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NONPOINT SOURCE POLLUTION POTENTIAL IN AN AGRICULTURAL WATERSHED IN NORTHWESTERN PENNSYLVANIA[1]

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ABSTRACT: A 155,947 ha portion of the Shenango River watershed in western Pennsylvania was evaluated as to the potential impact of agriculture drainage on water quality. Approximately a third of the area is being used as either cropland or pasture with approximately an equal percentage in forest lands. Eleven subwatersheds were evaluated as to their potential for nonpoint source pollution according to the criteria established by the Pennsylvania Department of Environmental Resources for the Chesapeake Bay Pollution Abatement Program. The individual components and overall rating for each subwatershed were then evaluated as to their correlation with four water quality variables based on 104 samples collected at 26 sampling stations throughout the watershed. There was a significant correlation between the overall rating factor for each subwatershed and each of the four water quality variables. In general, the watershed delivery factor, animal nutrient factor, and management factors were correlated with fecal coliform and phosphorus in the receiving streams, whereas the ground water delivery factor appeared to be more important in determining nitrate concentrations in these streams. These results indicate that manure and nutrient management, along with the exclusion of livestock from streams and the enhancement and/or replacement of riparian wetlands, are important approaches in reducing agricultural impacts in fresh water ecosystems.
(KEY TERMS: agriculture; aquatic ecosystems; nonpoint source pollution; water quality; watershed management.)

INTRODUCTION

Over the last several decades, it has been documented that agriculture is a major contributor to the degradation of surface and ground water systems in the United States, as well as elsewhere in the world (Clark *et al.*, 1985; Diebel *et al.*, 1992; EPA, 1983, 1987; Hill, 1985; Macharis, 1985; OECD, 1985; Reay *et. al.*, 1992; Schaller and Bailey, 1985; Tim *et al.*, 1992). Clark *et al.* (1985) estimated that nonpoint source (NPS) pollutants, primarily from agriculture, account for 73 percent of the Biochemical Oxygen Demand (BOD), 83 percent of the bacterial loads, and 92 percent of the suspended sediments in waterways in the United States. Moreover, the EPA (1987) estimated that 57 percent of the lake area, 64 percent of the river miles, and 19 percent of the estuarine areas are adversely impacted by the discharges from agricultural lands. Macharis (1985) indicated that croplands generate a large portion of nutrient load in the Chesapeake Bay drainage basin, and agriculture is by far the major contributor to NPS pollution throughout this watershed. Hill (1987) reported that nitrogen concentrations in the runoff from agricultural lands in North Carolina were four to five times greater than they were from a forested watershed.

Section 208 of the Federal Water Pollution Control Act (PL 92-500), as amended by the United States Congress in the Clean Water Act of 1977, as well as the Pennsylvania Clean Streams Law as amended in 1980, recognizes that nonpoint sources are major contributors to sediment, bacteria, and nutrient loads of fresh water ecosystems. In addition, these nonpoint sources from agriculture may also contain a variety of other pollutants.

The Shenango River Watershed drains a total of 170 km^2 in western Pennsylvania. The 1990 water quality assessment completed by the Pennsylvania Department of Environmental Resources Bureau of Water Quality Management indicated that approximately 3 percent, or 21 km of the 713 km of degraded streams in the Ohio River Drainage Basin, are impacted by agriculture. However, of the 22.2 km of streams assessed in the Shenango River subwatershed, 14.7 m or 6.2 percent are degraded by

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agriculture, with the remainder being impacted by industrial and urban sources.

To address the impacts of agriculture on water quality within the Shenango River Watershed, the current study (1) identified potential sources of non-point pollution within 11 subwatersheds in the drainage basin, (2) ranked these subwatersheds as to their potential for NPS pollution, and (3) determined the correlation and impact of these factors on water quality in receiving streams.

STUDY AREA

Only that portion of the Shenango River Watershed located within Mercer County was addressed in the current study. The study area was located in the Glaciated Provence of the Allegheny Plateau situated in northwest Pennsylvania (Figure 1). Soils within the study area are derived from glacial tills and are generally poorly drained, with over 25 percent being classified as hydric with seasonally perched water tables (Cunningham *et al.*, 1983). Extensive tile drainage systems were installed from 1945 into the mid 1970s to improve agricultural production and/or to bring new fields into production.

Drainage patterns in the watershed are also influenced by previous glaciation. Prior to preglaciation, the drainage was predominantly toward the north and to the Atlantic Ocean by way of the St. Lawrence River (Shepps *et al.,* 1959), but a reversal of drainage patterns occurred when stream channels became filled or partially filled with glacial material. The formation of new channels on top of the glacial till resulted in low gradient stream channels, characterized by wide, flat flood plains and numerous riparian wetlands (Poth, 1963).

Four major groundwater aquifers occur within the watershed (Schiner and Kimmel, 1976): (1) ground moraine aquifers containing calcium and sulfate ions, (2) shallow bedrock, (3) deep valley sediment and deep bedrock aquifers both having sodium bicarbonate characteristics, and (4) sodium chloride aquifers in rock strata underlying freshwater aquifers. Ground water recharge is almost entirely derived from precipitation and percolation through the various glacial and bedrock formations, and, hence, ground water quality may be impacted by surface contamination.

The Shenango River originates at the outflow from Pymatuning reservoir and, upon leaving, flows in a southerly direction for approximately 112 km, joining the Mahoning River south of New Castle to form the Beaver River.

Land use varied among the 11 subwatersheds, but, overall, agriculture and woodlots each comprised approximately 34 percent of the 155,947 ha study area, with wetlands and/or abandoned fields and urban areas comprising 27 and 6 percent of the watershed, respectively. Agricultural lands comprised over 40 percent of the land use in four of the 11 subwatersheds – Otter (subwatershed 4), Pymatuning (subwatershed 7), Neshannock (subwatershed 10), and Little Neshannock Creeks (subwatershed 11) – and between 14 and 40 percent in the other seven subwatersheds (Table 1). Dairy farming was by far the largest agricultural enterprise within the study area. Nine hundred and fifty farms were surveyed, and of these, 645 or 67.9 percent were dairy operations, compared to 190 or 20 percent that were beef operations and the remaining 12 percent being grain or other agricultural enterprises. Of the 52,296 ha of agricultural lands within the watershed, 30,122 ha (57.6 percent) was used for row crops, with corn being the principal crop. Crooked Creek was the only subwatershed where forestlands exceeded 40 percent of the drainage area (Table 1). Wetlands and abandoned farm fields comprised between approximately 14 and 51 percent of the land use among the 11 subwatersheds. The largest concentration of urban areas was in the lower portions of the Shenango River (subwatershed 8) (Table 1).

