | |
|---|---|---|---|---|
| | $R^2$ | E | $R^2$ | E |
| Streamflow | | | | |
| Annual | 0.97 | 0.97 | 0.94 | 0.94 |
| Monthly | 0.87 | 0.87 | 0.89 | 0.88 |
| Sediment | | | | |
| Annual | 0.97 | 0.93 | 0.89 | 0.79 |
| Monthly | 0.55 | 0.53 | 0.80 | 0.78 |
| Nitrate | | | | |
| Annual | 0.83 | 0.78 | 0.91 | 0.84 |
| Monthly | 0.76 | 0.73 | 0.79 | 0.78 |

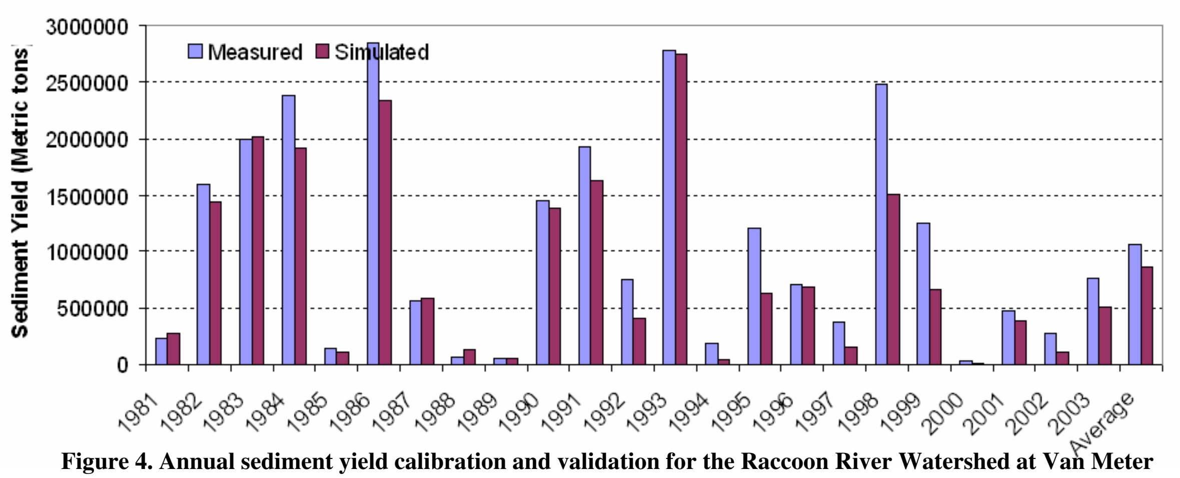



**Figure 4. Annual sediment yield calibration and validation for the Raccoon River Watershed at Van Meter**

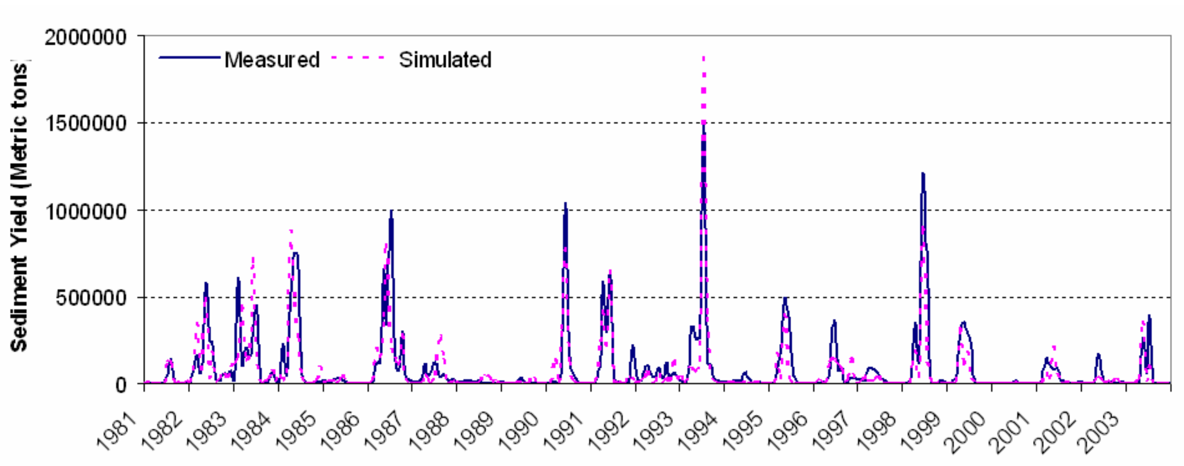



**Figure 5. Monthly sediment yield calibration and validation for the Raccoon River Watershed at Van Meter**

Similarly, calibration and validation were performed for the nitrate results and the simulated values were compared with the measured values at the watershed outlet (Figures 6 and 7). Again, a strong correlation was observed in both the calibration and validation periods (Table 2), indicating that the model is able to predict nitrate loadings accurately. However, it is again likely that some of the nitrate loss being predicted by means of the groundwater flow portion of the baseflow should in fact have been simulated as nitrate loss through the subsurface tile drains.

Figure 8 shows that SWAT accurately replicated both the annual and monthly time series of observed organic N values. Comparisons between the measured and simulated organic N levels resulted in $R^2$ and E values of 0.80 and 0.79 on an annual basis, and 0.86 and 0.85 on a monthly basis. Similar comparisons are shown in Figures 9 and 10 for organic P and mineral P, which reveal that SWAT tracked both indicators well. The $R^2$ and E statistics for organic P were found to be 0.96 and 0.54, and 0.68 and 0.74, for comparisons between measured and simulated annual and monthly values, respectively. Similar corresponding values for mineral P were computed to be 0.92 and 0.51 on an annual basis, and 0.85 and 0.86 on a monthly basis. In general, the temporal patterns and statistics indicated that the predictions of organic N, organic P, and mineral P at the watershed outlet corresponded well with the measured values. However, the E values for the annual calibration for organic P and mineral P indicate relatively poor correspondence of measured values versus simulated values, even though the $R^2$ values indicated a strong linear relationship between the measured and simulated loadings.

## SCENARIO ANALYSIS

The results of the five CRP land increase scenarios are shown in Figure 11 for both sediment and nitrate losses at the watershed outlet. As expected, as the CRP land area increased, sediment yield decreased. The maximum sediment reduction of 71% was achieved when all cropland was converted into CRP land. CRP lands decrease the surface runoff and hence erosion but increase water movement to the groundwater. The predicted nitrate loadings also decreased, which again follows expectations

