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FACTORS AFFECTING NUTRIENT LOADS IN SOME IOWA STREAMS*

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Abstract—The export and concentration of inorganic nitrogen and total phosphorus from 34 watersheds in a northwestern Iowa lake district were measured during March 1971–August 1973. Annual nutrient losses were approximately 0.35 kg ha^{-1} P, 6.7 kg ha^{-1} NO_3-N, and 1.0 kg ha^{-1} NH_3-N. A statistical analysis of the relationship between land-use and plant nutrients was used to determine differences among streams. Animal units in feedlots were significantly correlated with phosphorus and ammonia nitrogen (mg l^{-1} and kg ha^{-1} yr^{-1}). Nitrate nitrogen was negatively correlated with the percentage of watershed in marshland. Tile drainage and surface runoff from grasslands, feedlots, cornfields, and soybean fields were analyzed for nitrogen and phosphorus in spring 1974; mean values are given.

INTRODUCTION

In a recent study of eutrophication in a group of lakes in northwestern Iowa (Jones, 1974), measurements were made of the plant nutrient loads for a number of tributary streams. Consistent differences were noted in the concentrations of phosphorus and nitrogen among streams. To determine the effect of land use on these differences, an inventory of each watershed was undertaken. This paper presents the results of an analysis of the relationship between land use and nutrient output.

METHODS AND MATERIALS

The study area is in the Iowa lakes region in Dickinson County, Iowa, and Jackson County, Minnesota (Fig. 1). It is in the Cary glacial drift of the Des Moines lobe and is enclosed by morainal topography. Seventy per cent of the land is devoted to row-crop agriculture or to livestock production; nearly 20% of the watershed is covered by lakes, ponds or marshes. Populated areas are served by a modern sewage-collection and treatment system that diverts human wastes from the basin.

Water samples were collected from the streams approximately every 10 days from March 1971 to August 1973. At collection time stream flow was estimated by measuring the average stream depth, width and velocity of flow. Additional samples of surface runoff and tile drainage were collected from selected areas within the watershed during spring 1974.

Chemical analyses were made on unfiltered samples. Orthophosphate phosphorus was determined by the stannous chloride method. Ammonia nitrogen was determined by the direct Nesslerization method and nitrate nitrogen by cadmium reduction. Prepared reagents for these analyses were purchased from Hach Chemical Company, Ames, Iowa. Starting in September 1971, total phosphorus analyses (Murphy and Riley, 1962) were made after persulfate oxidation (Menzel and Corwin, 1965). A high correlation ($r = 0.83$) of ortho and total phosphorus values was found after analysis of both forms on 750 samples. A least-squares regression line was calculated to convert early measurements to total phosphorus.

In 1974, samples of surface runoff were filtered through a type HA, 0.45 μm Millipore filter. Filtrate samples were analyzed for total filterable phosphorus (American Public Health Association, 1965) and total particulate phosphorus was obtained by difference.

Boundaries of individual watersheds were delineated from USGS topographic maps, and a land-use inventory

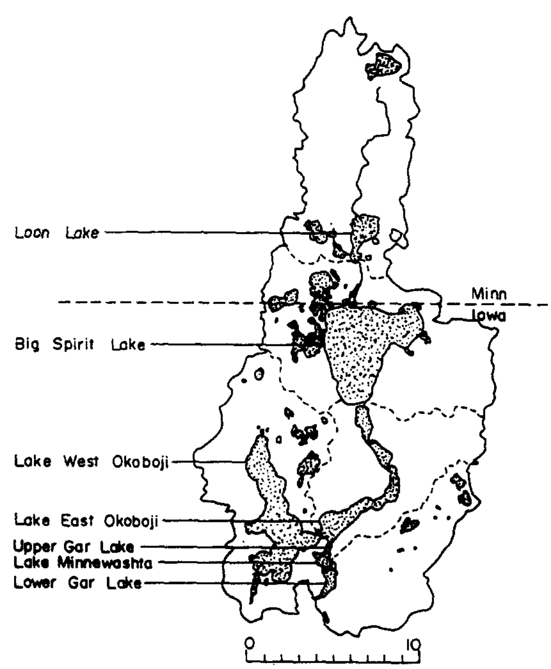

Fig. 1. Map of the watershed. Dashed lines indicate watershed boundaries.

