EPIC modeling of the effects of farming practice changes on water quality in two Lake Erie watersheds

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ABSTRACT: Agricultures contributions to Lake Erie water quality problems have been a concern for the^ past three decades. This research investigates the relationship^ between changes in water quality and changes in farming practices in two Lake Erie tributaries. Using the Erosion Productivity Impact Calculator (EPIC), simulations of pollutant emissions from farms in the Maumee and Sandusky River basins were conducted with 1985 and 1995 land use and cropping patterns. This information was compared with unit area loads derived from detailed water quality data collected at integrator stations near the mouths of the two rivers. The comparison showed large differences between the two data sets that cannot be explained by errors of load estimation, errors in application of the EPIC model, or differences between the modeled and monitored parameters. Rather, discrepancies in results are likely due to the fact that EPIC does not model in-stream delivery losses, and the observed loads are affected by these losses. However, EPIC simulations are generally accurate in predicting the direction of change of unit area loads of water quality parameters.

*Key **words:** EPIC model, nonpoint pollution, water quality.*

Agriculture's contributions to Lake Erie water quality problems have been a concern for the past three decades. In the 1970s, it was recognized that Lake Erie was more susceptible to pollutant loads than other Great Lakes (International Joint Commission 1974). Relatively high concentrations of pollutants within the lake and its tributaries were thought to be caused by a combination of forces: large cities and industries surrounding the lake, intensive crop production occurring within the basin, and the shallow depth of the lake. Because point source pollution was substantially reduced following implementation of the 1972 Federal Water Pollution Control Act Amendments (PL92-500), changes in the basin's farming practices were necessary for further improvements in Lake Erie's water quality to occur.

At the time this legislation was enacted, it was assumed that excessive phosphorus loadings were the principal cause of accelerated eutrophication in Lake Erie (Forster et al. 1985). Since that time, progress has been made toward achieving the phosphorus load reduction called for in the 1978 Great Lakes Water Quality Agreement between the United States and Canada. Lake Erie tributary loading data reveal that for the 1975-90 period, substantial reductions in the concentrations of total and soluble phosphorus have occurred (Richards and Baker 1993).

However, concern has increased about pollutants, other than phosphorus, since the 1970s. Of special concern in the Lake Erie basin are nitrate concentrations in rivers and sediment deposition in drainage ditches and harbors (Great Lakes Commission 1996). Research indicates that for most of the Lake Erie tributaries, concentrations of nitrates have increased and concentrations of sediment have remained about the same between 1975 and 1990. (Richards and Baker 1993).

In the Lake Erie Basin, row-crop agriculture is concentrated in the watersheds that drain into the western and central basins of the lake (Figure 1). The Maumee and Sandusky rivers, with watershed areas of 1.7 million ha (4.2 million ac) and 0.36 million ha (0.9 million ac), respectively, contain about 50% of the total cropland draining into Lake Erie from both the United States and Canada. Row-crop agriculture occupies 76 and 80% of the Maumee and Sandusky watersheds, respectively. These two watersheds are the focus of this research.

Objectives

One objective is to determine whether an association exists between observed changes in pollutant concentrations in two of the lake's major tributaries and changes in farming practices in those tributaries. This study compares simulations using the Erosion Productivity Impact Calculator (EPIC) of pollutant emissions from farms in the Maumee and Sandusky river basins under 1985 and 1995 farming practices, and unit area loads derived