METHODS

For the purpose of this study, the Shenango River drainage basin was divided into 11 subwatersheds (Figure 1). Soil characteristics were based on information within the county soil surveys (U.S. Department of Agriculture, 1971) and land use patterns determined from 1988 aerial photographs, the Pennsylvania Cooperative Extension Service, and landowner interviews.

Water quality information was based on 104 samples obtained from 26 sampling points within the watershed (Figure 1), augmented by water quality information obtained from databases maintained by the Pennsylvania Department of Environmental Resources and the Mercer County Conservation District. Water samples were collected between 0800 and 1000 hr in sterile 250 ml polyethylene bottles, and all analyses were completed by an Orion Nitrate-Ion electrode; phosphorus was determined according to ascorbic acid procedures as described by Greenberg *et al.* (1992). Fecal coliform concentrations were determined according to the most probable number (MPN) multiple tube fermination procedure as described by Greenberg *et al.* (1992). Dissolved oxygen was

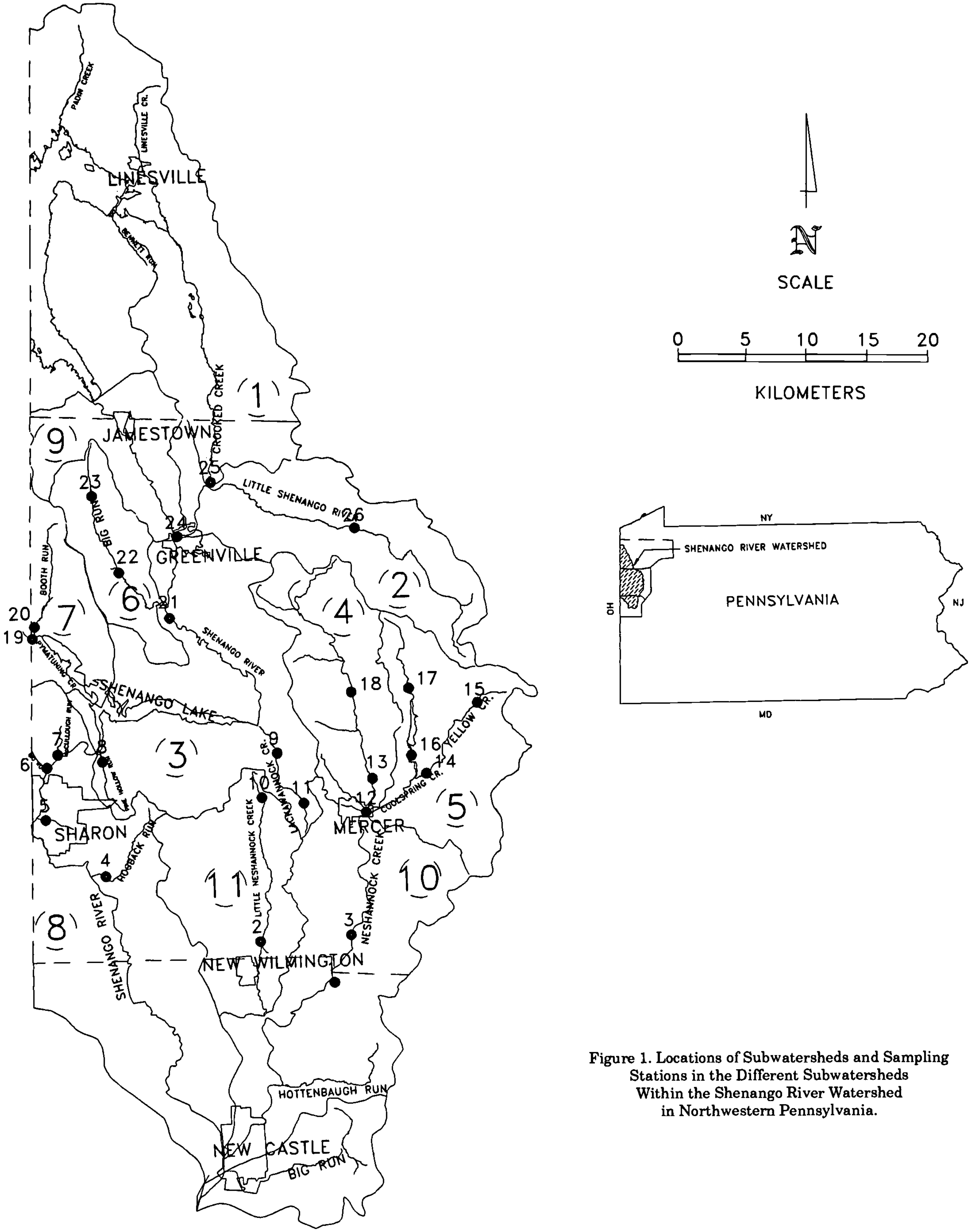

Figure 1. Locations of Subwatersheds and Sampling Stations in the Different Subwatersheds Within the Shenango River Watershed in Northwestern Pennsylvania.

TABLE 1. Land Use in the Different Subwatersheds in the Shenango River Subwatershed.

Subarea Watersheds	Farmland		Forestland		Urban		Wetlands		Total	
	ha	%	ha	%	ha	%	ha	%	ha	%
1. Crooked Creek	2,538	26.7	4,400	46.4	209	2.2	2,339	24.7	9,486	100
2. Little Shenango River	5,654	34.9	6,077	37.5	345	2.1	4,136	25.5	16,212	100
3. Shenango Lake	7,140	30.7	6,781	29.1	1,532	6.6	7,828	33.6	23,281	100
4. Otter Creek	5,016	42.6	3,464	29.4	206	1.7	3,086	26.2	11,772	99.9
5. Coolspring Creek	4,478	33.9	4,232	32.1	0	0.0	4,492	34.0	13,202	100
6. Big Run	942	13.7	2,227	32.5	210	3.1	3,482	50.8	6,861	100.1
7. Pymatuning Creek	2,759	43.0	1,835	28.6	0	0.0	1,822	28.4	6,416	100
8. Shenango River Reach 1	7,268	24.6	9,490	32.1	5,783	19.6	6,983	23.7	29,524	100
9. Shenango River Reach 2	2,354	39.6	2,153	36.2	241	4.1	1,192	20.1	5,940	100
10. Neshannock Creek	8,759	43.3	7,559	37.4	1,138	5.6	2,775	13.7	20,231	100
11. Little Neshannock	5,388	41.3	4,160	31.9	202	1.5	3,302	25.3	13,052	100
TOTAL	**52,296**		**52,378**		**9,866**		**41,437**		**155,947**	
Percent of Watershed Studied		**33.5**		**33.6**		**6.3**		**26.6**		**100**

determined in the field by the modified Winkler iodometric procedure (Greenberg *et al.*, 1992) and converted to percent saturation as described by Welch (1948). In addition, fecal coliform and nitrate concentrations were determined for 68 private water supplies in Mercer County.

