LPL-605

POTATO LAKE
WATER QUALITY
AND WATERSHED
STUDY

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Northern Region

SUMMARY

Potato Lake is a 537 acre lake located in southwestern Rusk County, Wisconsin. The lake is composed of two distinct basins. The 87 acre south basin is slightly eutrophic. The 450 acre north basin is hypereutrophic. The north basin has very high summer total phosphorus (TP) concentrations, which results in severe blue-green algae blooms, very poor water clarity, and an anoxic hypolimnion. Curly-leaf pondweed (*Potamogeton crispus*) grows to nuisance levels in the spring and early summer.

Monitoring of the lake and its tributaries, and a watershed assessment was conducted in 1999 to help determine the causes of the north basin's poor condition. Groundwater and wetland drainage monitoring, and aquatic plant surveys were also conducted. Additional lake data was also available from 1998.

Seasonal TP concentrations rose dramatically in the north basin, from a 1999 spring concentration of 33 micrograms/liter (ug/l) to a September concentration of 214 ug/l. The mean summer chlorophyll a concentration for 1998-99 was 78 ug/l and the mean summer Secchi depth was 3.2 feet. Hypolimnetic anoxia had developed by early June and was followed by massive increases in hypolimnetic TP concentrations due to sediment phosphorus release. Near-bottom TP concentrations as high as 3,960 ug/l were found.

Stream TP concentrations were moderately high, with flow-weighted means ranging from 84 to 148 ug/l. The average TP concentration of wetland drainage samples was also moderately high at 102 ug/l. Groundwater TP concentrations were unusually high and averaged 106 ug/l in upland wells. Groundwater from wells downgradient from large wetlands had TP concentrations averaging 388 ug/l.

A phosphorus model for the north basin and its watershed was developed. Fifty-four percent of the growing season mean (GSM) TP concentration was estimated to be supplied by watershed drainage, direct atmospheric deposition, and carp activity. Forty-six percent of the GSM TP concentration was estimated to be supplied by internal lake sources, mostly sediment phosphorus release with a small component from curly-leaf pondweed decomposition.

The modeling also indicated that the north basin was a moderately eutrophic lake even prior to watershed development due to high groundwater and wetland drainage TP concentrations. Under natural conditions a spring TP concentration of 28 ug/l was estimated. Sediment phosphorus release was probably also significant under natural conditions and would have contributed to higher summer TP concentrations. The current model-estimated spring TP concentration is 47 ug/l, which is 68% higher than under natural conditions. Diatom analysis of a sediment core also indicated that the lake was moderately eutrophic under natural conditions, but that current TP concentrations are higher.

Curly-leaf pondweed was present around most of the perimeter of the north basin at moderate to high densities. The good spring water clarity followed by the poor summer water clarity favors curly-leaf, since it grows quickly in spring and dies back by early July. Only four other submersed plant species were present. The maximum depth of aquatic plant growth in August was generally four feet.

Controlling phosphorus inputs to the north basin from the watershed does not appear to have the potential to produce substantial water quality improvement. This is because natural background phosphorus inputs are high and sediment phosphorus release is a large source of lake TP. A combined effort to control watershed phosphorus inputs and control sediment phosphorus release does have the potential to noticeably improve water quality, although the lake would still be quite eutrophic. A combined effort could produce a 45% reduction in summer mean TP concentration (119 to 65 ug/l), a 62% reduction in summer mean chlorophyll a concentration (78 to 30 ug/l), and a 34% increase in summer mean Secchi depth (3.2 to 4.3 feet).

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INTRODUCTION

Potato Lake is a 537 acre lake located in southwestern Rusk County, Wisconsin. The lake is composed of two distinct basins. The south basin is a slightly eutrophic 87 acre lake, located south of county trunk highway D. The south basin flows into the north basin, and so it is uninfluenced by conditions in the north basin. The north basin is a hypereutrophic 450 acre lake, located north of county trunk highway D. Summer conditions in this lake are characterized by very high total phosphorus concentrations, severe blue-green algae blooms, very poor water clarity, and an anoxic hypolimnion. Partial fish kills have occurred in both winter and summer in the past.

Potato Lake's north basin supports a good fishery and is a popular fishing lake. However, the severe and chronic summer blue-green algae blooms may be limiting maximum fishery development due to oxygen depletion and toxin production. Carp are also present in the lake. The ability of carp to thrive and effectively compete with game fish is favored by the poor water quality conditions that exist.

The severe algae blooms and the associated poor water clarity, scum formation, and odors reduce the aesthetic value of the lake. The blooms also limit other recreational activities such as swimming and boating.

The presence of moderate to dense beds of curly-leaf pondweed (*Potamogeton crispus*) around much of the north basin's perimeter further impairs recreational use.

Local concerns over the poor water quality of Potato Lake's north basin led to the initiation of this study in 1999. The study aimed to answer two basic questions:

- What is the cause of the poor water quality of Potato Lake's north basin?
- Do practical measures exist to improve the water quality?

The study was partially funded by a DNR Lake Management Planning Grant, with local funding from Rusk County, the Rusk County Wildlife Restoration Association, and the Potato Lake Association. Field work was conducted by Rusk County Land Conservation Department staff with assistance from DNR staff. An initial study report (Prohaska, 2001) was prepared by Rusk County Land Conservation Department staff. The following report expands upon portions of the previous report and provides additional information, especially water quality interpretation, watershed and lake phosphorus modeling, aquatic plant survey data, and management option evaluation.

METHODS

LAKE WATER QUALITY MONITORING

Two sites were monitored, one at the deepest spot in the north basin and one at the deepest spot in the south basin (figure 1). The north basin was monitored once in the spring, approximately twice per month in the summer, and once in the fall. The south basin was monitored once in the spring, and approximately once per month in the summer. Samples were collected with a Van Dorn sampler. Sample parameters were:

Total phosphorus – 0.5 meters below the surface and 0.5 meters above the bottom
Chlorophyll a – 0.5 meters below the surface
Total Kjeldahl nitrogen – August only, 0.5 meters below the surface
True color – spring only, 0.5 meters below the surface

Some additional parameters were also tested in the spring sample (appendix A). Field parameters were Secchi depth and temperature and dissolved oxygen profiles, measured every meter from top to bottom using a YSI 55 dissolved oxygen/temperature meter.

STREAM MONITORING

Seven stream sites were monitored (figure 2). Three were considered primary sites (MCD-1, MCU-2, and SPR-5). These sites represented larger drainage areas. Four sites were considered secondary sites (HLR-3, BLR-4, CTD-6, and CTF-7). Primary sites were monitored 12 times during May through December. Secondary sites were monitored 6 times during May through August. Monitoring dates were mostly runoff events, although some baseflow conditions were also monitored. Samples were tested for total phosphorus, dissolved phosphorus, and total suspended solids. Streamflows were estimated on each monitoring date using the floating chip method.

WETLAND DRAINAGE MONITORING

Surface drainage was monitored at two sites that drain areas dominated by wetlands, EWET-1 and SWET-2 (figure 12). Samples were collected on 4 dates and tested for total phosphorus concentration. Additional sampling was planned, but was limited by lack of flow during the monitoring period.

GROUNDWATER MONITORING

Groundwater samples were collected from 14 residential water supply wells at scattered locations in the Potato Lake watershed (figure 13). Samples were tested for total phosphorus. Samples were obtained from household taps. In cases where water softeners or filters were present, an untreated tap was used.

SAMPLE HANDLING AND LABORATORY ANALYSES

Total phosphorus samples were acidified in the field with sulfuric acid. Chlorophyll a samples were field filtered. All samples were shipped on ice to the lab. Laboratory analyses of all water samples were done by the Wisconsin State Laboratory of Hygiene.

SEDIMENT SAMPLING

A sediment core was collected from the deepest spot of the north basin of the lake in August, 1999 using a piston core tube. The sample was analyzed for diatom species at the sediment surface and at a depth of 55-57 cm. Sample collection and analysis were done by Paul Garrison of DNR Research.

Sediment cores were also collected at two sites in the north basin in May, 2000 using a piston core tube. One site was, again, in the deepest spot, and the second site was in the west-central portion of the basin in 13 feet of water. The top 8 cm of these cores was analyzed for metals, total phosphorus, and solids (appendix D).

AQUATIC PLANT SURVEYS

A survey for curly-leaf pondweed (*Potamogeton crispus*) was conducted on June 15th, 1999. Observations of the density and widths of curly-leaf beds were made around the entire perimeter of the lake and its islands. As observers traveled around the lake, shoreline segments with relatively uniform distributions of curly-leaf were identified and described. Forty-eight individual segments were identified. Density of beds was mapped (figure 16).

A survey for all other aquatic plants was conducted on August 8th, 1999. Fourteen transect locations were established at roughly equal distances around the shoreline of the north basin (appendix G). One site on each transect was sampled in the 0-4 feet depth range. For the south basin, six transects were established. Sampling was done at two sites on each transect, at depth ranges of 0-5 feet and >5-9 feet.

At each sampling site, four drags were made using a long handled rake. Species collected in each drag were recorded. Water depth and substrate type at each sampling site were also recorded (appendix G). Additional observations were made to identify other aquatic plant species present that were not collected at transect sampling sites.

LAKE WATER QUALITY – BACKGROUND INFORMATION

EUTROPHICATION

Lake eutrophication is a process of nutrient enrichment that frequently occurs when a lake's watershed undergoes agricultural and/or residential development and efforts are not made to control the increased inputs of nutrients to the lake. Phosphorus is the nutrient of most concern. Phosphorus is usually the limiting nutrient for the growth of planktonic algae, the microscopic plants that live suspended in the water column. Increasing a lake's phosphorus concentration will result in an increased abundance of algae, while decreasing a lake's phosphorus concentration will result in a decreased abundance of algae. . In most lakes, production of algae far exceeds the production of rooted aquatic plants.

Algal abundance is commonly measured by the chlorophyll a concentration in the water. Chlorophyll a is a photosynthetic pigment contained within algae cells.

Increasing algal abundance results in water becoming less clear and more green. Water clarity is commonly measured with a Secchi disk, a black and white disk that is lowered into the water to determine the depth at which it is no longer visible, the Secchi depth. In most lakes, algal abundance is the primary factor controlling water clarity.

Phosphorus concentration, chlorophyll a concentration, and Secchi depth are the three interrelated parameters which are commonly used to assess a lake's trophic state, or level of nutrient enrichment. Increasing phosphorus concentrations cause increasing chlorophyll a concentrations that cause decreasing Secchi depths. Decreasing phosphorus concentrations cause decreasing chlorophyll a concentrations that cause increasing Secchi depths. The range of lake trophic states is divided into four levels of increasing nutrient enrichment – oligotrophic (low), mesotrophic (medium), eutrophic (high), and hypereutrophic (very high).

Poor water clarity caused by an over abundance of algae results in recreational and aesthetic impairment of a lake. The quality of swimming, boating, and viewing activities is reduced in a lake with green, turbid water. Nutrient enriched lakes also commonly develop scums of floating algae that accumulate on downwind shores. These scums further limit lake use and produce noxious odors as the algae decays.

Studies have also shown that lake shore property values are linked to water clarity. Property values have been found to increase with increasing water clarity.

Abundant algae resulting from nutrient enrichment also strongly affects the distribution and availability of dissolved oxygen in a lake. Algae produce oxygen when they are photosynthesizing in daylight. Problems occur when dead algae are decomposing and consuming oxygen. Respiration by living algae at night or by algae to deep to receive adequate light for photosynthesis can also lead to oxygen depletion. Depletion of oxygen in the bottom water occurs rapidly in lakes with abundant algae. This oxygen depletion promotes the release of phosphorus from the sediment since iron-phosphorus complexes dissolve under low oxygen conditions. This sediment phosphorus release further fuels algae growth.

Oxygen depletion of bottom water also limits fish use of these areas and thus reduces available fish habitat. Winterkill problems become more likely due to oxygen depletion under ice cover. Summerkill of fish can also occur, especially when algae accumulates in downwind bays and is decomposing and respiring at night. Fish that can tolerate low oxygen levels such as carp and bullheads are favored in a lake with oxygen problems. Oxygen depletion also limits the types of insect larvae and other macroinvertebrates that can survive on the lake bottom.

Abundant algae can also cause wide fluctuations in pH levels. Algae draw carbon dioxide from the water when they are photosynthesizing in daylight. This causes pH levels to rise. At night, when algae are respiring, carbon dioxide is released which lowers pH levels. The pH fluctuations that occur, cause stress to fish and can contribute to summerkills.

Blue-green algae often become dominant in a nutrient rich lake. Blue-green algae are not palatable to zooplankton that feed on algae. Zooplankton are the primary food for young fish of all species as well as smaller adult species of fish. When blue-green algae dominate, much of a lake's production is directed to the sediment, and bottom-feeding organisms are favored.

Blue-green algae can also release toxins into the water. These toxins can cause skin and eye irritation to swimmers. Under some circumstances, these toxins can reach levels that kill fish.

In addition to supporting high densities of planktonic algae, high phosphorus concentrations also promote the growth of filamentous algae, periphyton, and duckweed. Filamentous algae looks like green cotton candy and often grows attached to aquatic plants and rocks. Floating mats of filamentous algae can develop over the top of aquatic plant beds. Periphyton includes a variety of algae and other microscopic organisms that grow attached to bottom materials and appear as slimy coatings. Duckweed are small, floating green plants about the size of oatmeal flakes. They can completely cover the water surface in backwater areas protected from the wind.