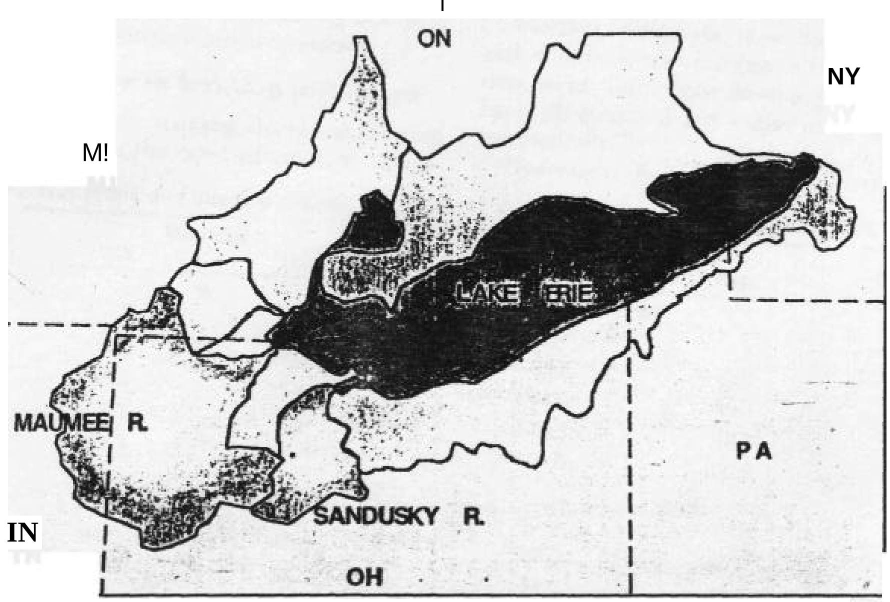

Figure 1. Location of Maumee and Sandusky River tributaries in the Lake Erie Basin.

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from water quality data collected at stations near the mouths of these rivers.

Another objective is to determine how well the EPIC model represents water quality in these two agricultural basins, even though EPIC is intended to model particular sites, not large geographic areas. Several studies have compared EPIC simulation results with observed nutrient/sediment transport or crop yields (Warner et al. 1997; Puurveen et al. 1997; Edwards et al. 1994; Easterling et al. 1996). For example, Edwards et al. applied the EPIC model to four fields in Arkansas, and concluded that there was significant correlation between observed and predicted calendar year total transport for all outputs, except nitrate-nitrogen.

Easterling et al. (1996) used the EPIC model to simulate yield response to various scenarios of climate change and concluded that EPIC reliably simulates crop yields under climate changes.

Methods

Observations of changes in water quality in this study are from Heidelberg College's Water Quality Laboratory (WQL), which has been conducting tributary loading studies in the Lake Erie basin since 1974. Water quality data are from the two major Lake Erie tributaries, the Sandusky River and the Maumee River. WQL's research-level monitoring program includes the collection of river water samples daily during low-flow periods and three times per day during storm runoff periods, at or near U.S. Geological Survey gaging stations on the Maumee River at Bowling Green, Ohio, and the Sandusky River near Fremont, Ohio. These samples are analyzed for concentrations of suspended sediment, total and soluble phosphorus, total Kjeldahl nitrogen, nitrate plus nitrite, and a number of other parameters. This sampling program, with minor modifications, has been operating continuously since 1975 at these stations, with the exception of a 3-yr gap at the Maumee station from October 1978 to October 1981.

Analysis of WQL data indicates that nonpoint sources contributed most of the suspended sediment, phosphorus, and nitrogen loadings. For example, nonpoint sources are estimated to be responsible for 91 to 96% of the total phosphorus export from 1985 to 1995. Furthermore, reductions in point sources could have contributed no more than 25% to the total load reductions observed. Changes in observed loads in these watersheds are thought to be largely attributable to changes in farming practices.

Pollutant emissions from farms are estimated by applying the EPIC simulation model to farms throughout the watersheds of these tributaries. Ideally, estimates of changes in pollution emissions from farms in the two watersheds, would involve using EPJC at different periods of time to simulate the effect of changes in existing farming practices. However, farming practices on individual farms are unknown. Secondary data provides county-level estimates of the acreages of various crops and acreages of alternative tillage practices in each year.