To assess the NPS pollution from agriculture in a watershed, a rating system was developed that accounts for the relative contributions from surface (20 percent), ground water (15 percent), livestock concentrations (25 percent), and the degree of management practiced by farmers within the watershed (40 percent) (Pennsylvania Department of Environmental Resources, 1990). Agriculture intensity was determined from 1988 (three-year old) aerial photographs, soils maps using a dot grid matrix, existing farm plans, Livestock Reports, on-farm interviews, and field observations. These data were then used to rate the 11 subwatersheds according to the criteria used by the Pennsylvania Department of Environmental Resources (1990) to assess potential agricultural impacts on aquatic systems:

$$RF = 20\,(WD/WD\ Max) + 25\,(AN/AN\ Max)$$
$$RF = +\ 15\,(GD/GD\ Max) + 40\,(MF/MF\ Max)$$

where RF = Rating Factor; AN = Animal Nutrient Factor; WD = Watershed Delivery Factor; GD = Ground Water Delivery Factor; MF = Management Factor; and Max = Maximum value computed for each factor for all subwatersheds.

The maximum values and minimum values were used to "normalize" the results to insure that no one value unduly influenced the Rating Factor. The factors used in the calculations of the various components of the NPS pollution rating factor are described in the Appendix.

The relationships among the various components of the NPS pollution rating factor and water quality parameters were analyzed by a Pearson correlation analysis, least square regression analysis, and a partial correlation analysis according to the procedures described by Brown and Downhower (1988) and Snedecor (1959). An alpha level of 0.05 or less was used as significant for all procedures.

RESULTS AND DISCUSSION

Livestock concentrations along with the storage and disposal of manure are principal sources of bacteriological and nutrient contamination of surface and ground water, but the nutrient content of manure may also be an asset if properly applied to croplands as a fertilizer. The majority of farmers within the study area did not apply practices designed to protect water quality within the watershed. For example, of the 190 farmers interviewed in the current study, 55 percent did not exclude livestock from streams and only 7 percent had an effective nutrient management plan. Although 97 of the 190 farmers interviewed indicated that manure was accounted for in their fertilizer applications, they did not have their manure analyzed for nutrient availability. Based on the number of animal units within the watershed, 435,000 metric tons of manure would be produced annually, which is equivalent to 2447 tons of nitrogen and 1198 tons of phosphorus available for application on agricultural lands within the watershed. Dairy cattle comprised a total of 21,922 or 60.6 percent of the animal units, producing 297,622 tons of manure/year and 1489 metric tons or 60.9 percent of the nitrogen and 595.1 metric tons or 49.7 percent of the phosphorus being applied to agricultural lands within the watershed. Poultry comprised 1687 or 4.7 percent of the animal units and produced 3.9 percent of the manure, producing 10.5 percent and 14.3 percent, respectively, of the nitrogen and phosphorus available for agricultural applications (Table 2). However, since poultry were concentrated in the Crooked Creek subwatershed (Watershed 1), they represented a potential NPS pollution problem in this portion of the watershed.

Subwatershed Rating

The numerical rating among the subwatersheds determined by using Equation (1) varied from 62.8 to 79.2 (Table 3), which according to the standards established for the Chesapeake Bay watershed (Pennsylvania Department of Environmental Resources, 1990) would indicate that all drainage basins had a medium to high potential for NPS source pollution from agriculture. The variation in the NPS pollution rating factor among the different subwatersheds reflects differences in drainage patterns (stream density), ground water geology, and livestock, as well as the degree of management by farmers within the watershed. For example, the concentration of a 300,000 unit poultry operation in the Crooked Creek subwatershed (Subwatershed 1) was the principal reason this watershed received the highest rating for NPS pollution from agriculture, whereas, in the other subwatersheds, watershed delivery and the lack of management by landowners were the principal factors affecting the final ranking. In any watershed, the number of animal units and management are the only factors that can be altered to reduce the impact from agricultural NPS pollution, with management being the most important. For example, the exclusion of livestock from streams and wetlands, controlled runoff from feedlots, and the proper storage and disposal of manure would reduce the NPS pollution from agricultural lands.

RELATIONSHIP BETWEEN WATER QUALITY AND NONPOINT SOURCE POLLUTION RATING FACTOR

The water quality within the 11 subwatersheds all exhibited some degree of degradation resulting from

TABLE 2. Number of Animal Units, Product, and Nutrient Value of Manure Available for Land Application in the Shenango River Watershed.

	Livestock Information				Manure Production			Nutrient Value of Manure						
								Kg/Ton			Tons/Years*			
Type	Avg. Wt. (Kg)	Farm (No.)	Animals (No.)	An. Units (No.)	Rate Kg/ A.U.	Daily Tons/ Da	Annual Tons/ Yr	N	P	K	N	P	K	Percent N-P-K
Dairy	595	645	11,007	14,430	37.2	537.2	196,080.4	5	2	4	980.4	392.2	784.3	0.5-0.2-0.4
Heifers	318		10,703	7,492	37.2	278.9	101,804.3	5	2	4	509.0	203.6	407.2	0.5-0.2-0.4
Beef	454	190	9,762	9,762	27.2	265.9	97,059.7	6	4	5	533.8	339.7	485.3	0.55-0.35-0.5
Swine	68	31	5,908	886	29.5	26.2	9,545.4	7	6	6	66.8	52.5	52.5	0.7-0.55-0.55
Poultry	2	6	337,320	1,687	27.7	46.7	17,048.7	15	10	5	255.7	170.5	85.2	1.5-1.0-0.5
Sheep	45	26	4,162	416	18.2	7.6	2,758.7	12	4	10	33.1	11.0	2.8	1.2-0.4-1.0
Horses	499	52	1,392	1,531	20.4	31.3	11,418.1	6	3	5	68.5	28.5	51.4	0.6-0.25-0.45
Totals		**950**	**380,254**	**36,204**		**1,193.7**	**435,715.3**				**2,447.4**	**1,198.0**	**1,868.7**	

*Based on Pennsylvania Agronomy Guide, 1992-1993.
Animal Unit = 400 Kg Live Weight.
Annual Manure Production = Animal Units x Rate x 365.

