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Full-scale harvest of aquatic plants: Nutrient removal from a eutrophic lake

SPENCER A. PETERSON, WINTFRED L. SMITH, AND KENNETH W. MALUEG

TO CONTROL EUTROPHICATION in lakes is to control the nutrients in them. Phosphorus, more frequently than any other element, has been cited as the factor limiting productivity in aquatic ecosystems.[1,2]

Once nutrients enter a water body, control becomes difficult because of the biogeochemical dynamics of the system; however, a number of *in situ* control methods have been suggested. Livermore[3] was among the first to advocate large-scale harvest of aquatic plants as a means of removing nutrients from lakes. While aquatic plants have been removed to clear canals or to produce livestock feed,[4,5] and relatively small areas have been harvested to study production and succession,[6,7] this procedure has not been used full scale on lakes to reduce nutrients. Yount[8,9] suggested that plant harvest was one of the most hopeful solutions for reducing productivity in lakes, particularly for polluted water.

Lake Sallie, Minn. (Figure 1), with a 60-yr history of nutrient enrichment by wastewater effluent from the city of Detroit Lakes, Minn.,[10] and steadily declining water quality since the early 1940's, was selected as the site to evaluate the effect of large-scale aquatic plant harvest on the nutrient dynamics of a eutrophic lake. Lake Sallie is located on a glacial outwash plain in west-central Minnesota. At an elevation of 1,329 ft (405 m), the lake covers 1,209 acres (489 ha), has a mean depth of 18.5 ft (5.6 m), a capacity of 22,000 acre-ft (27.1×10^6 cu m), and a flow-through time of approximately 1.1 yr.

The nutrient budget of a lake would be of little significance in itself; however, when a nutrient source has been manipulated, the budget becomes a valuable tool with which to measure effects of the manipulation. Therefore, the approach used was to construct an accurate phosphorus-nitrogen budget for Lake Sallie to which nutrient removal by harvest could be related.

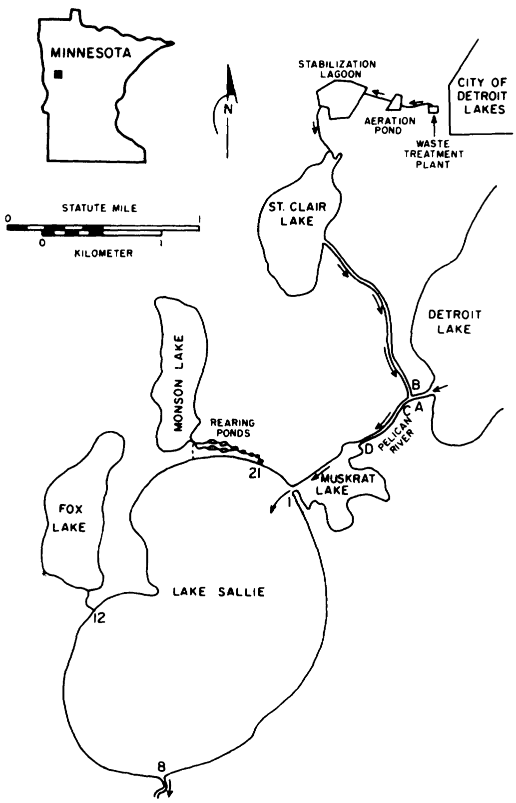

FIGURE 1.—Flow route of secondary wastewater effluent from the city of Detroit Lakes to Lake Sallie, Minnesota. (Sampling stations indicated by letters and numbers.)

TABLE I.—Specifications of Aquatic Plant Harvester*

Size	8 ft × 25 ft
Weight	20,000 lb
Number of operators	1
Propulsion power unit	155-hp, 6-cylinder, water-cooled engine, Merc-Cruiser drive unit
Hydraulic power unit	30-hp, 4-cylinder, air-cooled engine
Controls	Hydraulic valves, rubber lines, and hydraulic motors
Cutter type	One 8-ft cycle bar, horizontally and two 5-ft cycle bars, vertically
Capacity	Up to 25,000 lb/hr (depending on plant density and travel distance to shore)
Load capacity	8,000 lb
Speed (empty)	10 mph
Draft	16 in. of water empty, 24 in. fully loaded
Depth of cutting and picking unit below water surface	0–5 ft
Loading and unloading mechanism	Chain link conveyer belts

Note: Ft × 0.3048 = m; lb × 0.454 = kg; hp × 0.7457 = kw; mph × 1.6093 = km/hr; in. × 2.54 = cm.