In this study, pollutant emissions from farms are estimated at two points in time: 1985 and 1995. In each of these years, a mathematical programming algorithm is used to derive approximation of the distribution of crops and tillage practices across the farms in the basin. Once these distributions of crops and tillage practices are obtained, the EPIC model is used repeatedly to simulate emissions from farms, and these results are aggregated to estimate basin pollutant emissions.

Changes in farming practices

The most striking change in farming practices is the rapid adoption of conservation tillage in both basins (Table 1). Conservation tillage is defined as any tillage and planting system that covers 30% or more of the soil surface with crop residue after planting. Conservation tillage was used on only 5 to 14% of the basins' cropland in 1985. Ten years later, it was used on about one-half of it.

Another change has been the decrease in corn *(Zea mays* L) acreage in both basins (Table 1). In the case of the Maumee basin, farmers have replaced some corn plantings with both soybeans *[Glycine max* (L.) Merr.] and wheat *(Triticum aestivum* L.), while in the Sandusky basin, soybean acreage has increased at the expense of both corn and wheat.

EPIC modeling

The Erosion Productivity Impact Calculator (EPIC), also known as the Environmental Policy Integrated Climate, was created by teams of U.S. Department of Agriculture scientists from the Agriculture Research Service (ARS), Soil Conservation Service (SCS), and Economic Research Service (ERS) in the early 1980s (Sharpley and Williams 1990a). EPIC was designed to simulate biophysical processes and the interaction of cropping systems over long periods of time, during which changes in the environment occur at a relatively slow rate. A wide range of soils, climates, and crops can be simulated, using predefined management practices, in an efficient and convenient manner (Smith 1997).

The EPIC model contains the following 10 major biophysical and management components:

Weather. Daily rain, snow, maximum and minimum temperatures, solar radiation, wind, and relative humidity can be based on measured data and/or generated stochastically.

Hydrology. Runoff, percolation, later-

Table 1. Proportion of major crop acreage by various crops and tillage practices, Maumee and Sandusky River Basins, 1985 and 1995.

	Maumee		Sandusky 1985	
	1985	1995	1995	
Major crops				
Corn	35.	32.	35.6	32.1
Soybeans	4	2	44.9	49.1
Wheat	48.	49.1	19.	18.7
Total	4	19.	5	100.0
Tillage practices				
Conventional	94.8	43.5	86.0	50.5
Conservation	5.2	56.5	14.0	49.5
Total	100.0	100.0	100.0	100.0

al subsurface flow, and snowmelt are simulated.

Erosion. EPIC simulates soil erosion caused by wind and water. Sheet and rill erosion/sedimentation result from runoff from rainfall, snow melt, and irrigation.

Nutrient cycling. The model simulates nitrogen and phosphorus fertilization, transformations, crop uptake, and nutrient movement. Nutrients can be applied as mineral fertilizers, in irrigation water, or as animal manure.

Pesticide fate. The model simulates pesticide movement with water and sediment, as well as degradation on foliage and in soil.

Soil temperature. Soil temperature responds to weather, soil water content, and bulk density. It is computed daily in each soil layer.

Tillage. Tillage equipment affects soil hydrology and nutrient cycling. The user may change the characteristics of simulated tillage equipment, if needed.

Crop growth. A single crop model capable of simulating major agronomic crops, pastures, and trees is used. Crop-specific parameters are available for most crops. The user may adjust or create new sets of parameters as needed. The model can also simulate crops grown in complex rotations and, in certain cases, in mixtures.

Crop and soil management. The EPIC model is capable of simulating a variety of cropping variables, management practices and naturally-occurring processes. These include different crop characteristics, plant populations, dates of planting and harvest, fertilization, irrigation, artificial drainage systems, tillage, runoff control with furrow dikes and other methods, liming, and pest control. The model can also gauge the effects of such varied management practices as whether the crop is harvested for grain or fodder or if it is grazed or burned.