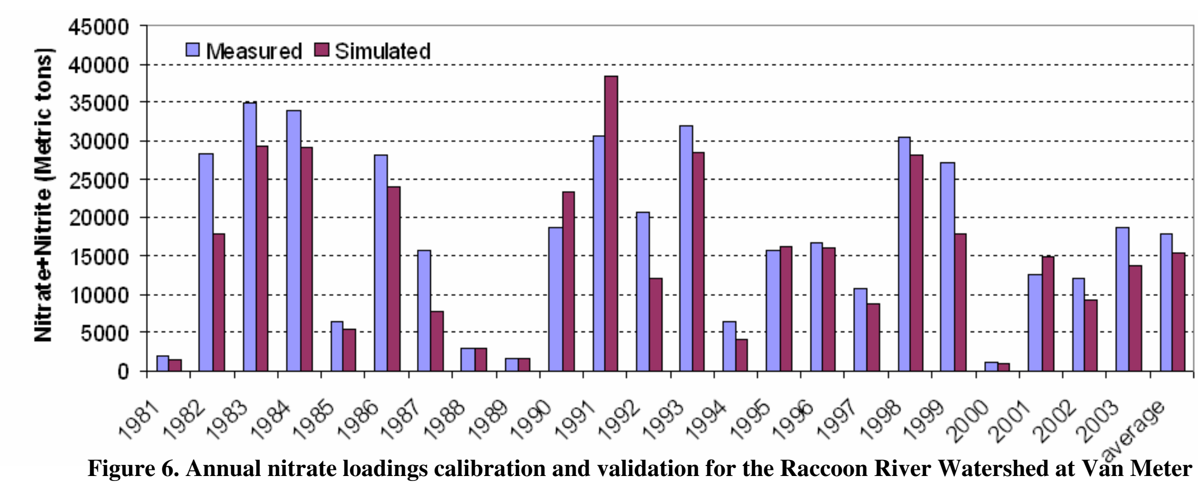



**Figure 6. Annual nitrate loadings calibration and validation for the Raccoon River Watershed at Van Meter**

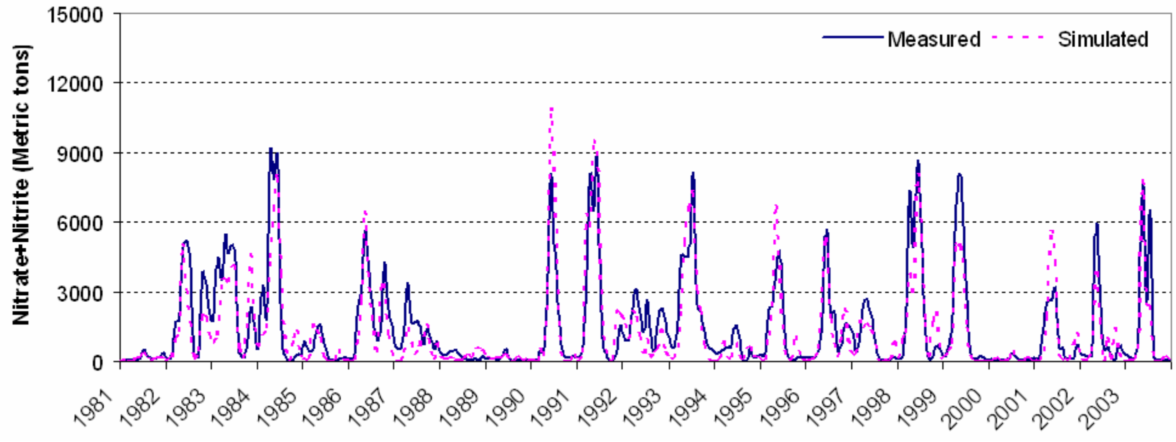



**Figure 7. Monthly nitrate loadings calibration and validation for the Raccoon River Watershed at Van Meter**

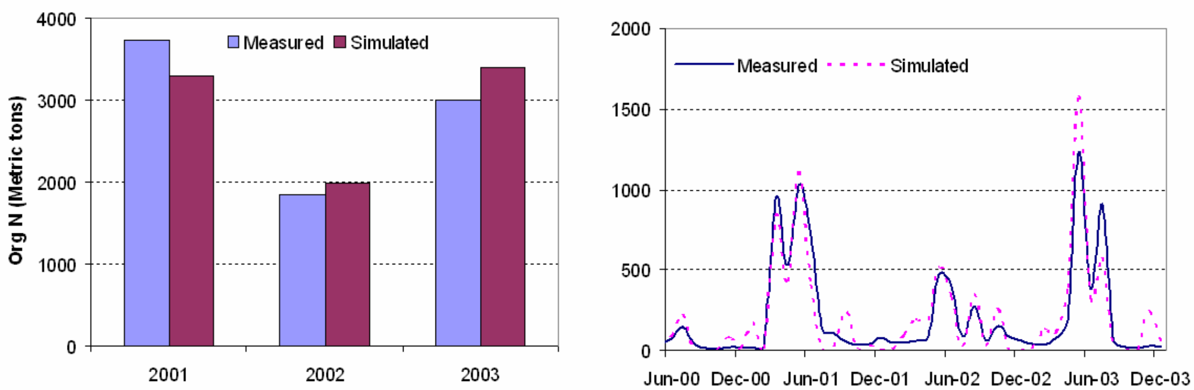



**Figure 8. Annual and monthly organic N comparisons for the Raccoon River Watershed at Van Meter**

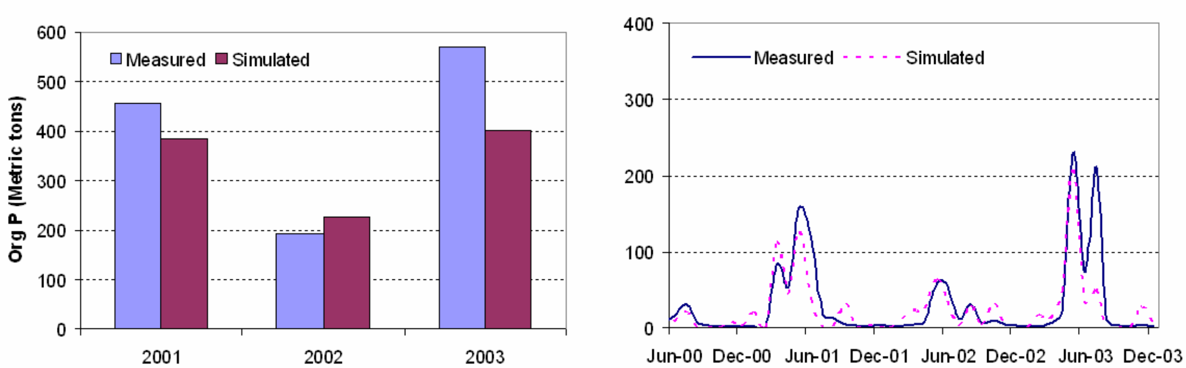



**Figure 9. Annual and monthly organic P comparisons for the Raccoon River Watershed at Van Meter**

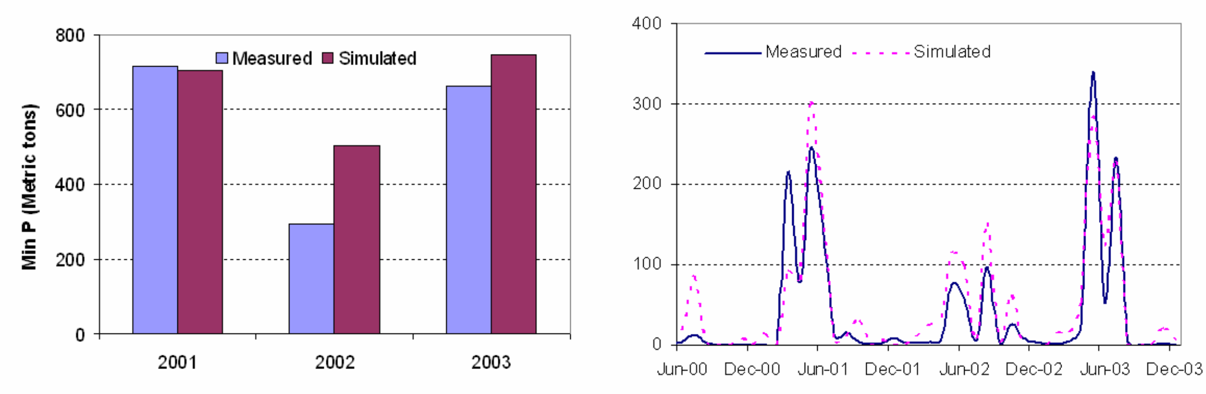



**Figure 10. Annual and monthly mineral P comparisons for the Raccoon River Watershed at Van Meter**

because no fertilizer applications were applied on the CRP land. These results show that significant reductions in sediment and nutrient loadings can be achieved by converting cropland into CRP land. Figure 12 shows the changes in nitrate loadings at the watershed outlet in response to the changes in nutrient application. As the application rates decreased, the nitrate loadings at the watershed outlet decreased, and vice versa. However, the predicted rate of change in nitrate loading is different for the decreasing application rates as compared to the increasing application rates. Decreases in the nutrient application rates of 10% and 50% resulted in approximately 12% and 50% reductions in the nitrate loadings at the RRW outlet. An increase in the nutrient application rates of 10% resulted in approximately the same relative impact as the 10% decrease, but a 50% increase in the nutrient application rates resulted in almost an 80% increase in nitrate loadings at the RRW outlet. Overall, the corn yield versus nitrate loading loss relationship indicates that decreases in RRW nitrate loadings can be achieved with minimal effects on crop yield with relatively low nitrogen application rate reductions (e.g., 10% to 20%).