* Marine Scavenger Model 258-II, Aquatic Control Corp., Waukesha, Wis.

METHODS

Hydrology. The U. S. Geological Survey (USGS) installed staff gauges at the inlets and a continuous recorder at the outlet of Lake Sallie. Actual flow measurements were made monthly during ice cover (November through April) and biweekly during open-water periods (May through October); gauges were read daily. Estimates of daily flow were extrapolated from these data by the USGS. Groundwater level was measured weekly in 32 observation wells around the lake, and a flow net was constructed to calculate groundwater contributions to the lake.

Precipitation data were obtained from a U. S. Weather Bureau station 3 miles (4.8 km) northeast of Lake Sallie. Evaporation from the lake was computed according to Veihmeyer,[11] who used mean annual Class A pan evaporation rates and a Class A pan coefficient of 0.8 for converting pan to lake evaporation. Changes in storage capacity of the lake were calculated by the USGS from gauge data at Stations 1 and 8 (Figure 1).

Water chemistry. Chemical analyses were performed on samples collected at flow gauging stations (Stations 1, 8, 12, and 21) at biweekly or monthly intervals during ice cover and at semiweekly, weekly, or biweekly intervals during open-water periods. All analyses except Kjeldahl nitrogen were performed immediately on unpreserved samples. Ammonia nitrogen, nitrite nitrogen, and soluble orthophosphate analyses were performed according to "Standard Methods."[12] Nitrate nitrogen was analyzed by the cadmium reduction method.[13] Total phosphorus determinations followed the Federal Water Pollution Control Administration (FWPCA) potassium persulfate digestion technique.[14] Surface water samples for Kjeldahl nitrogen analyses and groundwater samples for nitrogen and phosphorus analyses were preserved with mercuric chloride (40 g/l) and analyzed by the University of North Dakota, Grand Forks, according to FWPCA methods.[14]

Difficulty was encountered in obtaining reliable estimates of Kjeldahl nitrogen. When split samples from Stations 1 and 8 were analyzed under rigid quality control procedures, it was determined that the Kjeldahl nitrogen being reported at the North Dakota laboratory was consistently low. Therefore, the mean annual total nitrogen concentrations of 0.95 and 0.92 mg N/l as reported for Stations 1 and 8 include a factor to compensate for the error in Kjeldahl nitrogen.

Nutrient contribution to Lake Sallie from precipitation was calculated using local Weather Bureau records and chemical content of precipitation, as reported by Kluesner,[15] who found the mean total nitrogen and phosphorus concentrations for precipitation near Madison, Wis., to be 1.09 and 0.032 mg/l, respectively. Chemical composition of precipitation at Ely, Minn.,[16] 200 miles (320 km) northeast of Lake Sallie, was comparable to that in Wisconsin.

Approximately 75 percent of the inflow to Lake Sallie is from channeled surface runoff; therefore, nutrient content of the lake's storage-change volume (water volume resulting from stage level fluctuations above or below the mean elevation) was calculated from mean monthly nutrient concentrations and tributary flows.

Plant harvest. Aquatic plant harvest began June 22, 1970, when sufficient growth had occurred to warrant operating the harvester. Harvesting was carried out 8 hr a day, 5 days a week through September 30, 1970. The only departure from this schedule was that necessitated by machine repair or unfavorable weather conditions, approximately 8 working days during the season. The entire littoral zone, nearly 390 acres (158 ha) or one-third of the surface area of the lake, was cut over repeatedly during the harvest period. Specifications of the aquatic plant harvester *† used during this study are listed in Table I.

Plant material from the harvester was subsampled and weighed periodically to establish an average wet weight for 1-cu ft (0.028-cu m) samples. The entire load of plants was then weighed, and the mean plant volume per harvester load was calculated.

After weighing, the wet samples were placed indoors on drying racks for several days. They were reweighed to establish air-dry weight per cubic foot. This value was used to estimate the total dry weight of plant material removed per harvester load.

