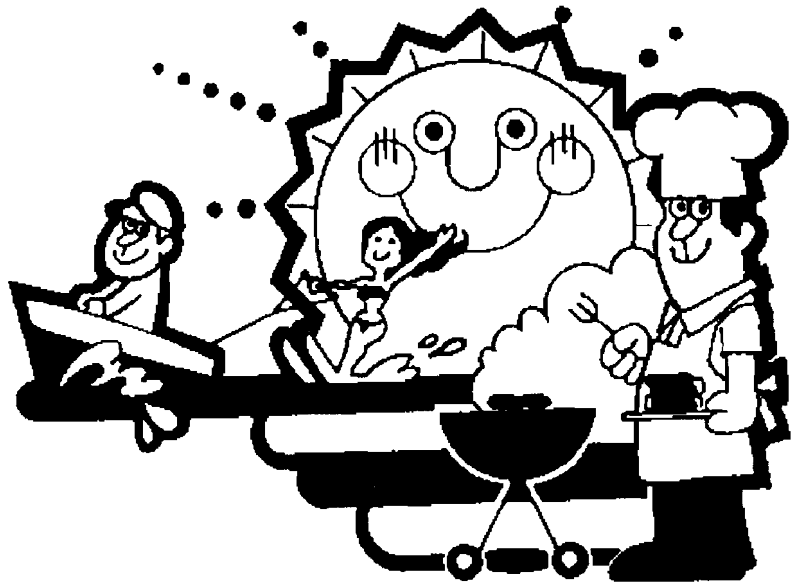
LPL-064, 66, 74

AMERY LAKES DISTRICT

1991 - 1992
LAKES MANAGEMENT STUDY



PREPARED BY

AMERY LAKES DISTRICT

INTRODUCTION

In 1991 the Amery Lakes District in cooperation with the City of Amery applied for grant money to undertake a lakes study of the three lakes lying within the Amery Lakes District. The grant was approved and we received a grant totaling $18,938.52 which is a 75% share of the estimated cost of the project.

The study included topographical mapping of the Amery Lakes watershed which will be used for present projects as well as for planning in future development in and around Amery. They will be extremely helpfull in spotting target areas where potential runoff in developing areas could be a problem for the Amery lakes.

We will also be taking water samples in the lakes to compare to the samples taken in 1980 and to help us in understanding and spotting problem areas to the lakes. Our sampling was testing for Nitrogens and Phosphorus and an explanation of those readings is contained later in this booklet.

Aerial photographs were taken of the Amery area and the topographical maps have been made. Copies of the map are on display at Amery City Hall. They are continuing to upgrade the maps, and they should be a usefull tool for Amery for years to come.

We feel it is important to review the data collected in the 1980 study. For that reason the colored pages following this cover letter are reprints of the pages from the 1980 study. We have omitted the charts and graphs in an effort to keep costs of printing down.

Drainage Basin

The combined area draining to the Amery Lakes is 1,182 acres. Figure 1 represents the direct drainage boundary about each lake. Table 1 lists each lake and its physical characteristics.

TABLE 1. Physical Characteristics of the Amery Lakes.

Pike Lake (Figure 2)	
Watershed Area (A_d)	764 acres
Lake Area (A)	159 acres
Lake Volume (V)	2,140 acre-feet
Mean Depth (V/A)	13.5 feet
Maximum Depth	33 feet
Hydraulic Residence Time	3 years
North Twin Lake (Figure 3)	
Watershed Area (A_d)	1,061 acres
Lake Area (A)	135 acres
Lake Volume (V)	1,422 acre-feet
Mean Depth (V/A)	10.5 feet
Maximum Depth	27 feet
Hydraulic Residence Time	1 year
South Twin Lake (Figure 4)	
Watershed Area (A_d)	1,182 acres
Lake Area (A)	74 acres
Lake Volume (V)	360 acre-feet
Mean Depth (V/A)	4.9 feet
Maximum Depth	9 feet
Hydraulic Residence Time	0.25 years

The hydraulic residence times were estimated from a series of 8 instantaneous flow measurements made at the outlet of North Twin Lake and 12 instantaneous flow measurements made at the outlet of South Twin Lake. In addition to the instantaneous surface water flows, the groundwater contribution was estimated from a series of observation wells installed about each lake. The direction of groundwater flow is illustrated in Figure 5.

TABLE 2. Total Phosphorus Loading to the Amery Lakes.

LAKE/SOURCE	LBS/YR	KG/YR	PERCENT
PIKE LAKE			
Urban	39	(17.6)	13
Woodlands	15	(7.0)	5
Agricultural	64	(29.1)	22
Atmospheric to lake	45	(20.5)	15
Atmospheric to lake via wetlands	9	(3.9)	3
Septic systems about lake	21	(9.4)	7
Septic systems from trailer park	13	(6.0)	4
Groundwater	88	(40)	30
TOTAL	294	(133.5)	99
NORTH TWIN LAKE			
Urban	395	(179.4)	73
Woodlands	2	(0.9)	--
Atmospheric to lake	38	(17.4)	7
Atmospheric to lake via wetlands	5	(2.4)	1
Pike Lake	65	(29.5)	12
Apple River	5	(2.4)	1
Groundwater	31	(14.0)	6
TOTAL	541	246	100

LAKE/SOURCE	LBS/YR	KG/YR	PERCENT
SOUTH TWIN LAKE			
Urban	65	(29.6)	35
Woodland	3	(1.4)	2
Atmospheric to lake	21	(9.5)	11
Atmospheric to lake via wetlands	1	(0.6)	--
North Twin Lake	77	(35)	41
Septic systems	8	(3.7)	4
Groundwater	12	(5.3)	6
TOTAL	187	85.1	99

Water quality

The total phosphorus loadings to each lake from the watershed and their respective water quality characteristics will be considered individually.

1. Pike Lake

Agriculture is the most significant land use in the Pike Lake watershed, contributing 20% of the annual phosphorus budget. However, much of the agricultural runoff is from the east side of Highway 47 and the impact to the lake is lessened considerably owing to the existence of wetlands. In general, the phosphorus loading to Pike Lake appears to be reasonable and suggests that the water quality of the lake should be acceptable to the lake users. The trophic position for Pike Lake is illustrated in Figure 8. The model used in this illustration does not, however, account for rooted aquatic plants and is limited to relationships between the free floating microscopic plants (algae), water transparency, and nutrient concentrations within the open water area of the lake. The rooted aquatic plants cover approximately 100 acres of the 159 acre lake and interfere somewhat with recreational usage. A lake map showing the location of the major plant species is presented in Figure 9. During the summer, the plants are growing to a maximum depth of approximately 20 feet. A species list is presented in Table 3.

These plants also contribute phosphorus loading to the lake through an internal recycling process. A certain amount of phosphorus taken from the lake sediments by the rooted aquatic plants during their seasonal growth can be recycled back into the lake upon death of the plants. Figure 10 illustrates the seasonal patterns of whole lake weighted average total phosphorus for Pike Lake and also the weighted average for just the surface to 7.5 foot depth. The increases in the phosphorus concentration in the lake during May, June and July are a result of a combination of events: (1) The lake thermally stratified beginning in May and the bottom waters became anoxic, without oxygen, (Figure 11). As a result of anoxic conditions in the bottom waters, phosphorus was released from the sediments and this resulted in an increase in the total amount of phosphorus in the lake; (2) There were several major rain events during the month of June that may have resulted in phosphorus influx from the watershed via surface runoff (Figure 10), and (3) Between the two dates of the macrophyte surveys, June 30 and August 14, there was a decrease in certain plant species, e.g. *Potamogeton pectinatus*, and elimination of others, e.g. *Potamogeton richardsonii*. A portion of the phosphorus within the dead plant tissue was probably recycled to the lake.

