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WATER QUALITY MODELING OF ALTERNATIVE AGRICULTURAL SCENARIOS IN THE U.S. CORN BELT[1]

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ABSTRACT: Simulated water quality resulting from three alternative future land-use scenarios for two agricultural watersheds in central Iowa was compared to water quality under current and historic land use/land cover to explore both the potential water quality impact of perpetuating current trends and potential benefits of major changes in agricultural practices in the U.S. Corn Belt. The Soil Water Assessment Tool (SWAT) was applied to evaluate the effect of management practices on surface water discharge and annual loads of sediment and nitrate in these watersheds. The agricultural practices comprising Scenario 1, which assumes perpetuation of current trends (conversion to conservation tillage, increase in farm size and land in production, use of currently-employed Best Management Practices (BMPs)) result in simulated increased export of nitrate and decreased export of sediment relative to the present. However, simulations indicate that the substantial changes in agricultural practices envisioned in Scenarios 2 and 3 (conversion to conservation tillage, strip intercropping, rotational grazing, conservation set-asides and greatly extended use of best management practices (BMPs) such as riparian buffers, engineered wetlands, grassed waterways, filter strips and field borders) could potentially reduce current loadings of sediment by 37 to 67 percent and nutrients by 54 to 75 percent. Results from the study indicate that major improvements in water quality in these agricultural watersheds could be achieved if such environmentally-targeted agricultural practices were employed. Traditional approaches to water quality improvement through application of traditional BMPs will result in little or no change in nutrient export and minor decreases in sediment export from Corn Belt watersheds.
(KEY TERMS: watershed management; future scenarios; agricultural watersheds; modeling; water quality; SWAT.)

INTRODUCTION

Despite advances in our knowledge and understanding of the sources of agriculturally-derived nonpoint source pollution (NPS) and the development of best management practices intended to reduce NPS pollution (USDA-SCS, 1994), aquatic ecosystems linked to agricultural regions in the United States continue to receive high loadings of agricultural pollutants (Becher *et al.,* 2000; Schilling and Thompson, 2000; Goolsby and Battaglin, 1997; Runge, 1996). In addition, owing to hydrologic modifications of agricultural landscapes (loss of wetlands, tile drainage, channelization of streams and channel incision), streamflow increases following precipitation and snowmelt in agricultural watersheds are rapid and annual discharge elevated relative to historic conditions. In 1995, the U.S. Corn Belt was identified by the Office of Technology Assessment as the number one priority region for water quality concern in the U.S. (OTA, 1995).

Here we report results of research on the potential influence of changes in land use and management on water quality based on comparisons of simulations for three alternative future scenarios and current land use in Walnut and Buck Creek watersheds, Iowa. The future scenarios contrasted landscapes that could evolve over the next 25 years from perpetuation of current trends with two alternatives. In Scenario 1, the projection of current trends, priority is given to maximizing agricultural production and profit on a one- to five-year time scale. In Scenario 2, both public support and agricultural policy place highest priority on achieving substantial improvement in water quality; and in Scenario 3, highest priority is given to restoration of native biodiversity as well as improvement in water quality.

Current water quality conditions in Walnut Creek have been characterized through analysis of water quality data collected monthly since 1990 for Walnut

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Creek, Story County watershed (Hatfield *et al.,* 1999; Cambardella *et al.,* 1999; Jaynes *et al.,* 1999). Water quality conditions in Buck Creek watershed were characterized as part of the current project. The Soil and Water Assessment Tool (SWAT) (Arnold *et al.,* 1995) was calibrated to current conditions in each watershed. This model was then applied to evaluate water quality for the three alternative future scenarios. Additionally, to provide another benchmark for comparison of simulated water quality in these watersheds, the model was applied to historic land cover to estimate historical discharge and surface water chemistry. The purpose of the comparison with historic landscapes is not to promote a return to historical conditions in these watersheds, but rather to provide an estimate of the upper bound for potential water quality improvements attainable in the region.

The objective of this paper is to evaluate the effects of agriculture on water quality at the watershed scale and provide quantitative estimates of how landscape and management changes might affect water quality. We present two steps towards accomplishing the objective. The first is an analysis of the water quality conditions in Buck Creek watershed, as compared to conditions characterized by Cambardella *et al.* (1999) and Jaynes *et al.* (1999) in Walnut Creek watershed. The second is an evaluation of alternative future scenarios with respect to modeled water quality endpoints and a discussion of the potential of land use and management practices to improve water quality. Our research adds to a body of literature (Mitsch *et al.,* 2001; Schilling and Thompson, 2000; Becher *et al.,* 2000; Wolf, 1995) indicating that significant water quality improvement, on the order of 50 percent loading reductions, will require land managers to develop fully integrated watershed plans including innovative land use and management practices. Because such practices will entail a higher degree of economic uncertainty, agricultural policy and public support for such practices must be a part of these plans, as assumed in our scenarios.

STUDY AREA

Walnut Creek (Story County) and Buck Creek (Poweshiek County) are located in central Iowa (Figure 1). Both watersheds were selected as representative of their respective physiographic regions in central Iowa as part of the Midwest Agrichemical Surface-Subsurface Transport and Effects Research

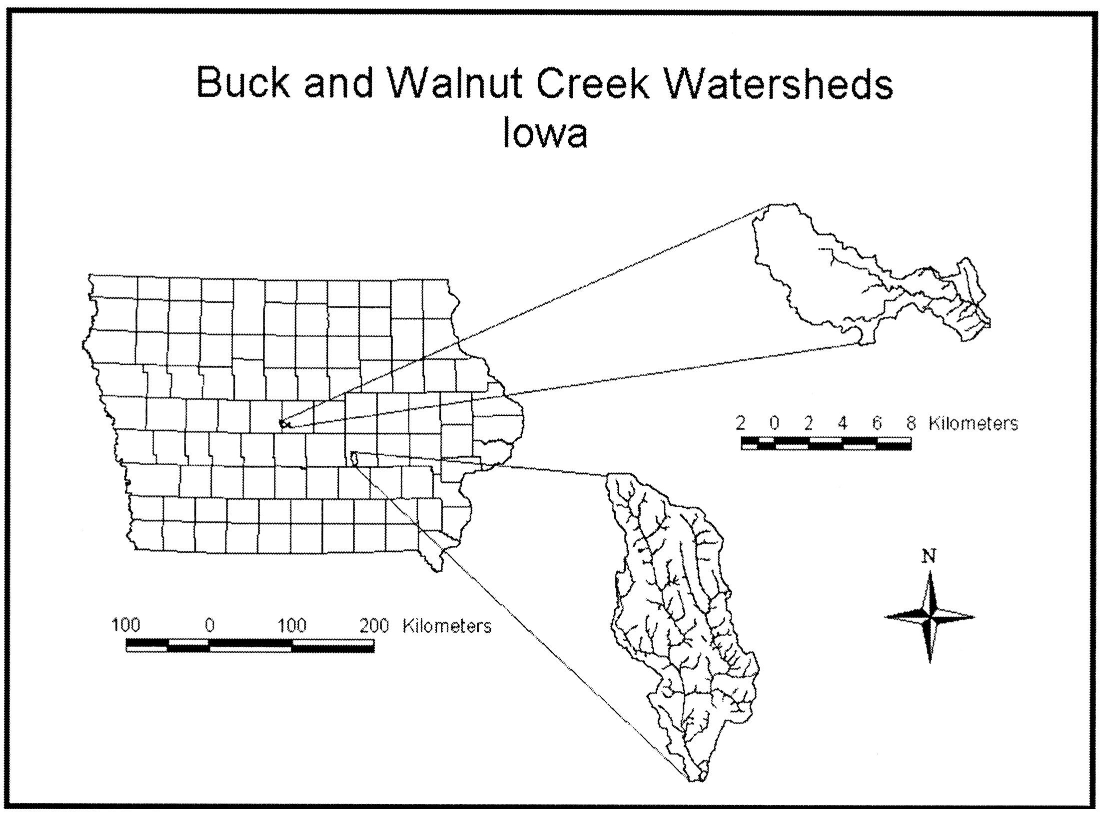

Figure 1. Buck and Walnut Creek Watershed Site Map.