Tissue analysis. Air dried subsamples of harvested plants were ground in a Wiley mill to pass a 60 mesh screen and dried further for 16 hr in a circulating air oven at 140°F (60°C). They were then analyzed for total nitrogen on a hydrogen-nitrogen-carbon gas analyzer ‡ and for total phosphorus using the persulfate digestion and one solution ascorbic acid technique.[14]

During 1970, samples of fish harvested from Lake Sallie by commercial and sport fishermen were obtained for nutrient analyses. The fish were ground in entirety, dried, shredded in a food blender, and analyzed for total phosphorus and nitrogen content by the methods previously described for plants. These data coupled with catch records of commercial fish (live weight) and sport fish (creel census) provided by the Minnesota Conservation Department were used to compute nutrients removed as fish biomass.

Water budget. The hydrologic budget of a lake describes the relationship between water input and output. A net positive or negative storage or volume change (ΔV) may result for the lake depending on the dynamics of the relationship. Therefore, the following equation may be used to describe the water budget:

$$\Delta V = I_t - O_t \qquad (1)$$

where

ΔV = change in volume,
I_t = total water input, and
O_t = total water output.

Ideally, a water budget should account for all inputs and outputs; thus an expanded version of Equation 1 might be as follows:

$$\Delta V = (S_i + G_i + P + R) - (S_o + G_o + E) \qquad (2)$$

where

S_i = surface water input,
G_i = groundwater input,
P = precipitation,
R = runoff,
S_o = surface water output,
G_o = groundwater output, and
E = evaporation.

Details of the Lake Sallie water budget for 1969–70 have been reported by Mann and McBride,[17] who used the above relationships.

* Marine Scavenger Model 258-II, Aquatic Control Corp., Waukesha, Wis.

† Mention of commercial products by the Environmental Protection Agency does not constitute endorsement or recommendation for its use.

‡ Model #185, Hewlette-Packard Co., Avondale Div., Avondale, Pa.

TABLE II.—Water Budget of Lake Sallie, Minnesota, for the 1970 Water Year*

Source	Percent of Flow
Inputs	
Surface water	73.3
Precipitation	10.9
Net groundwater flow	15.8
Outputs	
Surface water	82.7
Evaporation	17.2

* Modified from Mann and McBride.[17]

Nutrient budget. Calculation of nutrient contribution to Lake Sallie from various sources used USGS flow records with weekly or biweekly measurements of nutrient concentrations. Measurements used in compiling the nutrient budget included total phosphorus, ammonia, nitrite, nitrate, and Kjeldahl nitrogen. Mean nutrient loads were computed for weekly (summer) or monthly (winter) time periods and totaled for each source at the end of the water year. Nutrient loads from each source were incorporated into the final nutrient budget according to Equation 3.

$$L_e = (C_x S_i + C_x G_i + C_x P + C_x R) - (C_x S_o + C_x G_o + C_x W_o + C_x F_o \pm C_x \Delta V) \quad (3)$$

where

L_e = net uptake or release of nutrients within the lake ecosystem,
C_x = nutrient concentration of each individual source per unit time,
W_o = weight of plants harvested, and
F_o = weight of fish harvested.

RESULTS AND DISCUSSION

Water budget. The Lake Sallie water budget for the 1970 water year gave a total surface water inflow of 14,196 acre-ft (17.5×10^6 cu m). Input from precipitation was 2,107 acre-ft (2.6×10^6 cu m); net groundwater flow was 3,059 acre-ft (3.7×10^6 cu m). Surface water outflow amounted to 15,661 acre-ft (19.3×10^6 cu m), while evaporation loss was 3,277 acre-ft (4.0×10^6 cu m). The percent contribution to the water budget from each major input and output is shown in Table II.

It is apparent that surface water was the principal factor in the water budget of Lake Sallie. Of the surface inflow, 96 percent was from the Pelican River; the inflows from Monson Lake, Monson Lake via the fish rearing ponds, and Fox Lake (Figure 1) added only 0.1, 1.6, and 2.3 percent, respectively.