The algal growth patterns in Pike Lake for the summer of 1980 are illustrated in Figure 12. The dominant algae during the months of July, August, September and October were in the blue-green classification. In general, the blue-green algae create more of a nuisance problem because they have gas vacuoles that allow the algal cells to be positioned anywhere in the water column. During periods of low water transparency, these algae can physiologically adjust their gas vacuoles to float near the surface, thereby creating a scum-like appearance.

During the summer months when blue-green algae were dominant, their total biomass (weight) in the lake was not overly large. Algae biomass is measured by determining the amount of plant pigment chlorophyll. If the amount of chlorophyll present is 10-20 milligrams per cubic meter of water (mg/m^3) or greater, a green color is usually evident. The only time that the algal biomass became a concern was during the months of late September and October when the genus Oscillatoria became dominant. The physiological requirements of Oscillatoria are generally associated with cooler water temperatures and its dominance in the surface water during the fall months is common.

2. North Twin Lake

The largest single external source of phosphorus loading to North Twin Lake is urban runoff, contributing 73% of the annual phosphorus budget (Table 2). This assumes that the Apple River is not allowed to be diverted into North Twin Lake except for short periods. The percent contribution from the river would be increased if the diversion were to be of any duration. For example, if the diversion were allowed to proceed at a modest flow of 2 cubic feet per second (cfs) for 3 months during the summer, its percent contribution would change from 1% to 8%. If the diversion would be at 2 cfs for 8 months, the contribution would change to 20% of the total budget.

The trophic position for North Twin Lake suggests that, relative to other lakes, the annual phosphorus loading rate should create some problems with nuisance algae growth (Figure 13). This was confirmed by the algae and chlorophyll data from the feasibility study (Figure 14). During late July through September there was an abundance of blue-green algae. The amount of chlorophyll present in the lake during that time period ranged from 19 mg/m^3 in July to a high of 45 mg/m^3 in late August. The two dominant blue-green algae were Anabaena and Lyngbya, and both can create nuisance conditions. The type of algae (blue-green) and the chlorophyll concentrations of greater than 10-20 mg/m^3 confirm that North Twin Lake is experiencing signs of excess fertility.

The attached aquatic plants were growing to a depth of 20 feet in North Twin Lake and the plants were growing over 125 of the 135 surface acres. A map showing the location of the major plant species is presented in Figure 15 and a species list is given in Table 4. There has been some aquatic weed control using chemicals, e.g. endothal; however, the area treated has always been less than one (1) acre since 1976.
The aquatic plants were surveyed on two occasions during the feasibility study, June 26 and August 11, 1980. Between the two sampling periods, there was a considerable die-off of one particular species, Potamogeton richardsonii. The resultant recycling of nutrients from the dead plant tissue may have been utilized by the algae and other aquatic plants. The seasonal pattern of whole lake weighted average concentration of total phosphorus for North Twin Lake is presented in Figure 16. There was a 33-pound increase of total phosphorus in the lake between June 23 and late July 28, 1980. Some of the total phosphorus increase may have been as a result of plant decay, while urban runoff during several storm events would also have been a contributor. In addition, sediment phosphorus would be released under the anoxic conditions present near the lake bottom (Figure 11).

3. South Twin Lake

South Twin Lake is much shallower than Pike and North Twin lakes, with a maximum depth of 9 feet. As a result of being shallow, the lake will only occasionally thermally stratify (Figure 11). When the lake stratifies, the dissolved oxygen in the bottom waters is rapidly depleted until the lake mixes again as a result of a strong wind and/or cooler weather fronts that move through the area.

The largest sources of phosphorus to South Twin Lake are urban runoff and the influx from North Twin Lake (Table 2, p.7). The total phosphorus loading rate suggests an acceptable water quality (Figure 17). A plot of the total phosphorus weighted average concentrations illustrates that levels are generally satisfactory (e.g. 10-30 mg/m^3), although exceptionally high values were present on occasion (e.g. 71 mg/m^3; see Figure 18). The model used in this illustration does not, however, account for rooted aquatic plants and is limited to relationships between the free floating microscopic plants (algae), water transparency and nutrients.

A graphical presentation of the algal biomass (chlorophyll) and seasonal succession of the various algal genera is presented in Figure 19. The chlorophyll concentrations were above 20 mg/m^3 on 5 occasions, June, August (2), and September (2). These chlorophyll levels are indicative of waters in the eutrophic category (nutrient rich) and show that the actual water quality is not as satisfactory to the lake users as suggested in Figure 18.

MANAGEMENT ALTERNATIVES

The three lakes -- Pike, North Twin and South Twin -- are partially within the urban setting of Amery. There are several environmental factors that differentiate these lakes, such as mean depth, thermal stratification, nutrient loading. Each lake was reviewed separately and the following management alternatives are suggested for Lake District consideration.

Pike Lake

Urban development has encroached upon the south shore of Pike Lake. During the present study, however, the urban contribution to the phosphorus loading was estimated at only 13 percent of the total annual loading to the lake. Because of the potential increase in phosphorus and sediment contributions that could occur from future urban development about the lake, the lake district should the practices in appendix A.

In most cases, a combination of limited grading, limited time of exposure and a judicious selection of erosion control practices and sediment trapping facilities will prove to be the most practical method of controlling erosion and the associated production and transport of sediment.

B. Divert new urban drainage towards existing wetlands within the watershed. Wetlands can play an important role in ameliorating stormwater runoff from a variety of developments and drainage areas. There are four apparent mechanisms at work in a wetland. These are: (1) physical entrapment, (2) microbial utilization, (3) plant uptake, and (4) adsorption. Physical entrapment is a reality; 94 percent of the total suspended solids discharged to the wetlands were retained during a detailed study of wetlands in Wayzata, Minnesota. Each of the other 3 mechanisms have also been shown to be important by research activities elsewhere.

C. Require of any new development either connection to city sewers or properly installed private waste disposal systems that have a minimum drainage field setback from the lake of 100 feet. Soils can sorb phosphates readily. However, the proper drainage and distance from the lake is important. Figure 21 was determined from a series of studies about septic system drain fields in Wisconsin and illustrates how the soils sorb phosphates. The farther from the source, the less phosphate was in the groundwater. Groundwater concentrations of phosphorus are already relatively elevated about Pike Lake and any further impacts upon the nutrient concentrations should be avoided.

At the present, Pike Lake does not appear to be plagued with algal problems, fish winterkills, or a poor fishery. The only apparent problem is an overabundance of attached aquatic vegetation in the western part of the lake. Much of the western basin is completely dominated by attached plants and during the summer months, very little open water is present.
However, the western basin offers a very diverse habitat for wildlife, fishery and aesthetics, and although some restriction of movement within the area is evident, the lack of any urban development about the basin precludes immediate pressures for creation of more open water. In addition, channels now exist between Pike and North Twin lakes and from the eastern to the western basins of Pike Lake.

The present condition of Pike Lake suggests that lake management efforts should be directed towards protecting the existing resource. Local units of government are a mechanism available to establish and enforce zoning requirements that will protect the water quality of Pike Lake into the future. Construction ordinances, waste disposal requirements, and diversion of any potential sources of sediment and nutrients away from the lake or through a biofiltration system (wetland) should be the primary concern of the lake district.

North Twin Lake - Watershed

The source of existing and potential water quality problems for North Twin Lake can be summed up in two words, "urban runoff." The lake is surrounded on 3 sides by residential and some light commercial development. The western end is generally undeveloped and is in communication with a substantial wetland area. Approximately 75 percent of the total phosphorus budget to the lake is from the urban setting. Any attempt to improve the water quality involves the treatment of the urban runoff.