(MASTER) program (Freemark, 1995). Landcover data from 1994 summarizing current conditions were available in a GIS database as a product of that research (Freemark and Smith, 1995).

Like many watersheds in the Des Moines Lobe physiographic region, Walnut Creek watershed has relatively little topographic relief and poorly drained soils (Prior, 1991). Much of Walnut Creek watershed has been extensively tile-drained. Land cover in 1994 consisted primarily of row crops, with 83 percent of the watershed area in corn/soybeans. Few livestock operations occur in the watershed, with pasture, hay, and grassland comprising approximately 5 percent of the land cover. The Walnut Creek watershed has an area of 51.3 km^2 with an elevation range from 267 m to 320 m, and has a stream channel density 50 percent less than Buck Creek watershed.

In contrast, Buck Creek is located in the Southern Iowa Drift Plain physiographic region. The watershed has a rolling topography, moderate topographic relief, and varied agricultural land cover. The area of Buck Creek watershed is 88.2 km^2 with elevations ranging from 236 m to 305 m. Land cover in Buck Creek in 1994 was 45 percent corn/soybean rotation, 15 percent Conservation Reserve Program (CRP), 14 percent pasture, and 26 percent in other land cover types. The watershed has a highly dendritic stream network with a total channel length of 115 km.

Land cover and other watershed attributes for Walnut and Buck Creeks are summarized for current conditions (1994) in Figure 2, and for the three scenarios in Tables 1a and 1b.

METHODS

Water Quality Data

Walnut Creek is one of the study sites in the U.S. Department of Agriculture (USDA) Management Systems Evaluation Area (MSEA) project. As part of MSEA, five sites within the watershed have been monitored for water quality monthly since 1990. Additionally, a network of stream gauges and tipping buckets have been operating in the basin since 1991. Data have been collected on stream nitrate concentrations since 1990 (Hatfield *et al.,* 1999). Nitrate concentrations during the study period often exceeded the 10 mg/l federal limitation, and watershed losses ranged from 4 to 66 kg/ha. These losses represented 4 to 115 percent of the nitrogen fertilizer applied each year (Jaynes *et al.,* 1999). These data were used in this study assist in the calibration of the SWAT model in Walnut Creek watershed. However, because the MSEA project focused on nitrogen and pesticide dynamics in agricultural systems, there are few data available on sediment in Walnut Creek. Two samples were collected in 1999 to assist in the determination of sediment loading in Walnut Creek.

Data collection in the Buck Creek watershed began in March of 1998 and continued through June of 1999. A single surface-water monitoring site was selected near the base of the watershed. Samples were collected from late winter to early spring in 1998 and 1999, and an effort was made to collect multiple samples during periods of high discharge. Grab samples were collected at an approximate monthly interval, while an ISCO™ 6700 sampler was used to collect close interval samples representing periods of rapidly fluctuating discharge. The sampler was tripped manually and collected at four-hour increments. Samples from six precipitation and snowmelt events were collected during the study period.

All samples were transported to either the Iowa State Health Lab or the Central Analytic Laboratory at Oregon State University in iced coolers. At a minimum, each sample was analyzed for total suspended solids (TSS), pH, specific conductance, nitrate+nitrite nitrogen as N, and total phosphate as P. A recording pressure transducer (Solinst 3400) was installed at the site in July 1998, and a rating curve developed to generate hourly discharge data. Additionally, rainfall data were collected with a standard tipping bucket gage and an Onset data logger. The daily Buck Creek hydrograph was extended to a synthetic eight-year dataset, using a transform function based on a linear regression with data collected by USGS near Hartwick, Iowa, in Walnut Creek (USGS Station Number 05452200) (Shoup, 1999).

Nitrate-nitrogen and total suspended solids data are summarized in Table 2. For the 116 samples, nitrate concentrations in Buck Creek never exceeded the 10 mg/l federal maximum even in samples collected during the spring and summer of 1998 and 1999, when nitrate concentrations tend to be greatest. In Walnut Creek, nitrate is a more significant issue, with concentrations exceeding 10 mg/l about 30 percent of the time between 1992 and 1995. The number increases to 45 percent exceedence when looking only at spring and early summer months (Table 2).

In studies of Midwestern water quality, TSS is often not considered, a fact commonly attributed to the lack of salmonid bearing streams (Waters, 1995). But links between agricultural activities and TSS are well established (Menzel *et al.,* 1984), as are detrimental effects on warm water fishes (Matthews, 1984; Lyons and Courtney, 1990). In addition, increases in stream sediments represent increases in soil loss. A total of 116 samples were collected for TSS analysis from Buck Creek. These data are summarized in

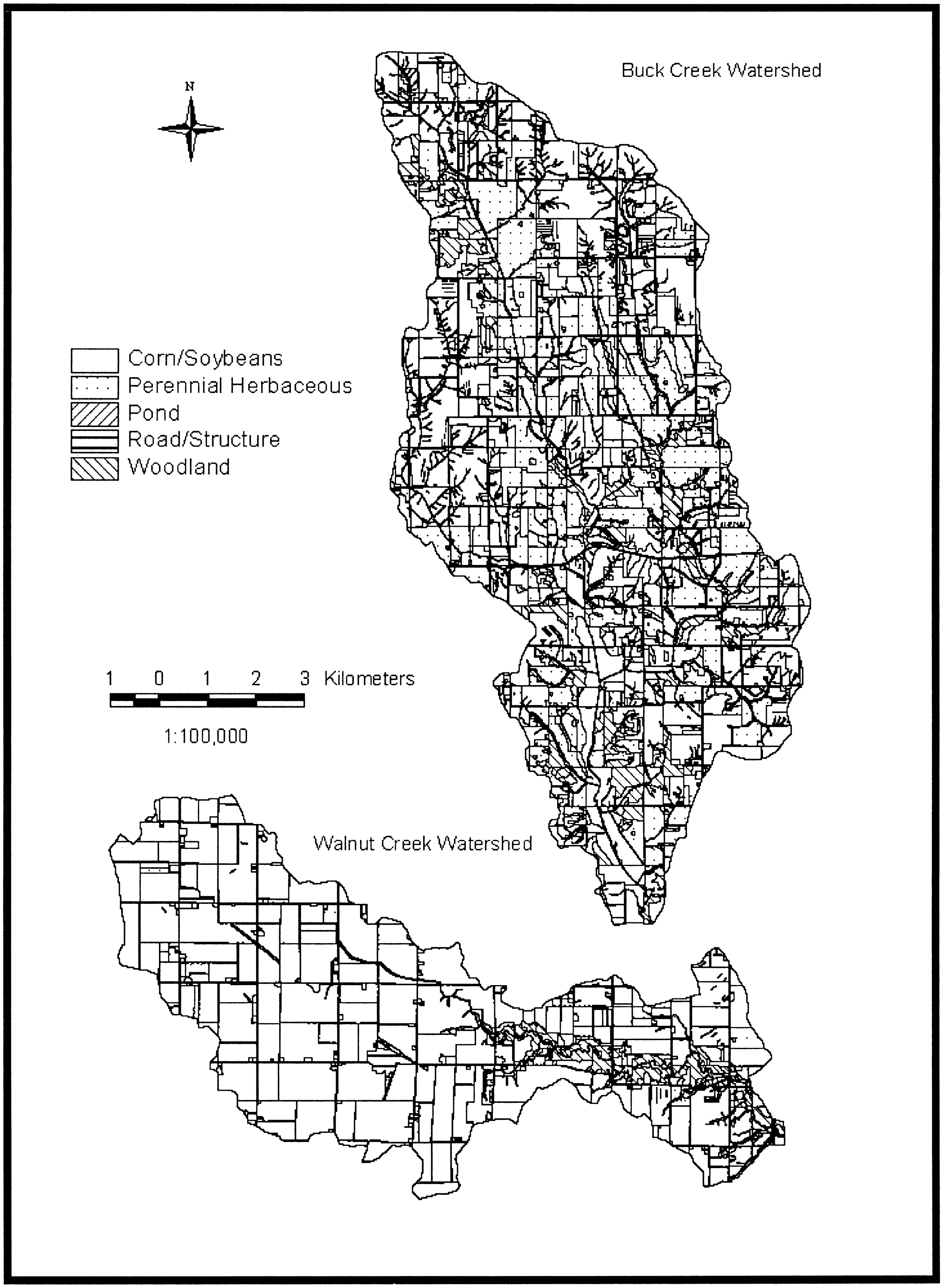

Figure 2. Current (1994) Land Use in the Buck and Walnut Creek Watersheds.