The accuracy of any nutrient budget is necessarily dependent on the accuracy of the water budget. Mann and McBride[17] indicated accuracy of the Lake Sallie water budget to be within the limitations shown in Table III.

Nutrient budget. The water, phosphorus, and nitrogen budgets for the 1970 water year are summarized in Table IV. It shows explicitly that the major nutrient input to Lake Sallie is from the Pelican River via Muskrat Lake, which receives inflow from Detroit and St. Clair lakes. The latter receives wastewater effluent from the city of Detroit Lakes.

Data from the University of North Dakota were used to compute the relative water and nutrient contributions to Lake Sallie from the Detroit Lake and St. Clair Lake outlets (Figure 2). When nutrients from both sources were totaled, nitrogen in the Pelican River below the Lake St. Clair confluence was equal to 110 percent of the nitrogen loading to Lake Sallie as measured at Station 1. Phosphorus equaled 176 percent of the phophorus loading to Lake Sallie at Station 1. Therefore, 10 percent of the total nitrogen and 76 percent of the total phosphorus entering from Detroit and St. Clair lakes were retained by the Pelican River-Muskrat Lake system.

TABLE III.—Water Budget Parameter Errors

Source	Error (%)	Magnitude of Error (acre-ft/yr)
Surface water input	5	760
Precipitation	5	110
Surface water output	5	850
Evaporation	10	310
Change in storage	5	20

Note: Acre-ft × 1,233.5 = cu m.

TABLE IV.—Water and Major Nutrient Contributions to Lake Sallie

Source	Volume (acre-ft)	Nutrient (lb)				
		NH_3-N	NO_2-N	NO_3-N	Total N	Total P
I. Input						
Muskrat Lake	13,598	11,077	195	1,037	34,054	15,543
Monson Lake (via ponds)	240	104	4	11	487	191
Monson Lake	21	8	0	1	29	20
Fox Lake	337	147	10	22	179*	123
Precipitation	2,107	2,234	—	2,520	6,243	183
II. Output						
Lake Sallie (outlet)	15,661	4,927	284	566	39,010	5,700
Fish harvest	—	—	—	—	2,603	705
Weed harvest	—	—	—	—	1,590	221
Evaporation	3,277	—	—	—	—	—
III. Storage change	+420	433	7	23	1,519	665

* Inorganic only.
Note: Acre-ft × 1,233.5 = cu m; lb × 0.454 = kg.

One of the most evident features of this water course was that the Detroit Lake outlet (Figure 1) contributed 71 percent of the total flow entering Lake Sallie at Station 1, but only 13 percent of the total phosphorus. St. Clair Lake, however, contributed only 29 percent of the flow at Station 1 but 87 percent of the total phosphorus. Similarly, 43 percent of the total nitrogen input at Station 1 was from St. Clair Lake and 58 percent from Detroit Lake. Relative concentrations of both phosphorus and nitrogen were much higher in the wastewater enriched flow from St. Clair Lake.

Data from July 27, 1970, illustrate the dramatic difference between the outflows of Detroit and St. Clair Lakes (Table V). The river bottom at Station A was clearly

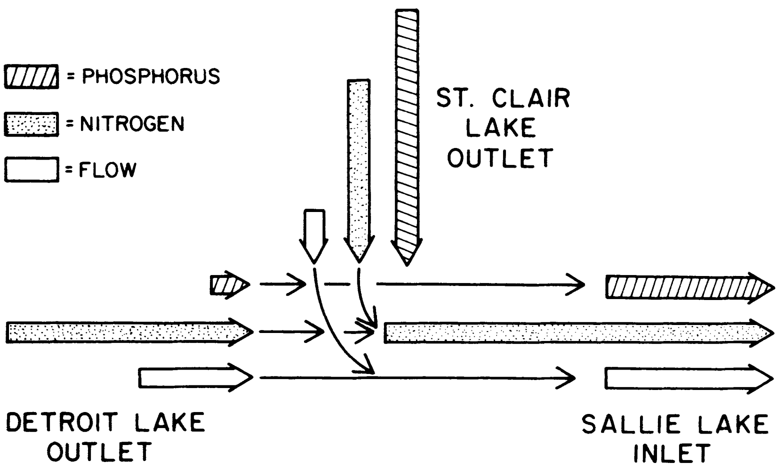

FIGURE 2.—Relative water and nutrient inputs (indicated by arrow lengths) to Lake Sallie, Minnesota, from Detroit and St. Clair lakes during the 1970 water year.