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determined the areas in row crops (corn, soybeans and oats), grasslands (pastured and unpastured), marshland (including permanent water) and urban areas within each watershed. Livestock numbers in each watershed were determined and converted to animal units by using the U.S. Environmental Protection Agency formula (one animal unit being defined as the number of animals required to produce wastes with a biochemical oxygen demand equivalent to one beef steer). One animal unit consists of 1 beef animal, 0.7 dairy animal, 4.5 slaughter hogs, 35 feeder pigs, 12 sheep or lambs, 180 laying hens, or 55 turkeys.

RESULTS

Annual mean concentrations of total P, NO_3-N and NH_3-N from the 34 tributaries samples are given in Table 1. Weighted averages were found by dividing the accumulated total load by the accumulated total discharge. Output of N and P in kg ha^{-1} from 17 watersheds greater than 100 ha in area are given in Table 2. Outputs were determined by integrating flow and concentration measurements over time to yield annual losses from each watershed. Smaller watersheds were omitted from this analysis because most had intermittent flows and, subsequently, nutrient losses may not have been adequately measured by the sampling schedule. The land-use and livestock inventory for the 34 watersheds is presented in Table 3. Totals do not equal 100% because areas in roads, farmsteads and fence rows were not considered.

A linear model was used to assess the relationship between land-use practices on the watersheds and the N and P in the streams. A unique contribution, that part of the variability in a particular variable that can be ascribed to a given factor after adjusting for all other measured factors, was judged significant if the probability of the test statistic was equal to or less than 0.01.

Significant correlations between P and N concentrations at 34 stations and the land use variables measured are given in Table 4. Similar significant correlations between P and N losses (kg ha^{-1}) at 17

Table 1. Mean concentrations (mg l^{-1}) of total phosphorus, nitrate nitrogen, and ammonia nitrogen from the 34 tributaries sampled during 1971–1973

Station	P 1971	P 1972	P 1973	NO_3-N 1971	NO_3-N 1972	NO_3-N 1973	NH_3-N 1971	NH_3-N 1972	NH_3-N 1973
1	1.04	0.47	0.35	3.80	6.31	7.10	1.63	1.09	0.64
2	0.07	0.04	0.05	3.94	5.35	10.19	0.15	0.08	0.12
3	0.38	0.25	0.35	1.44	4.19	2.31	0.69	0.25	0.47
5	0.11	0.25	0.10	3.43	2.91	3.51	0.67	0.56	0.73
6	0.12	0.09	1.11	0.15	0.11	0.10	0.84	0.64	0.91
8	0.43	0.45	0.33	7.45	10.52	12.81	0.91	1.52	0.83
9	0.21	0.21	0.16	7.96	12.85	12.38	0.20	0.21	0.41
10	0.22	0.25	0.16	5.14	5.53	9.59	0.44	0.44	0.28
11	0.18	0.50	0.13	4.97	6.54	9.16	0.40	0.77	0.25
12	0.27	0.22	0.28	1.52	0.62	0.93	0.41	0.29	0.69
13	0.20	0.17	0.15	5.12	6.24	7.35	0.24	0.11	0.17
15	0.57	0.18	0.47	3.13	2.82	5.78	0.95	0.29	0.74
16	0.28	0.16	0.14	3.89	3.33	7.93	0.28	0.17	0.21
17	0.62	0.61	0.59	1.04	1.77	0.94	1.09	1.08	1.04
18	0.31	0.22	0.25	2.26	4.88	5.60	0.65	0.21	0.65
19	0.30	0.17	0.14	3.17	4.04	8.00	0.51	0.37	0.27
22	0.17	0.14	0.25	4.49	5.90	7.27	0.52	0.44	0.59
23	0.17	0.10	0.09	2.76	1.95	4.20	0.42	0.21	0.18
24	0.25	0.18	0.16	3.71	5.15	5.69	0.14	0.07	0.15
28	0.92	0.71	0.78	4.54	6.65	4.74	1.46	0.53	2.44
29	0.15	0.13	0.13	0.23	0.14	0.29	0.93	0.51	0.61
30	0.08	0.11	0.27	1.67	1.22	1.00	0.17	0.11	0.53
31	0.24	0.12	0.13	5.46	7.16	4.47	0.32	0.08	0.17
32	0.28	0.32	0.21	0.05	0.04	0.07	0.39	0.24	0.37
33	0.17	0.07	0.11	2.76	4.12	5.11	0.28	0.12	0.26
38	0.55	0.37	0.36	2.74	4.80	7.06	0.77	0.49	0.48
39	2.76	8.18	3.52	3.74	8.00	3.85	2.72	0.90	8.00
40	0.39	0.16	0.19	3.37	4.95	7.49	1.01	0.93	0.55
41	0.23	0.08	0.24	8.24	9.49	9.40	0.75	0.21	0.77
42	2.96	1.33	2.40	3.52	1.91	4.18	4.65	0.89	6.32
44	0.14	0.10	0.07	5.37	7.92	9.97	0.29	0.37	0.26
46	0.23	0.13	0.21	5.11	10.02	10.97	0.30	0.15	0.25
47	0.21	0.12	0.15	5.95	7.91	8.40	0.28	0.06	0.23
48	0.19	0.19	0.14	1.69	2.35	2.78	0.67	0.56	0.60