TABLE 1a. Land-Use Change in Walnut Creek.

Land Use	Area (ha)	Scenario 1 Area (ha)	Scenario 1 Change (ha)	Scenario 1 Change (percent)	Scenario 2 Area (ha)	Scenario 2 Change (ha)	Scenario 2 Change (percent)	Scenario 3 Area (ha)	Scenario 3 Change (ha)	Scenario 3 Change (percent)
Woodland Closed	66.4	61.9	-4.5	(-6.9)	21.4	-45.0	(-67.7)	126.4	59.9	(90.2)
Woodland Open	114.2	69.4	-44.8	(-39.2)	82.8	-31.4	(-27.5)	109.1	-5.0	(-4.5)
Savannah	41.3	24.3	-16.9	(-41.1)	39.8	-1.4	(-3.5)	34.4	-6.8	(-16.6)
Corn/Soybeans	4190.5	4510.4	319.8	(7.6)	2882.3	-1308.2	(-31.2)	1725.1	-2465.4	(-58.8)
Crp	0	128.2	128.2	(100.0)	302.1	302.1	(100.0	0.0	0.0	(-100.0)
Alfalfa	89.7	0.0	-89.7	(-100.0)	400.9	311.1	(346.5)	0.0	-89.7	(-100.0)
Pasture	118.6	0.0	-118.6	(-100.0)	826.7	708.0	(596.9)	0.9	-118.6	(-100.0)
Pond/Lake	3.7	3.6	-0.1	(-4.3)	6.1	2.3	(61.9)	3.7	-99	(-0.3)
Fencerow	67.4	0.2	-67.2	(-99.7)	58.5	-8.8	(-13.2)	0.0	-67.3	(-99.9)
Riparian Areas	25.1	46.7	21.5	(85.8)	72.9	47.7	(189.6)	263.2	238.0	(945.1)
Intercropping	0.0	0.0	0.0	(0.0)	0.0	0.0	(0.0)	1931.7	1931.7	(100.0)
Biodiversity Garden	0.0	0.0	0.0	(0.0)	84.1	84.1	(0.0)	91.5	91.5	(100.0)
Organic Crops	0.0	0.0	0.0	(0.0)	0.0	0.0	(0.0)	153.8	153.8	(100.0)
Setaside	0.0	0.0	0.0	(0.0)	0.0	0.0	(0.0)	91.4	91.4	(100.0)
Wetland	0.0	0.0	0.0	(0.0)	0.0	0.0	(0.0)	197.9	197.9	(100.0)
Other	343.1	285.3	-57.8	(-16.8)	352.4	9.3	(2.6)	400.9	57.8	(14.4)

TABLE 1b. Land-Use Change in Buck Creek.

Land Use	Area (ha)	Scenario 1 Area (ha)	Scenario 1 Change (ha)	Scenario 1 Change (percent)	Scenario 2 Area (ha)	Scenario 2 Change (ha)	Scenario 2 Change (percent)	Scenario 3 Area (ha)	Scenario 3 Change (ha)	Scenario 3 Change (percent)
Woodland Closed	406.1	210.7	-195.3	(-48.1)	60.6	-345.4	(-85.1)	582.4	176.2	(43.4)
Woodland Open	240.4	98.0	-142.4	(-59.2)	171.4	-69.0	(-28.7)	235.2	-5.1	(-2.2)
Savannah	126.3	59.4	-66.8	(-52.9)	123.1	-3.1	(-2.5)	155.6	29.3	(23.2)
Corn/Soybeans	3923/3	5277.1	1453.8	(38.0)	1063.1	-2760.1	(-72.2)	88.2	-3735.0	(-97.7)
Crp	1392.2	1919.2	526.9	(37.8)	371.6	-1020.6	(-73.3)	0.0	-1392.2	(-100.0)
Alfalfa	353.8	590.2	236.3	(66.8)	3640.9	3287.0	(928.8)	0.0	-353.8	(-100.0)
Pasture	1217.9	0.0	-1217.9	(-100.0)	1689.4	471.5	(38.7)	0.0	-1217.9	(-100.0)
Pond/Lake	33.5	31.7	-1.7	(-5.4)	38.8	5.3	(15.8)	41.6	8.0	(24.1)
Fencerow	123.4	0.0	-123.4	(-100.0)	366.4	243.0	(196.8)	0.0	-123.4	(-100.0)
Riparian Areas	51.6	95.1	43.5	(84.4)	384.4	332.8	(644.8)	1113.8	1062.2	(2057.6)
Intercropping	0.0	0.0	0.0	(0.0)	0.0	0.0	(0.0)	5432.1	5432.1	(100.0)
Biodiversity Garden	0.0	0.0	0.0	(0.0)	80.0	80.0	(100.0)	117.2	117.2	(100.0)
Organic Crops	0.0	0.0	0.0	(0.0)	0.0	0.0	(0.0)	28.0	28.0	(100.0)
Setaside	0.0	0.0	0.0	(0.0)	0.0	0.0	(0.0)	233.4	233.4	(100.0)
Wetland	0.0	0.0	0.0	(0.0)	0.0	0.0	(0.0)	0.0	0.0	(100.0)
Other	1051	538.6	-512.4	(-48.8)	830.3	-220.7	(-21.0)	792.5	-285.5	(-24.5)

TABLE 2. TSS and NO_3-N Summary for Buck Creek and Walnut Creek Outlet Stations. Walnut Creek data provided by J. Hatfield. A. All MSEA data collected between 1992 and 1995. B. MSEA data taken during March, April, May, June, and July between 1992 and 1995.

	Mean	Standard	Median	Maximum	n	Percent Greater Than 10 mg/l
Buck Creek						
NO_3-N (mg/l)	6.02	1.85	6.45	9.6	116	0
TSS (mg/l)	2208	3939	1012	27200	116	N/
Walnut Creek						
A. NO_3-N (mg/l)	8.0	3.6	8.3	20.9	966	33
B. NO_3-N (mg/l)	9.0	3.4	9.3	20.9	628	45

Table 2. Collection was targeted toward storm events, and these values therefore represent likely maximums. The median value was approximately 1 g/l, with a maximum of 26 g/l. These values are highly elevated, suggesting that erosion is a much more significant problem in the Buck Creek watershed than surface water nitrate runoff. The evaluation is limited because of the relatively small sample size. This suggests the need for additional watershed-scale studies, similar in scope to the MSEA work in Walnut Creek that include the evaluation of erosion and TSS.

The relationship between nitrate and TSS during events appears consistent with other studies. Nitrate concentrations decrease during high flows due to dilution and TSS concentrations increase due to the increased erosive potential of the higher discharges (Figure 3).