TABLE 3. Criteria Used in the Development of the Nonpoint Source Pollution of Eleven Subwatersheds Evaluated Within the Shenango River Watershed, Mercer County, Pennsylvania.

	Factors				
Subwatershed	20 Watershed Delivery	25 Animal Nutrient	15 Ground Water Delivery	40 Management	Overall Rating
Crooked Creek	12.9	25.0	13.9	27.4	79.2
Little Shenango	17.7	5.0	15.0	38.1	75.1
Shenango Lake	12.3	5.9	8.87	39.1	66.1
Otter Creek	20.0	6.6	10.4	38.9	75.9
Coolspring Creek	16.0	5.0	8.3	4.0	69.3
Big Run	19.7	5.9	8.6	36.7	70.9
Pymatuning Creek	18.8	7.8	8.9	33.0	68.5
Shenango River I	17.2	5.9	8.5	38.0	69.6
Shenango River II	18.2	6.6	7.6	36.2	68.6
Neshannock Creek	16.8	4.6	8.8	37.2	67.5
Little Neshannock	14.1	3.4	8.5	36.8	62.8

NPS pollution from agricultural lands (Figure 2). Although phosphate and nitrate concentrations averaged less than 0.1 and 0.8 mg/liter, respectively (Figure 2), there was a significant correlation between these two parameters and the percent saturation of dissolved oxygen in the receiving streams (Table 4).

The median fecal coliform concentration was 1292/100 ml throughout the 11 subwatersheds, with the highest average concentration of 2028/100 ml occurring in the Little Shenango Watershed (Subwatershed 2). In all subwatersheds, except Coolspring Creek (Subwatershed 5) and Pymatuning Creek (Subwatershed 7), median fecal coliform concentrations exceeded 1100/100 ml (Figure 2). In contrast to nutrient concentrations, a significant correlation did not occur between fecal coliform concentration and percent saturation of dissolved oxygen in the receiving streams (Table 4).

Overall, there was a significant correlation between the NPS pollution rating factor and the four water quality parameters used to evaluate the streams within each subwatershed area (Figure 3, Table 5), but variations occurred among the individual components of the rating factor and the different water quality parameters (Table 5). Except for the animal nutrient factor (AN), fecal coliform concentrations were significantly correlated with all components of the overall rating factor (RF). Phosphate concentrations were significantly correlated with all components of the rating factor except the groundwater delivery factor (GD) (Table 5). The percent saturation of dissolved oxygen in the receiving stream was significantly correlated with all components of the rating factor except the watershed delivery factor (WD). It appears therefore that stream nitrate concentrations are a function of ground water discharges while fecal coliforms, phosphate, and dissolved oxygen are adversely impacted by overland flows.

An analysis of the relationship among the different components of the rating factors and the individual water quality parameters by a partial correlation analysis also revealed variations in the relative importance of the different rating factor components (Table 6) and water quality.

In regard to fecal coliforms, if there is no change in the watershed delivery factor but if an increase both in the animal nutrient levels and the watershed delivery factor occurs, there would be a corresponding increase in fecal coliform concentrations in receiving streams. On the other hand, a change in the animal nutrient levels and the ground water delivery factor would not significantly affect stream coliform concentrations, providing there were no changes in management practices. However, changes in the watershed delivery factor and animal nutrient levels along with changes in management practices all would significantly impact fecal concentrations in the receiving streams (Table 6). These factors would impact the overland flows, thereby transporting fecal coliforms in receiving streams.

In regard to phosphorus, when the number of animal units remains constant and variations occur in the management and watershed delivery factors, there would be an adverse impact on phosphorus concentrations in receiving streams. Similarly, if the ground water delivery factor remained constant and variations occurred in the animal units and the watershed delivery factors, this would also impact phosphorus concentrations in receiving streams. A change in the number of animal units along with the ground water delivery factor would significantly impact nitrate concentrations. The interaction