Table 2. Output (kg ha^{-1}) of total phosphorus, nitrate nitrogen and ammonia nitrogen from 17 watersheds over 100 ha in 1971–1973

Station	P 1971	P 1972	P 1973	NO_3-N 1971	NO_3-N 1972	NO_3-N 1973	NH_3-N 1971	NH_3-N 1972	NH_3-N 1973
1	2.86	0.68	0.89	10.40	9.20	17.96	4.46	1.59	1.61
5	0.47	0.24	0.09	14.31	2.78	3.38	2.81	0.53	0.71
6	0.36	0.04	0.17	0.50	0.04	0.16	2.74	0.29	1.41
8	0.96	0.45	0.64	16.62	10.56	25.31	2.03	1.53	1.64
9	0.47	0.27	0.27	17.71	16.69	20.68	0.45	0.28	0.69
10	0.46	0.41	0.21	10.91	9.03	12.34	0.93	0.72	0.37
11	0.23	0.53	0.18	6.65	6.91	12.32	0.54	0.82	0.34
18	0.50	0.10	0.43	3.65	2.11	9.51	1.04	0.09	1.10
19	0.72	0.21	0.34	7.68	4.88	19.88	1.24	0.45	0.66
22	0.32	0.23	0.48	8.32	9.68	14.09	0.97	0.73	1.14
23	0.38	0.24	0.18	6.33	4.68	8.67	0.95	0.50	0.37
29	0.19	0.06	0.18	0.29	0.07	0.42	1.17	0.24	0.86
33	0.38	0.10	0.39	5.99	5.83	18.12	0.61	0.17	0.94
38	1.29	0.60	0.67	6.42	7.84	13.08	1.80	0.80	0.89
40	0.68	0.23	0.33	5.91	6.97	13.15	1.77	1.32	0.96
41	0.62	0.14	0.55	21.54	16.09	21.81	1.97	0.36	1.78
48	0.15	0.17	0.16	1.30	2.13	3.37	0.51	0.51	0.73

Table 3. Land use in 34 watersheds

Station	Area (ha)	% Row Crop	% Grasslands	% Marsh	% Urban	Animal Units/ha
1	136	74.3	15.4	0.2	0.0	1.91
2	10	100.0	0.0	0.0	0.0	0.0
3	73	60.3	38.3	0.0	0.0	0.34
5	109	91.7	0.0	3.8	0.0	0.0
6	142	79.6	4.2	15.8	0.0	0.14
8	495	85.0	7.5	0.0	0.0	0.79
9	656	92.0	0.9	0.0	0.0	0.80
10	199	62.3	20.6	0.1	0.0	0.29
11	651	84.8	4.4	0.1	1.1	0.96
12	68	82.3	4.4	0.0	2.9	0.42
13	66	87.9	0.0	0.0	0.0	0.20
15	34	97.1	0.0	0.0	0.0	0.0
16	17	94.1	0.0	0.0	0.0	0.0
17	61	49.2	41.0	4.9	0.0	0.59
18	1175	73.4	19.2	2.9	0.5	0.51
19	277	74.3	10.1	0.4	9.7	0.09
22	732	72.7	22.8	0.5	0.0	0.37
23	125	68.8	21.5	0.0	0.0	0.17
24	36	38.9	41.7	9.7	11.1	0.0
28	12	66.7	0.0	0.0	33.3	4.17
29	1341	56.3	20.2	16.2	4.5	0.29
30	6	0.0	66.7	0.0	33.3	0.0
31	25	76.0	16.0	0.0	8.0	0.0
32	48	8.3	66.7	12.9	10.4	0.09
33	145	55.2	11.0	0.0	29.0	0.05
38	702	71.6	10.4	0.0	13.0	0.39
39	13	61.5	30.7	0.0	0.0	3.77
40	1164	79.0	12.6	0.3	0.0	0.67
41	742	90.4	3.6	0.1	0.0	0.99
42	19	68.4	26.3	0.0	0.0	2.63
44	37	86.5	13.5	0.0	0.0	0.0
46	59	72.9	23.7	0.0	0.0	0.0
47	78	88.5	6.4	0.0	0.0	0.0
48	3917	72.5	12.8	10.1	0.0	0.26

