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Abstract

Water quality of drainage influents and the lone effluent at Eagle Lake marsh, Iowa, was studied for 4 years (1976-1979). Because of drought conditions, there was no effluent from the marsh in 1976, 1977, or 1978. In 1979, the marsh was effective at removing inorganic N, especially N03-N, from runoff water passing through. It had little impact on levels of inorganic-P, total-P, and Kjeldahl-N; it was a net exporter of soluble organic carbon.

Disciplines

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PRAIRIE POTHOLE MARSHES AS TRAPS FOR NITROGEN AND PHOSPHORUS IN AGRICULTURAL RUNOFF*

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ABSTRACT

Water quality of drainage influents and the lone effluent at Eagle Lake marsh, Iowa, was studied for 4 years (1976-1979). Because of drought conditions, there was no effluent from the marsh in 1976, 1977, or 1978. In 1979, the marsh was effective at removing inorganic N, especially NO_3-N, from runoff water passing through. It had little impact on levels of inorganic-P, total-P, and Kjeldahl-N; it was a net exporter of soluble organic carbon.

INTRODUCTION

A major environmental problem in the American Midwest is the degradation of stream, lake, and reservoir water quality by addition of nutrients from nonpoint sources of surface agricultural runoff and drainage tile effluents. Hanway and Laflen (1974) monitored surface and subsurface drainage for soluble inorganic nitrogen (NH_4-N, NO_3-N, NO_2-N) from 1970 through 1972 and found that annual flow-weighted inorganic N in surface runoff ranged from 1 to 12 ppm, with an overall average of 7 ppm. The range for subsurface drainage during the same period was 7 to 21 ppm, with an overall average of 16 ppm. Annual losses of N ranged from 0.1 to 16 kg/ha for surface runoff and from 0.0 to 33 kg/ha for subsurface drainage. In that same study, Hanway and Laflen also found that soluble inorganic P concentrations in surface runoff ranged from 0.01 to 0.23 ppm, whereas concentrations of P in tile drainage ranged from 0.002 to 0.026 ppm. Annual losses averaged 0.018 kg/ha for surface runoff and 0.004 kg/ha for subsurface drainage. Other researchers indicate that these values are typical for N and P runoff and drainage from midwestern agricultural lands (Viets and Hageman, 1971; Johnson and Baker, 1973; MacKenzie and Viets, 1974).

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In most locations, these nutrients pass into streams, rivers, lakes, and reservoirs, causing eutrophication and other undesirable effects. An effective method of controlling this type of pollution is to remove the pollutants from agricultural runoff and drainage before this water reaches major distributaries.

Recently, considerable interest has been focused on the effectiveness of wetlands as sinks for nutrients in various types of effluents (see Tourbier and Pierson, 1976; Tilton et al., 1976; and Greeson et al., 1979 for reviews of this topic). The purpose of our study was to determine the effectiveness of the Eagle Lake marsh as a nutrient sink. Nutrients studied were NH_4-N, NO_3-N, Kjeldahl-N, PO_4-P, total-P, and soluble organic C.

STUDY SITE

Eagle Lake marsh (Fig. 1) is located in north-central Iowa and is owned and managed by the Iowa Conservation Commission. It has a surface area of 365 ha and receives runoff and drainage from a basin of 2,562 ha. The marsh is shallow; water depth rarely exceeds 1 m and is controlled by a dam at the northern end of the marsh.

The Eagle Lake basin comprises two drainages, one 1570 ha, the other 992 ha. Land use in the basin is almost entirely row-crop agriculture. Drainage flow enters the marsh at its southern end and along its eastern shore. A morainal ridge along the western shore limits flow into the marsh from that direction.