Economics. A simple accounting package is included to calculate the costs of inputs and compute returns (Sharpley and Williams 1990b).

The EPIC model requires the user to input sets of parameters representing weather patterns, soil type, cropping practices, tillage practices, and other crop inputs, such as fertilizers and pesticides.

By varying the parameters in the model, one is able to simulate pollutant emissions under various farming practices. In this research, each EPIC simulation of farming practices at a particular site is for a 50-yr period. Results are reported for the 50-yr mean value of each output variable.

Table 2. Rotation-tillage systems combinations evaluated with the EPIC model.

1 Continuous corn	(CC)	Moldboard	(MB)
2 Continuous corn	(CC)	Chisel plow	(CP)
3 Continuous corn	(CC)	No-till	(NT)
4 Corn /soybean	(CS)	Moldboard	(MB)
5 Corn /soybean	(CS)	Chisel plow	(CP)
6 Corn /soybean	(CS)	No-till	(NT)
7 Corn /soybean	(CS)	Moldboard corn/no till soybeans	(MBNT)
8 Corn /soybean /wheat /soybean	(CSWS)	Moldboard	(MB)
9 Corn/soybean/wheat/soybean	(CSWS)	Chisel plow	(CP)
10 Corn /soybean /wheat /soybean	(CSWS)	No-till	(NT)
11 Corn/soybean/wheat/soybean	(CSWS)	Moldboard corn/no-till other crops	(MBNT)

The EPIC model requires a long series of daily weather data for precipitation, air temperature, solar radiation, wind speeds, and direction. To complete long-run simulation, predictions of daily weather are required (Richardson and Nicks 1990). In this study, the Toledo, Ohio, weather station is the closest weather station to the study region, and its historic weather data were used in the EPIC model.

The Sandusky River Basin consists primarily of three counties, and the Maumee Basin, consists of 14 counties (Figure 1). For each county, 15 to 20 soils were selected to represent the county's cropland. Based on total acreage in the county, the five most predominant soil series were selected and the remaining soils were chosen randomly by picking every fourth soil series listed in the county's soil survey (ODNR and USDA). Using this procedure, farming practices were simulated on 50 to 85% of each county's total acreage.

Western Lake Erie Basin cropland agriculture was represented by three crops (corn, soybeans, winter wheat) in four rotations (continuous corn, corn/soybean, soybean/wheat, corn/soybean/wheat). Corn/soybean and soybean/wheat rotations are 2-yr rotations with no cover crop planted between the designated crops. In the soybean/wheat rotation, winter wheat planting immediately follows soybean harvesting. The corn/soybean/wheat rotation is a 3-yr cycle, with no cover crops planted between the designated crops.

Conventional tillage, mulch tillage, and no-till management practices were simulated to predict the impact that tillage has on crop yields and the environment. For purposes of the EPIC model, a set of farming practices was specified to represent a particular tillage system. For conventional tillage, soil preparation activities for corn, soybean, and wheat consisted of moldboard plowing, discing, and field cultivating before planting. A rotary hoe was used to reduce weeds in corn and soybean rotations. For corn and soybean, plowing was assumed to occur in the fall. Mulch tillage was characterized as having more than 30% of the soil surface covered by residue from the previous crop. In this research, it was assumed that mulch tillage was achieved by using a chisel plow and a field cultivator prior to planting and a rotary hoe operation after planting. No-till eliminated perturbation of the soil surface with a tillage operation. Instead, pesticides were used to control weeds and a specialized no-till drill was used to plant crops directly in the previous year's post-harvest debris.

For each soil series in each county, 11 different rotation-tillage systems (described in Table 2) were simulated. In a county with a 15-soils series, a total of 165 EPIC simulations were performed (11 rotation-tillage systems x 15 soils) to depict farming practices. In total, more than 3,000 EPIC simulations were run to represent the possible rotation-tillage-soil series combinations in the two watersheds.