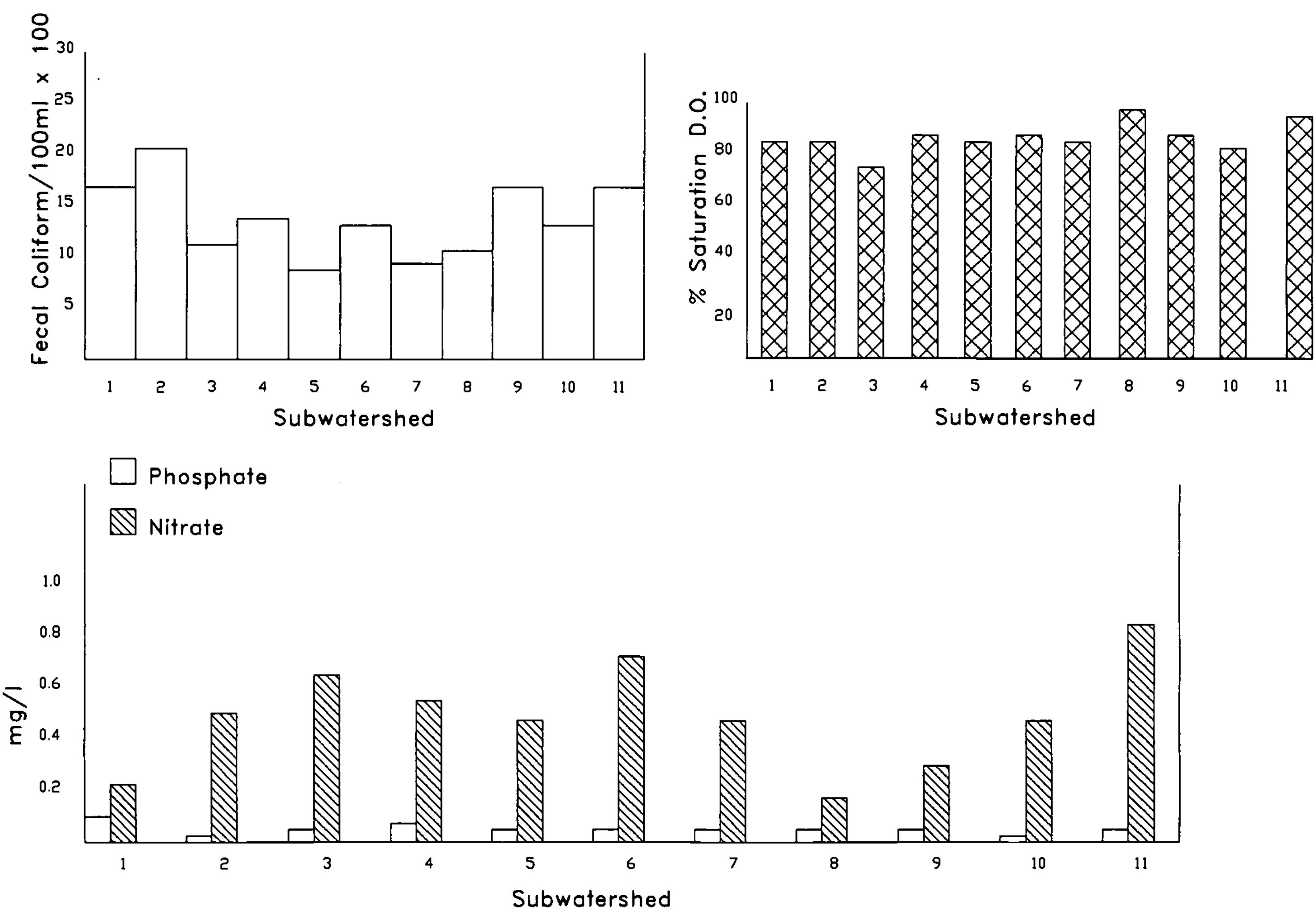

Figure 2. Comparison of Median Water Quality Characteristics Among the 11 Subwatersheds Within the Shenango River Watershed in Northwestern Pennsylvania (refer to Table 1 for names of each subwatershed).

TABLE 4. Correlations Between Four Water Quality Parameters Obtained from 104 Samples from 26 Stream Sampling Stations Within the Shenango River Watershed in Northwestern Pennsylvania.

	Fecal Coliform	Phosphate	Nitrate	Percent Saturation Oxygen
Fecal Coliform	–	0.331	0.324	0.370
Phosphate	0.331	–	0.26	–0.854*
Nitrate	0.324	0.260	–	0.698*
Percent Saturation Oxygen	0.370	–0.854*	–0.698*	–

*P < 0.01.

between these factors would also impact receiving streams (Table 5) since there is a significant correlation between nutrient concentrations and the percent saturation of dissolved oxygen in the receiving streams (Table 4).

GROUND WATER

A total of 68 private water supplies on farms in Mercer County were analyzed for fecal coliforms and

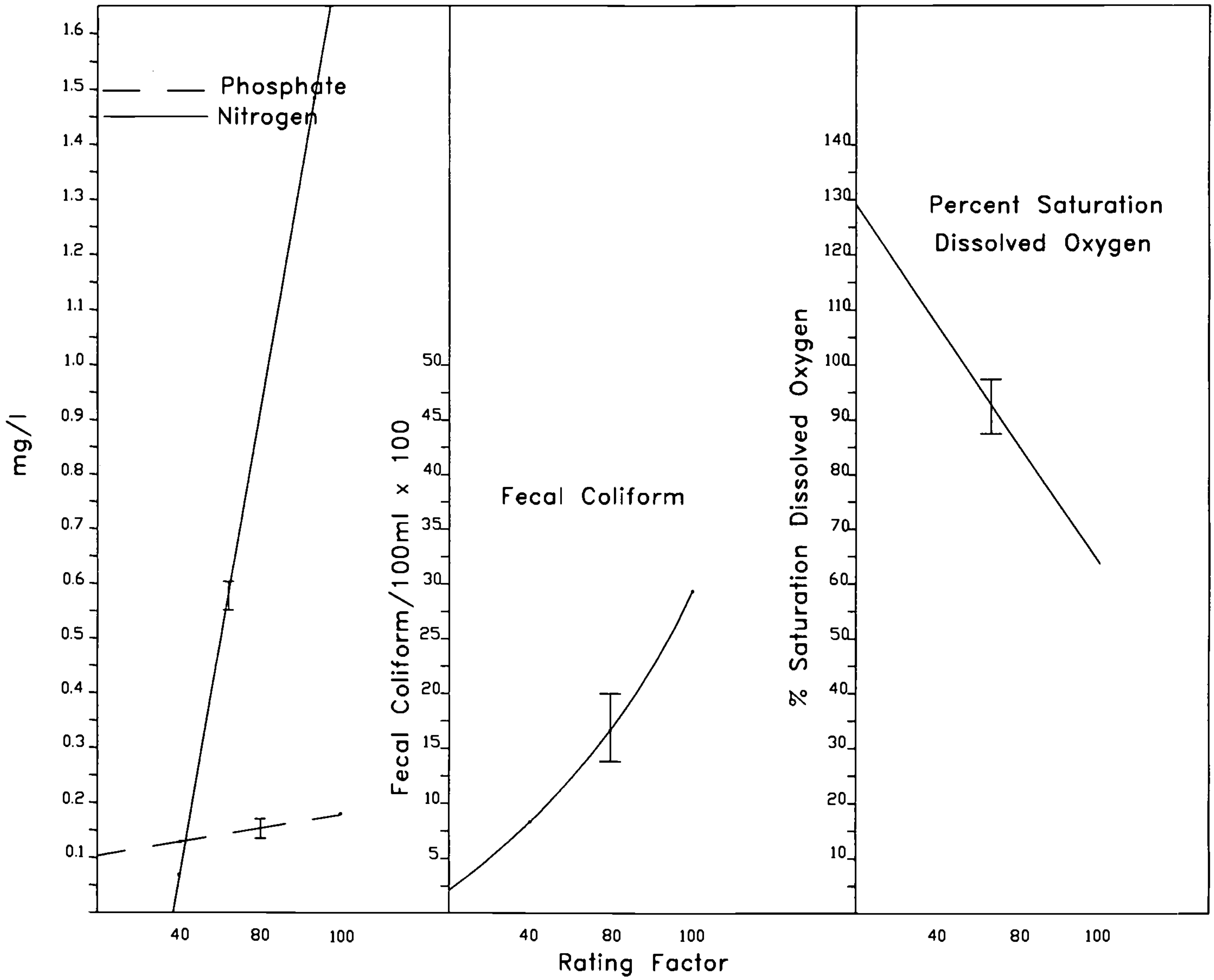

Figure 3. Relationship Between the Overall Rating Factor for Agricultural Nonpoint Source Pollution Potential and Four Water Quality Parameters.