There are several practices available for treating the urban runoff to North Twin Lake.

1. Use of wetlands as sediment traps and filters. The existing channel between the Apple River and North Twin Lake could be developed into a wetland and sedimentation basin. A semi-wetland already exists along the present channel. A sediment basin would have to be constructed and the channel enlarged to accommodate urban stormwater from the northeast

portion of the watershed (see Figure 22). A diversion ditch under Highway 47 would be sized to handle the increased flow to the lake through the existing wetland on the northeast corner of North Twin, or the stormwater could preferably be pumped to the Apple River Flowage. The small existing wetland should be modified to spread the incoming water over the soils rather than following the present channel.

Advantages - Urban runoff has the highest yield of nutrients and sediments of the various land-use categories. The use of wetlands and sedimentation traps can be beneficial in reducing the nutrient/sediment loading to North Twin Lake. Similar practices elsewhere, using wetlands to control urban runoff, reduced phosphorus by 70-80 percent and suspended solids by 90 percent. The decreased phosphorus input into North Twin Lake, as a result of wetland utilization, would have a beneficial effect upon the nutrient status of the lake. The possible reduction in phosphorus loading is presented in Figure 23.

Disadvantages - The development of a wetland and sedimentation pond in the city park would decrease the usable area for public enjoyment. There is a possibility of stagnant water remaining in the wetlands and pond for extended periods of time. Trash collection would be necessary periodically to clean debris from the outlet structure. The potential for greater mosquito production will exist, although stagnant water is already present in the channel.

2. Diversion of remaining urban runoff to the outlet channel from South Twin Lake. It may be possible to divert a portion of the remaining urban runoff to the outlet of South Twin Lake. A possible diversion could encompass the area shown in Figure 22. The direct effect of this practice on the phosphorus loading to North Twin Lake is illustrated in Figure 26.

3. Combination of (1) and (2). This would offer the most complete management program for North Twin Lake. The combined effect on the phosphorus loading rate to North Twin is presented in Figure 23.

Other lake districts have diverted urban stormwater runoff away from their lakes. For example, the Waupaca Inland Lake Rehabilitation District (City of Waupaca) diverted storm drainage away from two lakes, Mirror and Shadow lakes. The watershed area involved was 94 acres and the cost of the diversion project was approximately $400,000.

Also, the Eau Claire Inland Lake Rehabilitation District diverted the major storm sewer draining to Half Moon Lake. The watershed area diverted was 1,200 acres and the cost of the diversion was approximately $230,000.

A project using wetland treatment of urban runoff in Waseca, Minnesota, has improved the water quality of Clear Lake considerably. The majority of urban storm drainage from the City of Waseca has been diverted to a 50-acre wetland for "treatment" before being pumped to Clear Lake. The total cost of the project was approximately $700,000.

Another area of local concern has been the high water level of North Twin Lake. There have been periodic problems associated with debris that accumulates at the outlet channel and causes some damming effect. The culvert between North Twin and South Twin lakes appears to have shifted through the years and the lower edge of the culvert on the North Twin Lake side may now be higher than previously, thereby causing some increase in water level elevation for North Twin Lake. This problem is not one that directly affects water quality and therefore is not eligible for state cost-sharing, however, the problem does affect local riparians and should be resolved within the district.

South Twin Lake

The basic problems associated with South Twin Lake are shallowness (maximum depth of 9 ft) and extensive growth of attached aquatic plants. The largest singular source of phosphorus to South Twin Lake is the inflow from North Twin Lake. Improvement of water quality in North Twin Lake may reduce the loading to South Twin Lake; however, because of the morphological factors (shallowness) there would be little visible improvement from the present condition.

Direct approaches to alleviating the restrictions on recreational usage are, however, available. Weed harvesting and use of aquatic herbicides are the most practical options. Each method offers economical and logical relief to the problem of weed control in South Twin Lake. Weed harvesting would be the recommended technique because of nutrient and organic tissue removal benefits. State cost sharing may be available in the future.

Other techniques, such as water level drawdown, may not be practical. Drawdown would dewater the associated wetlands and may cause slumping of organic material towards the lake basin. Dredging could be used to deepen the lake basin, thereby changing the basin morphometry and possibly reducing weed growth. However, because of the close proximity of two relatively deep lakes (Pike and North Twin), such a project would not be recommended by the Department.

South Twin Lake has experienced fish winterkills. The most recent documentation of winterkills were the winters of 1956, 1975 and 1979. The most practical solution to this problem would involve the installation of an aeration system to protect the fishery resource. An aeration system would involve a blower unit, plastic tubing and weights and a building to house the blower. More detailed plans can be prepared if the lake district wishes to proceed with this alternative. The approximate installation cost would be $12,000 and the system is cost-sharable with state funds. The operational cost should be approximately $100/month.

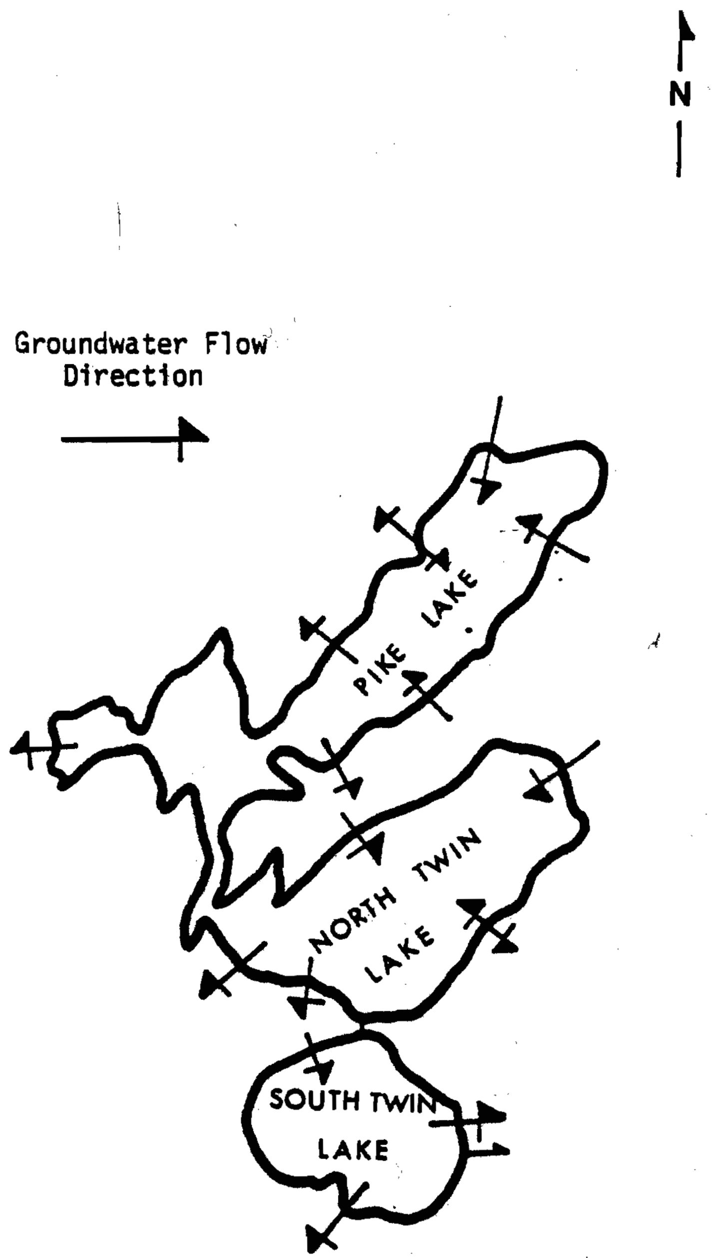


FIGURE 5

GROUNDWATER FLOW DIRECTION FOR THE AMERY LAKES

The following charts are a summary of the lake study done in 1980 as a beginning project of the Amery Lakes District. We do not have Nitrogen values for that study.