Table 4. Correlation coefficients between phosphorus (mg l^{-1}), nitrogen (mg l^{-1}) and land-use categories from 34 subwatersheds from 1971 to 1973 ($P = 0.01$)

	P	NO_3-N	NH_3-N	Marshlands
Row Crop	-	0.468	-	-0.360
Grasslands	-	-0.395	-	0.278
Marshlands	-	-0.525	-	-
Urban	-	-	-	-
Animal units/ha	0.662	-	0.628	-
P	-	-	0.549	-

Table 5. Correlation coefficients between phosphorus (kg ha^{-1}), nitrogen (kg ha^{-1}) and land-use categories from 17 watersheds from 1971 to 1973 (P = 0.01)

	P	NO_3-N	NH_3-N	Row Crop
Row Crop	-	0.394	-	-
Grasslands	-	-	-	-0.750
Marshlands	-	0.635	-	-
Urban	-	-	-	-0.535
Animal units/ha	0.556	0.422	0.412	-
P	-	-	0.789	-

stations are given in Table 5. A regression analysis of P concentrations was carried out by using animal units per hectare, percentages of each watershed in row crops, grasslands, marshland and urban area, and year classes as independent variables ($R^2 = 0.54$). Only the unique effect of the number of animal units ha^{-1} (AUHA) was significant. The partial regression of phosphorus on AUHA indicated that P increased by 0.67 ± 0.07 mg l^{-1} with each watershed animal unit ha^{-1}.

The same model was used in analysis of NO_3-N (mg l^{-1}) ($R^2 = 0.45$) and NH_3-N (mg l^{-1}) ($R^2 = 0.49$). Percentage of the area in marshland had a significant negative relationship with NO_3-N concentrations, indicating a 0.26 ± 0.07 mg l^{-1} reduction for each percentage point increase in marshland. There were significant differences in NO_3-N concentrations in the streams during the years of study. NO_3-N concentrations were greater in 1973 than in 1971 or 1972. NH_3-N (mg l^{-1}) was significantly related to the number of animal units within the watersheds. The partial regression indicates that NH_3-N was increased by 0.74 ± 0.08 mg l^{-1} for each animal unit per hectare within the watershed. None of the other independent variables made significant unique contributions to the variability in the ammonia or nitrate nitrogen concentrations.

Total P, NO_3-N, and NH_3-N outputs (kg ha^{-1}) from the 17 largest watersheds were used separately in a regression analysis against land-use variables. The R^2 values are 0.50, 0.65 and 0.42, respectively. Year differences were significant in all three analyses. Plant nutrient losses from the watersheds in 1972 were significantly less than in 1971 and 1973. In the analysis, P output was significantly increased by 0.55 ± 0.11 kg ha^{-1}, and NH_3-N output was significantly increased by 0.77 ± 0.23 kg ha^{-1}, for each additional animal unit per hectare in the watershed. NO_3-N (kg ha^{-1}) was significantly decreased by 0.67 ± 0.18 kg ha^{-1} for each percentage point of the watershed in marshland. None of the other independent variables showed significant unique effects in these analyses.