TABLE 5. Correlation Coefficients Between the Different Components of the Agricultural Nonpoint Source Pollution Rating System and Four Water Quality Parameters Used in 104 Samples from 26 Streams Within the Shenango River Watershed.

	Fecal Coliform	Phosphate	Nitrate	Percent Stream Dissolved Oxygen
Watershed Delivery Factor (WD)	0.722*	0.558**	0.238	0.382
Animal Nutrient Factor (AN)	0.258	0.765*	0.194	0.579**
Ground Water Delivery Factor (GD)	0.421**	0.140	0.478**	0.406**
Management Needs Factor (MF)	0.598**	0.611**	0.359	0.477**
Overall Rating Factor (RF)	0.835*	0.603**	0.538**	0.624*

*P < 0.01.
**P < 0.05.

TABLE 6. Partial Correlation Between the Different Components of the Agricultural Nonpoint Source Rating Systems and from Water Quality Parameters Based on 104 Samples from 26 Streams Within the Shenango River Watershed in Northwestern Pennsylvania.

		Parameter			
Variables	Constant	Fecal Coliform	Phosphate	Nitrate	Percent Saturation
WD:AN	GD	0.788*	0.700**	0.162	0.315
AN:GD	WD	0.281	0.537**	0.454**	0.244
AN:GD	MF	0.0117	0.860*	0.0271	0.480**
GD:MF	AN	0.558**	0.790*	0.304	0.325
MF:WD	AN	0.934*	0.309	0.329	0.340
AN:WD	MF	0.643**	0.533**	0.132	0.607
MF:AN	GD	0.558**	0.784*	0.309	0.325
AN:GD	MF	0.267	0.484**	0.446**	0.181
MF:GD	WD	0.746*	0.644*	0.0823	0.382
GD:WP	MF	0.785*	0.378	0.00651	0.234

*P > 0.01.
**P > 0.05.

nitrates during the study, and of these, 22 or 32.3 percent tested positive for fecal coliforms and thus were regarded as unsafe for drinking. Four or 5.9 percent of the water supplies testing positive for fecal coliform also had detectable amounts (1 mg/l or greater) of nitrates in the sample. Of the five water supplies with detectable amounts of nitrate, only one did not test positive for fecal coliforms as well. All homes had on-lot sewage systems of varying ages and operating efficiency. Based on these results, it appears that improper land-use farming practices and possibly on-lot sewage systems will affect not only surface waters but also the quality of ground water supplies as well.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study, as well as previous studies (Brenner *et al.,* 1987, 1990, 1991; Hill, 1987; Macharis, 1985; Schlosser and Karr, 1981; Worthington, 1986), indicate the adverse impact of agricultural runoff on freshwater ecosystems, besides emphasizing the need for proper land and livestock management. Brenner and Artuso (1981) found that in areas with no or limited concentrations of manure and livestock, fecal coliforms and nutrient concentrations in the discharges from subsurface tile drains were low, whereas, in areas where cattle were concentrated, the concentrations of these pollutants were elevated in the discharges. A variety of practices designed to reduce erosion may also decrease nutrient influx into receiving streams, but the effectiveness of these "traditional" conservation practices have been shown to vary seasonally (Brenner *et al.,* 1990). For example, strip cropping and contour strips were only effective during the spring, not during the other seasons of the year. Grass waterways tended to decrease phosphate levels throughout the year, whereas earthen manure storage structures tended to increase phosphate levels in receiving streams – especially after major storm events during summer, winter, and early spring. In saturated soil conditions, typical of many glaciated soils, seepage from these impoundments can occur because of the pressure head behind the embankment (Sowers, 1979). To be effective, a nutrient management plan should be designed to reduce the amount and time of manure storage, and all storage structures should be constructed with impervious linings.

Previous studies (Brenner *et al.,* 1991; Hammer, 1989; and Hey, 1987) demonstrated the effectiveness of riparian vegetation and natural and constructed wetlands in reducing nutrient loads from NPS pollution sources in receiving streams. Based on the results of these studies, prime consideration should be given to development of wetlands for water and nutrient management on agricultural lands.

Although there is neither a large portion of cropland within the Shenango watershed nor large concentrations of livestock, there is appreciable potential for NPS pollution from agriculture. Major problems throughout the watershed include pastures where livestock have free access to streams, large concentrations of animals resulting in nutrient overloads in the soil, and tillage practices in or near water courses, as well as fertilizers being applied routinely rather than as needed. To reduce the impact of NPS pollution of fresh water ecosystems, natural and constructed wetlands along with other appropriate conservation and management practices should be incorporated into agricultural water quality management programs.

APPENDIX
SUMMATION OF CRITERIA USED FOR CALCULATION OF POLLUTION RATING FACTOR

Agriculture intensity data were obtained from 1988 aerial photographs, soil maps, existing farm plans, crop and livestock reports, on-farm interviews, and field observations. The Nonpoint Source Pollution Rating Factor was calculated for each subwatershed according to this formula:

$$RF = 20\,(WD/WD\ Max) + 25\,(AN/AN\ Max) + 15\,(GD/GD\ Max) + 40\,(MF/MF\ Max)$$

where RF = Rating Factor, AN = Animal Nutrient Factor, WD = Watershed Delivery Factor, GD = Ground Water Delivery Factor, MF = Management Factor, and Max = maximum value computed for each factor for all subwatersheds.