Pike Lake 1980 Study - Phosphorus

June 55 ug/L
July 45 ug/L
Sept. 43 ug/L

North Twin 1980 Study- Phosphorus
June 15 ug/L
July 25 ug/L
Sept. 27 ug/L

South Twin 1908 Study- Phosphorus
35 ug/L
70 ug/L
20 ug/L

On May 1, 1991 the Amery Lakes Board addressed the Amery City Council with the following issues:

1) On May 5, 1989 the drainage basin (Creek) in North Park was closed for a two year study period. It was noted at that time that during the years 1987-88 the creek in North Park was running Apple River water to North Twin Lake with the gate all the way open. Drought conditions of 1988 caused lower water level everywhere and the South Creek leaving South Twin Lake dried up at times. We agreed that during times of drought the south creek may not have much water flow, but improving the lakes was our goal and the 1980 study said closing the North Park Creek would help improve the water quality in North Twin and South Twin Lakes.

It appears that the lake clarity is improving slightly, and the south creek has continued to flow without the north creek flowing Apple River water. It is our recommendation to the council that the North Park creek be permanently closed and no longer divert Apple River water to North Twin Lake. This study period has shown that the underground water flow will maintain the lakes just like the 1980 study showed.

2) In an effort to help eliminate some of the urban runoff problems we would like to see the city make an effort to divert storm sewers away from the lakes instead of to them. Urban runoff is the major problem facing our lakes. It is much easier and less expensive to keep them clean than to pollute them and then try to clean them up. Because of this we applied for a grant to do topographic mapping of the Amery area. (Note: In 1992 a major storm sewer project was done in North Amery which diverts the runoff to the Apple River below the Amery dam instead of to North Twin Lake.) We hope that further projects may do the same.

****

In this report we are including the secchi disc readings for North Twin and Pike Lakes, rainfall data for the past ten years, and chemical analysis summaries of this grants testing.

The water samples were taken by volunteers of the Amery Lakes District in several locations in each of the lakes. Both surface and bottom samples were taken as well as runoff areas to each of the lakes. The testing was done by the State Lab of Hygiene. The secchi disk readings are done by Tom Butcher, a member of the Lakes District and are registered with the DNR. The annual rainfall reports are from the Amery weather station.

GRANT WATER ANALYSIS SUMMER 1991-92

Sample Taken 6/27/91

North Twin:

Total Nitrogen	.4 mg/l to .6 mg/l
Total Phosphorus	Maximum of 20 ug/l
Tot Nit to Phos	20:1 to 30:1

South Twin:

Total Nitrogen	.5 mg/l to .78 mg/l
Total Phosphorus	Maximum of 30 ug/l
Tot Nit to Phos	25:1 to 30:1

Pike Lake:

Total Nitrogen	.2 mg/l to .81 mg/l
Total Phosphorus	Maximum of 20 ug/l
Tot Nit to Phos	20:1 to 40:1

Sample Taken 7/15/91

North Twin:

Total Nitrogen	.4 mg/l to .6 mg/l
Total Phosphorus	Maximum of 20 ug/l
Tot Nit to Phos	20:1 to 30:1

South Twin:

Total Nitrogen	.5 mg/l to .80 mg/l
Total Phosphorus	Maximum of 30 ug/l
Tot Nit to Phos	16:1 to 26:1

Pike Lake:

Total Nitrogen	.2 mg/l to .84 mg/l
Total Phosphorus	Maximum of 20 ug/l
Tot Nit to Phos	10:1 to 40:1

GRANT WATER ANALYSIS SUMMER 1991-92

Sample Taken 8/29/91

North Twin:

Total Nitrogen	1.0 mg/l to 1.4 mg/l	
Total Phosphorus	Maximum of 96 ug/l	
Tot Nit to Phos	14:1 to 20:1	

South Twin:

Total Nitrogen	1.0 mg/l to 1.75 mg/l	
Total Phosphorus	Maximum of 181 ug/l	
Tot Nit to Phos	25:1 to 70:1	

Pike Lake:

Total Nitrogen	.506 mg/l to 1.45 mg/l	
Total Phosphorus	Maximum of 48 ug/l	
Tot Nit to Phos	17:1 to 30:1	

Sample Taken 6/22/92

North Twin:

Total Nitrogen	.4 mg/l to .9 mg/l	*
Total Phosphorus	Maximum of 40 ug/l	
Tot Nit to Phos	10:1 to 30:1	

South Twin:

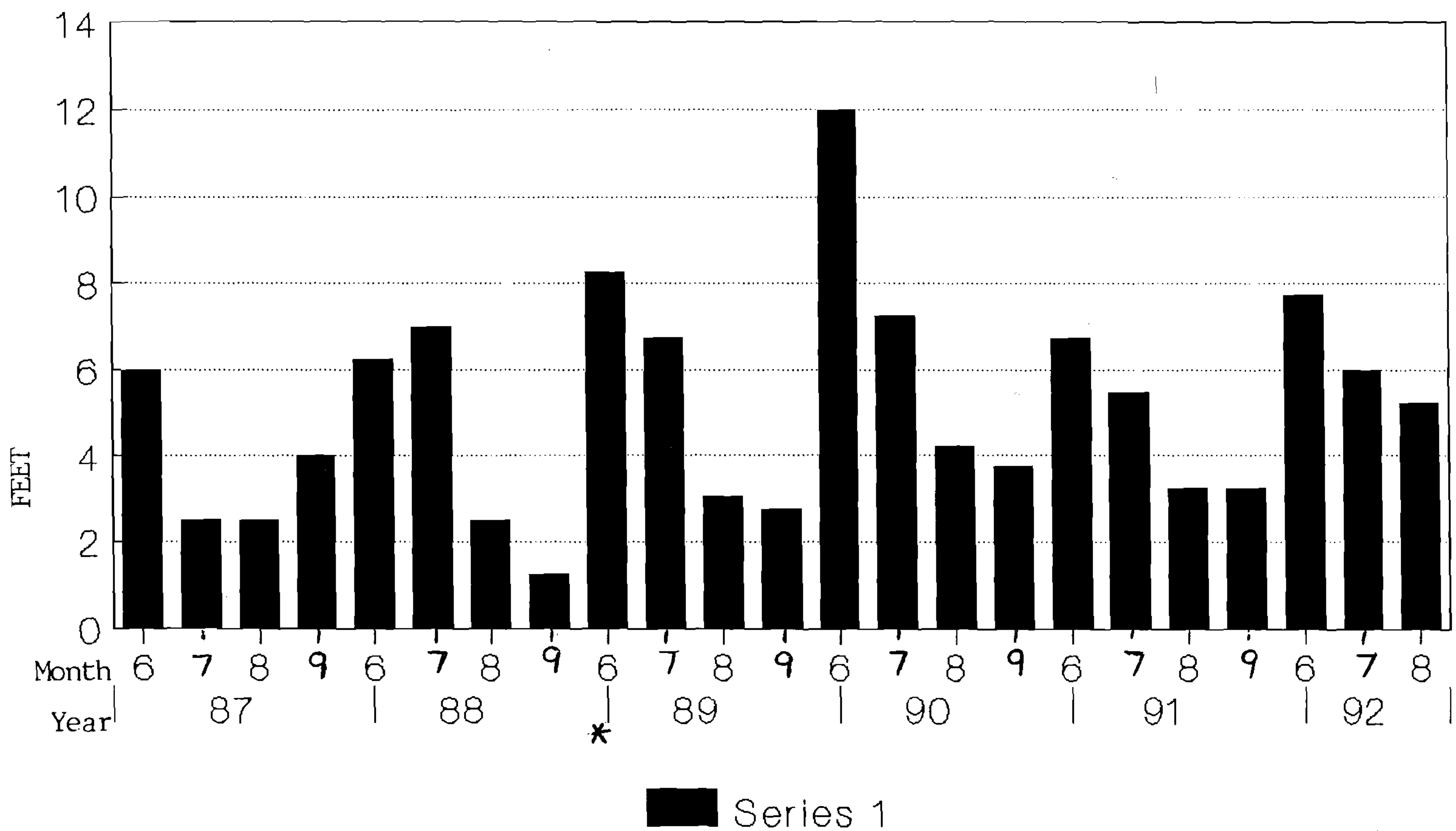
Total Nitrogen	.5 mg/l to .71 mg/l	
Total Phosphorus	Maximum of 52 ug/l	
Tot Nit to Phos	12:1 to 27:1	