Rooted aquatic plants also become more abundant with nutrient enrichment.
These plants can be either phosphorus or nitrogen limited, but are more frequently found to be nitrogen limited. Rooted aquatic plants derive most of their nutrients from the sediment. The sediment is a substantial reservoir of nutrients, so it requires long time periods for these plants to respond to reductions in nutrient inputs to a lake. Phosphorus and nitrogen inputs are often derived from common sources. Most nutrient management efforts target phosphorus, but efforts to reduce phosphorus will also reduce nitrogen.

Rooted aquatic plants are also influenced by the abundance of planktonic algae. In a nutrient enriched lake, planktonic algae can become dense enough to effectively shade rooted aquatic plants and limit their growth. The diversity of aquatic plants that can survive is also reduced with increased shading by planktonic algae. Some aquatic plants, such as curly-leafed pondweed, are favored in lakes that have fair water clarity in spring and early summer and very poor water clarity in middle to late summer. Curly-leaf pondweed grows rapidly in spring and dies back by the beginning of July, so it can make effective use of the period of clearer water and becomes dormant when water clarity is poor.

POTATO LAKE BASINS AND WATERSHEDS

Potato Lake is composed of two distinctive lake basins (figure 1). The north basin lies north of CTH D and is the larger of the two basins at 450 acres. It has a maximum depth of 24 feet. The south basin lies south of CTH D and has an area of 87 acres. It is deeper, with a maximum depth of 40 feet. A narrow channel at the CTH D bridge connects the two basins. Water movement is from the south basin to the north basin, so the south basin functions independently of the north basin. The watershed for the south basin consists of sub-watershed units CTD-6, SPB-9, and three internally drained units (figure 2.) The watershed for the north basin includes the south basin watershed and all additional sub-watershed units shown in figure 2. Water quality for the two lake basins is discussed below.

LAKE WATER QUALITY – MONITORING RESULTS

NORTH BASIN

Phosphorus concentrations

Water quality data for the north basin of Potato Lake in 1999 and 1998 is summarized in table 1 and figure 3. Additional water chemistry data for a May, 1999 sample is contained in appendix A. The 1999 spring total phosphorus concentration near the lake surface was 33 micrograms per liter (ug/l), a value considered to be eutrophic. The 1998 concentration was 86 ug/l, a value considered to be hypereutrophic. Nearly all the phosphorus concentrations found through the remainder of both years indicate hypereutrophic conditions.

Both years showed a pattern of increasing phosphorus concentrations from spring through September. This pattern was more pronounced in 1999 (figure 4). A maximum concentration of 214 ug/l was found that year. This is a 648% increase from the spring concentration.

The ratio of nitrogen to phosphorus during August of each year ranges from 14 to 15. Nitrogen to phosphorus ratios greater than 12 indicate that phosphorus, not nitrogen, is the nutrient limiting to the growth of algae.

FIGURE 1. LAKE SAMPLING SITES

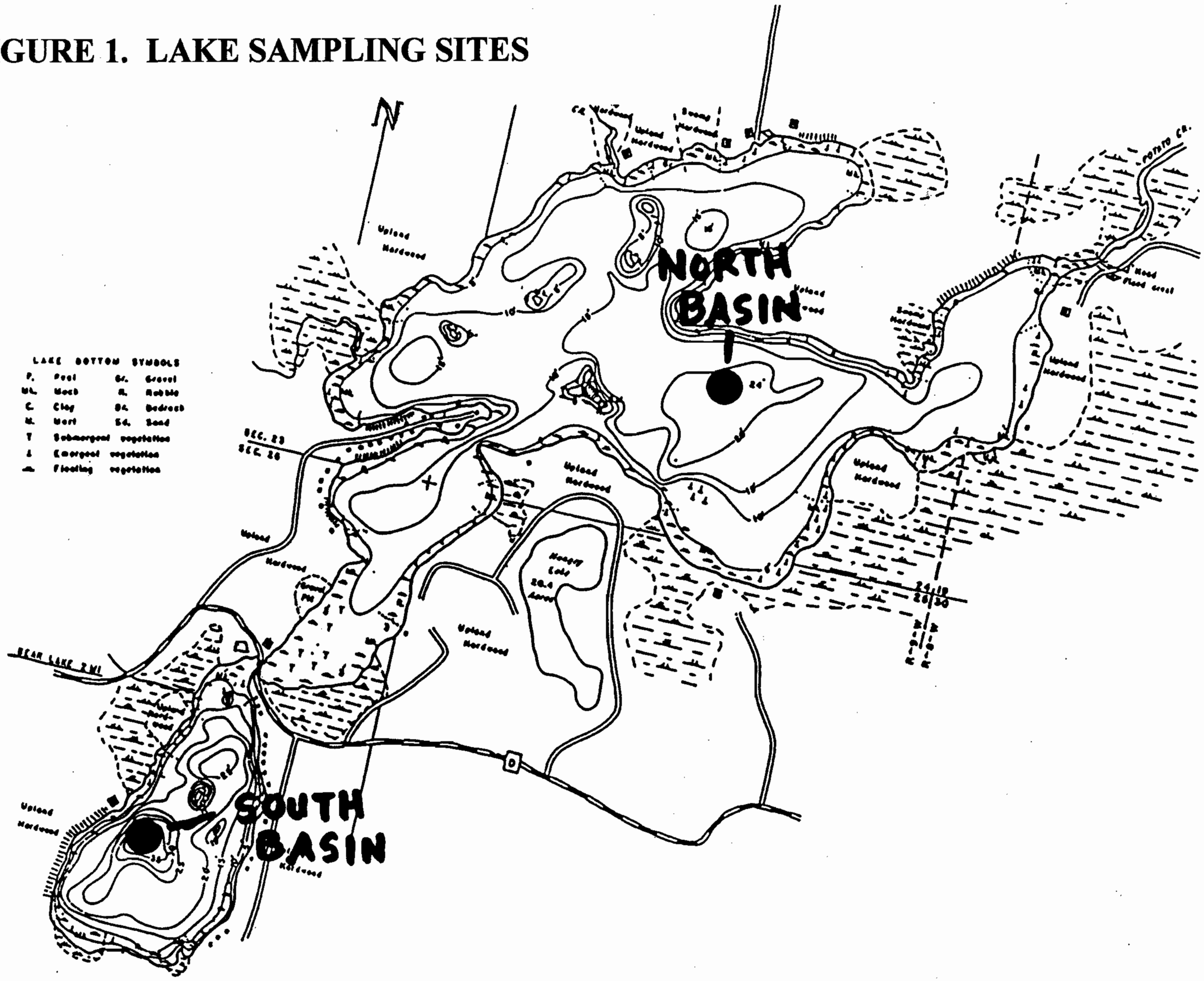


TABLE 1.

SUMMARIZED POTATO LAKE WATER QUALITY DATA, 1999 AND 1998

	NORTH BASIN						SOUTH BASIN					
DATE	TP (near surface) (ug/l)	TP (near bottom) (ug/l)	Chl. A (ug/l)	S.D. (feet)	TKN (mg/l)	Color (pt-co un.)	TP (near surface) (ug/l)	TP (near bottom) (ug/l)	Chl. A (ug/l)	S.D. (feet)	TKN (mg/l)	Color (pt-co un.)
06-May-99	33	76	4.1	10.8		20	26	48	16.2	7.5		20
04-Jun-99	78	503		5.2								
21-Jun-99	52	428	8.2	8.2			25	383	8.4	4.9		
14-Jul-99	90	2140	71.4	2.3								
04-Aug-99	141	1440	75	2	2.04		33	373	28.3	3.3		
11-Aug-99	162	1830	139	1.3								
25-Aug-99	177	2390	80.4	3			29	652	23	3.3	1.24	
15-Sep-99	214	199	79.5	3								
26-Oct-99	76	85		3.6								
30-Apr-98	86	230	3.1	9.5	0.99	55						
12-Jun-98	83	151	87.2	3.7		55				7.3		
22-Jul-98	115	2030	75.8	2.6		55						
14-Aug-98	135	3810	82.8	2.6	2.01	50	31			9		
20-Sep-98	125	3960	97	2.8		30						

TP = total phosphorus
Chl. A = chlorophyll a
S.D. = Secchi depth

TKN = total Kjeldahl nitrogen
Color = true color (platinum-cobalt units)

FIGURE 3.

POTATO LAKE 1999 SUMMER MEAN VALUES (JUNE - AUGUST)

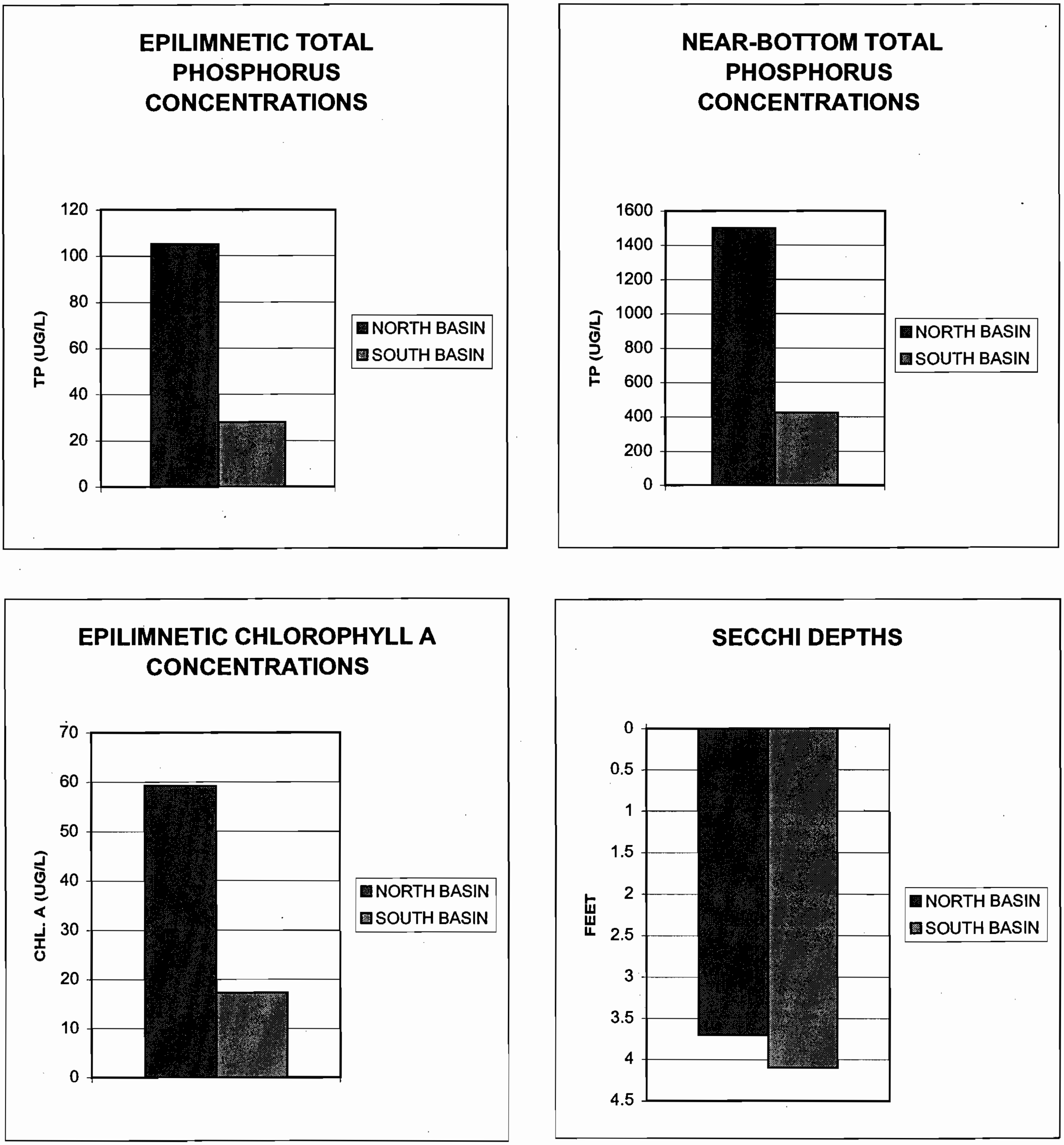
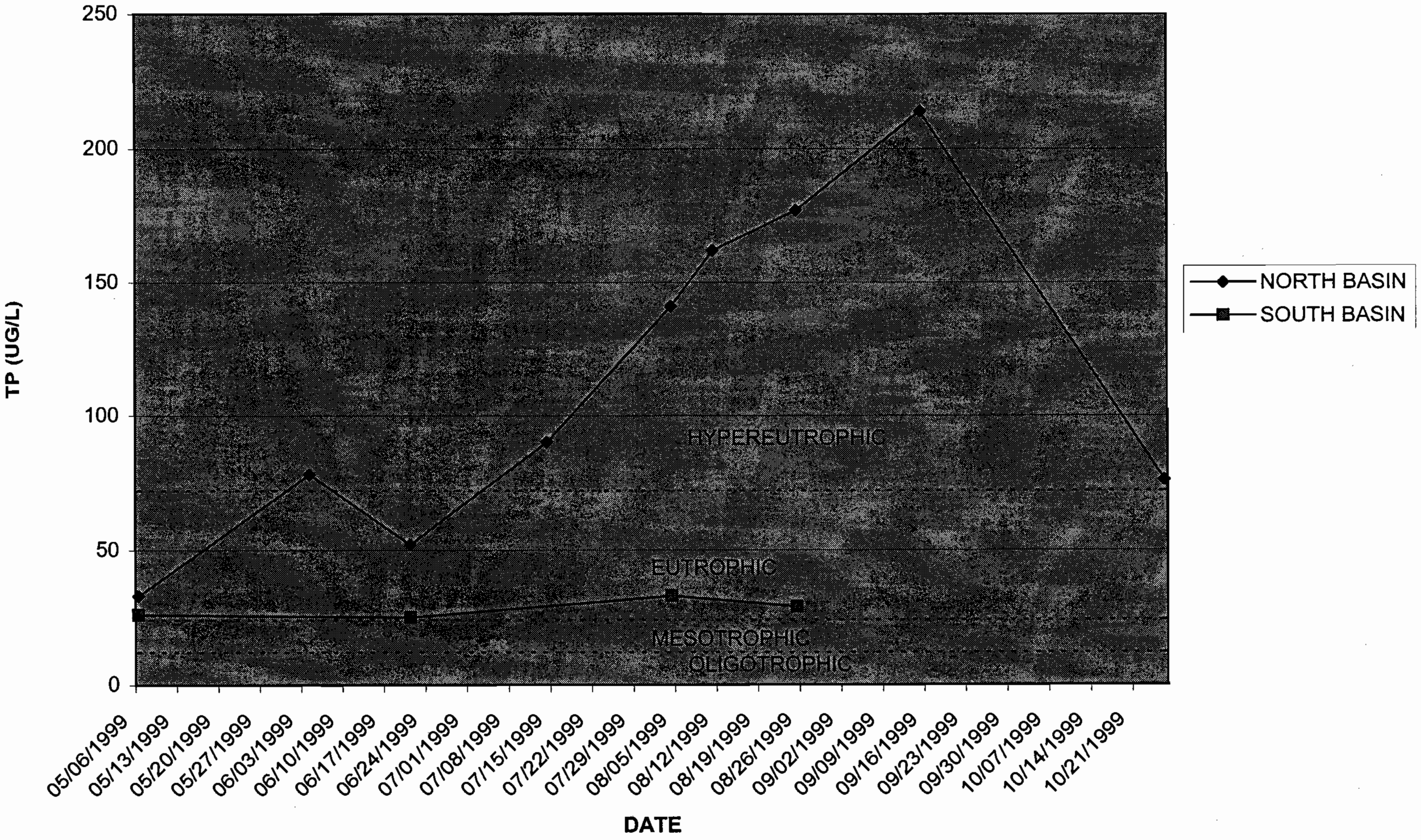


FIGURE 4.