The area allocated to each rotation-tillage-soil series combination in a county was computed by a linear programming algorithm. Acreages of various crops (i.e., corn, soybeans, and wheat), acreages of alternative tillage systems (i.e., moldboard plow, mulch till, and no-till), and acreages of each soil series in a county were known from secondary data. The linear programming technique that was used solved for the area allocated to each county's rotation-tillage-soil series combination. It was assumed that farmers choose those crops and tillage practices that maximize net revenues on a particular soil series, subject to the constraint that the sum of various crop acreages and tillage acreages must equal known county totals.

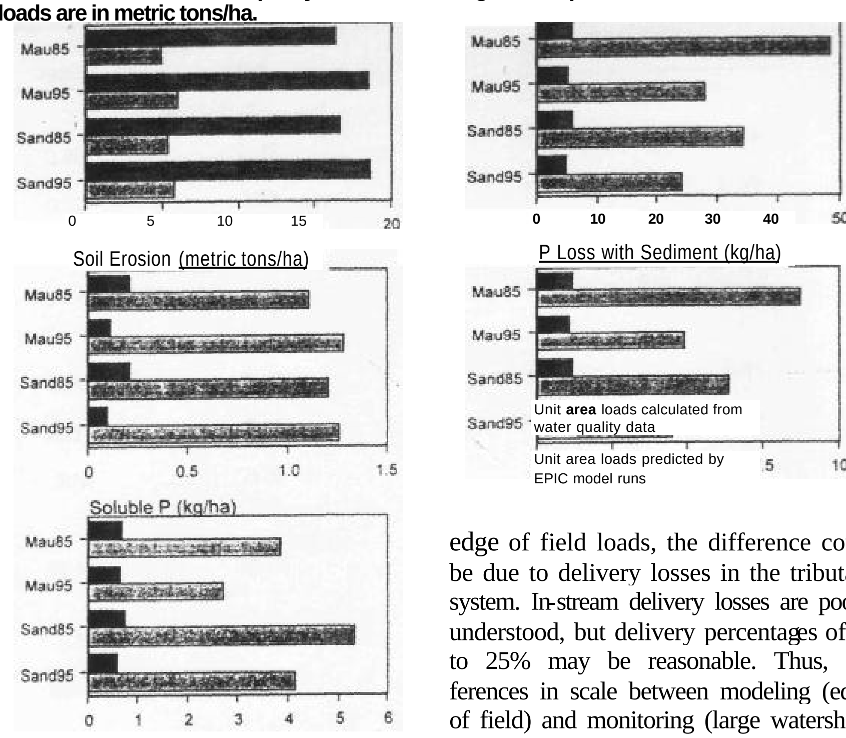
Environmental parameters used in analyses

Five environmental parameters were chosen for their relevance to Lake Erie Basin water quality concerns. For each management system simulated with EPIC, delivery of these parameters to the edge of the field was computed. While these losses are not equal to the amount of these materials entering the water system, they are representative of effluents leaving the field and approximate losses of resources to the farmer. In general, the five parameters depict soil, nitrogen, and phosphorus losses from farms. Soil losses were computed using the Universal Soil Loss Equation (USLE). Nitrogen losses were estimated in two ways, as organic loss of nitrogen in sediment and as nitrate loss in surface runoff. Phosphorus losses were estimated as soluble phosphorus loss in runoff and as phosphorous loss in sediment.