Pike Lake:

Total Nitrogen	.4 mg/l to .52 mg/l	
Total Phosphorus	Maximum of 20 ug/l	
Tot Nit to Phos	18:1 to 25:1	

* A sample taken on the West end near the houses on Baker Terrace had a total Nitrogen of 1.422 mg/l, Phos of 130 ug/l and a ratio of Nit to Phos of 11:1. This one reading for an unknown reason was much higher than all the others taken with this sampling.

SECCHI DISK READINGS
NORTH TWIN LAKE

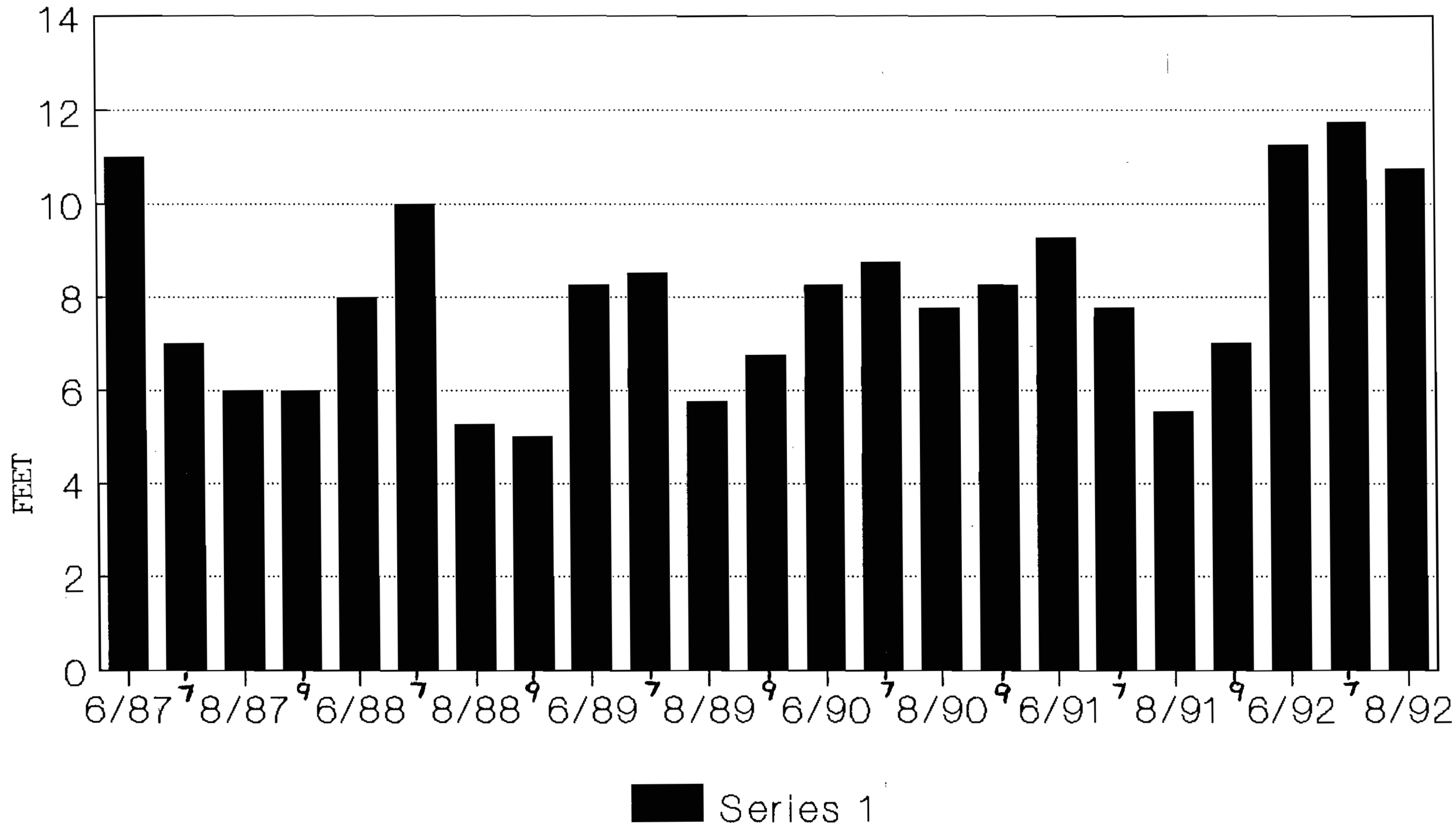


AMERY LAKES DISTRICT

These are the tests taken the closest to the end of each month. Other samples are taken during the course of each month and registered with the DNR Self Help Lake Monitoring Program.

*The creek flowing water from the Apple River to North Twin was closed on May 5, 1989.