Table 6. Placement of animal units per hectare within the 17 watersheds over 100 ha

Station	Feedlot animal units with surface drainage	Pasture animal units with surface drainage	Feedlot animal units without surface drainage	Pasture animal units without surface drainage
1	1.75	0.16	0.0	0.0
5	0.0	0.0	0.0	0.0
6	0.0	0.0	0.14	0.0
8	0.71	0.0	0.04	0.04
9	0.0	0.0	0.80	0.01
10	0.0	0.24	0.05	0.0
11	0.14	0.01	0.81	0.003
18	0.09	0.07	0.21	0.12
19	0.0	0.06	0.02	0.0
22	0.0	0.05	0.22	0.10
23	0.0	0.10	0.0	0.07
29	0.07	0.11	0.09	0.03
33	0.0	0.02	0.01	0.03
38	0.09	0.06	0.19	0.04
40	0.27	0.15	0.25	0.0
41	0.74	0.06	0.20	0.0
48	0.02	0.12	0.09	0.03

An additional regression analysis was conducted to determine if animal placement within the watersheds influenced P or NH_3-N losses (kg ha^{-1}) in the 17 largest watersheds. This analysis used, as independent variables, year classes and the watershed animal units per hectare divided into four classes: (1) feedlots with drainage to streams or tile intakes, (2) pastures with drainage to streams or tile intakes, (3) feedlots with no surface drainage to streams or tile intakes, and (4) pastures with no surface drainage to streams or tile intakes (Table 6) ($R^2 = 0.54$ for P and $R^2 = 0.59$ for NH_3-N). Differences among years were significant. Total P and NH_3-N outputs in 1972 were less than in 1971 and 1973. The number of feedlot animal units per hectare with drainage to streams or tiles was the only significant variable in either analysis. Partial regression coefficients indicated that 0.61 $\pm$ 0.10 kg ha^{-1} P and 0.96 ± 0.18 kg ha^{-1} NH_3-N were associated with each feedlot animal unit per hectare with drainage to a stream or tile intake.

Surface runoff

Each of the streams monitored in 1971–1973 received drainage from a number of different land

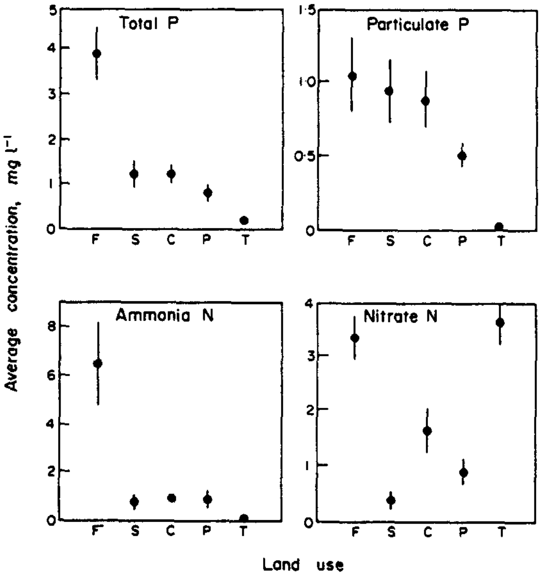

Fig. 2. Mean and standard error of the mean for total phosphorus, particulate phosphorus, ammonia nitrogen and nitrate nitrogen concentrations (mg l^{-1}) in feedlot (F), soybean (S), corn (C), pastures (P) and tile (T) runoff during spring 1974.

Table 7. Results of t-tests of mean plant nutrient concentrations ($mg\,l^{-1}$) in measured runoff from grasslands (G), tiles (T), feedlots (F), pastures (P), corn (C), and soybean (S) fields.[a]

	Comparisons of:			
	Tile vs. F,G,C,S	Feedlot vs. G,S,C	Pasture vs. S,C	Soybean vs. C
Total P	x	x	x	
Filtered P	x	x		
Particulate P	x		x	
NO_3-N	x	x		
NH_3-N	x	x	x	x

[a] x indicates significant difference at P=0.01

uses. To define more closely the nutrient contributions from specific land uses, samples were collected during March–May 1974 (Borofka, 1974) during runoff conditions from 3 tile drains, 13 grasslands, 7 feedlots, 13 cornfields, and 13 soybean fields. Most runoff events occurred during March and April when the ground was frozen or saturated. Figure 2 shows the mean and standard error of the mean for each measured variable. Table 7 summarizes t-tests of mean nutrient concentrations from five types of land runoff. The comparisons made were (1) tile vs the mean of feedlot, soybean, corn, and grassland, (2) feedlot vs the mean of soybean, corn, and grassland, (3) grassland vs the mean of soybean and corn, and (4) soybean vs corn. Analyses were run of logarithms of original data to make the variance more homogeneous across the groups.