The SWAT Model

The SWAT (Soil and Water Assessment Tool) model is a continuous, spatially explicit simulation model. The model is designed to quantify the effects of land use and management change on water quality in agricultural basins (Arnold *et al.,* 1995). It was developed by the USDA Agricultural Research Service (USDA-ARS) and is based on the ROTO, CREAMS, and SWRRB models. SWAT represents an improvement upon its predecessors through incorporation of increased spatial detail and routing of water and sediment (Binger, 1996). A version of the model incorporating a Geographic Information System (GIS) was utilized. The GIS interface simplifies the process of watershed discretization and parameter assignment through the use of spatially-explicit data sets representing elevation surface, soils, land use, and management (DiLuzio *et al.,* 2000).

SWAT simulates hydrology using a mass balance with terms representing surface runoff, percolation, lateral surface flow, and evapotranspiration. Surface runoff is estimated with the SCS formula (Arnold *et al.,* 1995). The percolation component is treated using a storage model in combination with a crack flow model to simulate rapid macropore flow through desiccated soils (Arnold *et al.,* 1995). Lateral surface flow is generated using a kinematic storage model, and evapotranspiration is modeled after methods described by Hargreaves and Samani (1985).

The model uses a modified version of the Universal Soil Loss Equation (MUSLE), developed by Williams and Berndt (1977) to estimate sediment yield. The nitrogen subroutine includes estimates of surface water nitrate loss, nitrate leaching, denitrification, mineralization, immobilization, organic nitrogen movement with soils and crop uptake.

Watershed Parameterization

Recent developments in computer hardware, software, and remote sensing techniques have greatly accelerated the use of data-rich distributed models, including SWAT. The SWAT model provides users with the choice of a detailed grid-based approach, including cell to cell routing, or a less detailed hydrologic response unit (HRU) configuration. Manguerra and Engel (1998) concluded that for most cases, the simpler HRU configuration provided essentially the same results as a more complicated grid based scheme. Given this and the difficulty in obtaining grid-cell specific data related to current and future management practices we employed the HRU scheme.

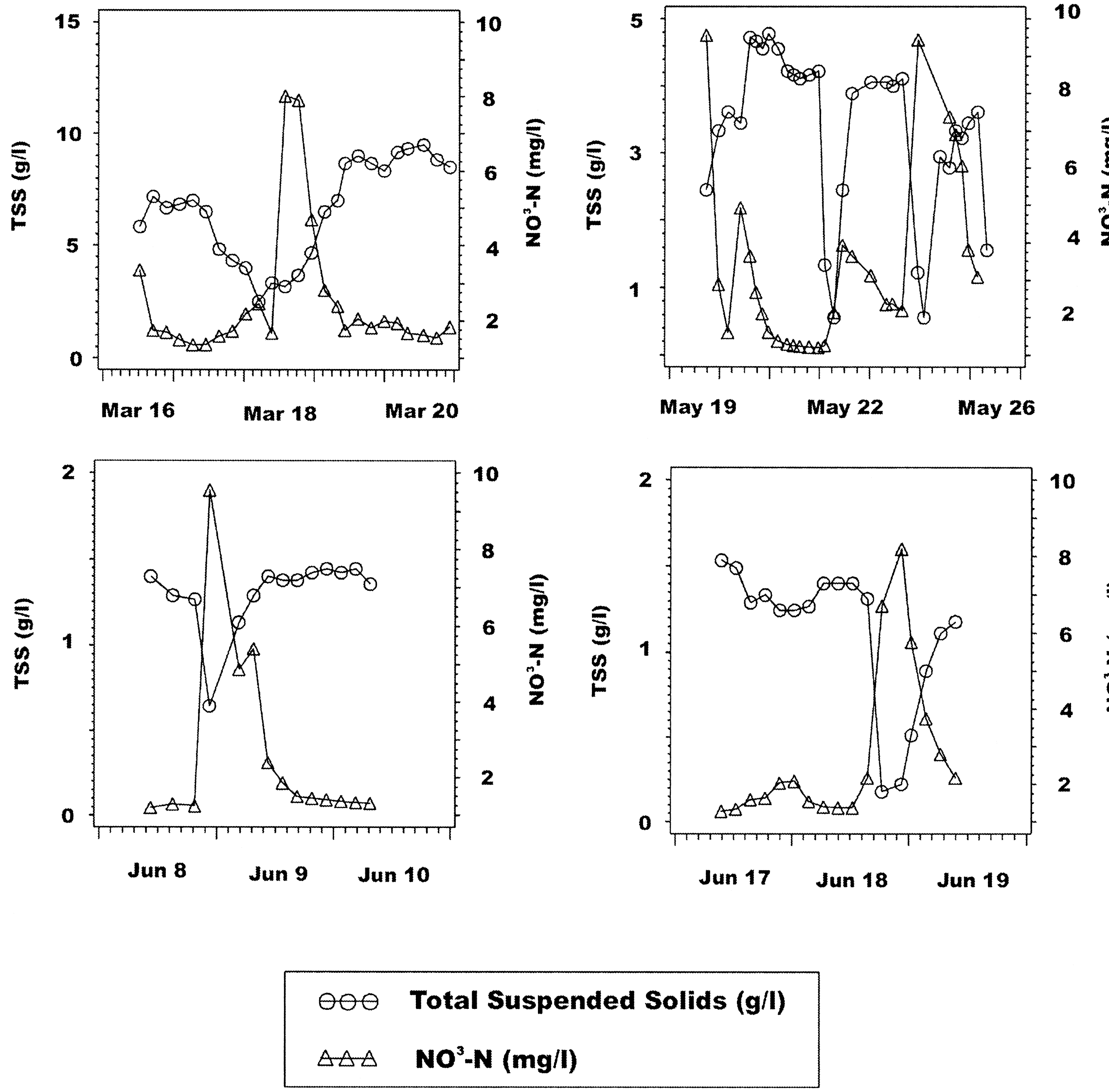

Figure 3. Total Suspended Sediment and Nitrate-Nitrogen for Four Storm Events in the Buck Creek Watershed.

Use of Future Scenarios

Evaluations of the local effects of specific restoration and management changes on surface water quality are common in the literature (Daniels and Gilliam, 1996). Many of these studies include plot or field-scale experiments employing detailed sampling schemes, intensive chemical analyses, and field-scale manipulation of land cover and management practices. The current study is not designed to simulate effects of field-scale change. Rather, the intent is to quantify the cumulative effects of changes in watershed land use and management practices, using a modeling framework. The basin wide changes are expressed as spatially-explicit GIS datasets that embody the agricultural and conservation practices of the alternative future scenarios developed by Nassauer *et al.* (2001).

Alternative future scenarios have been used for years in Europe to assist in land-use planning and the evaluation of the potential environmental consequences of different choices for landowners and policymakers (Harms *et al.,* 1993; Schoonenboom, 1995). The use of future scenarios, whose land use and land cover can be represented in GIS databases, coupled with GIS-based modeling approaches, allows the exploration of the outcomes of different management alternatives on real landscapes, using data on soils, topography, and biota of those landscapes. Alternative future scenarios coupled with GIS-based evaluative approaches can be powerful tools for guiding policy and land-use decision making (Ahern, 1999; Santelmann *et al.,* 2001). In the U.S., only a handful of such studies have been done (Steinitz *et al.,* 1994; Hulse *et al.,* 2000) and this project is one of the first to focus on specific changes in agricultural practices and to use a spatially distributed model to evaluate water quality responses.

Future Scenarios for Iowa watersheds

Scenario 1 represents a projection of current trends in Midwestern agriculture to the year 2025 applied to the study watersheds. Under this scenario, management decisions are based largely on maximizing production of agricultural commodities, although in cases where no decrease in production is projected, management practices that enhance water quality are employed. The most significant of these management practices with projected water quality benefits employed in Scenario 1 are precision agriculture and no-till cultivation. The increased area in production envisioned in Scenario 1 results in an increase in the mass of fertilizer applied to each basin.

Scenario 2 includes a variety of management techniques designed specifically to address water quality concerns. The most noteworthy of these design elements was the implementation of riparian buffers to 30 m on both sides of perennial streams and 15 m on both sides of ephemeral streams. Other management strategies include no-till cultivation, strip cropping where appropriate, and alfalfa production on all fields adjacent to streams.