POTATO LAKE EPILIMNETIC TOTAL PHOSPHORUS CONCENTRATIONS, 1999



Near bottom total phosphorus concentrations also increase from spring through late August or September (figure 5). Concentrations during the 2 years ranged from a low of 76 ug/l in May 1999, to a high of 3,960 ug/l in September 1998. The extremely high concentrations that develop in late summer are among the highest observed in northwestern Wisconsin lakes.

The development of very high near bottom phosphorus concentrations is due primarily to the release of phosphorus from the bottom sediment. This typically occurs when bottom water becomes depleted of oxygen. Once oxygen is depleted, iron-phosphorus compounds in the sediment dissolve and release phosphorus and iron into the water column.

The released phosphorus accumulates in the hypolimnion, the layer of cooler bottom water in the lake. The hypolimnion and the epilimnion, the upper layer of warmer water, do not readily mix due to density differences between warm and cold water. Because of this, the phosphorus that builds up in the hypolimnion is not rapidly transported to the epilimnion. However, this phosphorus is gradually transported to the epilimnion as the summer progresses. The epilimnion deepens as periods of high winds cause mixing that incorporates more and more of the hypolimnion, and its high phosphorus concentrations, into the epilimnion.

Eventually the lake becomes completely mixed in September (turnover). This restores oxygen to the water overlying the lake sediment and sediment phosphorus release ends. Lake phosphorus concentrations decline as phosphorus returns to the sediment. The precipitation of iron-phosphorus compounds causes some phosphorus to settle. Dying algae and other suspended particulates also settle and carry additional phosphorus back to the sediment. In 1999, surface phosphorus concentrations declined from 214 ug/l on September 15th to 76 ug/l on October 26th.

The pattern of phosphorus concentrations in Potato Lake's north basin clearly shows that sediment phosphorus release plays a dominant role in regulating summer phosphorus concentrations. Inputs of phosphorus from watershed sources cannot usually account for dramatically increasing summer phosphorus concentrations in a lake. Most Wisconsin stratified drainage lakes actually show a decline in phosphorus concentrations from spring to summer (Lillie and Mason 1983).

Temperature and dissolved oxygen profiles

Temperature and dissolved oxygen profiles for 1999 (figures 6.1, 6.2 and 7.1,7.2) further document the pattern of events described above. The epilimnion-hypolimnion boundary is seen moving downward from a depth of about 2.5 meters (8.2 ft) on June 3rd to a depth of 5.5 meters (18 ft) on August 25th. Over the same time period, temperature at the bottom gradually warms from 13.5°C (56.3°F) to 19.5°C (67.1°F). This warming indicates that partial mixing and heat transfer between the epilimnion and hypolimnion is occurring. By September 15th, the lake is completely mixed and temperatures are uniform from top to bottom.

FIGURE 5.