North-central Iowa has a continental climate. Average temperatures in January are -7° to -9°C and, in July, are 23° to 24°C. Average annual precipitation at Eagle Lake marsh (measured at Britt, the nearest town) is 802 mm. Approximately half falls in the spring. A severe drought hit the area during the summer of 1976. Spring rains and water levels were normal in the marsh through early June. Through the rest of the summer, however, water level decreased, and by mid-September, the marsh was dry. The drawdown lasted until August 1977 when heavy rains abruptly ended the drought. In 1978, water level in the marsh rose to near capacity, and in 1979, excessive precipitation and saturated soils produced the first effluent from Eagle Lake marsh in 4 years.

Vegetation at Eagle Lake marsh is dominated by *Typha glauca*, *Sparganium eurycarpum*, *Carex atherodes*, and *Scirpus validus*. Vegetation dynamics and production have been studied by Currier et al. (1978) and van der Valk and Davis (1978a, 1979, 1981).

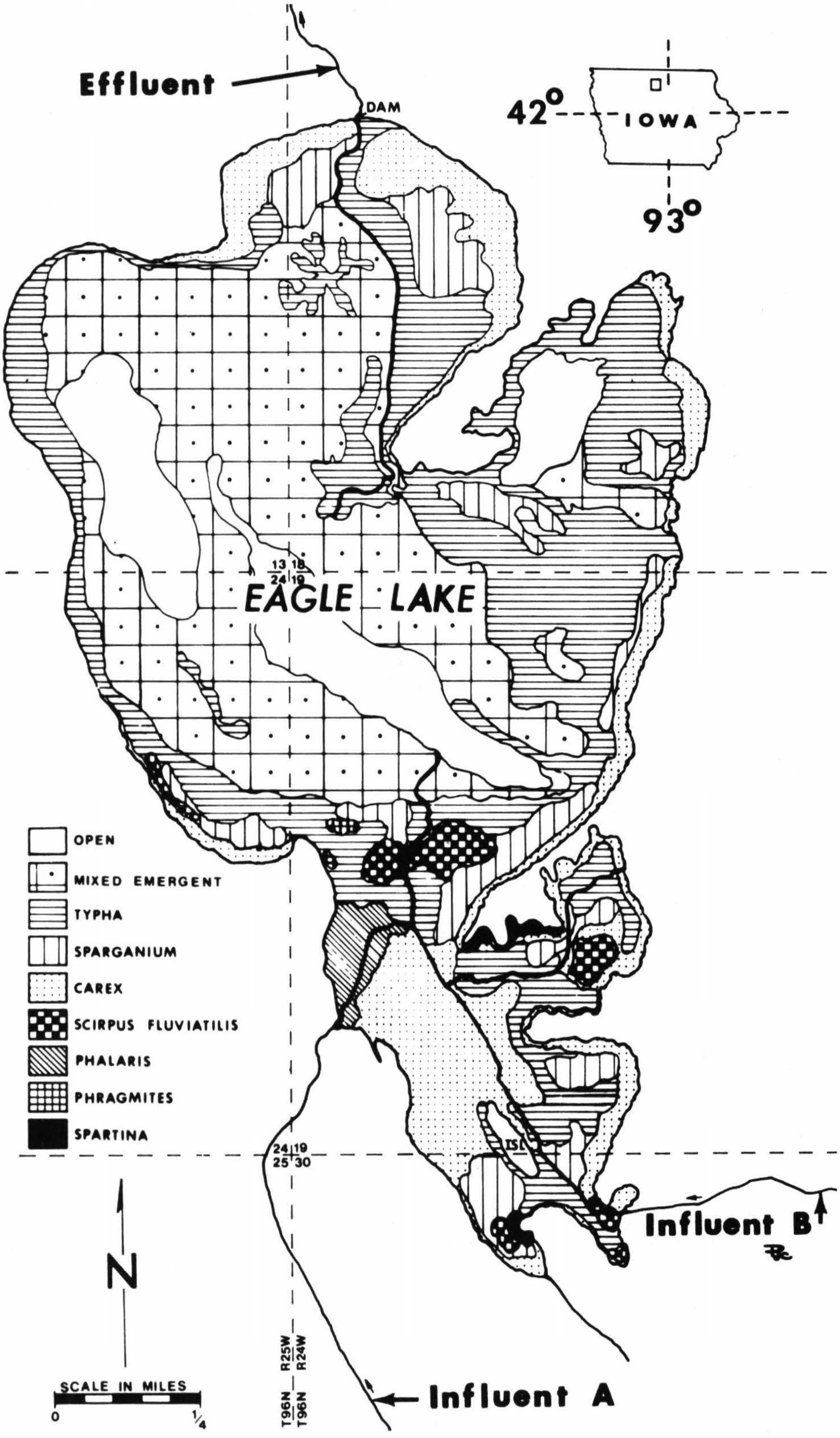

Figure 1. Vegetation cover at Eagle Lake, Iowa in 1976.

METHODS

Land Use

Cropping patterns were determined in 1978 and 1979 from aerial photographs and personal interviews with farmers. Interviews also provided information on fertilization practices.

Water Sampling and Analysis

The 992-ha drainage was monitored for flow and water quality, but the 1570-ha drainage was monitored for water quality only. To estimate inputs to the marsh, we assumed that flow from the ungauged area was proportional to the gauged drainage on an area basis; i.e., X 1.58. Outflow (in 1979 only) was monitored for flow and water quality.

Water samples were collected at the two principal influents (Fig. 1) and from the effluent every other day during the spring, summer, and fall. When there was no effluent, water samples were taken from the stagnant water immediately behind the dam gates. During storms, samples were collected every 4 hours. All samples were collected in polyethylene bottles and frozen until they could be analyzed. Samples that contained suspended sediment were centrifuged before being analyzed for N and P.