SECCHI DISK READINGS
PIKE LAKE

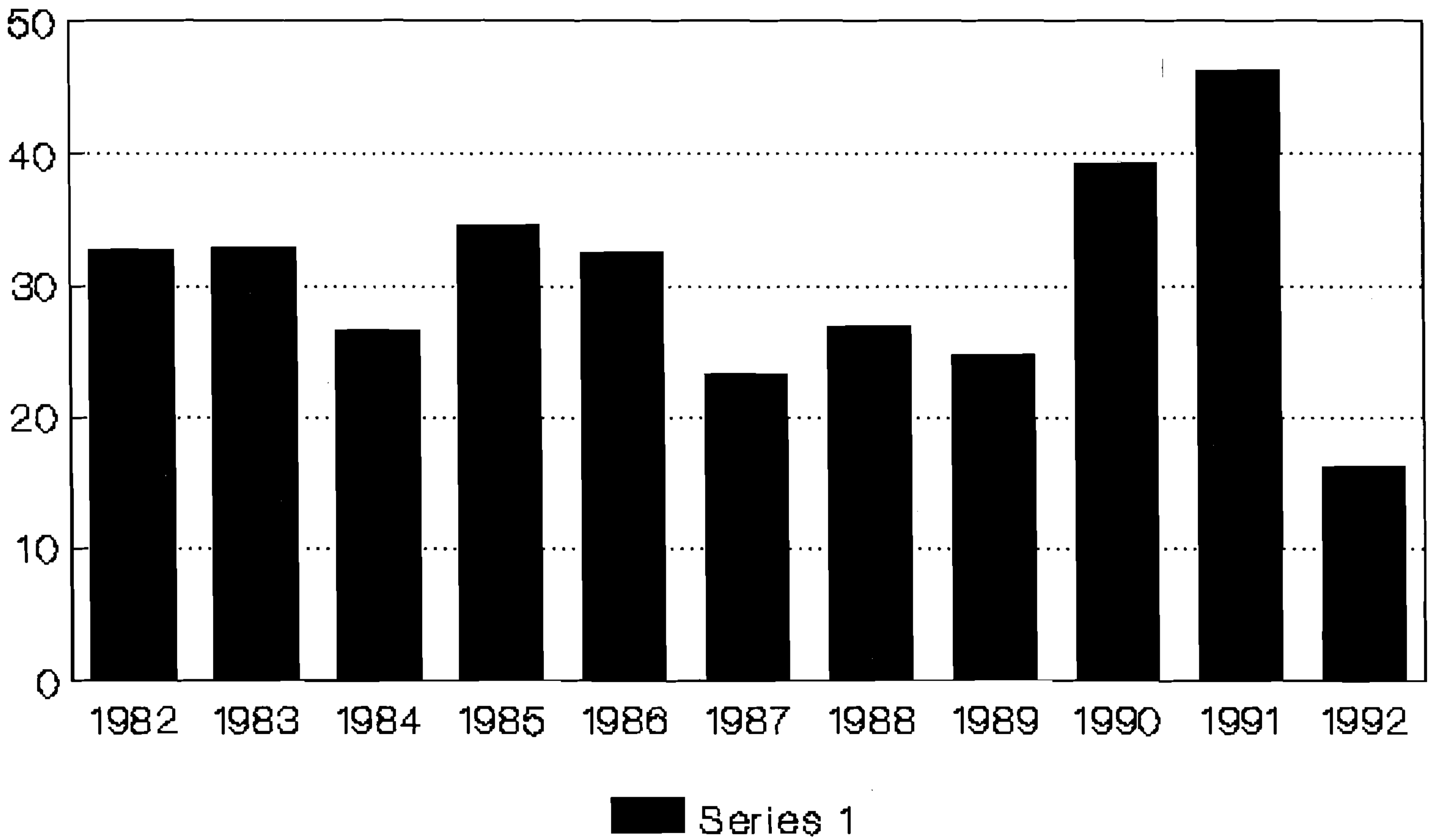


AMERY LAKES DISTRICT

These are the tests taken the closest to the end of each month. Other samples are taken during the course of each month and registered with the DNR Self Help Lake Monitoring Program.

YEARLY RAINFALL IN AMERY

INCHES OF ANNUAL RAIN



AMERY WEATHER STATION

10 Year Average: 32.01 inches

1992 reading through 8-18-92

The following pages are excerpts from the booklet, Interpreting Lake Water Quality Data: A Citizens Guide, which is published by the College Of Natural resources at the University of Wisconsin- Stevens Point. It may be helpfull in understanding the data charts from our study.

Lake Water Levels

Fluctuations in lake levels occur naturally in response to precipitation which varies widely from season to season and year to year. While some lakes with stream inflows respond almost immediately to precipitation, other lakes (seepage lakes) do not reflect changes in precipitation until months later. As an example, heavy fall rains often result in gradually rising lake levels during the following winter as the rain enters the lake as groundwater.

Lake level fluctuations can have significant effects on lake water quality and usability. Low water levels may lead to stressful conditions for fish and an increase in the amount of nuisance aquatic plants. High water levels may result in increased nutrients from runoff and newly flooded lakeshore soils. Older septic systems installed near the lake may not function properly with high groundwater levels. Water level fluctuations can also result in shoreline erosion. Records of lake water elevations can, therefore, be very useful in understanding changes that may occur in lakes.

Water Clarity

Water clarity has two main components: true color (materials dissolved in the water) and turbidity (suspended materials such as algae and silt). The algae population is usually the largest and most variable component. Water clarity gives an indication of the overall water quality in a lake, especially the amount of algae present. Figure 3 shows the inverse relationship between *Secchi disc* depth (a measure of clarity) and *chlorophyll a* (a measure of algae) for different lake types. Secchi disc readings are taken using an 8 inch diameter weighted disc painted black and white. The disc is lowered over the downwind, shaded side of the boat until it just

Water Quality Index	**Secchi Depth (ft)**
Very poor	3
Poor	5
Fair	7
Good	10
Very good	20
Excellent	32

Figure 3. Water quality index based on Secchi disc depth.

disappears from sight, then raised until it is just visible. The average of those two depths is recorded. These readings should be taken on calm, sunny days between 10 a.m. and 2 p.m.; as cloud cover, waves, and the angle of the sun can affect the Secchi disc reading.

Secchi disc values will vary throughout the summer months as algal populations increase and decrease. Measurement at several sites may be useful in some lakes, depending on how uniform the water quality is. Year to year changes result from weather and nutrient loading. Weekly or biweekly Secchi records (April-November) over a number of years provide an excellent and inexpensive way to document long-term changes in water quality.

The Wisconsin Department of Natural Resources has initiated a "Self-Help Monitoring Program" for lakes. Local volunteers take Secchi disc readings and the Department provides computer data storage and annual reports. For further information, contact a district DNR office or write to DNR Lake Management Program, WRM/2, PO Box 7921, Madison WI 53707.

Color of lake water is related to the type and amount of dissolved organic chemicals. It is measured and reported as standard color units on filtered samples. Its main significance is aesthetics; it may also reduce light penetration which affects weed and algal growth. Many lakes have naturally occurring color compounds from decomposition of plant material in the watershed. Brown-colored water results from drainage of bogs into the lake. The color compounds are largely humic and tannic acids from plant decomposition. As algae decompose, they may also impart a greenish color to the water.

Color will affect the Secchi disc reading. Table 2 lists color values associated with varying degrees of water color.

Table 2. Water color. (Adapted from Lillie and Mason, 1983)

0-40 units	Low
40-100 units	Moderate
greater than 100 units	High

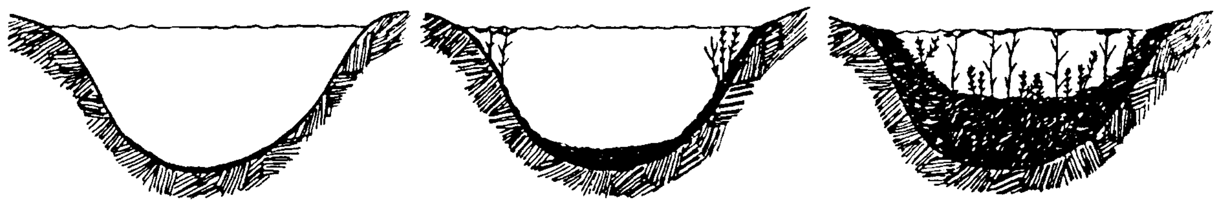
Turbidity is another measure of water clarity, but is due to particulate matter rather than dissolved organic compounds. It affects light penetration due to scattering of light and therefore also affects the depth at which plants can grow. It obviously also affects the aesthetic quality of water. High turbidities are often found in lakes receiving runoff from silt or clay soils. Values will vary widely due to seasonal runoff events. Turbidity is also caused by suspended plants and animals. Many small organisms will have a greater effect on turbidity than a few larger ones. The turbidity caused by algae is the most common cause for low Secchi disc readings.

Trophic State

Lakes can be divided into three categories based on trophic state: oligotrophic, mesotrophic, and eutrophic. These categories are a general indicator of nutrient levels and observed water clarity in a lake. *Oligotrophic* lakes are generally clear, cold, and free of weeds or large blooms of algae. Although beautiful to look at, they are low in nutrients and don't support large fish populations. However, they often have an efficient food chain with a very desirable fishery of large game fish. *Eutrophic* lakes are high in nutrients and therefore support a large *biomass*. They are likely to be either weedy or experience algae blooms, and sometimes both. They often support large fish populations, but are also susceptible to oxygen depletion. Small, shallow lakes are especially vulnerable to "winterkill" which can reduce the number and types of fish. Rough fish are often common in eutrophic lakes. *Mesotrophic* lakes are in an intermediate stage between oligotrophic and eutrophic. Their hypolimnions often are devoid of oxygen in late summer months, limiting cold water fish and resulting in phosphorus cycling from sediments.