TABLE V.—Surface Water Chemical Characteristics

Parameter	Station		
	A*	B†	C‡
Temperature, °F	71.6	69.8	71.6
pH	8.3	8.9	8.7
CO_3 alkalinity, mg/l	14	70	32
HCO_3 alkalinity, mg/l	150	158	152
Total hardness, mg/l	166.6	225.4	196.0
Ca^{2+} hardness, mg/l	49.0	107.8	63.7
Mg^{2+} hardness, mg/l	117.6	117.6	132.3
Total P, mg/l	0.15	0.60	0.42
Soluble Ortho-P, mg/l	<0.02	0.54	0.26
NH_3-N, mg/l	0.15	0.69	0.77
NO_2-N, mg/l	<0.001	0.088	0.031
NO_3-N, mg/l	0.024	0.041	0.011

* Pelican River 33 ft (10 m) upstream from wastewater effluent ditch.

† Confluence of wastewater effluent ditch and Pelican River.

‡ Pelican River 33 ft (10 m) downstream from wastewater effluent ditch.

Note: 0.555(°F − 32) = °C.

visible at a depth of 3 ft (1 m), while at Station B the Secchi disk disappeared at 18 in. (46 cm) because of the abundance of phytoplankton. Reduced concentrations of all chemical parameters at Station C (Figure 1), following the sharp rise at the confluence, reflects dilution of St. Clair Lake water by the relatively nutrient-poor flow of the Pelican River. This system produced an annual mean nitrogen to phosphorus ratio of only 2.2 at Station 1. The extremely low ratio indicates a high degree of pollution and is more typical of wastewater lagoon effluent than of lake water.[18, 19]

With the possible exception of spring snow melt, unchanneled surface runoff to Lake Sallie was insufficient to sample.[17] The reasons were that the direct drainage area of the lake is only 520 acres (210 ha), less than half its surface area, and that the soil is extremely sandy, allowing rapid infiltration. Therefore, precipitation falling on the direct drainage area rapidly became part of the groundwater system and was ultimately sampled, analyzed, and reported as groundwater.

Approximately 15 percent of the hydrologic input to Lake Sallie in 1970 was from groundwater. Although 43 groundwater samples from 13 wells around the lake were analyzed, sampling was conducted only from March through July 1970. Phosphorus concentrations showed considerable variation from month to month, while the mean total phosphorus concentration for all wells over the 5-month sampling period was 0.10 mg P/l. Extreme variability of the groundwater nutrient concentrations led the authors to discard them as unreliable, and thus the nutrient loading from this source was omitted from the final budget. However, if mean nutrient concentrations over the sampling period considered were applied to the annual groundwater input, they would indicate a groundwater nutrient contribution of approximately 619 lb (281 kg) of phosphorus and 2,071 lb (940 kg) of nitrogen. This amounts to only 3.7 percent of the total phosphorus and 4.8 percent of the total nitrogen input to the lake, and, therefore, its omission should not result in serious error. It should be noted that precipitation contributed nearly 15 percent of the total nitrogen input to Lake Sallie.

The data indicate that the Detroit Lake-St. Clair Lake-Pelican River-Muskrat Lake system was the major supplier of plant nutrients to Lake Sallie, contributing 97 percent of the total phosphorus and 83 percent of the total nitrogen. Nutrient loss from Lake Sallie was primarily from surface outflow, aquatic plant harvest, and fish harvest. Nitrogen loss by outflow was 39,010 lb (17,710 kg) for the 1970 water year. Phosphorus loss for that period was 5,700 lb (2,588 kg).

The wet weight of plants harvested from Lake Sallie during 1970 was 944,000 lb (428,576 kg), which, when converted to dry weight, equaled 66,950 lb (30,395 kg). The mean dry weight phosphorus and nitrogen concentrations of these plants were 0.27 and 2.34 percent, respectively. Plant harvest, therefore, removed 221 lb (100 kg) of phosphorus and 1,590 lb (722 kg) of nitrogen.