The maximum values were used to "normalize" the results to ensure that no one value unduly influences the Rating Factor. Each variable factor is expressed as a relative value in order to compare each subwatershed with each of the others in the Shenango River Watershed:

$$\text{Watershed Delivery Factor } (WD) = 20\,(Sd/Sd\ Max + RCI/RCI\ Max + HEL/HEL\ Max)$$

where:

Stream density (sd) is determined for each subwatershed by measuring the length of all perennial streams identified on the 7.5 USGS topographic maps within the subwatershed boundary. The cumulative stream length is then divided by the subwatershed area.

Row crop intensity (rci) is determined by dividing the subwatershed acreage in row crops by the total subwatershed area.

Highly erodible land (hel) is a measure of the potential erodibility of soils in the subwatershed and is dependent on slope length and steepness (LS), rainfall intensity (R), and the inherent erodibility of the soil type (K).

The HEL INDEX = 8T/RK

where T = soil loss tolerance value. Measured in metric tons per ha per year is the maximum amount of soil that can be lost due to erosion and still sustain long-term productivity. Each soil type has been assigned a "T" value by the U.S. Soil Conservation Service.

If the LS factor exceeds the HEL INDEX for a given soil type, the land is considered to be highly erodible. The LS factors for the slopes of soil types identified in the Soil Survey for each county were determined randomly, selecting 40 ha sample blocks in each subwatershed from soil maps and aerial photographs and then measuring with a planimeter and area of the various soil mapping units occurring on cropland . . . expressed as a percentage of each soil type within the major mapping unit for the subwatershed. Mapping units accounted for at least 80 percent of the subwatershed cropland acreage. The average LS factor was divided by the HEL index for each of the mapping units and multiplied by the percentage of the acreage represented by that mapping unit. The sum of these values was used as *hel factor* for each subwatershed.

Animal Nutrient Factor

$$(AN) = 25\ \frac{\text{[sum of (animal units x nutrient factor for each animal type]}}{\text{cropland/hayland acreage}}$$

This factor was considered to be both a surface and a ground water potential pollution factor. It is a means of estimating the pollution potential of livestock operations by considering the number and types of animals in each subwatershed, the amount of waste generated, and the amount of land available for spreading manure. The various animal types were equated by assigning a nutrient factor per the following:

Animal Type	Nutrient Factor (per animal unit)
Dairy Cow	1.0
Beef	1.0
Horse	0.7
Hog	1.4
Sheep	1.1
Poultry	2.7
Veal	0.6

Note: 1 animal unit = 400 kg live weight.

Animal waste production for each animal type was then multiplied by the nutrient (nitrogen and phosphorus) in the manure (1992 Pennsylvania Agronomy Guide). The resulting nutrient values were standardized by using a base value of 1.0 for dairy. The nutrient values for young animals were adjusted according to the average weight of the animal.

The number of animals and their average weight was obtained from crop and livestock reports and consultation with extension service personnel. The *animal nutrient factor* is obtained by multiplying the animal units in the subwatershed by the nutrient factor for each animal type, summing these products, and dividing by the cropland-hayland-pastureland acreage in the subwatershed.

Ground Water Delivery Factor (GD) =
15 (AG/AG Max + SIP/SIP Max)

This ground water potential factor includes aquifer geology (AG) and soil leaching potentials (SIP).

Aquifer Geology (ag) – values for various geology types were assigned the following values (Pennsylvania Department of Environmental Resources, 1990):

Carbonate Rock	10
Glacial Sand and Gravel	8
Glacial Till Deposits	4
Noncarbonate Rock Formations	2

The ag was then calculated by determining the geology associated with each soil mapping unit in the sample blocks and assigning a value from the list above to it. The sum of all the types was the ag or each subwatershed.

Soil Leaching Potential (slp) – estimates the ability of the soil to absorb or retain nutrients and influences the ability of these pollutions to reach the ground water. "slp" values developed by the SCS are listed below:

Nitrogen Leaching (NL)

Values	Score
High	10
Moderate	7
Low	4
Very Low	1

The appropriate value was assigned to the soil types obtained in the 40 ha sample blocks, summed, and the sum multiplied by the percent of the soil type in each subwatershed.

Management Needs Factor (MF) = 40 weighted value

Management can reduce the pollution potential inherent in the subwatershed soils and animal factors. It is a combination of field conservation practices and animal and nutrient management. It is based on the results of the farmer interviews and is the most subjective of the ranking factors. Each of the four subfactors were assigned a value of 10 for farms with little or no management, 2-9 for farms with some management, and 1 for farms with full management. The "MF" was obtained by summing the accumulated scores for each of the subfactors on each farm evaluated in the subwatershed and dividing by the number of farms evaluated.

Judgment in assigning values to the subfactors were based on the following definitions:

S & W Conservation Practices

- little/no management – no conservation plan; few practices from plan implemented; observed evidence of major stream problems.
- full management – fully implemented conservation plan; extensive use of conservation tillage; cover cropping; no visual evidence of stream problems.

Animal Management

- little/no management – livestock have unlimited access to streams; evidence of streambanks being broken down by animals; overgrazed pastures; barnyards barren of vegetation; extensive manure buildup in buildings where animals are housed.
- full management – limited access to streams; rotational grazing system implemented; vegetated riparian zones; concrete or other impervious material used where animals are concentrated.

Nutrient Management

- little/no management – little or no routine soil testing; if livestock, no manure tests taken; no consideration of where or how much manure is spread; no nutrient management plan; does not follow soil test recommendations.
- full management – has nutrient management plan and follows it to the best of his/her ability; has some manure storage facility; follows routine soil tests; and has manure analyzed for nutrient availability.

LITERATURE CITED

Brenner, F. J. and F. Artuso, 1981. Chemical and Biological Characteristics of Agricultural Drainage Tile Outflows. Water Pollution Control Assoc. Magazine, Sept-Oct.:46-52.

Brenner, F. J., R. P. Steiner, and J. J. Mondok, 1987. Use of Water Quality Models to Predict Non-Point Source Pollution In An Agricultural Watershed. *In:* Monitoring, Modeling and Mediating Water Quality, S. J. Nix and P. E. Black (Editors). American Water Resources Association, Herndon, Virginia, pp. 295-301.

Brenner, F. J., R. P. Steiner, J. J. Mondok, and R. J. McDonald, 1990. Non-Point Source Pollution: A Model Watershed Approach to Improve Water Quality. *In:* Water Resources in Pennsylvania: Availability, Quality and Management, S. K. Majumdar, E. W. Miller, and R. R. Parizek (Editors). Pennsylvania Academy of Science, pp. 70-84.