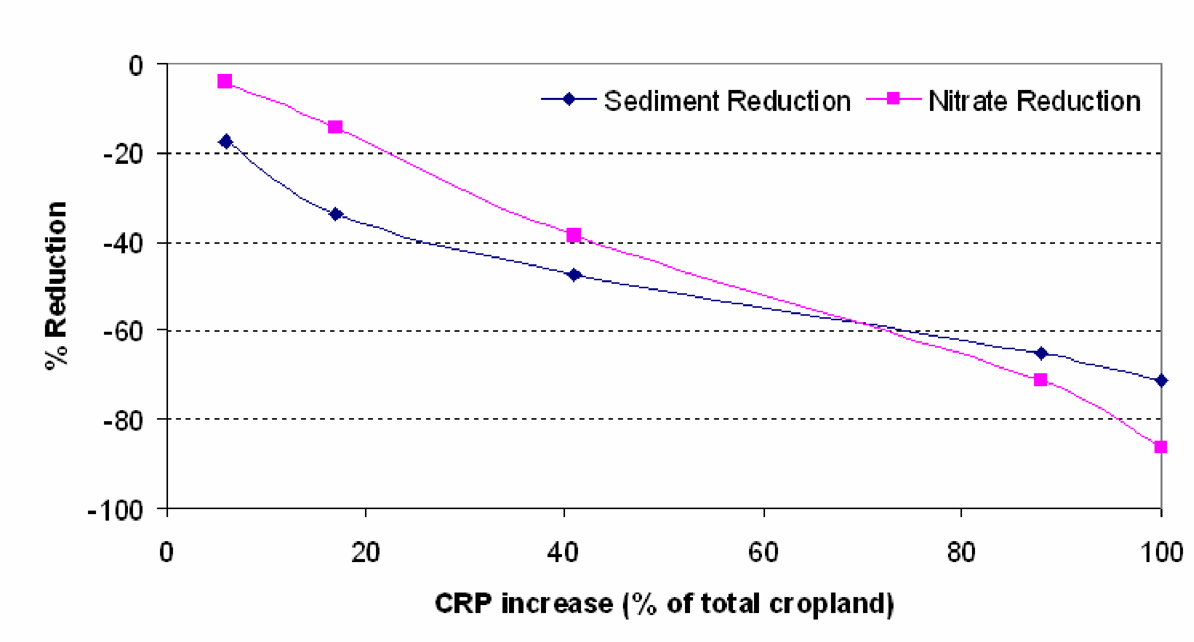



**Figure 11. Reduction in sediment and nitrate loadings due to increase in CRP lands**

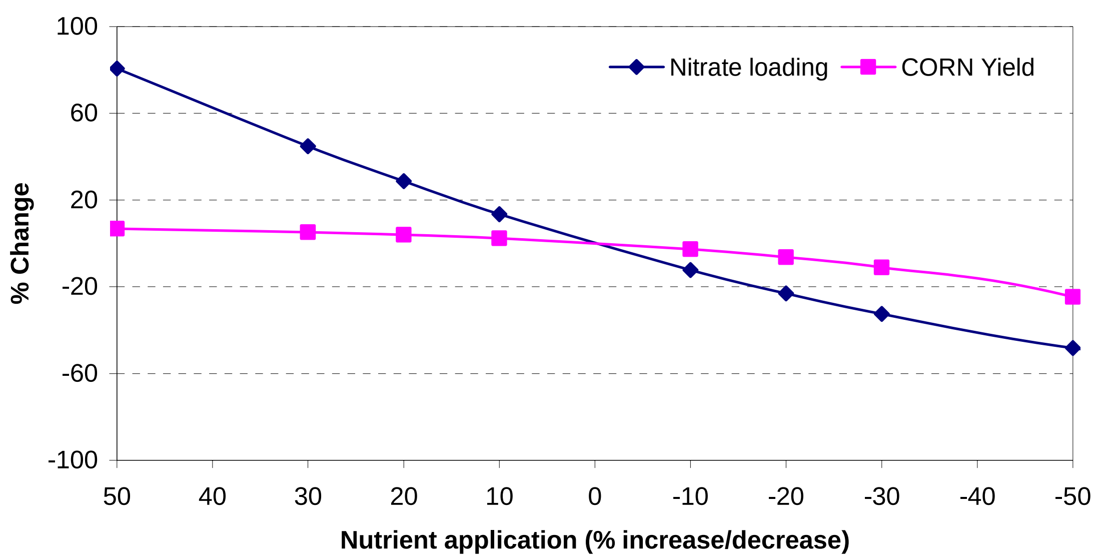



**Figure 12. Effect of nutrient application in nitrate loadings and corn yield**

Table 6 shows the impacts of the two alternative manure-related scenarios on the predicted annual average nutrient loadings, relative to the observed loadings and the loadings estimated for the previously discussed baseline simulation. The largest predicted impacts were reductions of roughly 25% and 23% in the nitrate and mineral P loads for alternative scenario 1 (no application of manure), as compared with the baseline simulation. The nitrate load was predicted to decline by about 18% when fertilizer was not applied to the manured HRUs (alternative scenario 2), relative to the baseline. Other predicted impacts were generally minor; no impact was predicted for the organic P loadings for alternative scenario 2 because the P fertilizer consists only of inorganic P. These scenario results clearly reveal that the model is sensitive to the manure and fertilizer application rates that are assumed for the HRUs that are managed with manure.

**Table 6. Comparison of average annual Raccoon River Watershed nutrient loadings between observed levels, the standard baseline simulation, and two alternative manure management scenarios**

| Scenario or observed | Nitrate (1981-2003) | Organic N (2001-2003) | Organic P (2001-2003) | Mineral P (2001-2003) |
|---|---|---|---|---|
| | ($t\ y^{-1}$) | | | |
| Observed levels | 17,743 | 2,863 | 406 | 556 |
| Standard baseline simulation | 15,898 | 3,189 | 387 | 726 |
| Scenario 1: manure not applied | 12,068 | 3,100 | 344 | 557 |
| Scenario 2: fertilizer not applied to manured HRUs | 13,055 | 3,094 | 387 | 721 |

## CONCLUSIONS

Simulated output generated with the SWAT model was compared with measured data at the assumed outlet (Van Meter, IA) of the Raccoon River Watershed, for both calibration (1981-1992) and validation (1993-2003) periods. The $R^2$ and E values (> 0.7 in most cases) indicated that that model was able to replicate annual and monthly streamflow, sediment, nitrate, organic N, organic P, and mineral P with reasonable accuracy. The calibrated model was used to study the effects of CRP lands and nutrient application on