POTATO LAKE NEAR-BOTTOM TOTAL PHOSPHORUS CONCENTRATIONS, 1999

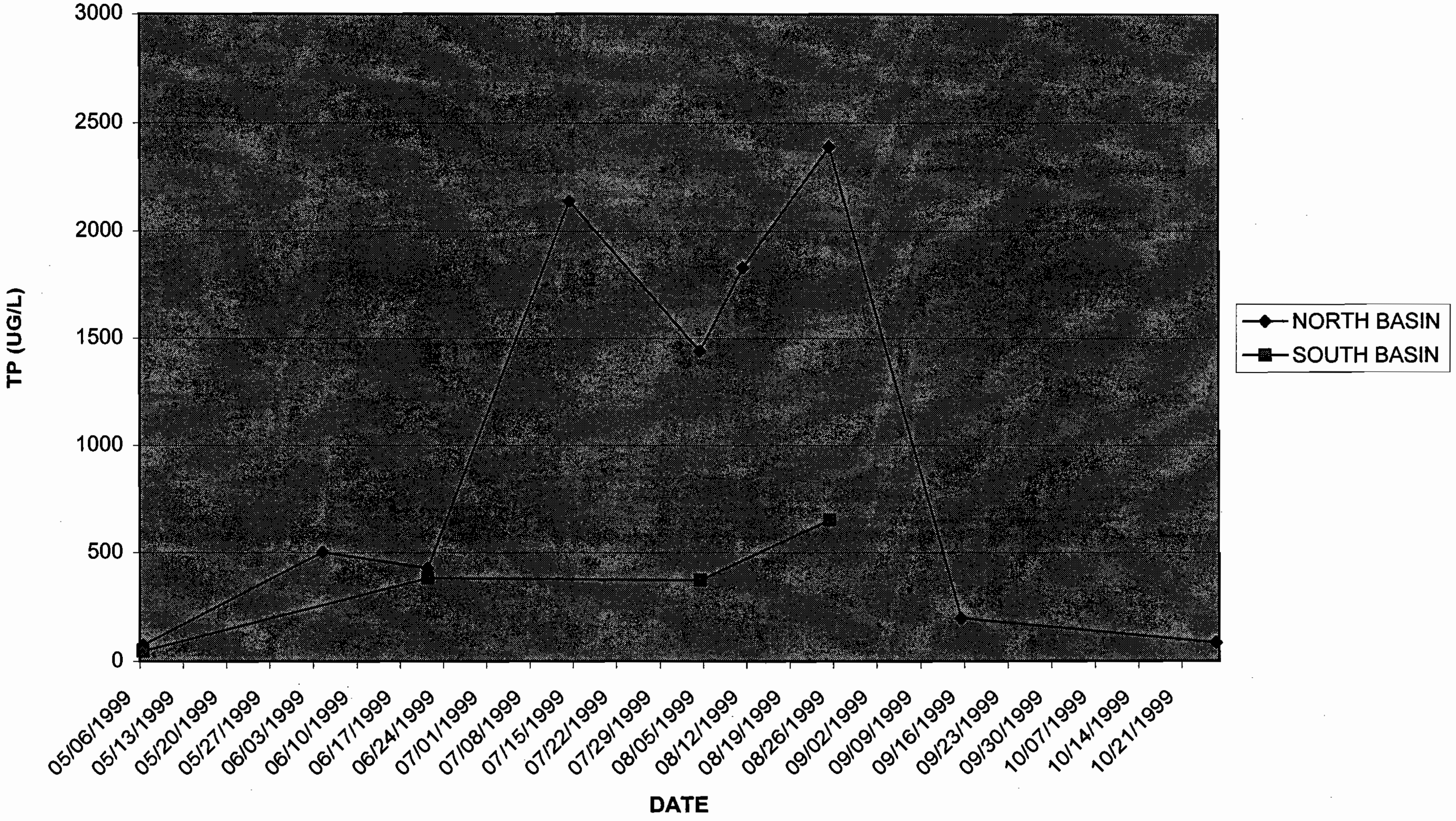


FIGURE 6.1

1999 POTATO LAKE TEMPERATURE PROFILES

North Basin

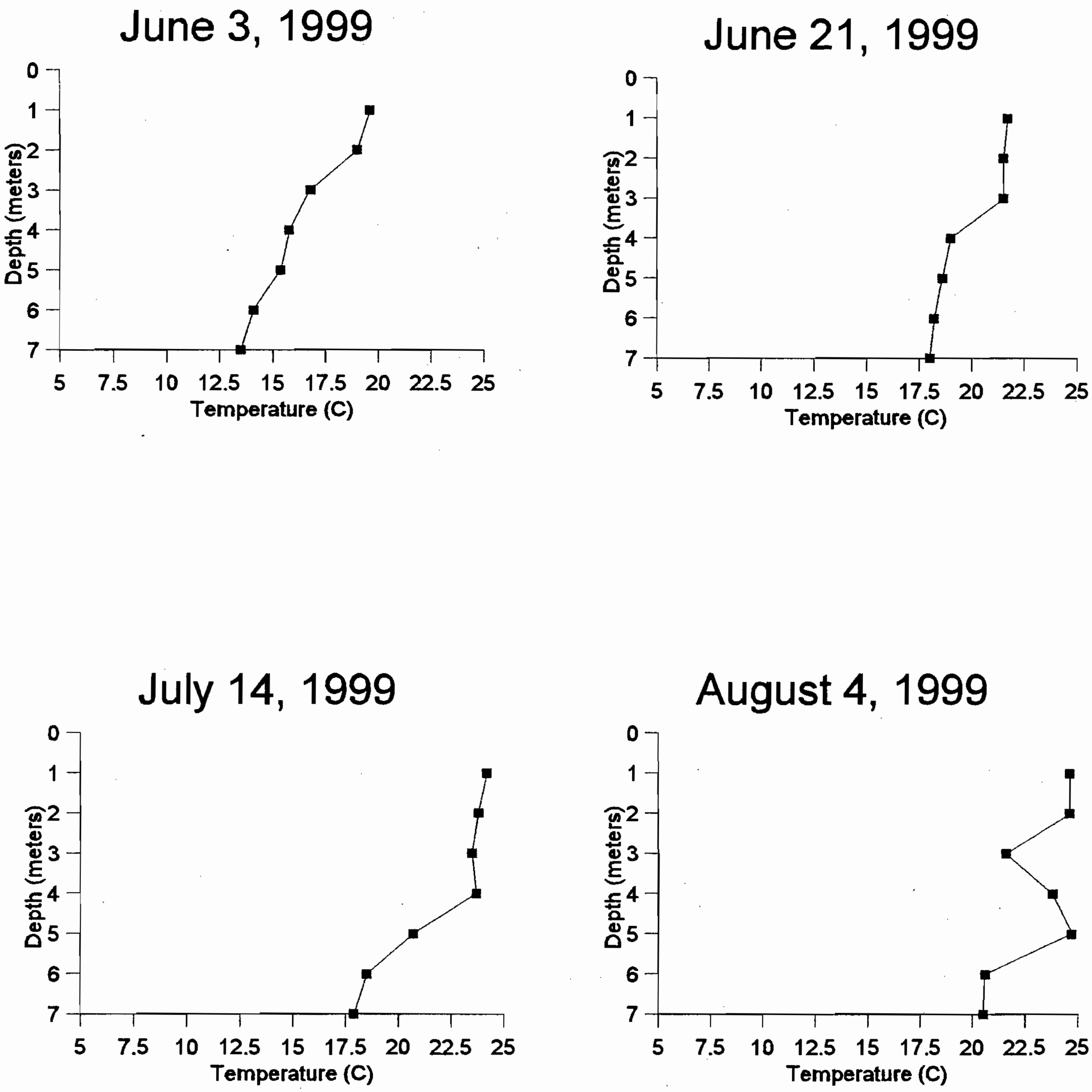


FIGURE 6.2

1999 POTATO LAKE TEMPERATURE PROFILES

North Basin

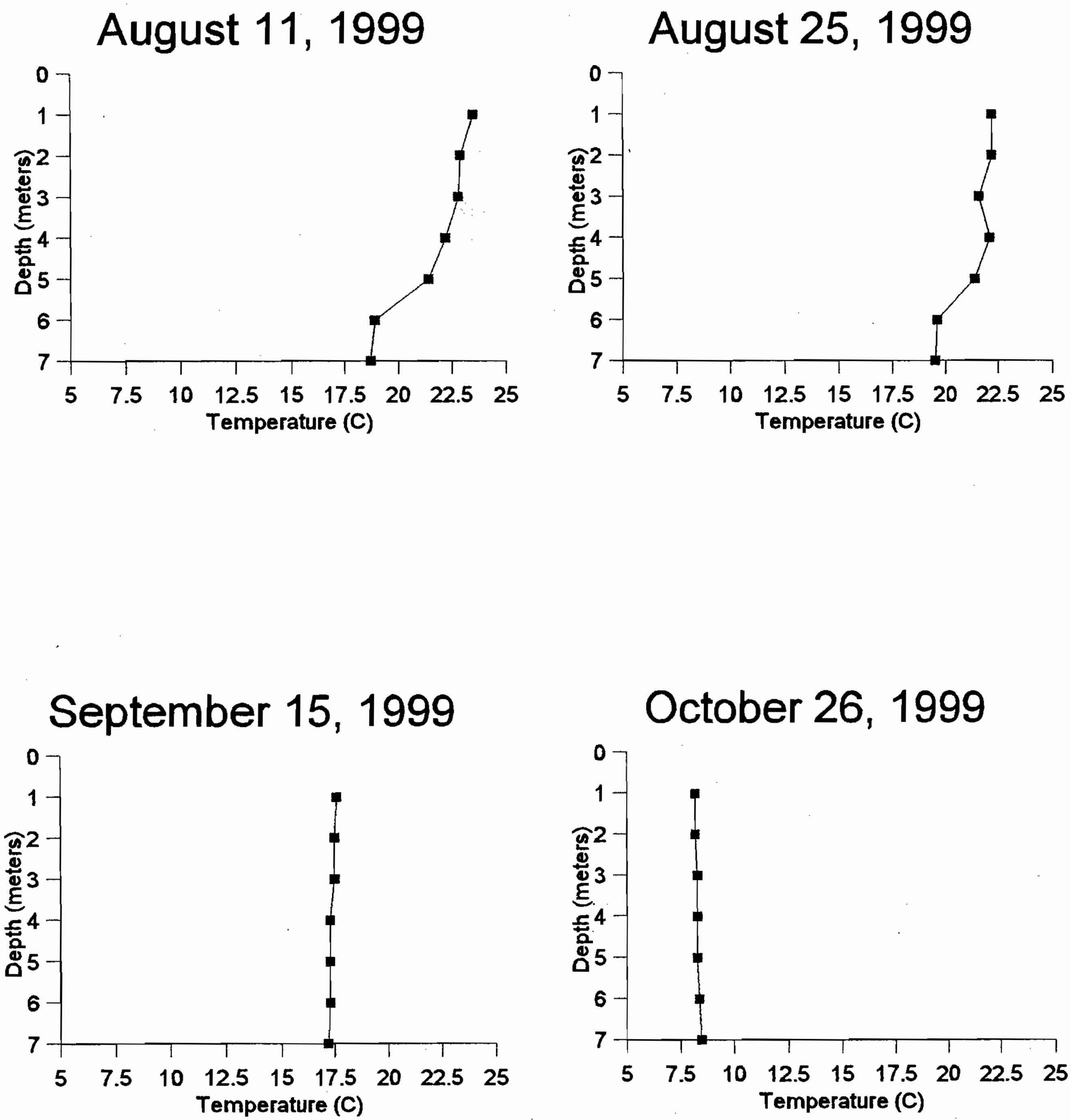
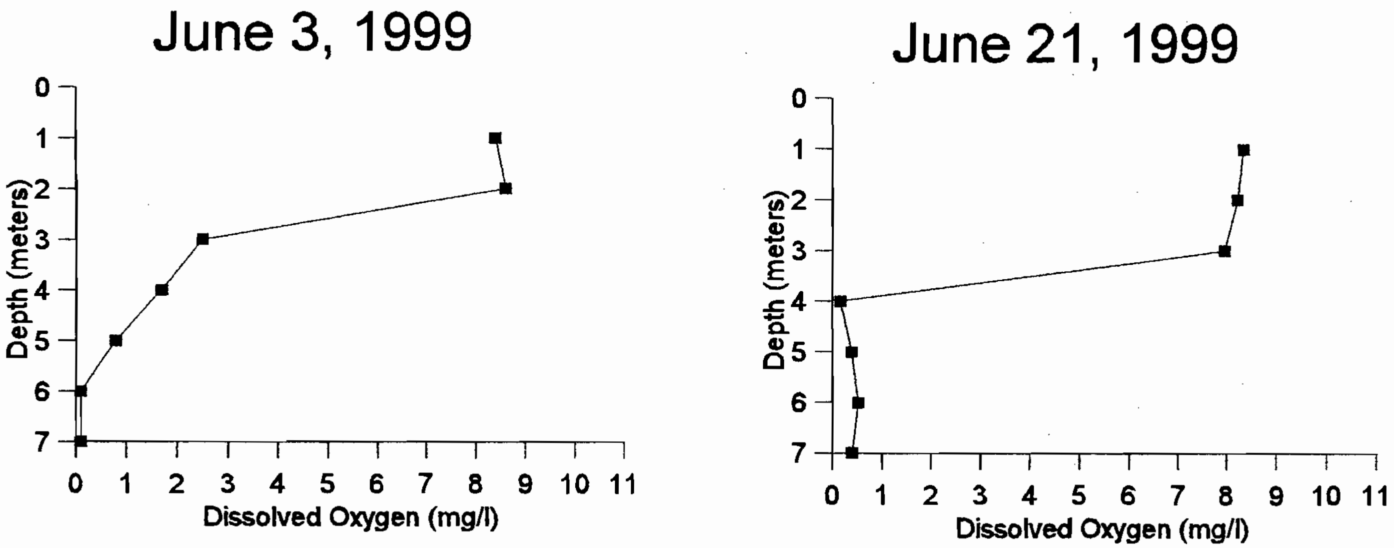


FIGURE 7.1

1999 POTATO LAKE DISSOLVED OXYGEN PROFILES

North Basin



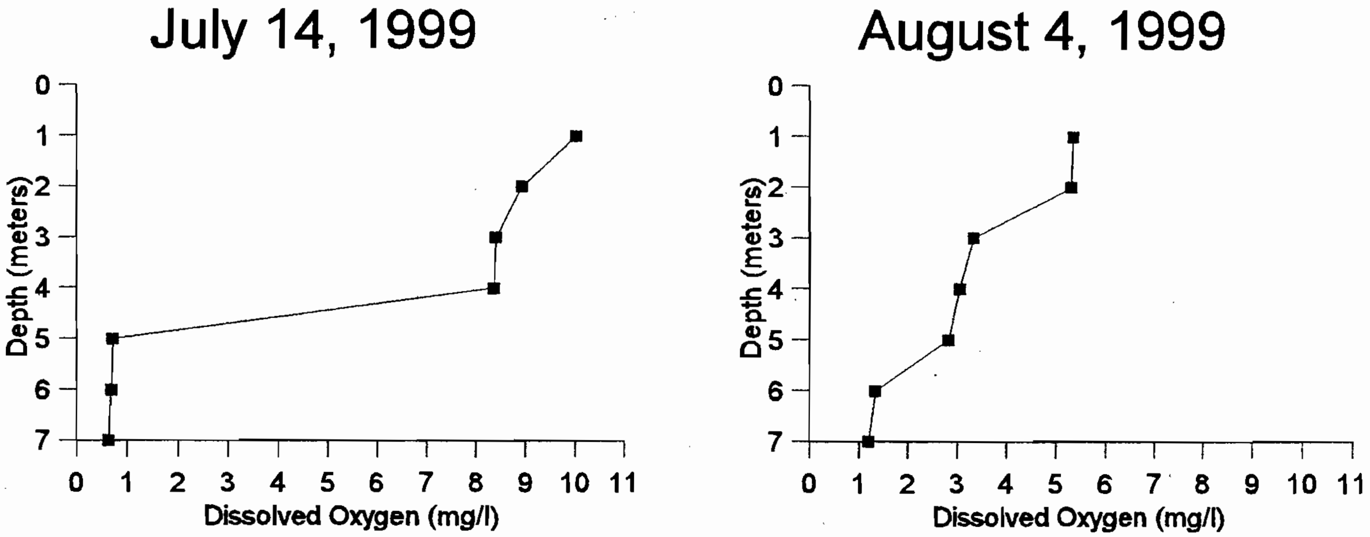
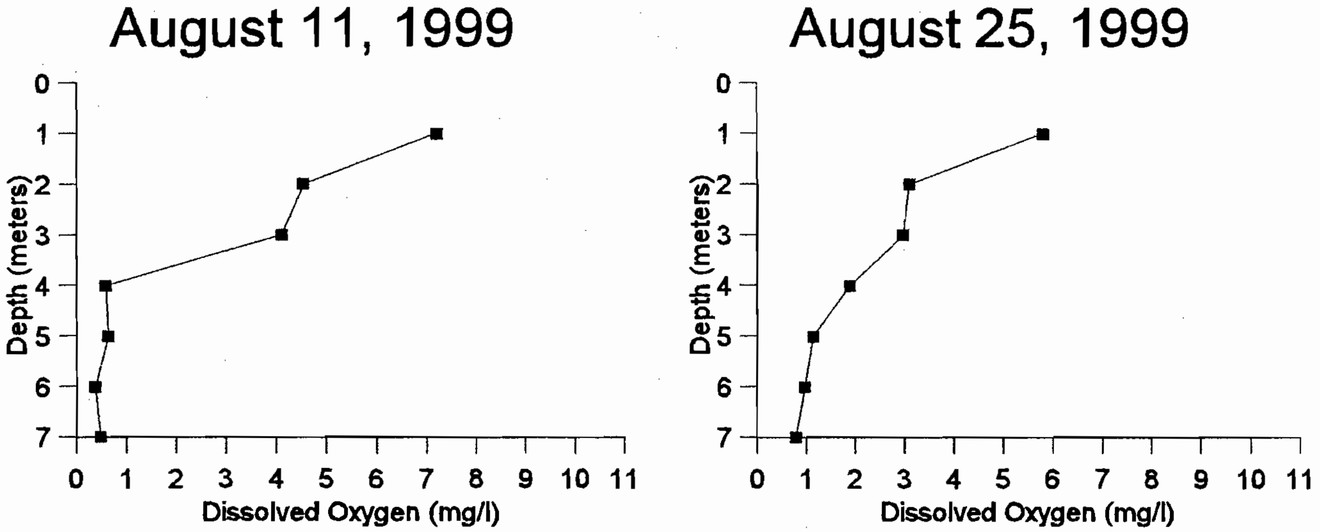


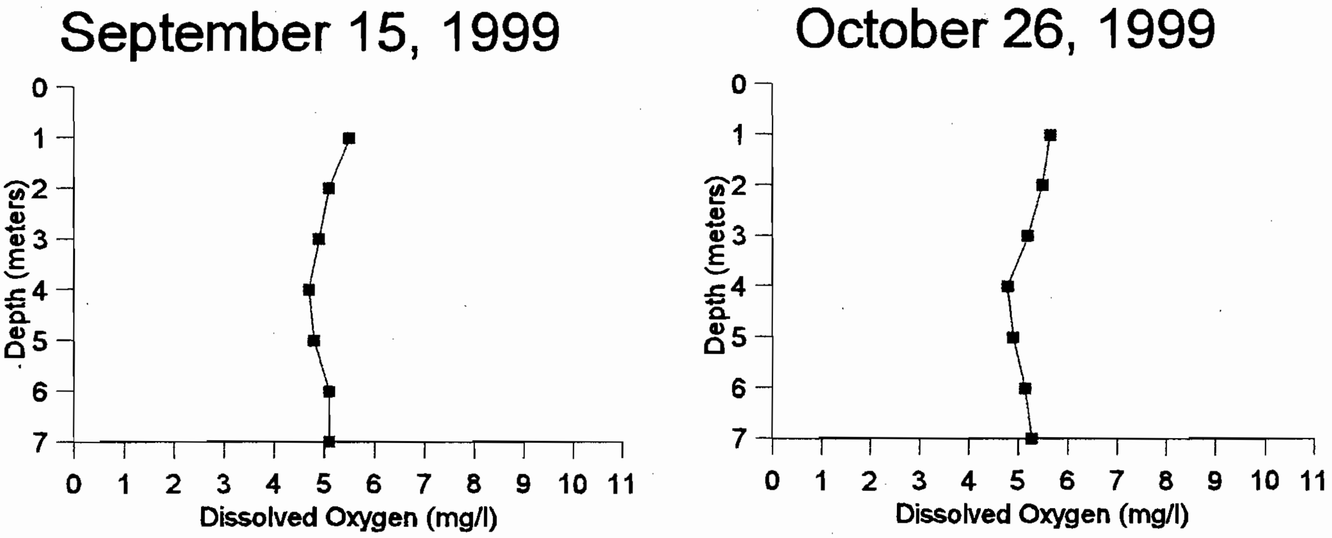
FIGURE 7.2

1999 POTATO LAKE DISSOLVED OXYGEN PROFILES

North Basin


August 11, 1999

August 25, 1999


September 15, 1999

October 26, 1999

Near bottom dissolved oxygen concentrations are generally less than 1 milligram per liter (mg/l) from June 3rd to August 25th. Near bottom dissolved oxygen concentrations were restored to about 5 mg/l on September 15th, following complete mixing. During most of the summer, dissolved oxygen concentrations below a depth of 4 to 5 meters (13.1 to 16.4 ft) are inadequate for fish survival, so fish will tend to be restricted to shallower water.

Chlorophyll a concentrations

Chlorophyll a concentrations show that algal abundance also increases dramatically over the summer when phosphorus concentrations increase. Chlorophyll a concentrations ranged from a low of 4.1 ug/l on May 6, 1999 to a high of 139 ug/l on August 11, 1999. Chlorophyll a concentrations above 20 ug/l indicate bloom conditions and concentrations above 30 ug/l indicate severe bloom conditions. Most concentrations found during the summer months also indicate hypereutrophic conditions.

Algal counts and identifications have not been done for Potato Lake. However, visual observations indicate that *Aphanizomenon*, a variety of blue-green algae makes up a large portion of the summer algae community in the north basin.