NH_4-N and NO_3-N were analyzed by using the Technicon Auto-Analyzer II system. The alkaline phenol method was used for NH_4-N analyses, and NO_3-N analyses were performed according to the cadmium reduction method. The ascorbic acid reduction method of Murphy and Riley (1962) was used to analyze for PO_4-P, and soluble organic carbon (SOC) was determined by using a Beckman carbon analyzer. Kjeldahl-N and total P were determined after sulfuric acid digestion.

RESULTS

Land Use

Cropping practices in the Eagle Lake basin during 1978 and 1979 are shown in Table 1. Approximately 55% of the land was planted to corn and 20% to soybeans in both years. Amounts of fertilizer applied to corn and soybean fields in 1978 and 1979 are shown in Table 2. These applications are about average for Iowa. All the N was applied to cornfields.

Table 1. Cropping Practices in the Eagle Lake Watershed

CROP	AREA IN HECTARES	
	1978	1979
Corn	1033	1035
Soybeans	682	692
Hay	42	63
Oats	81	59
Alfalfa	9	9
Grass	5	0
Pasture	110	70
Diverted	0	6

Table 2. Fertilizer Applied to the Eagle Lake Watershed

NUTRIENT	APPLIED KILOGRAMS	
	1978	1979
Nitrogen	126,536	124,137
Phosphorus	45,406	35,445
Potassium	140,430	105,030

Water Quality

Nutrient Concentrations: For the 4-year period of 1976-79, the flow-weighted average NH_4-N, NO_3-N, and PO_4-P concentrations in agricultural runoff and drainage to the marsh were 0.2, 13.0 and 0.23 ppm, respectively. Kjeldahl-N, total-P, and soluble organic carbon, measured in 1978 and 1979, averaged 1.5, 0.17, and 18.0 ppm, respectively. With the exception of the drought period, NO_3-N concentration in agricultural drainage usually exceeded 10 ppm, and often exceeded 20 ppm.

Care must be taken in interpreting nutrient concentration data. A decrease in concentration may reflect an actual decrease in the amount of nutrient present, or it may only reflect dilution by increased water flow. Accurate nutrient balances can be developed only when absolute amounts of nutrients are determined. Flow data are required for such determinations.