Anglers and commercial fishermen took 126,031 lb (57,218 kg) of fish from the lake during the 1970 water year. The commercial fish catch consisted mostly of ictalurids (catfish family). Fish removed by anglers were 48 percent centrarchids (sunfish family), 35 percent ictalurids, and 17 percent percids (perch family). The overall mean phosphorus concentration of these fish on a wet weight basis was 0.63 percent; nitrogen was 2.02 percent. Phosphorus removal by fish harvest amounted to 705 lb (320 kg); nitrogen removal was 2,603 lb (1,182 kg).

Phosphorus and nitrogen loss from Lake Sallie thus occurred primarily by outflow; measurements at the lake outlet (Station 8) accounted for 78 percent of the total phosphorus output. Fish harvest was responsible for 9.6 percent and plant harvest 3.0 percent of the phosphorus output (Table VI). Nitrogen loss from the lake at Station 8 amounted to 87 percent of the total nitrogen output, fish harvest removed 5.8 percent, and plant harvest removed 3.5 percent. Mathematically, these percentages plus the one accounted for by volume change equaled 100 percent of the phosphorus and nitrogen loss from the lake.

In relation to the total phosphorus input to the lake, plant harvest was successful in removing only 1.37 percent of the phosphorus contained in the inflows. In terms of phosphorus present in the lake at fall circulation, the harvest of plants would have reduced that quantity by 1.03 percent. In spite of the increased phosphorus uptake by plants in phosphorus enriched waters, it seems that plant harvest alone is incapable of appreciably reducing the nutrient content of a hypereutrophic lake.

Phosphorus loading to Lake Sallie during the 1970 water year amounted to a net gain of 8,769 lb (3,981 kg), or 55 percent of the total input. There was, however, a net loss of nitrogen amounting to 3,730 lb (1,693 kg); nitrogen output from the lake exceeded input by approximately 9 percent (Table VI).

An inverse relationship was indicated between flow and phosphorus concentration at Station 1 during the peak flow period (Figure 3). Phosphorus loading to Lake Sallie began rising with the advent of ice cover and continued to increase until mid-March when the flow rate began to rise. Two 8-in. (20-cm) planks were removed from the Lake Sallie inlet spillway on March 26, 1970, by the Minnesota Conservation Department in an attempt to break up the ice on the lake. The resultant flow increase was Muskrat Lake storage water, anaerobic since ice cover began, coupled with some snow melt. The phosphorus concentration of this water remained at a relatively high level for several days, but gradually declined as the flow rate continued to increase. Phosphorus loading to Lake Sallie, therefore, corresponded with phosphorus concentrations but not with flow rate (Figure 3).

The foregoing does not agree with the observations of Shannon and Lee,[20] who correlated high spring phosphorus concentrations (>0.8 mg P/l) in Black Earth Creek, Wis., with maximal spring flow rates. The effect was an extremely high phosphorus loading over a short period of time. They concluded that high rates of runoff from manured farm land were responsible. Data from this study indicate, however, that increased spring discharge to Lake Sallie played a significant role in diluting or flushing the system. Reduction in phosphorus levels over the summer probably reflect organism uptake and precipitation of phosphorus when carbonate alkalinity

TABLE VI.—Phosphorus and Nitrogen Balance of Lake Sallie

Source*	Nutrient	
	Phosphorus (lb)	Nitrogen (lb)
C_xS_i	15,877	34,749
C_xG_i	0	0
C_xP	183	6,243
C_xR	0	0
C_xS_o	5,700	39,010
C_xG_o	0	0
C_xW_o	221	1,590
C_xF_o	705	2,603
$C_x\Delta V$	665	1,519
L_e	8,769	−3,730

* Sources identified in Equation 3.
Note: Lb × 0.454 = kg.