Secchi depths

Spring water clarity was good both years with Secchi depths of 10.8 and 9.5 feet (3.3 and 2.9 meters). Clarity remained good in June of 1999 when a Secchi depth of 8.2 feet (2.5 meters) was found on June 21st. The water clarity decline began earlier in 1998 when a Secchi depth of only 3.7 feet (1.1 meters) was found on June 12th. July, August, and September water clarity was very poor in both years, with Secchi depths of 1.3 to 3 feet (0.4 to 0.9 meters) occurring. The pattern of declining clarity corresponds, inversely, to the patterns of increasing phosphorus and chlorophyll a concentrations.

Water color (true color) during the two years ranged from 20 to 55 platinum-cobalt units. These levels are considered low to moderate, and reduce water clarity somewhat. However, they would not have a major influence on the seasonal shifts in water clarity that occur. Water color is due to the presence of dissolved organic acids. These acids are derived from plant decomposition in wetlands that drain to the lake, as well as from additional plant decomposition which occurs within the lake. These acids cause a brown, tea-like staining of the water.

SOUTH BASIN

Phosphorus concentrations

Water quality data for the south basin of Potato Lake in 1999 and 1998 is also summarized in table 1 and figure 3. The 1999 spring total phosphorus concentration near the lake surface was 26 ug/l, a value considered to be eutrophic. Phosphorus concentrations found through the remainder of the two years range from 25 to 33 ug/l, and also indicate eutrophic conditions. Phosphorus concentrations show a slight increase from spring to summer (figure 4).

Near bottom total phosphorus concentrations increase substantially from spring to summer. In 1999, concentrations ranged from a low of 48 ug/l on May 6th to a high of 652 ug/l on August 25th (figure 5). However, these are much lower concentrations than those found in the near bottom samples from the north basin.

The increase in near bottom phosphorus concentrations is, again, due to primarily to the release of sediment phosphorus that occurs when bottom waters become depleted of oxygen. Unlike the north basin, the increase in near bottom phosphorus concentrations that occurs has only a small effect on near surface phosphorus concentrations. This is because the south basin is smaller and deeper and has much less mixing of the epilimnion and hypolimnion occurring over the summer. The smaller surface area reduces wind fetch and limits wind-induced mixing. There is probably an increase in near surface phosphorus concentrations that occurs in fall, when turnover of the basin takes place. However, the monitoring period did not extend late enough into the fall to identify when this occurs. Turnover of the south basin is likely to occur considerably later in the year than turnover of the north basin, which takes place in September.

Temperature and dissolved oxygen profiles

The temperature and dissolved oxygen profiles for the south basin (figures 8 and 9) document the limited mixing which occurs. Between June 21st and August 25th, the epiliminion expands downward by only about 1 meter. Water temperatures near the bottom remain close to 50°F (10°C) throughout this period.

Dissolved oxygen concentrations in the hypolimnion are generally less than 1 mg/l on the 3 summer monitoring dates. Dissolved oxygen concentrations below 3 to 5 meters (9.8 to 16.4 feet) are inadequate for fish survival, so fish will tend to be restricted to shallower water.

Chlorophyll a concentrations

Chlorophyll a concentrations show that algal abundance increases from spring and early summer to mid-summer. Concentrations range from 8.4 to 28.3 ug/l, and indicate eutrophic conditions. Concentrations above 20 ug/l indicate bloom conditions.

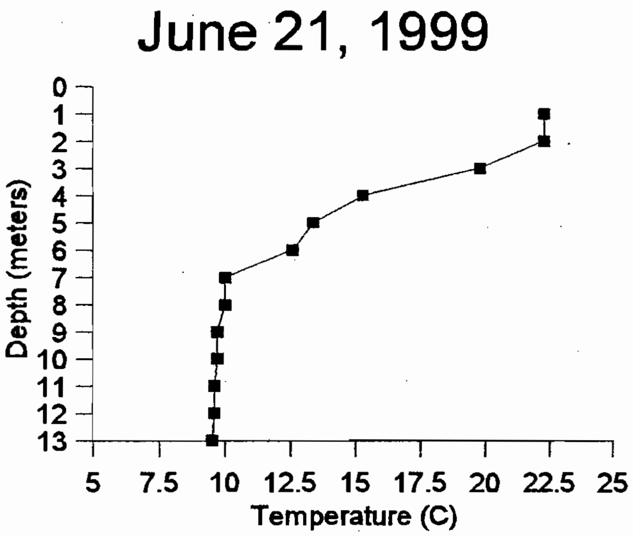
Secchi depths

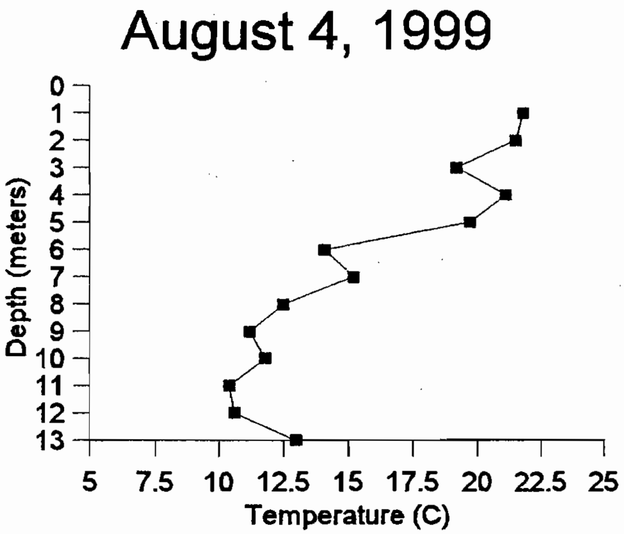
Spring water clarity was fair in 1999 with a Secchi depth of 7.5 feet (2.3 meters). Water clarity declined in June (4.9 ft) and was poor by August with Secchi depths of 3.3 feet (1.0 meter). Average summer (June-August) water clarity in the south basin was only slightly better than that in the north basin during 1999 despite a very large difference in phosphorus concentrations.

FIGURE 8.

1999 POTATO LAKE TEMPERATURE PROFILES

South Basin


June 21, 1999


August 4, 1999

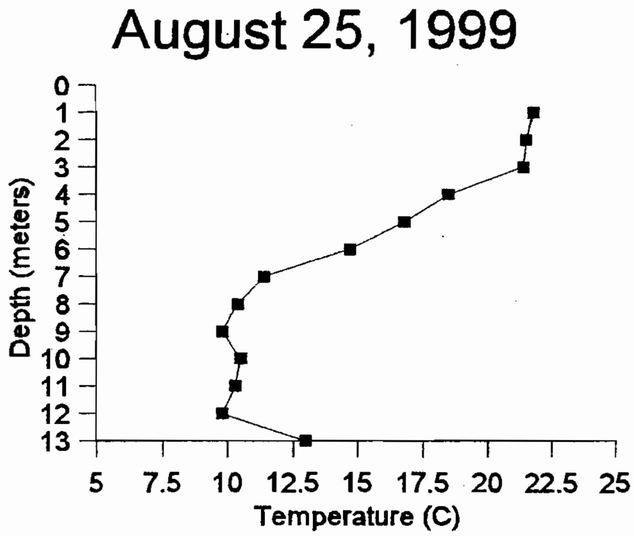
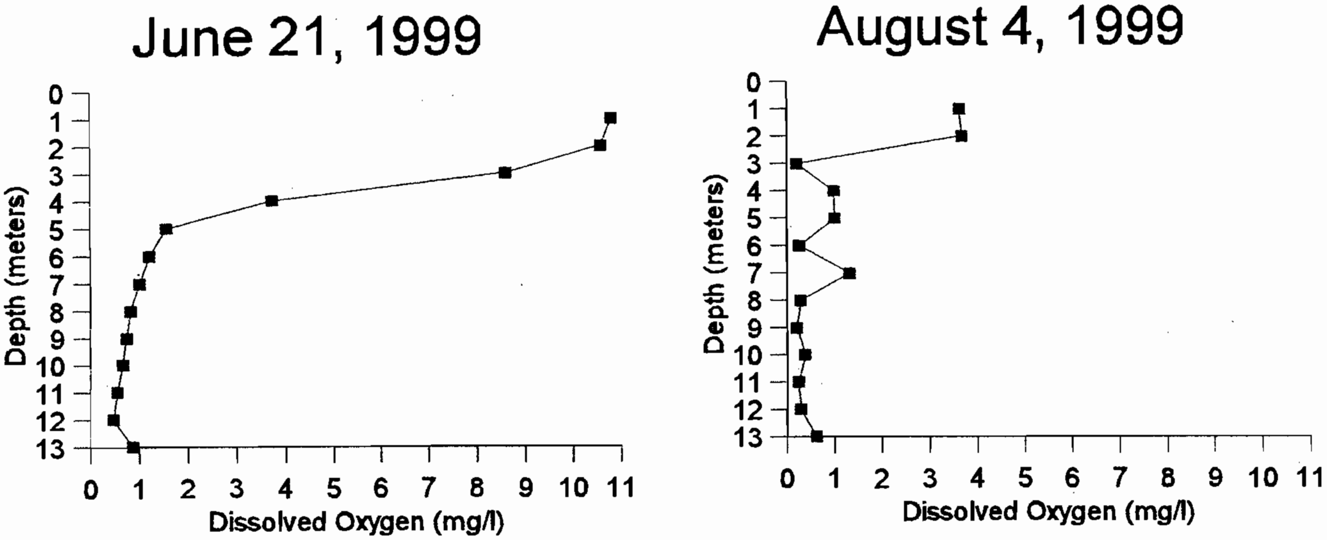

August 25, 1999

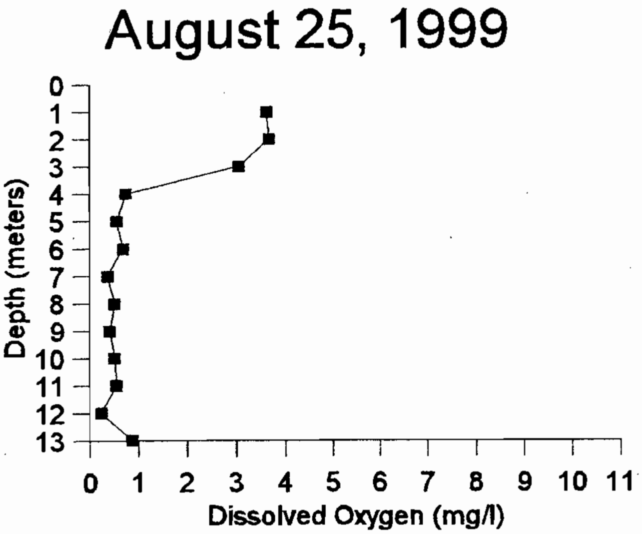
FIGURE 9.

1999 POTATO LAKE
DISSOLVED OXYGEN PROFILES

South Basin


June 21, 1999

August 4, 1999


August 25, 1999

Water clarity in the south basin was dramatically better in 1998. A Secchi depth of 7.3 feet (2.2 meters) was found in June and a Secchi depth of 9.0 feet (2.7 meters) was found in August. Phosphorus concentrations were very similar in August of both years (29-33 ug/l). Average phosphorus-clarity relationships found in Wisconsin stratified natural lakes indicate a lake with a summer phosphorus concentration of 31 ug/l would have a Secchi depth of 5.9 feet (1.8 meters) (Lillie, et al. 1993). The average of the August Secchi depths found in the two years is 6.2 feet, which is quite close to 5.9 feet. This suggests water clarity in August 1998 was better than average, and water clarity in August 1999 was worse than average for the south basin. Summer Secchi depths of about 6 feet may be more typical in most years.

Additional monitoring of the south basin would be needed to verify what average water clarity is. Although phosphorus concentration is the primary regulator of algal abundance and water clarity, a variety of other factors can alter average relationships at times. The type of algae present can make a difference. Some types have higher chlorophyll a content than others. An equal biomass of small-celled algae can reduce water clarity more than large celled or colonial algae. Fluctuations in zooplankton populations, which feed on planktonic algae, can also influence the abundance of algae present. Longer term monitoring is sometimes needed to average out the variations these other factors can cause.

STREAM MONITORING RESULTS

Stream monitoring site locations are shown in figure 2. Monitoring results for the seven stream sites are listed in table 2. Stream total phosphorus (TP) concentrations are graphically presented in figure 10 and 11.

With the exception of stream monitoring site CTD-6, mean TP concentrations are moderately high and range from 84 to 148 ug/l. TP concentrations tend to be highest in the summer (figures 10 and 11). Wetland drainage is likely to contribute to these higher concentrations (see Wetland Monitoring Results).

The two stream monitoring sites with the highest TP concentrations are MCD-1 and MCU-2 (148 and 139 ug/l). The drainage areas that supply water to these sites have greater percentages of their areas in more intensive land uses, such as pasture, corn, hay, residential use, and farmsteads. Runoff from these areas tends to carry higher loads of TP. Barnyard runoff is another contributor to the higher TP concentrations at these two stream sites.

The stream monitoring site with the lowest mean TP concentration (41 ug/l) is CTD-6. This site is just below the outlet of Lake Four. Most lakes function as effective phosphorus traps, with capture rates commonly in the 50 to 75% range. Thus, most of the TP load from the sub-watershed above Lake Four is removed by the lake and does not reach the monitoring site.

TABLE 2.