A natural aging process occurs in all lakes, causing them to progress from oligotrophic to eutrophic over time, and to eventually fill in (Figure 4). However, people can greatly accelerate this process of *eutrophication* by allowing nutrients from agriculture, lawn fertilization, streets, septic systems, and urban storm drainage to enter lakes. In areas that are nutrient poor, the aging process may lead instead to dystrophic lakes, bog lakes that are highly colored, acid, and lower in productivity than eutrophic lakes.

Various methods have been used by researchers to calculate the trophic state of lakes. The three water quality characteristics often used to classify the trophic state are: total phosphorus concentration (an indicator of the nutrients available for algae growth); chlorophyll *a* concentration (a measure of the amount of algae present); and Secchi disc readings (an indicator of water clarity). The trophic states associated with these three



Oligotrophic

Clear water, low productivity
Very desirable fishery
Few rough fish

Mesotrophic

Increased production
Organic matter accumulation
Occasional algal bloom
Good fishery

Eutrophic

Very productive
May experience oxygen depletion
Rough fish common

Figure 4. Lake aging process.

measures are shown in Table 3. Clearly, low levels of phosphorus are associated with low levels of algae (chlorophyll *a*), which are associated with high Secchi disc readings.

Natural lakes which do not stratify are subject to nutrient inputs from sediment during summer months. Impoundments differ from other lake types, as their summer weed and algae growth is often related to the quality of water flowing into the impoundment during summer months.

Table 3. Trophic classification of Wisconsin lakes based on chlorophyll *a*, water clarity measurements, and total phosphorus values. (Adapted from Lillie and Mason, 1983)

Trophic class	Total phosphorus ug/l	Chlorophyll a mg/l	Secchi Disc ft
Oligotrophic	30	2	12
	100	5	8
Mesotrophic	180	8	6
	270	10	6
Eutrophic	300	11	5
	500	15	4

NUTRIENTS AND CHEMICAL PROPERTIES

Phosphorus

Phosphorus reactions in lakes can be complex. Phosphorus is known to be the most important nutrient limiting the amount of algae and weed growth in over 80% of Wisconsin lakes. Addition of phosphorus to these lakes will result in additional production of algae. Phosphorus originates from a variety of sources, many of which are related to cultural (human) activities. Major sources are human and animal wastes, soil erosion, runoff from farmland or lawns, and detergents.

Phosphorus analysis often includes both soluble reactive phosphorus and total phosphorus. The soluble reactive phosphorus is dissolved in the water and thus is readily available for plant growth. Its concentration, however, varies widely in most lakes over short periods of time, as plants take up and release this nutrient. Total phosphorus has, therefore, been found to be a better indicator of the lake's nutrient status. Total phosphorus includes the plant and animal fragments suspended in lake water.

Water Quality Index	Total Phosphorus (ug/l)	
Very Poor	150	
————	140	
	130	
	120	
	110	
Poor	100	
	90	
	80	
	70	_Average
	60	for im-
————	50	poundments
Fair	40	
————	30	_Average
Good	20	for natural
Very Good	10	lakes
Excellent	1	

Figure 5. *Total phosphorus concentrations for Wisconsin natural lakes and impoundments. (Adapted from Lillie and Mason, 1983)*

Ideally, soluble reactive phosphorus concentrations should be 10 ug/l or less at spring turnover to prevent summer algal blooms. A concentration of 10 micrograms per liter is equal to 10 parts per billion (ppb) or 0.01 milligrams per liter (mg/l). A concentration of total phosphorus below 20 ug/l for lakes and 30 ug/l for impoundments should be maintained to prevent nuisance algal blooms (Figure 5).

Phosphorus is not highly soluble in water and forms insoluble precipitates with calcium, iron, and aluminum. In hard water areas of Wisconsin, where limestone is dissolved in the water, *marl* (calcium phosphate) precipitates on the bottom. This marl formation helps to control phosphorus concentrations and therefore algae growth. The sediment phosphorus in marl lakes will still be available for aquatic weeds with roots in the marl bottom. These lakes often have clear water, but may be weedy.

Iron can also precipitate phosphorus and store it in the lake sediments--but only if oxygen is present. When lakes lose oxygen in winter or when the deep water (hypolimnion) loses oxygen in summer, the iron and phosphorus become soluble again. The iron and phosphorus are then both released into the overlying water and may be cycled into surface water by strong summer winds or by spring and fall turnover. For this reason, algae blooms may continue in lakes for many years after all possible sources of phosphorus input are controlled. Figure 6 shows this increase in total phosphorus for stratified water bodies following fall turnover. Shallow and wind-swept lakes that stay mixed do not experience a summer anaerobic layer (oxygen

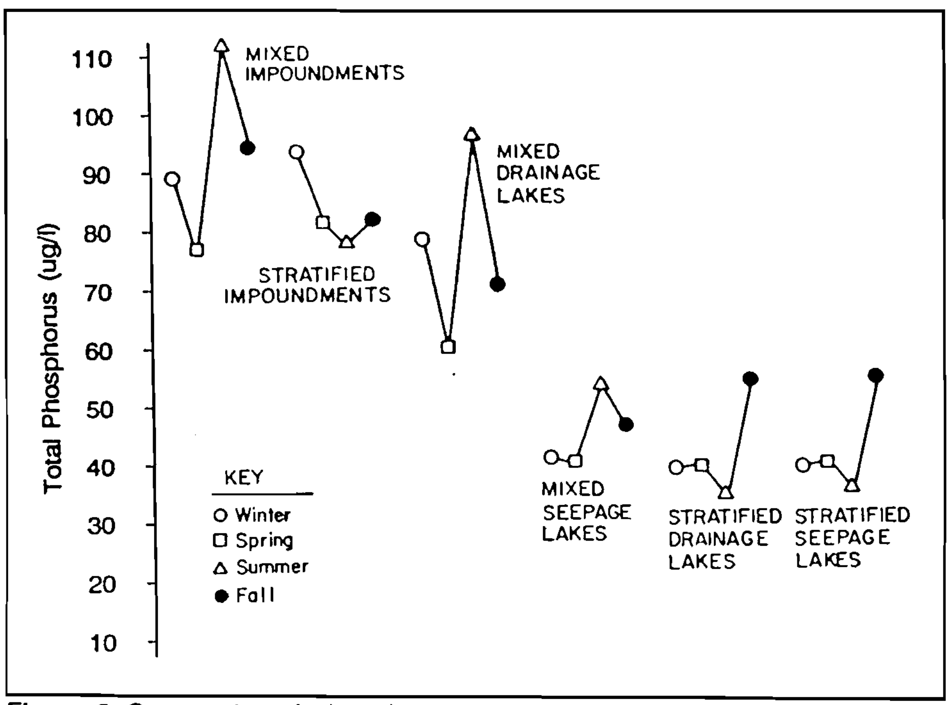


Figure 6. *Seasonal total phosphorus averages for six lake types by season. (Lillie and Mason, 1983)*

depletion) over the sediment; they have highest total phosphorus levels in summer following spring and early summer runoff.

The amount of iron in a lake that might react with phosphorus varies widely in Wisconsin. Southern lakes are often low in iron due to a higher pH and more sulfur, both of which limit iron solubility. This in turn affects whether phosphorus cycled into lakes during fall turnover will be reprecipitated or stay in solution during the winter.

In other words, lakes with low iron and insufficient calcium (limestone) to cause marl formations are the most likely ones to retain phosphorus in solution once it is released from sediments or brought in from external sources. These lakes are the most vulnerable to naturally-occurring phosphorus or to phosphorus loading from human activities and often respond with increased frequency and extent of algae problems.