Maumee and Sandusky Basin water quality in 1985 and 1995

Monitoring data from the WQL's Maumee and Sandusky River data sets were combined with mean daily flow data from the U.S. Geological Survey to calculate daily loads for the period 1975 to 1995. No attempt was made to correct for sampler malfunction or analytical problems. Trend analysis was carried out for parameters that are directly comparable to output from the EPIC model, as follows. The WQL analytical program provides concentrations for nitrate plus nitrite (NO23) rather than nitrate alone, but nitrite was always near detection limits, hence, nitrate plus nitrite was very comparable to nitrate (NO3) alone. Similarly, total Kjeldahl nitrogen (TKN) is organic nitrogen plus ammonia, but ammonia concentrations were generally small compared to organic nitrogen concentrations in these rivers; hence, TKN was a good estimator of organic nitrogen. Suspended solids (SS) is directly related to soil loss. Soluble reactive phosphorus (SRP) is the component of soluble phosphorus, which is chemically active without digestion; limited studies in these rivers indicate that it ranges from 35 to 75% of the total soluble phosphorus. Particulate phosphorus (PP) was estimated as the difference between total phosphorus and SRP. Because SRP underestimates soluble phosphorus, PP should overestimate P lost with sediment. However, because PP comprises 80 to 90% of total phosphorus in these watersheds, this bias should be small.

Figure 2. Graphical comparison of loads predicted by the EPIC model and those calculated from the water quality data. Loads in kg/ha except for sediment, for which loads are in metric tons/ha.



The EPIC model, as used here, calculates average losses under long-term weather conditions, not the specific conditions that occurred in particular years. Thus, it was necessary to calculate "average" tributary loads for comparison purposes. This was done by calculating the time trend in annual loads using least-squares linear regression, and using the resulting equation to estimate the mean annual load for 1985 and 1995.

Results

Losses estimated by the EPIC runs and the loads derived from water quality data (WQD) are listed in Table 3.

Absolute results. The EPIC model substantially and consistently over-predicts the particulate parameters SS, TKN, and PP, as well as soluble P, and consistently under-predicts N023. As a result, the ratios of organic N to nitrate predicted by the EPIC model (4 to 10, depending on river and year) compare very poorly with those calculated from the water quality data (0.25 to 0.36). These discrepancies are too large to be accounted for by the differences between the modeled and measured parameters described earlier.

The EPIC model generally over-predicts particulate parameters by a factor of 4 to 8. Because the EPIC model predicts edge of field loads, the difference could be due to delivery losses in the tributary system. In-stream delivery losses are poorly understood, but delivery percentages of 10 to 25% may be reasonable. Thus, differences in scale between modeling (edge of field) and monitoring (large watershed) may be adequate to explain the differences in results for particulate parameters.

The nitrate parameter predicted by EPIC is nitrate loss in surface runoff. The study watersheds are extensively tiled, and the drain tiles are an important pathway for nitrate delivery to the tributary network. It is reasonable to hypothesize that the failure of EPIC to model the most important pathway of nitrate export from these fields is the main reason for the observed underestimation. Unlike the particulate parameters, delivery losses of nitrate within the tributary network should be minor, particularly during high-flow periods when most of the nitrate is exported.

Relative Results. Models represent real world phenomena, and models may successfully provide this representation if they accurately depict the relative amount of change between alternative scenarios. The ability of EPIC simulations can be gauged to represent changes in river tributary water quality by expressing the modeled and monitored values as a per-

Table 3. EPIC-calculated losses and estimated annual loads derived from water quality data (WQD) for cropland, Maumee and Sandusky River Basins, 1985 and 1995.

	Maumee		Sandusky	
	1985	1995	1985	1995
	t/ha		t/ha	
1. Soil loss, EPIC	3.85	2.69	5.34	4.14
Suspended sediment, WQD	0.69	0.65	0.73	0.59
EPIC/WQD	560%	*410%*	730%	700%
	Kg/ha		Kg/ha	
2. NO_3 loss in surface runoff, EPIC	4.90	5.97	5.34	5.81
Nitrate plus nitrite, WQD	16.31	18.57	16.6	18.6
EPIC/WQD	30%	30%	9	2
3. Organic N loss with sediment, EPIC	48.4 7	27.7 2	34.2 2	23.8 2
Total Kjeldahl nitrogen, WQD	5.81	5.05	5.9	4.73
EPIC/WQD				
4. Soluble P loss in runoff, EPIC	1.1 0	1.2 8	1.2 0	1.25
Soluble reactive phosphorus, WQD	0.21	0.11	0.21	0.1 0
EPIC/WQD				
5. P Loss with sediment, EPIC	8.72	4.88	6.37	4.45
Paniculate phosphorus, WQD	1.16	1.07	1.19	1.10
EPIC/WQD	750%	460%	530%	*400%*

cent of their corresponding 1985 levels. Results of this transformation are shown in Figure 3.