Development of Scenario 3 proceeded under the assumption of broad-based public support for restoration of native biodiversity and improvement in water quality, with an emphasis on maximizing terrestrial biodiversity. Monocultures of corn and soybean rotations are significantly reduced under this scenario, replaced over large areas by strip intercropping, including strip intercropping that incorporates a strip of native perennials in fields of corn and soybeans. The widths of riparian buffers in Scenario 3 are, in all instances, doubled compared to Scenario 2. Additionally, production of organic crops is increased and large areas are set-aside as high quality habitat reserves (Nassauer *et al.,* 2001).

Coiner *et al.* (2001) provide an economic analysis of the current and three future scenarios for the Walnut Creek watershed. Among other results, they indicate that in Walnut Creek, Scenario 3, with a 58 percent decrease in the area under production of corn and soybeans, results in approximately the same economic return as current practices. The suggestion is that carefully chosen management decisions can both significantly reduce NPS pollution and maintain the economic viability of the Corn Belt region.

The land cover changes among the scenarios are summarized in Tables 1a and 1b for Walnut Creek and Buck Creek, respectively. Assumptions regarding the agricultural practices (amount and timing of fertilizer, tillage, etc.) used in each scenario are listed in Appendix 1.

Historic land cover was generated using a detailed (1:12000) regional soils database. Classifications are based on characteristics of soils formed under prairie and forest vegetation. Areas defined as prairie were sub-divided into upland prairie, ephemeral wetland, seasonal wetland, semi-permanent wetland, permanent wetland, and pond according to the relationships between soil types and wetland types described in Galatowitsch and van der Valk (1994) (see Rustigian, 1999).

Model Calibration

SWAT is often described as a physically based model designed for use in ungauged basins (Arnold *et al.,* 1995; Rosenthal, 1995; Binger, 1996). While the claim has merit, calibration was considered an important step in this study. The studies cited above concentrated on the hydrology components of SWAT, whereas our project required estimation of sediment and nutrient export as well as hydrologic change. The nutrient components of SWAT are highly parameterized and there is no reason to assume that default values correctly account for watershed-specific nutrient dynamics. Although a complete long-term dataset including discharge, TSS and NO_3-N was unavailable, we attempted to make reasonable comparisons to all available data.

Figure 4 represents calibration results for Walnut and Buck Creek. The stream discharge results match measured values reasonably well. The coefficient of determination (r^2) based on the monthly discharge data for the Buck Creek simulation is 0.64. For the Walnut Creek simulations the r^2 for the discharge results is 0.67. The Buck Creek sediment plot was developed based on an average TSS stream concentration of 150 mg/l to represent the entire seven year time period. This average was developed from low flow samples collected in 1997 and 1998. Though a more complete TSS dataset might allow for significant improvement in these results, we present the figure as qualitative evidence that SWAT can effectively reproduce instream sediment concentrations for watersheds in Iowa. Very little TSS data were available in the Walnut Creek watershed, and we used the Buck Creek calibrations in the Walnut Creek simulations.

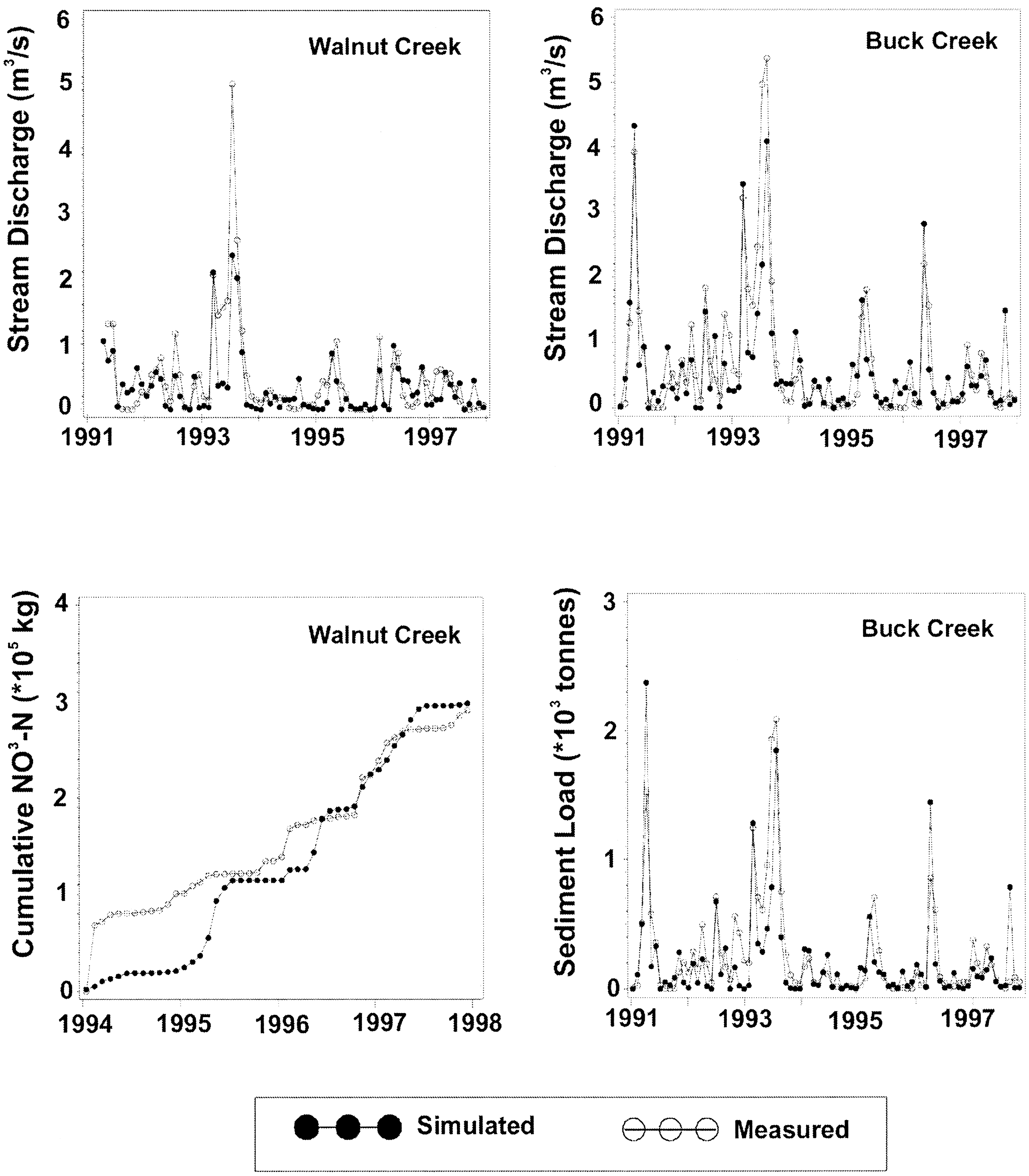

Figure 4. Calibration Results for Walnut and Buck Creeks.

The cumulative distribution of NO_3-N for the period when nitrate measurements were available in Walnut Creek is also included in Figure 4. The model accounts for most of the nitrate in Walnut Creek for the period, though discrepancies in the timing and magnitude are apparent. One of the difficulties encountered in these relatively large watersheds was a lack of field-specific data on the magnitude and timing of fertilizer applications. Model simulations represent best estimates of current nutrient management practice, on average, for the region (Hatfield *et al.,* 1999) but no attempt was made to verify nutrient application regimes on a field-scale basis. Improved estimates of nitrate inputs would likely reduce model error, but given the complexity of nitrogen dynamics and the successful long-term mass balance of NO_3-N demonstrated by Figure 4, we elected to accept this calibration of the SWAT model as representative of general watershed practices.