Inputs and outputs of water, nitrogen, phosphorus, and soluble organic carbon for 1976 through 1979 are summarized in Table 3.

Water: In 1976, the Eagle Lake marsh received only 575 mm of precipitation (72% of normal); no rain fell after mid-June. Drainage into the marsh was slight, and there was no effluent. In 1977, precipitation was above average for the year, but all came in late summer and fall. Dry soils in the basin adsorbed nearly all this precipitation. Runoff and drainage were even less than in 1976, and there was no effluent. In 1978, precipitation was only 88% of normal, but runoff and drainage increased slightly over 1976 and 1977 levels. Water level in the marsh rose to near capacity, but there was no outflow.

In 1979, precipitation fell on saturated soils and a full marsh. There was considerable drainage into the marsh, and, for the first time since 1975, there was an effluent. Effluent volume was 69% of the volume of combined inputs from precipitation and drainage in the two main ditches.

Absolute Amounts of Inorganic N and P: Annual inputs of inorganic N and P in precipitation were fairly constant on a per-millimeter basis during the 4 years of this study; NH_4-N and NO_3-N were about 0.007 kg/mm/ha each, and PO_4-P was about 0.0003 kg/mm/ha each year.

In 1979, 9.1 kg of allogenic NH_4-N entered the marsh. Only 27% of this arrived in drainage from agricultural fields; the rest arrived in precipitation. Agricultural crops absorb most of the NH_4-N that arrives in precipitation. Most of the remaining NH_4-N usually is adsorbed in upland soils. Effluent flow contained 2 kg NH_4-N/ha in 1979.

During periods of low flow, very little NO_3-N was leached from surrounding fields. When drainage was high, as in 1979, large amounts

Table 3. Inputs and Outputs of Water and Nutrients from Eagle Lake, Iowa.

	PRECIP.	INFLOW A*	INFLOW B*	OUTFLOW*
WATER (mm)				
1976	575	13	20	0
1977	963	10	16	0
1978	709	63	100	0
1979	944	627	993	1758
NH_4-N (kg/ha)				
1976	4.0	<0.1	<0.1	0
1977	6.7	0.2	0.3	0
1978	5.0	0.2	0.6	0
1979	6.6	0.8	1.7	2.0
NO_3-N (kg/ha)				
1976	4.1	2.2	4.9	0
1977	6.8	0.8	2.9	0
1978	5.0	10.9	14.5	0
1979	6.7	69.1	133.7	29.8
PO_4-P (kg/ha)				
1976	0.20	0.01	0.04	0
1977	0.33	0.06	0.12	0
1978	0.24	0.25	0.50	0
1979	0.32	1.51	1.69	2.81
Kjeldahl-N (kg/ha)				
1978	**	1.2	1.6	0
1979	**	13.6	10.1	28.5
TOTAL PHOSPHORUS (kg/ha)				
1978	**	0.25	0.57	0
1979	**	1.51	2.54	3.60
SOLUBLE ORGANIC (kg/ha) CARBON				
1978	**	10	9	0
1979	**	156	146	516

*See Figure 1

**No Measurements Made

of NO_3-N were washed through subsurface drainage tiles and into the two ditches that flow to the marsh. In 1979, approximately 210 kg NO_3-N/ha entered the marsh in precipitation and runoff; 97% arrived in runoff. The effluent from the marsh contained only about 30 kg/ha (about 14% of precipitation and drainage influents).

Very little PO_4-P drained into the marsh in low-flow years. When runoff was heavy, however, sheet erosion at the soil surface moved large amounts of inorganic P into drainage ditches serving the Eagle Lake marsh. In 1979, heavy precipitation and runoff brought approximately 3.5 kg PO_4-P/ha into the marsh, and the effluent removed about 2.8 kg/ha.