In every case but soluble P, EPIC correctly predicted the direction of change. The failure to predict direction of change for soluble P probably reflects the assumptions that phosphorus fertilizer rates were affected only by crop mix. In fact, farmers may have reduced phosphorus application rates on all crops during this period, and this change was not accounted for in EPIC simulations.

Although EPIC was not very successful at predicting the absolute loads of nitrate, it predicted the relative change in nitrate between 1985 and 1995 better than it did for any other parameter. For particulate parameters, EPIC tended to over-predict the amount of relative change (Figure 3). This might be due to the lag time in the watershed between changes in management and changes in particulate matter, which would not be accounted for in the EPIC model.

Finally, it is noted that while^ the water quality data indicates larger decreases in particulate parameters in the Sandusky than in the Maumee, the EPIC model predicts the opposite. While it is a consistent pattern, this observation has no obvious explanation.

Conclusions

We compared EPIC simulations of pollutant emissions in the Maumee and Sandusky River basins under 1985 and 1995 land use and cropping patterns with unit area loads derived from detailed water quality data at integrator stations near the mouths of these rivers. Our results indicate that relative changes in observed pollutant concentrations are closely correlated to our estimates of relative changes in pollutant emissions from farms, which have been caused by changes in farming practices

However, there are large differences

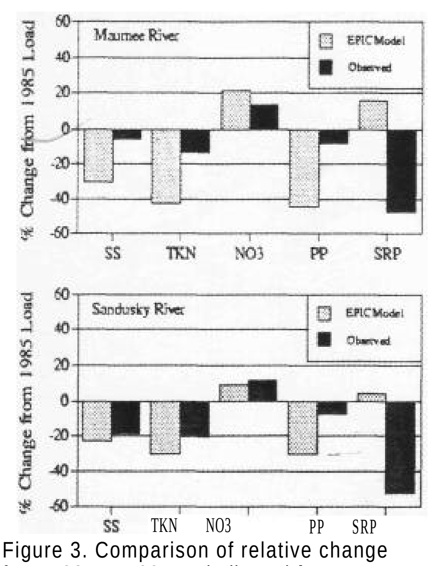


Figure 3. Comparison of relative change from 1985 to 1995 as indicated **by** water quality monitoring and as predicted b*-••*•" EPIC model.

between the absolute values of pollutant emissions calculated by EPIC simulations and unit area loads derived from water. We believe these differences cannot be explained by errors of load estimation, errors in application of the EPIC model, or differences between the modeled and monitored parameters.

EPIC predicts direction of change better than percent of change, and percent of change better than absolute levels. From this analysis, it appears that EPIC can be used to represent relative changes in water quality parameters for tributaries with some accuracy.

We hypothesize that discrepancies in results for particulate parameters are because EPIC does not model in-stream delivery losses, but the observed loads are affected by these losses. Discrepancies in results for nitrate may be because EPIC does not accurately model tile runoff of nitrate, which is a major pathway of nitrate export in these watersheds. Discrepancies in soluble phosphorus results may reflect changes in phosphorus fertilizer application rates, which we were unable to model.

To model pollutant loads at a large watershed scale, better understanding is needed of the extent and timing of delivery of particulate and dissolved loads within the tributary network. For these watersheds, better understanding is needed of relative importance of surface and tile-drainage pathways of export of nitrate from fields, and this understanding must be incorporated into models.

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