Tile drainage had the lowest total P concentration, with only a small fraction as particulate P. NH_3-N values also were lower than in other runoff types. NO_3-N samples were variable, but normally above $2.5\,mg\,l^{-1}$.

Each of the grassland sites had pastured animals during the summer and fall preceding the sampling period. More than half the P was carried by particulate material in grassland runoff. NO_3-N and NH_3-N were normally less than $1\,mg\,l^{-1}$.

Runoff from the feedlots had the highest P values, only one-quarter of which was particulate P. NH_3-N concentrations averaged $6.5\,mg\,l^{-1}$, but were quite variable. Corn and soybean field runoff were similar with about 70% of the total P in the particulate fraction.

DISCUSSION

From analyses of watershed factors associated with nutrient concentrations and loads, livestock are an identifiable source of P and NH_3-N within the studied watersheds. Significant positive relationships were found between the concentration ($mg\,l^{-1}$) ($r = 0.55$) and losses ($kg\,ha^{-1}$) ($r = 0.79$) of P and NH_3-N from the watersheds. Because both are positively correlated with animal units in feedlots with surface or tile drainage, these feedlots are a source of nutrients to the watershed lakes. This is further supported by P and NH_3-N losses being greater in 1971 and 1973, years of high runoff.

Phosphorous and NH_3-N were found in high concentrations in feedlot surface drainages in this and other studies (Miner *et al.*, 1966; McCalla *et al.*, 1969; Gilbertson *et al.*, 1970; Townshend, Black and Janse, 1970; McQuitty, Robertson and Barber, 1971; Taylor *et al.*, 1971; U.S. Environmental Protection Agency, 1971; Edwards, Simpson and Frere, 1972). Others also have found feedlot drainage a high local source of these nutrients in streams (Taylor, 1967; Frink, 1969; Taylor and Kunishi, 1971; Morris, 1973; Muir, Sein and Olson, 1973; Burwell *et al.*, 1974; Loehr, 1974). These nutrients are high in feedlot drainage because NH_3-N results from the hydrolysis of urea (Martin and Goff, 1972) and because P is contained in the solid waste (Taiganides and Hazen, 1966; Vollenweider, 1968).

It is difficult to measure accurately the nutrients lost from feedlots within the watershed because delivery of cattle feedlot wastes often is intermittent and difficult to measure (McQuitty *et al.*, 1971). Most injection to streams occurs in the spring runoff or during periods of rainfall (Miner *et al.*, 1966), which can result in a slug load to the tributary stream (Loehr, 1970). Frequent samples and good measures of the runoff volume of feedlot drainage are necessary to estimate the quantity of nutrients lost.

In this study, the loss of plant nutrients from feedlots with drainage to a stream or tile intake can be estimated from the partial regressions of the number of animal units held in these feedlots on P and NH_3-N. An annual loss of 0.61 kg P per feedlot animal unit was found. Approximately 2630 animal units were held in feedlots having surface drainage within the lake basin studied. The P contribution from these feedlot animal units, therefore, was approximately $1600\,kg\,yr^{-1}$. This was equal to about 16% of the P that annually entered the lakes from the terrestrial watershed (Jones and Bachmann, 1975). Approximately 0.68 kg of NH_3-N is attributed to each feedlot animal, which equaled 6% of the annual terrestrial loss of NH_3-N.

Within the watershed, NO_3-N was negatively related to the percentage of area in marshland. To a lesser extent, grassland areas within the watershed may reduce NO_3-N concentration ($r = 0.39$), but this was not a significant variable in the multiple-regression analysis. Marshlands likely reduce NO_3-N because they are areas of anaerobic decomposition, resulting in denitrification and a gaseous loss of N_2 from these areas. Also, marshlands and many pasture areas do not drain toward streams via subsurface tiles. Tile drainage is high in NO_3-N (Johnson *et al.*, 1965; Erickson and Ellis, 1971; Zwerman *et al.*, 1972; Jackson *et al.*, 1973). Much of the watershed has been tiled to eliminate wetlands and facilitate row-crop agriculture. Watersheds with less tile drainage, such as marshlands, would tend to have lower NO_3-N concentrations and losses. Thomas and Barfield (1974) found NO_3-N in tile effluents much higher than non-tile drainage. In water that did not flow through tiles, the NO_3-N was lower originally or was denitrified as water moved through the soil. From the slope of the partial regression of marshland (%) on NO_3-N (kg ha^{-1}) (−0.26 kg ha^{-1} NO_3-N), it was estimated that the 2200 ha of marshland area within the basin reduces the annual NO_3-N loss by 4000 kg.