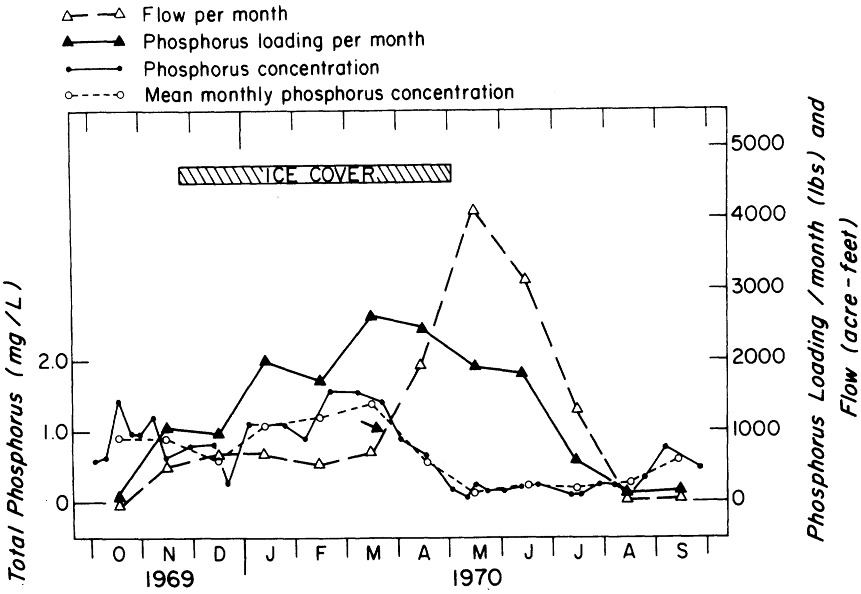

FIGURE 3.—Phosphorus concentration, loading, and flow at Station 1 during the 1970 water year. Arrow marks the time of plank removal from the spillway. (Note: Lb × 0.454 = kg; acre-ft × 1,233.5 = cu m.)

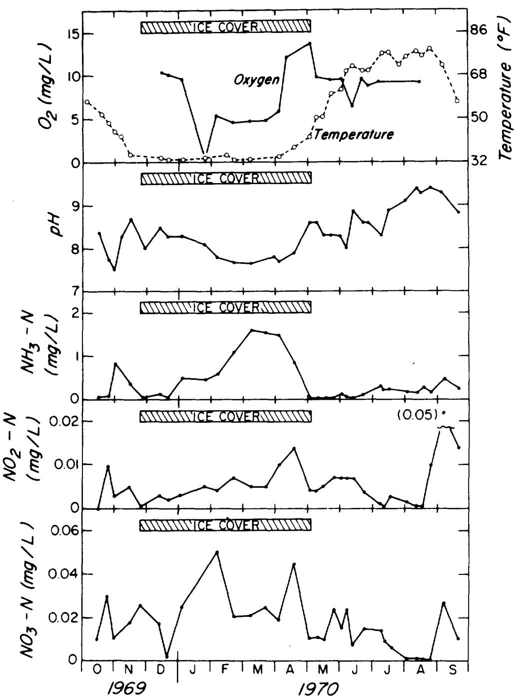

FIGURE 4.—Chemical parameters of inflowing water at Station 1 during the 1970 water year.

and pH become elevated by the photosynthetic activity of algae and macrophytes.

Figure 4 indicates that the concentrations of ammonia and nitrite nitrogen entering Lake Sallie from Muskrat Lake (Station 1) paralleled that of phosphorus under ice cover as shown in Figure 3. This pattern is not unusual for shallow, eutrophic lakes during winter because oxygen and pH normally decrease under the ice. As might be expected in water with declining pH and oxygen content, the nitrate levels under ice cover were extremely low relative to those of ammonia and nitrite.

Phosphorus output from Lake Sallie at Station 8 corresponded with flow more closely than that at Station 1 (Figure 5). This was not unexpected because Lake Sallie for the most part did not exhibit the near-anaerobic conditions found in Muskrat Lake.