POTATO LAKE STREAM SAMPLING DATA 1999

SITE MCU-2 (McDermott Ck. At Horshoe Lake Rd)

DATE	FLOW (CFS)	TP (ug/l)	DP (ug/l)	TSS (mg/l)
05/17/1999	6.5	115	74	2.5
05/18/1999	13.3	125	63	5
06/15/1999	0.5	164	65	47
07/01/1999	0.61	98	62	7
07/08/1999	0.61	423	55	8
07/13/1999	0.94	192	88	22
08/03/1999	0.97	240	151	8
08/11/1999	0.93	179	116	2.5
08/25/1999	0.91	159	103	2.5
09/15/1999	0.5	76	35	2.5
10/26/1999				
12/07/1999				

FLOW-WEIGHTED TP AVERAGE = 138.6205
FLOW-WEIGHTED DP AVERAGE = 72.60652
FLOW-WEIGHTED TSS AVERAGE = 5.808692

SITE MCD-1 (McDermott Ck. At CTH F)

DATE	FLOW (CFS)	TP (ug/l)	DP (ug/l)	TSS (mg/l)
05/17/1999	12.6	128	86	2.5
05/18/1999	37.3	110	59	2.5
06/15/1999	4.5	144	84	10
07/01/1999	5.4	199	83	5
07/08/1999	2.4	260	95	8
07/13/1999	3.5	200	122	8
08/03/1999	5.2	211	138	2.5
08/11/1999	2.5	191	130	2.5
08/25/1999	17	194	105	2.5
09/15/1999	3	135	70	2.5
10/26/1999	3	120	42	2.5
12/07/1999	2.5	97	55	2.5

FLOW-WEIGHTED TP AVERAGE = 148.0546
FLOW-WEIGHTED DP AVERAGE = 81.5632
FLOW-WEIGHTED TSS AVERAGE = 3.305865

TABLE 2. (continued)

SITE SPR-5 ("Sunrise Pt. Rd." Creek)

DATE	FLOW (CFS)	TP (ug/l)	DP (ug/l)	TSS (mg/l)
05/17/1999	4.4	127	4	10
05/18/1999	6	116	4	12
06/15/1999	0.37	149	77	7
07/01/1999	0.16	158	81	6
07/08/1999	0.49	210	56	23
07/13/1999	0.62	149	68	11
08/03/1999	1.3	216	72	32
08/11/1999	0.54	123	74	2.5
08/25/1999	2	129	73	2.5
09/15/1999	0.4	93	44	6
10/26/1999	0.75	53	28	2.5
12/07/1999	0.5	86	24	19

FLOW-WEIGHTED TP AVERAGE = 128.6743
FLOW-WEIGHTED DP AVERAGE = 27.54193
FLOW-WEIGHTED TSS AVERAGE = 11.37279

SITE HLR-3 ("Horseshoe Lake Rd." Creek)

DATE	FLOW (CFS)	TP (ug/l)	DP (ug/l)	TSS (mg/l)
05/17/1999	1.6	57	22	2.5
05/18/1999	2	62	20	6
06/15/1999	0.006	380	230	5
07/01/1999				
07/08/1999				
07/13/1999	0.07	260	151	11
08/03/1999	0.32	503	273	86
08/11/1999				
08/25/1999	0.35	94	41	6
09/15/1999				
10/26/1999				

FLOW-WEIGHTED TP AVERAGE = 98.83571
FLOW-WEIGHTED DP AVERAGE = 43.45605
FLOW-WEIGHTED TSS AVERAGE = 10.68109

TABLE 2. (continued)

SITE BLR-4 ("Buck Lake Rd." Creek)

DATE	FLOW (CFS)	TP (ug/l)	DP (ug/l)	TSS (mg/l)
05/17/1999	2.7	69	29	2.5
05/18/1999	3.6	73	24	2.5
06/15/1999	0.14	393	96	10
07/01/1999				
07/08/1999				
07/13/1999	0.18	129	36	10
08/03/1999	0.17	176	77	7
08/11/1999				
08/25/1999	0.29	125	56	2.5
09/15/1999				
10/26/1999				

FLOW-WEIGHTED TP AVERAGE = 83.8291
FLOW-WEIGHTED DP AVERAGE = 30.21893
FLOW-WEIGHTED TSS AVERAGE = 2.947034

SITE CTF-7 ("CTH F" Creek at Access Rd)

DATE	FLOW (CFS)	TP (ug/l)	DP (ug/l)	TSS (mg/l)
05/17/1999	0.12	44	17	7
05/18/1999	0.16	42	17	2.5
06/15/1999	0.002	181	98	2.5
07/01/1999				
07/08/1999				
07/13/1999	0.03	110	76	2.5
08/03/1999	0.44	170	84	18
08/11/1999				
08/25/1999	0.29	118	57	18
09/15/1999				
10/26/1999				

FLOW-WEIGHTED TP AVERAGE = 119.6564
FLOW-WEIGHTED DP AVERAGE = 58.27831
FLOW-WEIGHTED TSS AVERAGE = 13.87716

TABLE 2. (continued)

SITE CTD-6 ("CTH D" Creek - Lake Four Outlet)

DATE	FLOW (CFS)	TP (ug/l)	DP (ug/l)	TSS (mg/l)
05/17/1999	1.7	40	7	2.5
05/18/1999	3.1	39	4	2.5
06/15/1999	0.035	33	4	2.5
07/01/1999				
07/08/1999				
07/13/1999	1.4	38	4	2.5
08/03/1999	0.5	71	3	8
08/11/1999				
08/25/1999	3.4	39	3	7
09/15/1999				
10/26/1999				

FLOW-WEIGHTED TP AVERAGE = 40.58757
FLOW-WEIGHTED DP AVERAGE = 4.118402
FLOW-WEIGHTED TSS AVERAGE = 4.280957

FIGURE 10.

Total Phosphorus Concentrations at Primary Stream Sampling Sites

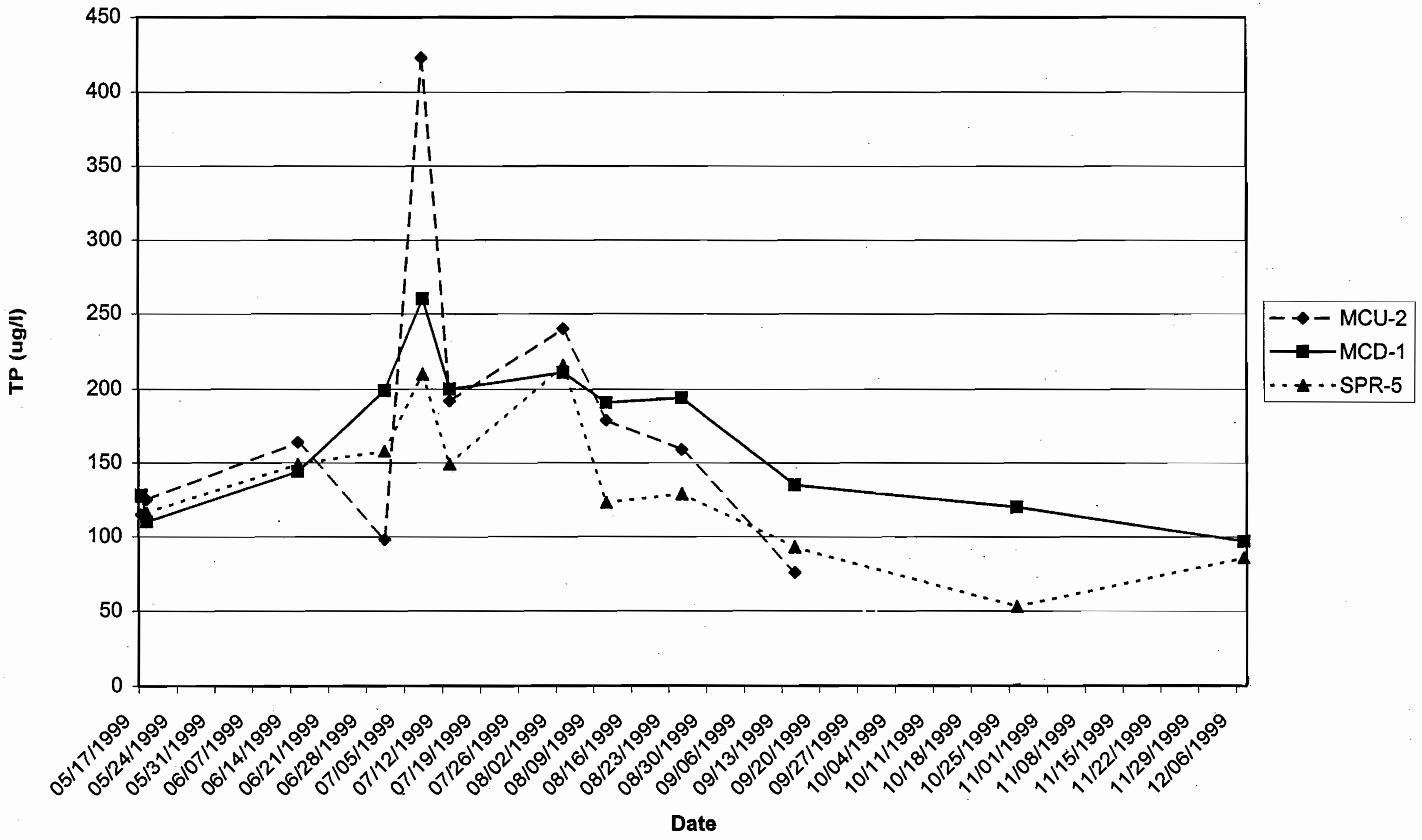
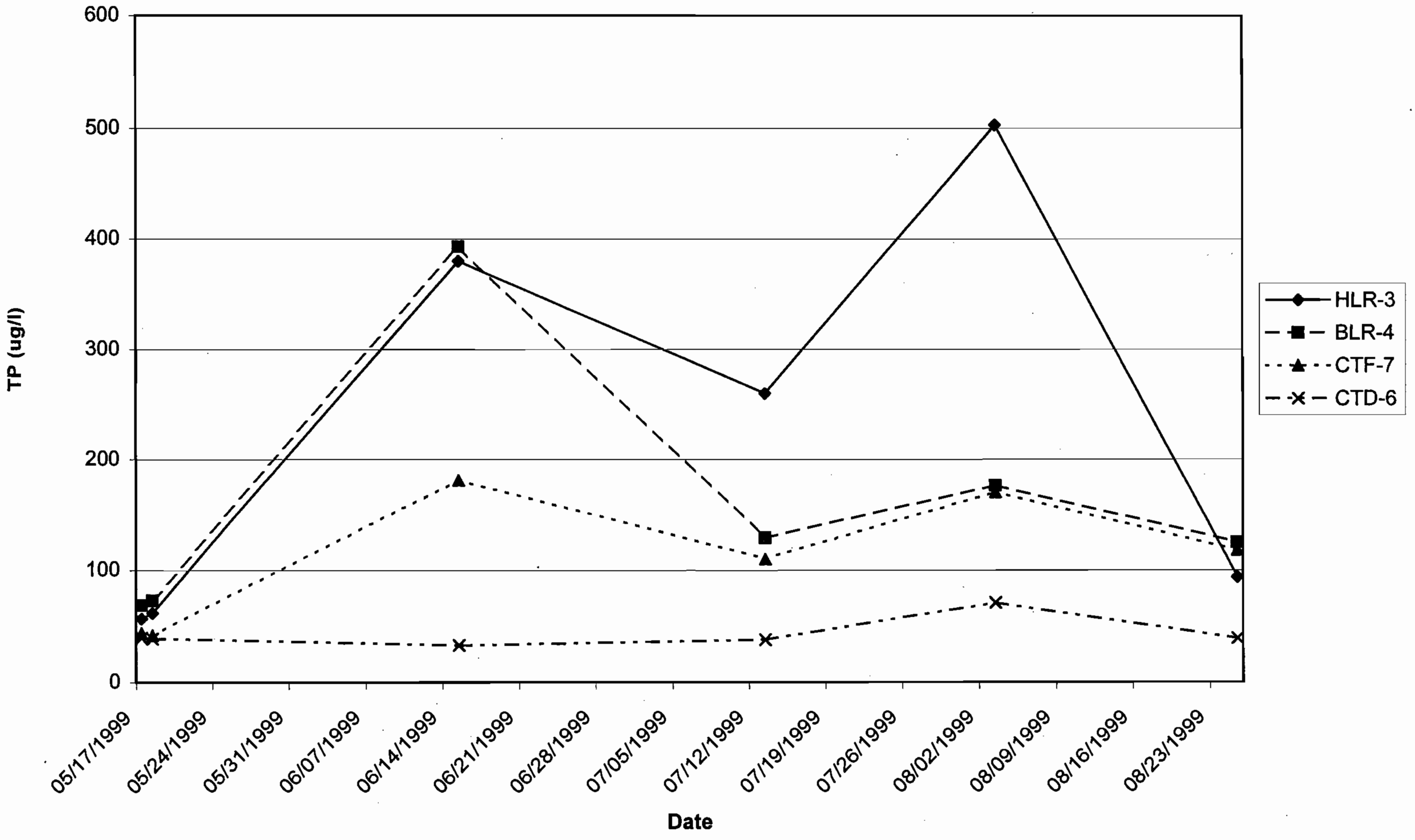


FIGURE 11.

Total Phosphorus Concentrations at Secondary Stream Sampling Sites



With the exception of stream monitoring site CTD-6, mean dissolved phosphorus (DP) concentrations are also moderately high and range from 28 to 82 ug/l. Stream monitoring sites MCD-1 and MCU-2 have the highest DP concentrations (82 and 73 ug/l). Barnyard runoff may be a major reason for the highest concentrations at these sites. A large percentage of total phosphorus consists of dissolved phosphorus (except at site CTD-6). Percentages range from 36 to 55%.

High groundwater phosphorus concentrations (see Groundwater Monitoring Results) contribute to the relatively high levels of DP found at all stream sites (except CTD-6). Dissolved phosphorus concentrations tend to be highest during periods of low flow (table 2), when groundwater discharge to stream channels is the source of most streamflow. Wetland drainage will also contribute to high levels of DP during the summer.