Statistically, P and N losses have not been identified with the percentage of the watershed in row crops, grassland or urban areas. Yet, our sampling of these specific watersheds indicated high P and NO_3-N and NH_3-N in runoff from these areas. From other studies, pastured watersheds are known to contribute P and NH_3-N to surface waters from cattle wastes (Witzel *et al.*, 1969) and plant leachates (Timmons, Holt and Latterell, 1970; Holt, Timmons and Latterell, 1970; White and Williamson, 1973; Klausner, Zwerman and Ellis, 1974). Phosphorus losses from cropland are the result of soil erosion (Holt *et al.*, 1970; Romkens, Nelson and Mannering, 1973; Schuman, Spomer and Piest, 1973; Taylor, 1967; Timmons, Burwell and Holt, 1968). Erosional losses of P from row-crop watersheds are indicated in this study because a major fraction of the phosphorus lost from cultivated fields was associated with particulate material.

Runoff from urban areas within the watershed contained high concentrations of plant nutrients. Total P concentrations averaged 0.56 mg l^{-1}, NH_3-N averaged 1.21 mg l^{-1}, and NO_3-N averaged 1.83 mg l^{-1} in storm water (Jones, 1974). But urban areas constitute only 4% of the terrestrial watershed, making the total amount of P and N resulting from this source less than 5% of the terrestrial loss.

The nutrient concentrations found in a tributary near its mouth represent an integration of hydrologic and chemical processes after derivation from the initial sources. It is unlikely that losses are equal from all parts of the watershed (Gburek and Heald, 1974). Forces within the watershed tend to decrease P concentrations during movement from the initial nutrient source to the outlet. Soils and sediments scavenge P even within the tributary (Taylor and Kunishi, 1971; Kunishi *et al.*, 1972; and Gburek and Heald, 1974). Much of the cropland within the watershed has less than a 5% slope, and some areas drain to depressions, thus reducing erosion losses of nutrients. These forces tend to mask the input of nutrients from pastures and cultivated fields so that they could not be distinguished statistically.

Annual nutrient losses from the terrestrial watershed were approximately 0.35 kg ha^{-1} P, 6.7 kg ha^{-1} NO_3-N, and 1.0 kg ha^{-1} NH_3-N during 1971–1973. This is within the range of 0.18–1.0 kg ha^{-1} P and 3–90 kg ha^{-1} inorganic N annually lost in runoff from agricultural land as determined by other researchers (Johnson *et al.*, 1965; Vollenweider, 1968; Biggar and Corey, 1969). This annual P loss also compares with P outputs from the Des Moines River basin in Iowa. From July 1971 to August 1973, the average total P loss from this basin was 0.38 kg ha^{-1} yr^{-1} (Baumann, Oulman and Naylor 1973). During the period of study, precipitation contributed 0.32 kg ha^{-1} yr^{-1} of P to the basin (Jones and Bachmann, 1975).

The effect of the major lakes in the basin can be estimated by dividing the annual P loss from the outlet of the lake system by the total area of the basin. This amounts to 0.06 kg ha^{-1} yr^{-1} (Jones, 1974), which is significantly lower than the areal losses of the tributary watersheds. This illustrates the role of lakes in trapping P.

Although livestock were the only factor that could be correlated with P and NH_3-N inputs to the lakes, they were not the sole source of these nutrients. Runoff from grasslands, cultivated land, and urban areas had high nutrient concentrations. The nutrients attributable to feedlot livestock accounted for less than one-sixth of the P and one-tenth of the NH_3-N carried in the inflows from the watersheds. This is a reflection of the high background nutrient levels that could not be attributed to a specific source. Retention of soil material on the cropland by conservation practices would help reduce nutrient losses from the watershed.

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