Figure 6 also shows that impoundments have the highest phosphorus levels; drainage lakes have intermediate levels, and seepage lakes have the lowest. Even with internal cycling of phosphorus, the deeper stratified lakes still tend to have lower phosphorus levels than their mixed counterparts.

Control of internal phosphorus has been attempted in some deep lakes by using alum (aluminum sulfate) to precipitate phosphorus. Sewage treatment plants with tertiary treatment use the same process to remove phosphorus. This aluminum phosphate precipitate, unlike iron phosphate, is not redissolved when oxygen is again depleted.

Nitrogen

Nitrogen is the second most important nutrient, after phosphorus, causing weed and algae problems in Wisconsin lakes. Sources of nitrogen to a lake vary widely. Nitrogen compounds often exceed 0.5 mg/l in precipitation; thus, rainfall may be the major source for seepage lakes and some drainage lakes. However, concentrations of nitrogen in lake water usually correspond to local land use. Nitrogen may enter the lake from surface runoff or groundwater sources, including fertilizer

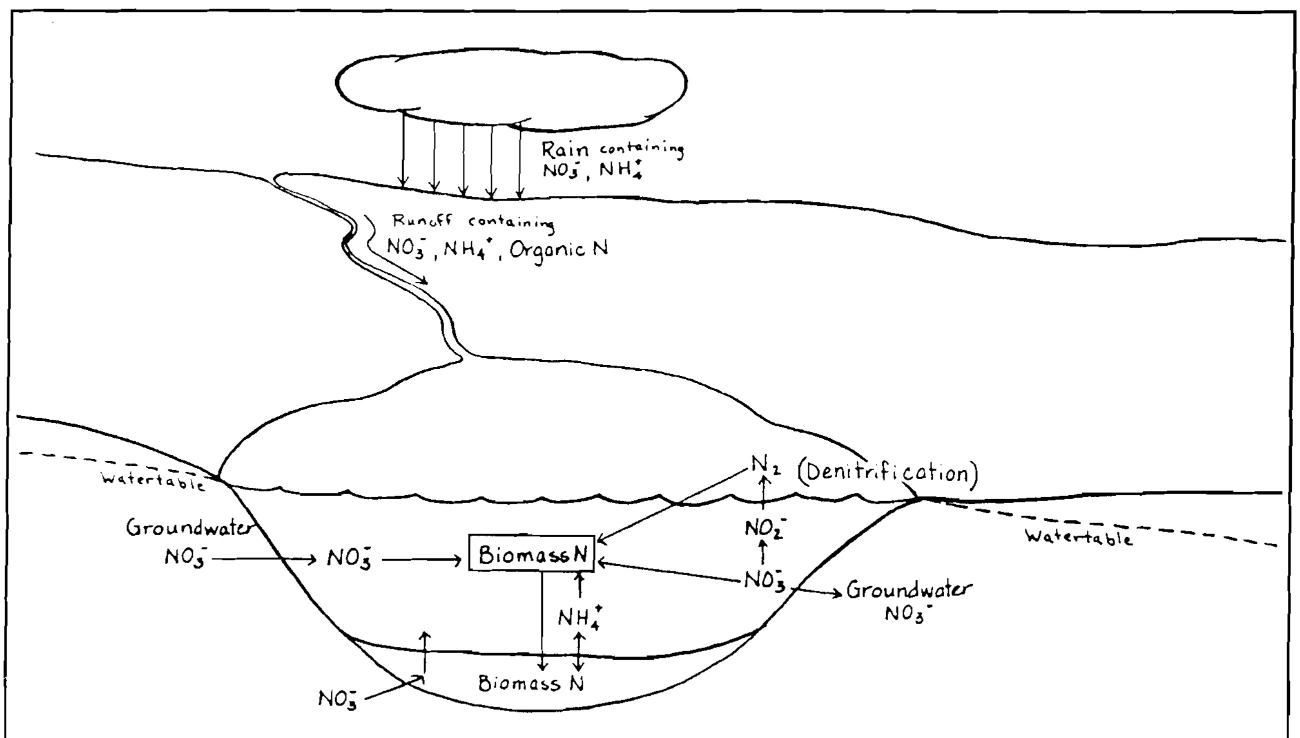


Figure 7. Sources and cycling of nitrogen in lake.

and animal wastes on agricultural lands, human waste from sewage treatment plants or septic systems, and lawn fertilizers used on lakeshore property.

The algae growth in about 10 percent of Wisconsin's lakes is limited by nitrogen rather than by phosphorus. Nitrogen is believed to limit growth if the ratio of total nitrogen to total phosphorus is less than 10:1. Values between 10:1 and 15:1 are considered transitional, while lakes with values greater than 15:1 are considered phosphorus limited.

Low levels of nitrogen will not guarantee limited algae growth the way low levels of phosphorus will. Nuisance blue-green algal blooms are often associated with lakes that have low nitrogen to phosphorus (N:P) ratios. These algae are able to use atmospheric nitrogen gas (N_2) dissolved in lake waters as a nitrogen source; other types of algae and plants depend on the inorganic nitrate and ammonium forms of nitrogen.

Nitrogen occurs in lakes in several forms. Analysis usually includes nitrate (NO_3^-) plus nitrite (NO_2^-), ammonium (NH_4^+), and organic plus ammonium (Kjeldahl nitrogen). Total nitrogen is calculated by adding nitrate and nitrite to Kjeldahl nitrogen. Organic nitrogen is often referred to as biomass nitrogen.

Nitrogen does not occur naturally in soil minerals, but is a major component of all organic (plant and animal) matter. Decomposition of organic matter releases ammonia, which is converted to nitrate if oxygen is present. This conversion occurs more rapidly at higher water temperatures. All inorganic forms of nitrogen (NO_3^-, NO_2^-, and NH_4^+) are available to aquatic plants and algae. If these inorganic forms of nitrogen exceed 0.3 mg/l in spring, there is sufficient nitrogen to support summer algal blooms.

Figure 7 shows the various ways that nitrogen enters and cycles within a lake. Nitrogen clearly undergoes a number of changes in a lake, including sediment release. Nitrogen recycled back into overlying water at spring and fall turnover will increase the levels of ammonia in samples taken during turnover, similar to what occurs with phosphorus. Nitrogen can also be lost from the lake by denitrification as shown in Figure 7. This only occurs if oxygen is depleted, allowing nitrate to be converted back to nitrogen gas.

Since the beginning of the Amery Lakes District we have tried to carry out those projects that are economically possible. The original study made some recomendations that have been carried out.

1) The water flow from the Apple River has been stopped eliminating one source of nutrient loading to the lakes.

2) South Twin Lake had an aeration system installed in 1989. The oxygen levels have been sustained high enough to avoid the usual fish kill that occured during the winter.

3) A storm sewer project in 1992 has diverted some of the urban runoff to the river below the Amery dam.

4) An ordinance is being implemented banning phosphate loaded fertilizers and controlling application of fertilizers along the lakeshore.

5) Docks have been installed at the public landings.

The topographical maps that have been made as a part of this study will help for years to come in avoiding possible runoff problems to the lakes as development continues around the Amery area. The set of water samples gives us a basis to compare to as other water sampling is done over the next few years.

The quality of our lakes are still good and it is much less expensive to work to keep them clean than to clean them up after we have damaged them.

The Lakes District is continuing to work with the DNR to increase the fish stocking that is done in the lakes. Hopefully through these efforts we can help restore the fishery nearer a level that it once was.

This study was made possible by the DNR Lakes Management Program. We appreciate their help and financial assistance in this matter.