Total P, Kjeldahl-N, and Soluble Organic Carbon: The two influent ditches brought 4.1 kg/ha total-P and 23.7 kg/ha Kjeldahl-N into the marsh in 1979, and effluent water removed 3.6 kg/ha total P and 28.5 kg/ha Kjeldahl-N during the same period. In contrast, influent ditches supplied about 300 kg/ha soluble organic C, but more than 500 kg/ha were released in the effluent.

DISCUSSION

Prairie glacial marshes are not static ecosystems. They undergo seasonal and long-term cycles that affect their ability to remove nutrients from water passing through them (Weller and Spatcher, 1965; van der Valk and Davis, 1976, 1978b, 1979, 1981). When attempting to evaluate the effectiveness of a marsh as a nutrient sink, one must realize that the marsh under consideration could be quite different in wetter or drier years.

Our study spanned an entire drawdown-refill cycle. Water level in the marsh was normal in the spring of 1976, the drought caused a drawdown that began in late 1976 and lasted through the 1977 growing season, and water level returned to normal in 1978 and 1979.

The marsh obviously served as a sink for N, P, and soluble organic C in 1976, 1977, and 1978; there was no outflow to remove these compounds. This extended residence time allowed more time for such reactions as denitrification and P precipitation. The extent to which nutrients removed from marsh water during 1976, 1977, and 1978 were immobilized in the substrate or removed via denitrification cannot be determined. Undoubtedly, some nutrients merely were "detained" until flushed from the lake in the 1979 effluent.

The effectiveness of the marsh in immobilizing or removing nutrients can best be evaluated by looking at data from years in which influents and effluents were normal or above normal. Data from 1979 indicate that the greatest impact of the Eagle Lake marsh was on inorganic N, particularly NO_3-N. Most of the inorganic N entering the marsh was NO_3-N (96%), and the marsh removed 86%. Denitrification undoubtedly was the most important cause of this removal. The amount of NH_4-N removed from the marsh in the effluent was only 22% of the amount entering in precipitation and runoff. This 78% reduction is more impressive when we realize that additional (autogenic) NH_4-N was generated in the marsh by decomposition of organic matter. Presumably, NH_4-N was nitrified, taken up by plants, or adsorbed by the soil in the marsh.

Levels of Kjeldahl-N and inorganic and organic forms of P in the marsh water were not affected appreciably as this water flowed through the marsh; inputs roughly equalled outputs. In contrast, output of soluble organic C exceeded inputs by 71%.

The biotic compartments of the marsh are important in uptake and release of nutrients in water passing through the marsh (Davis and van der Valk, 1978 a,b,c; van der Valk et al., 1980). Macrophytes act as nutrient pumps, removing nutrients from the substrate (Klopatek, 1978). When these macrophytes die, their decomposing tissues support populations of microorganisms that often extract nutrients, especially N, from marsh water. Finally, partly decomposed macrophyte tissues are incorporated into the peat layer on the floor of the marsh. This peat substrate seems to be a major sink for certain nutrients.

As an example of the impact that biotic communities have on marsh water quality, consider that the 1979 snowmelt, occurring in a period of low biotic activity, resulted in only 15% of the total outflow from the marsh in 1979. This outflow, however, carried 28% of the NH_4-N, 25% of the PO_4-P, 32% of the total-P, and 93% of the NO_3-N removed from the marsh in outflow in 1979.

CONCLUSIONS

This study indicates that the use of prairie glacial marshes to treat agricultural drainage water can be expected to be of most benefit with respect to removal of inorganic nitrogen, particularly nitrate. Inorganic and organic phosphorus and Kjeldahl nitrogen levels are not altered appreciably as runoff water passes through the marsh. But soluble organic carbon (SOC) content of this water increases considerably. The marsh can be a net exporter of SOC.

Managers must be aware of the cyclic nature of marsh hydrology and biota. These factors alter a marsh's effectiveness as a sink for nutrients.

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