RESULTS AND DISCUSSION

Simulation Results

The scenarios evaluated in this project were designed to improve water quality, albeit with different emphases on human priorities and watershed practices. The model was used to quantify the improvement that might be expected with the implementation of each scenario. Each scenario for both Walnut and Buck Creeks was simulated on a daily basis for an eight-year period from 1992 through 1998. Results from these long-term simulations are, throughout the text, presented as percentage change of median yearly loading, for the simulated six-year period. The median values were used in an effort to provide an indication of how water quality responded to changes in land use and not to extreme events.

Evaluation of Future Scenarios

Erosion. In all cases, the scenarios were forecast to decrease upland erosion and TSS concentrations in Walnut and Buck Creeks relative to current conditions (see Figures 5 and 6). The decreases forecast for Scenarios 2 and 3 were substantially greater than those for Scenario 1.

The major difference between the present landscape and Scenario 1 is the basin-wide implementation of no-till cultivation. There is an approximately 15 percent decrease in the median TSS loading in each of the two streams, while the area in corn and soybean production actually increases from 80 percent of the total watershed area to 86 percent of the watershed area in Walnut Creek and from 43 to 62 percent in the Buck Creek watershed. These results suggest that moderate reductions in soil loss could be achieved in this setting through the widespread implementation of no-till farming.

The simulated decreases in erosion from Scenarios 2 and 3 were significantly greater than from Scenario 1, ranging from 35 to 60 percent reductions in the median sediment yield. We attribute this improvement to a more complete set of management practices combined with decreased production of corn and soybeans. Surprisingly, TSS loadings under Scenario 2 are forecasted to exhibit the greatest decline from current values, whereas an examination of the scenarios might suggest Scenario 3 would show the most significant decreases. (Scenario 3 buffers are twice the width, strip intercropping often replaces corn and soybean rotation, and larger areas are set-aside as habitat reserves.) This result suggests that increasing the width of riparian buffers from 30 to 60 meters along perennial streams is unlikely to provide any significant decrease of in-stream sediment concentrations, beyond what is expected under the narrower buffer strips. Set-asides and alternative crops are not simulated to decrease erosion more than maintenance of perennial cover on erodible land, either in the form of alfalfa/hayfields or as carefully managed rotational pasture.

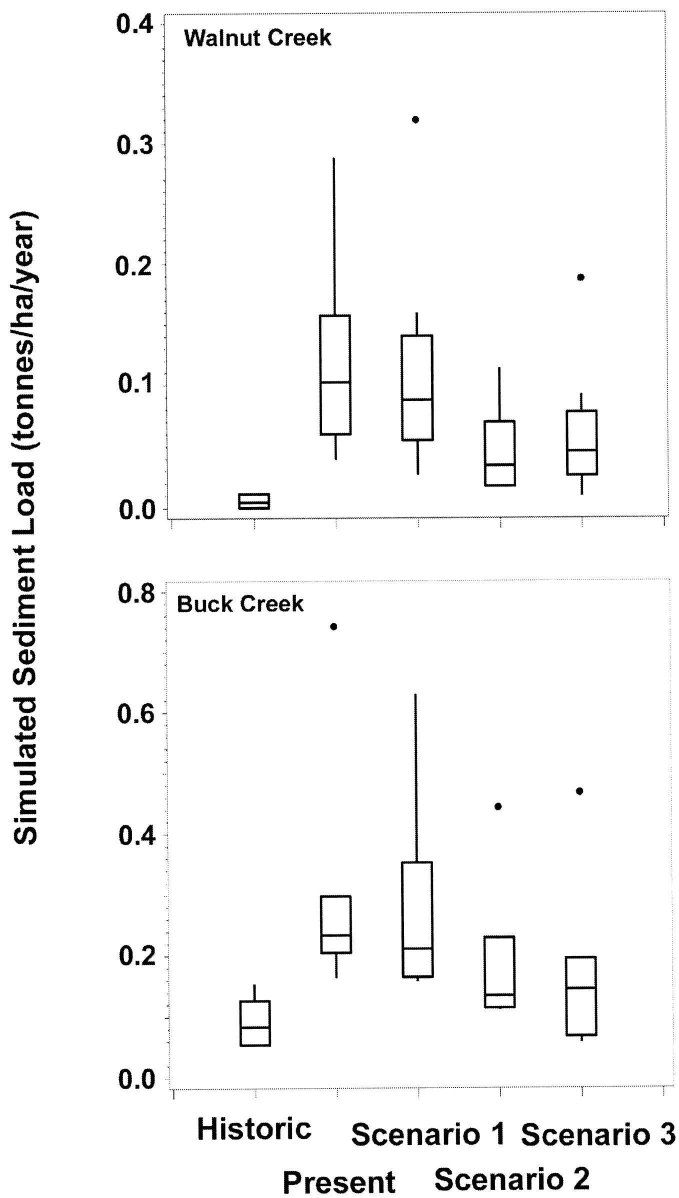

Figure 5. Boxplot Representing Sediment Loading in Walnut and Buck Creek Watersheds.

The pattern of erosion reduction is similar between Buck Creek and Walnut Creek, but the magnitude of the decrease is simulated to be larger in Walnut

Creek. Buck Creek is a well-developed stream system with much greater relief than Walnut Creek. Overland flow moves over steeper terrain in Buck Creek, which increases its potential to erode. Additionally, upland flow paths tend to be shorter in Buck Creek due to the dendritic nature of the channel. These shorter flow-paths result in higher TSS values, as sediment is less likely to be re-deposited before reaching the stream.

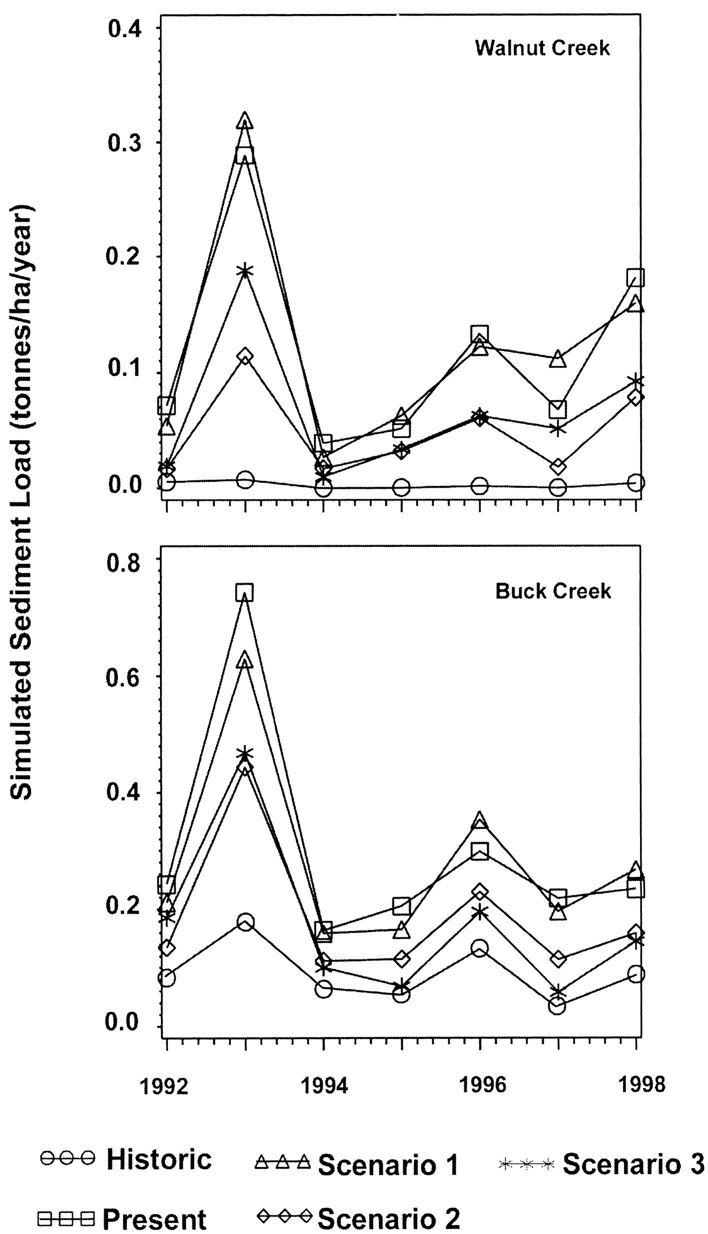

Figure 6. Time Series Plots of Yearly Sediment Loading in Walnut and Buck Creek Watersheds for the Study Period. The time series help explain the variation noted in Figure 6, particularly the high values which occurred in 1993, a year of widespread flooding throughout the Midwest.