Brenner, F. J., J. J. Mondok, and R. J. McDonald, Jr., 1991. Impact of Riparian Areas and Land Use on Four Non-Point Source Pollution Parameters in Pennsylvania. J. Penn. Acad. Sci. 65:65-70.

Brown, L. and J. F. Downhower, 1988. Analysis in Behavioral Ecology. Sinauer Associates, Inc., Sunderland, Massachusetts, 194 pp.

Clark, E. H., H. H. Haverkamp, and W. Chapman, 1985. Eroding Soils: The Off Farm Impacts. The Conservation Foundation, Washington, D.C.

Commonwealth of Pennsylvania, 1937. Water Quality Standards. Title 25, Subpart C, Article II, Chapter 93. P.L. 1987 as amended, pp. 93.1-93.130, Harrisburg, Pennsylvania.

Cunningham, R. L., G. H. Lipscomb, E. J. Peterson, R. F. Ciolkosz, R. D. Shipp, R. Pennock, Jr., R. C. Cronce, and C. J. Sacksteder, 1983. Soils of Pennsylvania, Characteristics, Interpretations and Extent. The Pennsylvania State University. College of Agriculture, Agricultural Experiment Station, University Park, Pennsylvania, 135 pp.

Diebel, P. L., D. B. Taylor, S. S. Batie, and C. D. Heatwole, 1992. Low-Input Agriculture as Ground Water Protection Strategy. Water Resources Bulletin 28(5):755-762.

Environmental Protection Agency, 1983. Chesapeake Bay: A Frame Work for Action. Chesapeake Bay Program. Environmental Protection Agency Chesapeake Bay Liaison Office, Annapolis, Maryland.

Environmental Protection Agency, 1987. Nonpoint Source Guidance. Nonpoint Source Branch, Office Water Regulations and Standards, U.S. Environmental Protection Agency, Washington, D.C., 35 pp.

Frey, R. F., 1990. Water Quality Assessment (305 (b) Report). Pennsylvania Department of Environmental Resources, Bureau of Water Quality Management, Harrisburg, Pennsylvania, 106 pp.

Greenberg, A. E., L. S. Clesceri, and A. D. Eaton, 1992. Standard Methods for the Examination of Water and Wastewater (28th Edition). American Public Health Association, American Water Works Association and Water Environment Federation.

Hammer, D. J., 1988. Constructed Wetlands for Treatment of Agricultural Waste and Storm Water. *In:* Wetland Ecology Conservation: Emphasis in Pennsylvania, S. K. Majumdar, R. P. Brooks, F. J. Brenner, and R. W. Tiner, Jr. (Editors). Pennsylvania Academy Science, pp. 33-44.

Hey, P. L., 1987. Construction of Wetlands for Stream Water Quality Improvements. *In:* Monitoring, Modeling and Mediating Water Quality, S. J. Nix and P. E. Black (Editors). American Water Resources Association, Herndon, Virginia, pp. 123-176.

Hill, C. L., 1987. Monitoring the Effects of Land Management Practices on Water Quality in Gulford County, North Carolina. *In:* Monitoring, Modeling and Mediating Water Quality, S. J. Nix and P. E. Black (Editors). American Water Resources Association, Herndon, Virginia, pp. 137-148.

Macharis, J., 1985. Chesapeake Bay Non-Point Source Pollution. *In:* Perspectives on Non-Point Source Pollution. United States Environmental Protection Agency, EPA 44015-85001.

OCED, 1985. The State of the Environment. Organization for Economic Cooperation and Development, Paris, France.

Pennsylvania Department of Environmental Resources, 1990. Criteria to Develop Ranking of Subwatersheds in 205(j) (5) Watershed Evaluations.

Pennsylvania State University, 1992. The Agronomy Guide. University Park, Pennsylvania, pg. 187.

Poth, P. W., 1963. Geology and Groundwater of the Mercer Quadrangle, Mercer, Lawrence, and Butler Counties, Pennsylvania. Groundwater Report W 16, Pennsylvania Geologic Survey, Harrisburg, Pennsylvania, 149 pp.

Reay, W. G., P. L. Gallagher, and G. M. Simmons, Jr., 1992. Groundwater Discharge and Its Impact on Surface Water Quality in a Chesapeake Bay Inlet. Water Resources Bulletin 28(6):1121-1134.

Schaller, F. W. and G. W. Bailey, 1985. Agricultural Management and Water Quality. Iowa State University, Ames, Iowa.

Schiner, G. R. and G. E. Kimmel, 1976. Geology and Ground-Water Resources of Northern Mercer County, Pennsylvania. Water Resources Report 33, Pennsylvania Geologic Survey, Harrisburg, Pennsylvania, 51 pp.

Schlosser, I. J. and J. R. Karr, 1981. Water Quality in Agricultural Watersheds: Impact of Riparian Vegetation During Base Flow. Water Resources Bulletin 17(2): 233-240.

Shepps, V. C., G. W. White, J. B. Droste, and R. D. Sitler, 1959. Glacial Geology of Northwest Pennsylvania. Commonwealth of Pennsylvania, Harrisburg, Pennsylvania, 136 pp.

Snedecor, G. W., 1959. Statistical Methods. Iowa State College Press, Ames, Iowa, 534 pp.

Sowers, V. C., 1979. Introductory Soil Mechanics and Foundations: Geotechnical Engineering (Fourth Edition). MacMillen Publishing Co., Inc., New York, New York, 615 pp.

Tim, U.S., S. Mostaghim, and V. O. Shanholtz, 1992. Identification of Critical Nonpoint Pollution Source Areas Using Geographic Information Systems and Water Quality Modeling. Water Resources Bulletin 28(5):877-887.

U.S. Department of Agriculture, 1971. Soil Survey of Mercer County, Pennsylvania. U.S. Government Printing Office, Washington, D.C., 125 pp.

Welch, P.S., 1948. Limnological Methods. McGraw-Hill, New York, New York, 381 pp.

Worthington, P., 1986. Regulatory Remedies for Agriculture Pollution. *In:* Effects of Land Use on Fresh Waters. Agricultural, Forestry, Mineral Exploitation, Urbanization, J. F. Solde and L. G. Solde (Editors). Ellis Howard Publishers, Chichester, United Kingdom, pp. 341-348.