sediment and nutrient loadings. The results show that the sediment and nutrient loadings at the watershed outlets can be significantly reduced by increasing CRP lands. Similarly, reductions in nutrient fertilizer application rates were predicted to have a significant effect on reducing nitrate loadings at the watershed without affecting crop yield significantly. Conversely, increases in application rates were also predicted to have minor impacts on corn yields but resulted in sizeable increases in nitrate loadings. The results were also found to be sensitive to the simulated manure application and fertilizer rates for those HRUs that were assumed to receive manure applications. Further research is needed to confirm whether the impacts of different nutrient application rates on nitrate loading losses at the watershed outlet and corresponding crop yields is consistent with measured data.

The overall results of this study also point to the importance of accurate input data. Future simulation work for the Raccoon River Watershed should incorporate improved estimates of fertilizer and manure nutrient inputs and associated application rates, if such data can be obtained. Further, there is a need to more clearly understand how much of the in-stream sediment load is being contributed from the stream channels relative to upland contributions. This would provide a more accurate accounting of land management needs, as suggested by Thoma et al. (2005) in their analysis of sediment sources for the Blue Earth River in southern Minnesota. Also, additional in-stream flow and pollutant loss monitoring data available for the North and South Forks of the Raccoon River (Personal communication, K.E. Schilling, Iowa Department of Natural Resources, Iowa City, IA) should be included for a more comprehensive validation of the model. Finally, the results of this study also underscore the need to perform further simulation research for the Raccoon River Watershed with SWAT2005, a forthcoming version of SWAT, which contains several enhancements, including a recently improved tile drainage component (Green et al., 2006). This will allow more accurate simulation of flow and nitrate discharge through subsurface tiles, which would be expected to result in overall improved simulation results.

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