Nitrate. The pattern of results for the nitrate simulations is somewhat different than that for the TSS simulations (Figures 7 and 8). One of the most notable differences occurs in Scenario 1, where nitrate concentrations are forecast to increase in both Walnut and Buck Creeks. In each watershed, the area in monoculture production of corn and soybeans increases. We assume fertilizer applications are targeted to locations where they will produce greatest yield increases, but average amounts per hectare of cropland are expected to remain the same. This greater mass of applied nitrogen results in increased nitrate runoff for Scenario 1.

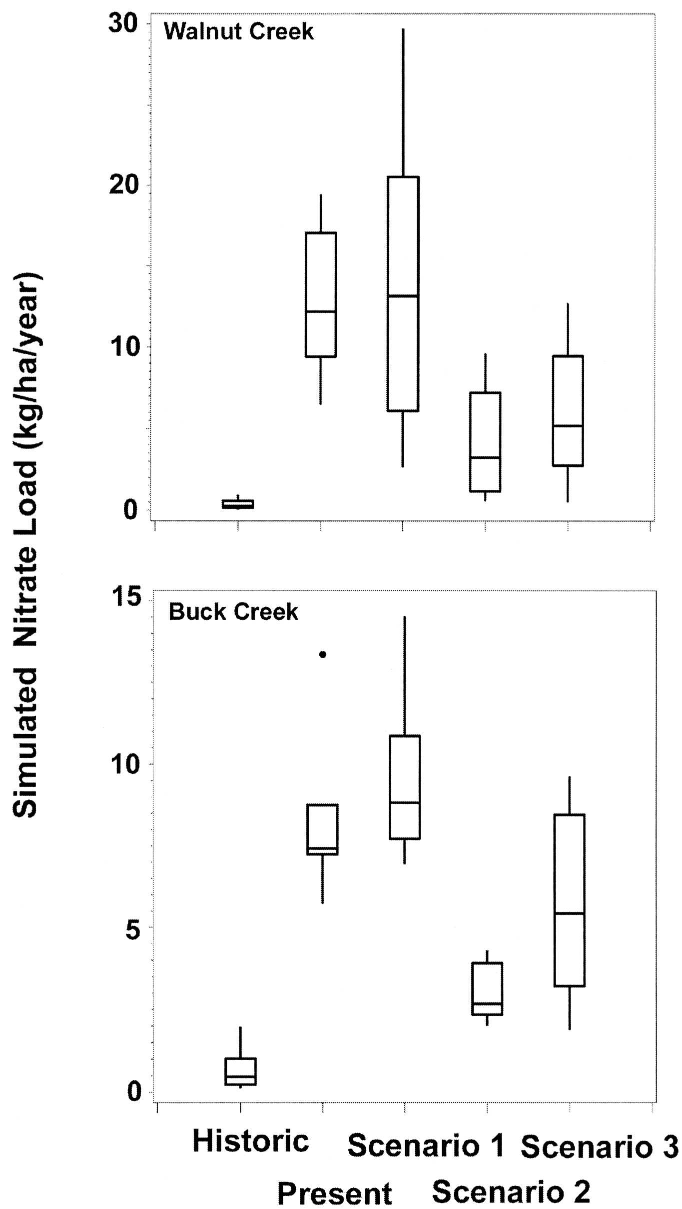

Figure 7. Boxplots Representing Nitrate Loading in Walnut and Buck Creek Watersheds.

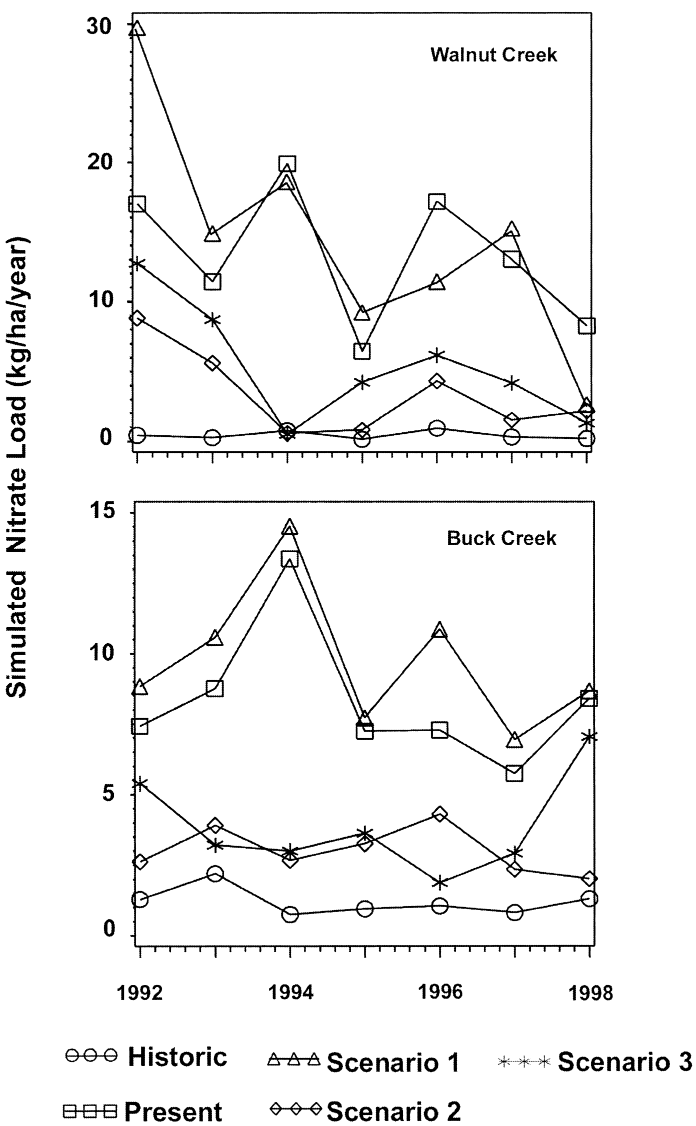

Figure 8. Time Series Plots of Yearly Nitrate Loading in Walnut and Buck Creek Watersheds for the Study Period. The time series help explain the variation noted in Figure 8.

The pattern of nitrate loading in Scenarios 2 and 3 mimics that of TSS, with significant decreases forecast in both cases, ranging from 57 to 70 percent reduction in the median nitrate load. In Scenario 2, much of the watershed area is still assumed to produce corn and soybeans (Table 1a) but the area is not in continuous corn and soybean rotation. Rather, the assumption is for a corn-soybean-alfalfa-alfalfa rotation. The two years of alfalfa are unfertilized and we assumed that application of nitrate to corn could be reduced by a modest 10 percent (to 120 kg/ha/year of rotation as anhydrous NH_3). Additionally, a significant area of both watersheds (400 ha in Walnut and 3640 ha in Buck Creek) is converted to alfalfa production under the assumptions of Scenario 2. Pasture land also increases substantially in Scenario 2. Over the simulation period, significantly less commercial nitrate is applied to these systems and as a result, significantly less nitrate is simulated being exported from the watershed in the stream system.