Stream monitoring site CTD-6 has the lowest mean DP concentration (4.1 ug/l). Again, this site is just below the outlet of Lake Four. DP in lakes is readily absorbed by planktonic algae, so DP in lake outflow is typically quite low.

Mean total suspended solids (TSS) concentrations are low at most stream monitoring sites. Four sites (MCD-1, MCU-2, BLR-4, and CTD-6) have mean TSS concentrations ranging from 2.9 to 5.8 mg/l. Three sites (HLR-3, SPR-5, and CTF-7) have moderate mean TSS concentrations ranging from 11 to 14 mg/l. Further investigation would be needed to determine the source of the higher concentrations at these sites. Areas of pastured stream channel above these sites are the only likely sediment sources apparent on the land use map (figure 15). Runoff from unpaved roads and from road or residential construction sites are other possible sources of suspended solids at these sites.

WETLAND MONITORING RESULTS

Wetland monitoring sites are shown in figure 12. Sampling results are listed in table 3.

Total phosphorus concentrations in spring were low and ranged from 13 to 48 ug/l. Summer concentrations were much higher and ranged from 170 to 266 ug/l. It is difficult to estimate the annual export of phosphorus from these wetland areas with the limited monitoring that was done. Spring flows were higher than summer flows, so spring concentrations would more strongly influence the annual average. The results do show that high concentrations of phosphorus can be released from wetlands in the summer months. Monitoring of wetlands elsewhere in northern Wisconsin has shown a similar pattern of increasing summer phosphorus concentrations.

GROUNDWATER MONITORING RESULTS

The 14 well sampling sites are shown in figure 13. An attempt was made to sample relatively shallow wells that would better represent shallow groundwater. For the twelve

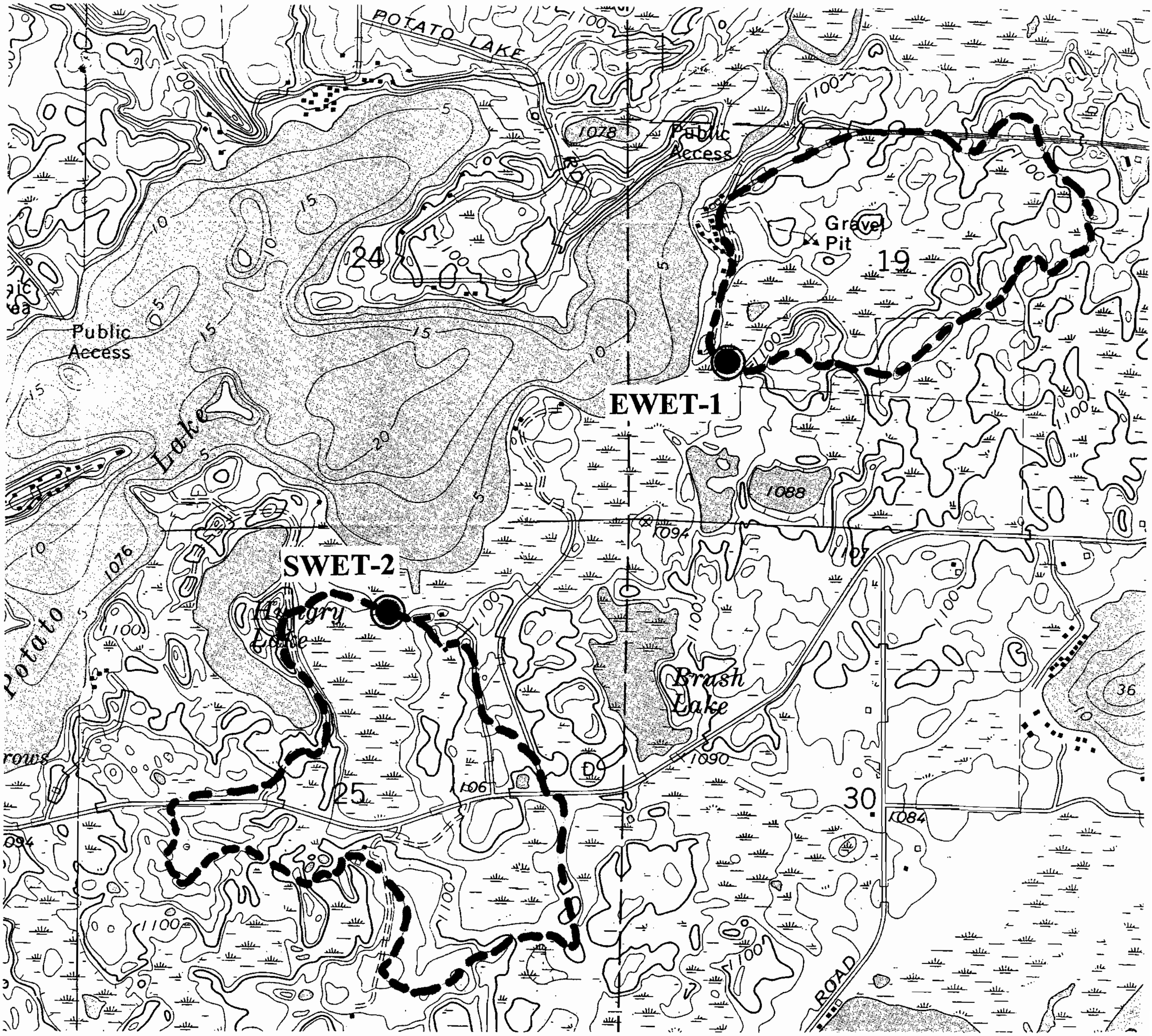


FIGURE 12. WETLAND DRAINAGE SAMPLING SITES

DRAINAGE AREA BOUNDARIES (— — —)

AND SAMPLING SITES (●)

FOR WETLAND DRAINAGE SAMPLING

TABLE 3. WETLAND SAMPLING TP RESULTS

	17-MAY-99		*18-MAY-99*		*13-JUL-99*		*3-AUG-99*	
SAMPLE SITES	TIME OF SAMPLE	(UG/L) TOTAL PHOSPH.	TIME OF SAMPLE	(UG/L) TOTAL PHOSPH.	TIME OF SAMPLE	(UG/L) TOTAL PHOSPH.	TIME OF SAMPLE	(UG/L) TOTAL PHOSPH.
EWET-1	15:30	17	14:00	48	14:11	174	13:10	170
SWET-2	16:00	24	13:24	13	NA	NA	12:45	266

wells with depth information, depths ranged from <20 to 160 feet, with a median of 55 feet. Two wells sampled on the north side of the lake were free-flowing.

Groundwater total phosphorus (TP) concentrations were surprisingly high and ranged from 70 to 421 ug/l (table 4 and figure 14). Groundwater TP concentrations in most areas of Wisconsin typically fall in the 20 to 40 ug/l range. Some wells could be affected by local sources, such as septic systems, but it is unlikely that most wells are affected. The results found are believed to represent natural background concentrations.

Four wells on the south side of the lake had exceptionally high TP concentrations, 368 to 421 ug/l (figure 14 and table 4). Three of these wells (1, 2, and 13) have an average TP concentration of 388 ug/l and are located down-gradient of large wetland areas. This indicates wetland areas produce very high groundwater TP concentrations. The fourth well (3) has a similar TP concentration (388 ug/l) and is likely to be influenced by lakebed sediment.

The remaining ten wells had lower, but still relatively high TP concentrations. Rejecting the sample with the highest concentration as an outlier, the remaining wells have a mean TP concentration of 106 ug/l.

The reason for this relatively high concentration is uncertain. Ten subsoil samples were collected in the watershed to determine if high phosphorus concentrations were present in soil parent material, which could be a source of groundwater phosphorus. Bray 1 phosphorus (a measure of plant available phosphorus) concentrations ranged from 3 to 34 parts per million (ppm), with a mean of 17 ppm. A study done in Polk County, Wisconsin (Muldoon, et al., 1990) found a mean subsoil Bray 1 phosphorus concentration of 24 ppm in an area where the mean groundwater TP concentration was 32 ug/l. Subsoil TP concentrations in the Potato Lake watershed do not appear to be a possible explanation for the high groundwater TP concentrations.

The local bedrock is Cambrian sandstone at a depth of 50-200 feet. Some areas of Cambrian sandstone in west central Wisconsin have been found to have high TP concentrations in groundwater. This sandstone could be a source of the high groundwater TP concentrations if substantial amounts have been incorporated into the overburden at depths below the subsoil.

LAKE AND WATERSHED PHOSPHORUS MODELING

BACKGROUND INFORMATION

Phosphorus modeling provides a means of evaluating sources and quantities of phosphorus from a lake's watershed and correlating phosphorus inputs to a lake with resulting phosphorus concentrations in the lake. Quantities of phosphorus provided from specific sources in the watershed can initially be estimated using literature values derived

FIGURE 13.

WELL SAMPLING SITES

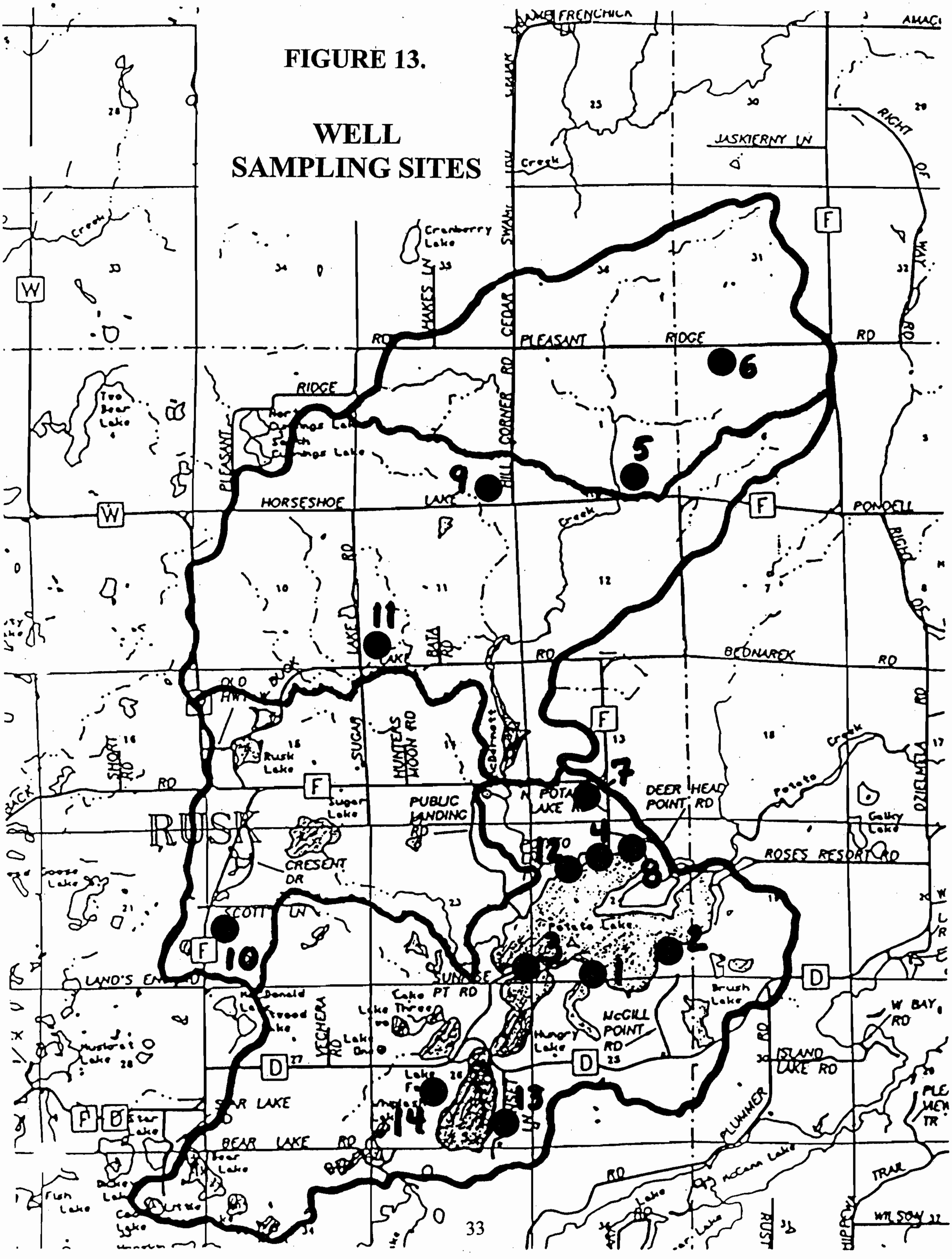


TABLE 4. WELL LOCATIONS, DEPTHS AND TP RESULTS

1. COLLECTION DATE:JUNE 28, 1999 HA
LOCATION: N1007 MCGILL POINT
DEPTH OF WELL: 28 FEET
TOTAL PHOSPHOROUS: 368 UG/L

2. COLLECTION DATE: JUNE 28, 1999 HA
LOCATION: N999 MCGILL PT RD
DEPTH OF WELL: 35 FEET
TOTAL PHOSPHOROUS: 421 UG/L

3. COLLECTION DATE: JULY 2, 1999 HA
LOCATION: N986 SUNRISE PT
DEPTH OF WELL: <20FT
TOTAL PHOSPHOROUS: 388 UG/L

4. COLLECTION DATE: SEPT 15, 1999 JP
LOCATION: N1211 POTATO LK RD
DEPTH OF WELL: 50 FT (ARTESIAN WELL)
TOTAL PHOSPHOROUS: 138 UG/L

5. COLLECTION DATE: SEPT. 20, 1999 JP
LOCATION: W14626 HORSESHOE LK RD(ELLIOT)
DEPTH OF WELL: 35 FT
TOTAL PHOSPHOROUS: 90 UG/L