Phosphorus apparently was continually incorporated into the lake system because the input far exceeded the output. Phosphorus loading to the lake system during the 1970 water year was 7.25 lb/acre (0.81

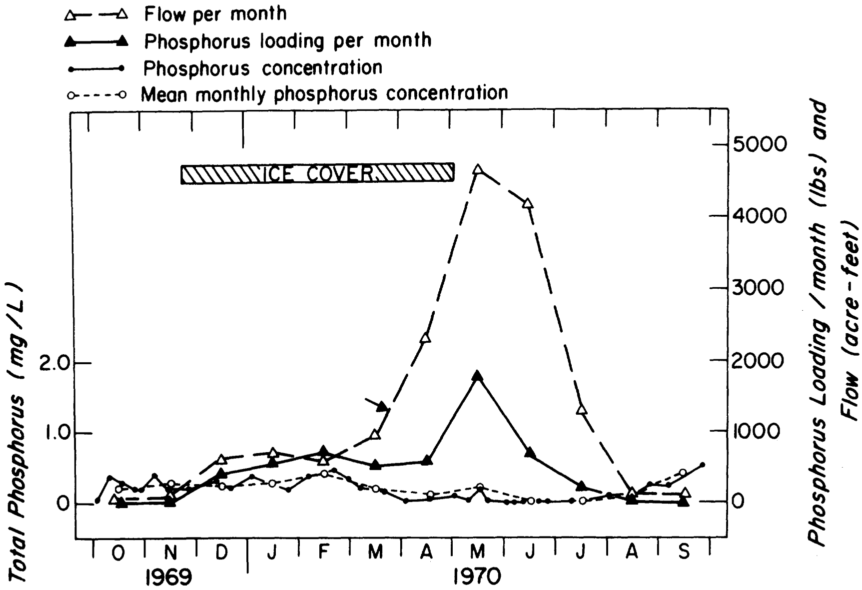

FIGURE 5.—Phosphorus concentration, loading, and flow at Station 8 during the 1970 water year. Arrow marks the time of plank removal from the spillway. (Note: Lb × 0.454 = kg; acre-ft × 1,233.5 = cu m.)

g/sq m), about the same as reported for Lake Monona, Wis.[21] According to Vollenweider's index of eutrophication,[22] Lake Sallie would be considered highly eutrophic.

Although Fitzgerald[23] reported that phosphorus in sediment under aerobic conditions is not readily available to phosphate limited algae, the same is not necessarily true in the case of rooted aquatic macrophytes, which obtain at least part of their nutrient supply from the sediment.[24-26] Schults[26] and Reimold[27] indicate that, in fact, rooted aquatic plants act as pumps to liberate phosphorus from the sediment and return it to the water.

Phosphorus loading rate, when used as an index of eutrophication, therefore, may have decreased significance for lakes where macrophyte growth is profuse. That is, the eutrophic state may be manifested in organisms capable of recycling sedimented nutrients with little dependence on current loading rates.

Summary and Conclusions

Aquatic plants were harvested for 3 months from the entire littoral zone of Lake Sallie, Minn. The primary purpose of this study was to determine whether the full-scale harvest of aquatic macrophytes might remove substantial amounts of plant nutrients from an artificially enriched lake, thus assisting in its restoration. In order to evaluate the harvest in terms of nutrient removal, a detailed nutrient budget was compiled for the lake.

Phosphorus loading corresponded with nutrient concentrations of the inflow but not with the volume of inflow. Phosphorus loading declined as spring flows increased, indicating that spring runoff in the Lake Sallie watershed had a beneficial effect on the lake with respect to phosphorus loading.

It is unlikely that groundwater contributed more than 4 percent of the total phosphorus and 5 percent of the total nitrogen to the lake during the study period. The Pelican River system supplied 97 percent of the phosphorus and 83 percent of the nitrogen to Lake Sallie. St. Clair Lake, which received wastewater effluent from the city of Detroit Lakes, furnished 87 percent of the phosphorus and 43 percent of the nitrogen load in the river. The waste effluent was presumably the reason for high nutrient concentrations from this source. The ultimate major contributor of plant nutrients to Lake Sallie, therefore, seems to have been the city of Detroit Lakes.

Perhaps the most significant conclusion to be derived from this study is that continuous harvest of aquatic plants from Lake Sallie during the growing season could not offset the high loading of phosphorus and nitrogen. The wet-weight harvest of 944,000 lb (428,576 kg) of plants was successful in removing only 1.37 percent of the total phosphorus input to the lake, or 1.03 percent of the phosphorus contained in the water volume of the lake during the fall circulation period.

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At the time the study was conducted Peterson and Smith were associated with the Department of Biology, University of North Dakota, Grand Forks.

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