Nitrate results from Scenario 3 suggest significant decreases from the present though, as with TSS, the largest improvements to water quality occur under Scenario 2. The area in corn and soybean production in both watersheds is greatly reduced in Scenario 3, replaced primarily with riparian areas and strip intercropping. In Scenario 3, the area in row crop production (as intercropping) is greater than in Scenario 2, and nitrate runoff is consistently higher in Scenario 3 as a result.

In Buck Creek, the scenario design results in an extreme decrease in corn and soybean production as monocultures (it drops from 3823 ha in the present to 88 ha under the assumptions of Scenario 3). This decrease is due, in large part, to conversions from corn and soybean monocultures to strip intercropping and to the implementation of a 60m wide riparian buffer along perennial streams; this removes a major portion of Buck Creek watershed from conventional row crop production. The dendritic nature of the stream system in Buck Creek gives this 60 meter buffer an area of 1114 ha, or approximately 13 percent of the basin area. In Walnut Creek, again in part due to a less complicated stream network, the scenario design produces a riparian buffer system of 263 ha or approximately 5 percent of the watershed area. Additionally, in Walnut Creek the area in corn and soybean production (including strip intercropping) in Scenario 3 is higher than in Buck Creek. Walnut Creek has 3656 ha or 70 percent of its area in enterprises that produce corn and soybeans whereas 5520 ha (62 percent) of Buck Creek is under corn and soybean production (intercropped) in Scenario 3. As a result of the physiographic differences between the watersheds, significantly less nitrate is applied to Buck Creek. Even given its larger area – it is 59 percent larger than Walnut Creek – model results and calibration data indicate loadings of nitrate are generally smaller than for Walnut Creek.

Evaluation and Comparison of Water Quality in Historic and Current Landscape

We include this analysis of historical water quality to provide a context for other simulation results and current water quality in the watersheds. All model results, and especially those attempting to model historical (or future) landcover have some degree of uncertainty – both in terms of accuracy of historical land use and model treatment of it. Despite this, we feel the analysis is useful in that it provides a benchmark to compare to the magnitude of change simulated for the future scenarios.

Simulated water quality under pre-development conditions appears significantly different than under current conditions. In Walnut Creek, the simulations using pre-development land cover yielded values representing reductions of 90 percent for TSS and 96 percent for nitrate. In Buck Creek, modeled reductions were 96 percent for TSS and 87 percent for nitrate. These very large simulated differences appear to result from three related factors. The first is our reconstruction of historical land-cover. Walnut Creek, with its relatively flat slopes, is modeled as a watershed with 2404 ha of wetlands. This represents 46 percent of the total watershed area and greatly changes the hydrology of the watershed. Estimated historic wetland area in Buck Creek is considerably less than in Walnut Creek, due for the most part to the greater topographic relief as compared to Walnut Creek. As a result, estimates of historic nitrate and sediment loading in Buck Creek are higher than similar estimates for Walnut Creek. The second factor involved in the significantly improved water quality under historic land cover is that nutrients were not added as chemical fertilizers to the systems, and so the potential for nutrient runoff was considerably less. The last factor responsible for the result is that in pristine prairie ecosystems, bare land surfaces are never developed through tillage. The relatively dense perennial cover results in reduced erosion potential and TSS concentrations. Historically, these watersheds stored more water in the upland wetlands, significantly reducing peak flows and development of stream channels. These reductions acted to reduce the potential for erosion and sediment delivery to streams, as well as bank erosion.

SUMMARY AND CONCLUSIONS

The results of this study lend support to an emerging view that to restore water quality and achieve substantial reductions (approximately 30 to 75 percent) in nutrient export in areas such as the Corn Belt will require major reconsideration of approaches. More specifically, this study indicates that achievement of major benefits in water quality will require major alterations of activities that take place in the watershed, in particular, modifications of the agricultural practices. In the current study, scenarios that included widespread implementation of agricultural enterprises in which nitrogen applications were substantially reduced (i.e., decreased by 10 to 33 percent) along with implementation of other BMPs, resulted in reductions in nitrogen export of greater than 50 percent.

Scenario 1, in which BMPs including 3- to 6-m wide riparian buffers, filter strips, conservation tillage, and precision agriculture were employed, but without substantial reductions in the total amount of nitrogen applied, showed increased nitrate export. These results indicate that continued use of present levels of nitrogen to fertilize crops will continue to result in nitrogen export to surface and ground waters greatly in excess of historical values.

Results indicate that conversion to no-till cultivation and residue management across large areas is, not surprisingly, an effective measure to reduce sediment concentrations. Only modest reductions in TSS occurred with exclusive no-till cultivation, as envisioned in Scenario 1. Significant reductions of up to 65 percent occurred when other changes (including decreased row crop production and wider riparian areas) were also incorporated.

These results were developed around two watersheds, representative of the Des Moines Lobe and the Southern Iowa Drift Plain physiographic provinces. We encourage the further testing of these ideas, both with modeling and with watershed-level experiments (cf., Likens *et al.,* 1977), on a wider selection of watersheds in other physiographic and agricultural settings. Such research is needed to understand the extent, costs, and benefits of various practices aimed at improving water quality in agricultural regions and downstream.

APPENDIX 1
KEY LAND-USE AND MANAGEMENT ASSUMPTIONS

CURRENT SCENARIO

Corn/Soybeans – Two year rotation of corn and beans on each field.

Single N application to corn in October. 183 kg/ha injected as anhydrous NH3.

Single elemental P application to both corn and soybeans – 56 kg/ha to corn and 40 kg/ha to soybeans.

Chisel plow, with a mixing ratio of 0.25 – approximately 75 percent residue left on field. Corn plowed under in the fall, soybean crop is not.

Pasture – Generic grazing application on all pastures. Grazing occurs during two 28-day cycles (beginning June 1 and August 1). Pasture is killed in fall and replanted in early April.

Alfalfa – Alfalfa is managed on a generic five-year multiple cut rotation. Planted early April of Year 1, harvested twice in the first year. Harvested four times in each of the second and third years. Harvested twice in the fourth, crop is killed, but is harvested and killed again in the fifth year.

No fertilization.

Riparian Areas – SWAT provides a method to incorporate the quality of riparian areas. Two coefficients provide a quality index related to cover density and to the ability of the streambed to resist erosion. The current riparian area in both watersheds is generally thin and disconnected. The cover density index was set to a value representing average cover density in an effort to reflect riparian density.

SCENARIO 1

Corn/Soybeans – Same rotation as current.

Single N application to corn. 143 kg/ha anhydrous NH_3.

Single P application to both corn and soybeans. Same amounts as in current.

No Till conservation practices, with a mix ratio of 0.05 (leaving 95 percent residue).

Riparian Areas – Design rules indicate that the riparian buffers are well established and maintained throughout all perennial and ephemeral streams. In an effort to incorporate these buffers the cover coefficient was set to 1.0 (on a scale from 0.0 to 1.0, with 1.0 representing a well-vegetated riparian area).

SCENARIO 2

Corn/Soybeans – Corn crop is on a four-year rotation of corn/soybeans/alfalfa/alfalfa. There is no application of N. The three-year rotations of N fixing crops provide available N for corn. All tillage practices are assumed to be conservation no till with a mix ration of 0.05.

Riparian Areas – As with Scenario 1, we assumed riparian areas were in very good condition and set the value of the cover coefficient to 1.0.

SCENARIO 3

Corn/Soybeans – The corn crop in Scenario 3 is modeled the as a two-year rotation with soybeans, using the same timing and amounts of fertilization as in Scenario 1.

Organic Crops – Modeled as a corn/soybean rotation, with no addition of N or P.

Strip Intercropping – SWAT does not have the ability to simulate the growth of two different crops in a single field at the same time. In an effort to simulate plausible effects of strip intercropping, the practice was modeled as a corn soybean oat rotation. Corn was fertilized at 25 kg/ha of anhydrous NH4 and P was applied at 56 kg/ha.

Riparian Areas – The coefficient was set to reflect well-maintained and complete riparian buffer systems.

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