6. COLLECTION DATE: SEPT. 20, 1999 JP
LOCATION: W14415 PLEASANT VIEW RD(SIEJA)
DEPTH OF WELL: 40 FT
TOTAL PHOSPHOROUS: 91 UG/L

7. COLLECTION DATE: SEPT. 20, 1999 JP
LOCATION: W14831 CTH F(HESTIKEN)
DEPTH OF WELL: 60 FT?
TOTAL PHOSPHOROUS: 118 UG/L

8. COLLECTION DATE: SEPT. 20, 1999 JP
LOCATION: N1230 POTATO LK RD(GRAY SHED)
DEPTH OF WELL: ARTESIAN FREE FLOWING
TOTAL PHOSPHOROUS: 80 UG/L

9. COLLECTION DATE: SEPT. 27, 1999 JP
LOCATION: W14942 HORSESHOE LK RD(DRIGGS)
DEPTH OF WELL: 117 FT
TOTAL PHOSPHOROUS: 160 UG/L

10. COLLECTION DATE: SEPT. 27, 1999 JP
LOCATION: (BILN) STANLEY BILLON
DEPTH OF WELL: 160 FT

TOTAL PHOSPHOROUS: 70 UG/L

11. COLLECTION DATE: SEPT. 27, 1999 JP
LOCATION: N1728 SUGAR LAKE RD(JACK PROROK)
DEPTH OF WELL: 60 FT
TOTAL PHOSPHOROUS: 74 UG/L

12. COLLECTION DATE: SEPT. 27, 1999 JP
LOCATION: W1189 POTATO LAKE RD(TJ'S)
DEPTH OF WELL: NA
TOTAL PHOSPHOROUS: 276 UG/L

13. COLLECTION DATE:
LOCATION: N541 SUNSET LN(WALKOWICZ)
DEPTH OF WELL: 100FT
TOTAL PHOSPHOROUS: 375 UG/L

14. COLLECTION DATE:
LOCATION: W15165 CTH D(TIMBER&TACKLE)
DEPTH OF WELL: 80FT
TOTAL PHOSPHOROUS: 134 UG/L

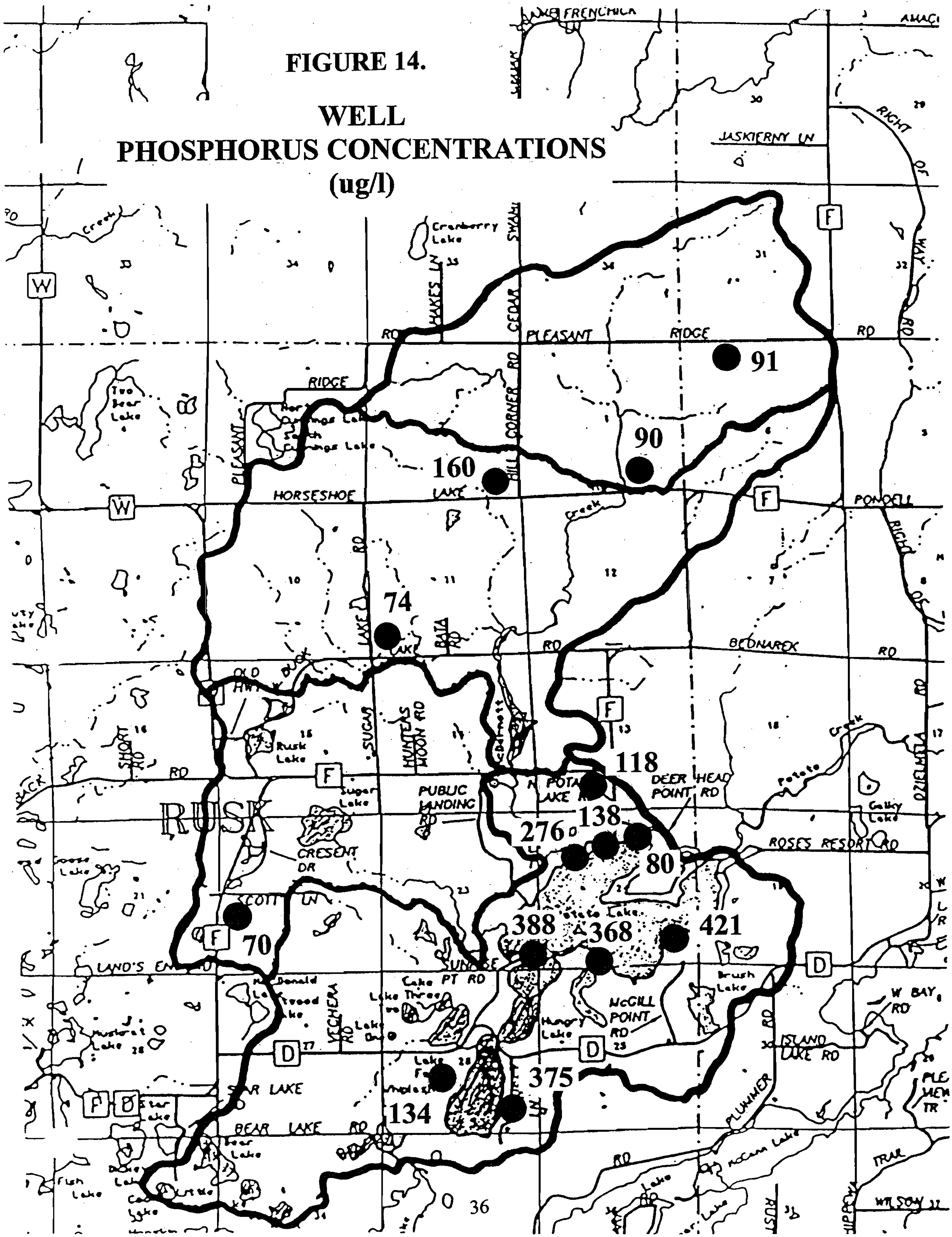


FIGURE 14.

WELL PHOSPHORUS CONCENTRATIONS (ug/l)

from numerous studies. These estimates can be refined using monitoring data from the watershed.

Lake phosphorus models are based on empirical data from many lakes. These models will predict lake phosphorus concentrations based on a lake's area, depth, and annual inputs of phosphorus and water.

Water draining from land surfaces, via both runoff and groundwater flow carries phosphorus to streams and lakes. Land surfaces that are more developed and erosive or are enriched with phosphorus tend to "export" higher amounts of phosphorus. Land use phosphorus export rates can be used to estimate total phosphorus export from a watershed.

TOTAL PHOSPHORUS (TP) EXPORT RATES FOR WATERSHED LAND USES

Due to the high groundwater phosphorus concentrations and high wetland drainage phosphorus concentrations, some modifications of typical Wisconsin TP export rates were needed. A commonly used rate for a forested area is 0.10 kilograms/hectare/year (kg/ha/yr). A typical Wisconsin groundwater TP concentration is 30 ug/l. In the Potato Lake area with 10 inches/unit area of stream discharge, and assuming half is derived from surface runoff and half via groundwater flow, surface runoff would have a mean TP concentration of 52 ug/l if the groundwater TP concentration was 30 ug/l. If the groundwater TP concentration is 106 ug/l (as measured), the export rate would be 0.19 kg/ha/yr.

The additional 0.09 kg/ha/yr is a result of the high groundwater TP concentrations in upland areas. This additional export rate has been added to all upland land use export rates.

Wetland areas were seen to have both high surface runoff TP concentrations (average = 102 ug/l) and very high groundwater TP concentrations (average = 388 ug/l). Using a surface runoff TP concentration of 82 ug/l (since the average was not flow-weighted), a groundwater TP of 388 ug/l, and assuming 75% of discharge is surface runoff and 25% is via groundwater flow, a TP export rate of 0.39 kg/ha/yr is indicated.

Monitoring at other wetland drainage sites in northern Wisconsin and elsewhere also indicates TP yields from softwater wetlands are substantially higher than TP yields from forested uplands. In the Island Chain of Lakes watershed, immediately to the south of the Potato Lake watershed, monitoring of two small streams that were heavily influenced by wetlands found very high TP concentrations (Brakke, 1992). Nurnberg (2001) showed a positive correlation between lake water color and TP concentration which also indicates softwater wetland drainage is a significant TP source.

The following land use TP export rates were applied to the Potato Lake watershed:

Land Use	TP Export Rate (kg/ha/yr)
woodland	0.19
wetland	0.39
pasture	0.44
corn field	1.09
hay field	0.39
fallow field	0.29
residential	0.59
farmstead	0.89

Tables 5.1-5.9 provide land use areas, TP export rates, and total TP export for each of the Potato Lake subwatersheds. Figure 15 shows the distribution of land uses across the watershed.

COMPARISON OF TP LOADS ESTIMATED FROM LAND USE EXPORT RATES TO TP LOADS ESTIMATED FROM STREAM MONITORING

Comparing TP loads estimated from land use export rates to those estimated from stream monitoring can help validate the land use export rates and improve confidence in the reliability of the model. This comparison is shown in table 6. Good agreement exists between the two estimates with most monitoring sites having differences within +/- 16%. The one exception is monitoring site BLR-4 with an 85% difference. Possible reasons for this difference include:

- An overestimated barnyard TP export
- The presence of beaver dams on stream channels which could trap TP
- Less intensively grazed pasture areas
- Lower groundwater TP concentrations

Three stream monitoring sites (MCD-1, SPR-5, and CTF-7) would be used to estimate total streamflow TP loads to the north basin. These sites have combined TP loads estimated from stream monitoring and from land use export rates that differ by only 2% (table 6). Thus, either estimate could be used for the model. However, the estimate derived from land use export rates has the advantage of allowing the significance of the various TP sources to be evaluated.

OTHER PHOSPHORUS SOURCE ESTIMATES

Internally drained areas

For internally drained areas, 10 inches/unit area of drainage via groundwater was assumed. For wetland areas, a groundwater TP concentration of 388 ug/l was applied. For upland areas, a groundwater TP concentration of 106 ug/l was applied.

Other watershed lakes

TABLE 5.1

LAND USE AND OTHER PHOSPHORUS SOURCES FOR STREAM SAMPLING SITE MCD-1. THIS SITE RECEIVES DRAINAGE FROM SUB-WATERSHEDS MCD-1, MCU-2, HLR-3, AND BLR-4.

LAND USE	AREA ACRES	AREA HECTARES	TP EXPORT RATE (KG/HA/YR)	TP EXPORT (KG/YR)
WOODS	2589	1047.8	0.19	199.1
WETLAND	266.7	107.9	0.39	42.1
PASTURE	1013	410	0.44	180.4
CORN	264	106.8	1.09	116.4
HAY	754	305.1	0.39	119
FALLOW	182.3	73.8	0.29	21.4
RESIDENTIAL	28.5	11.5	0.59	6.8
FARMSTEAD	5.1	2.1	0.89	1.9
			LAND USE SUBTOTAL =	687.1
OTHER TP SOURCES				
BARNYARDS				97.9
			TOTAL =	785

TP EXPORT ESTIMATED FROM STREAM SAMPLING = 776

TABLE 5.2

LAND USE AND OTHER PHOSPHORUS SOURCES FOR STREAM SAMPLING SITE MCU-2.

LAND USE	AREA ACRES	AREA HECTARES	TP EXPORT RATE (KG/HA/YR)	TP EXPORT (KG/YR)
WOODS	986	399	0.19	75.8
WETLAND	106	42.9	0.39	16.7
PASTURE	469	189.8	0.44	83.5
CORN	123	49.8	1.09	54.3
HAY	487	197.1	0.39	76.9
FALLOW	10.1	4.1	0.29	1.2
RESIDENTIAL	11.9	4.8	0.59	2.8
FARMSTEAD	2.2	0.9	0.89	0.8
		LAND USE SUBTOTAL =		312
OTHER TP SOURCES				
BARNYARDS				49.8
			TOTAL =	361.8
TP EXPORT ESTIMATED FROM STREAM SAMPLING =				314

TABLE 5.3

LAND USE AND OTHER PHOSPHORUS SOURCES FOR STREAM SAMPLING SITE HLR-3.

LAND USE	AREA ACRES	AREA HECTARES	TP EXPORT RATE (KG/HA/YR)	TP EXPORT (KG/YR)
WOODS	309.2	125.1	0.19	23.8
WETLAND	16.1	6.5	0.39	2.5
PASTURE	21.6	8.7	0.44	3.8
CORN	0	0	1.09	0
HAY	0	0	0.39	0
FALLOW	0	0	0.29	0
RESIDENTIAL	4	1.6	0.59	0.9
FARMSTEAD	0	0	0.89	0
		LAND USE SUBTOTAL =		31
OTHER TP SOURCES				
NONE				0
			TOTAL =	31

TP EXPORT ESTIMATED FROM STREAM SAMPLING = 36

TABLE 5.4

LAND USE AND OTHER PHOSPHORUS SOURCES FOR
STREAM SAMPLING SITE BLR-4.

LAND USE	AREA ACRES	AREA HECTARES	TP EXPORT RATE (KG/HA/YR)	TP EXPORT (KG/YR)
WOODS	585	236.7	0.19	45
WETLAND	27.5	11.1	0.39	4.3
PASTURE	188	76.1	0.44	33.5
CORN	0	0	1.09	0
HAY	131	53	0.39	20.7
FALLOW	103	41.7	0.29	12.1
RESIDENTIAL	7.6	3.1	0.59	1.8
FARMSTEAD	1.9	0.8	0.89	0.7
		LAND USE SUBTOTAL =		118.1
OTHER TP SOURCES				
BARNYARDS				48.1
			TOTAL =	166.2
TP EXPORT ESTIMATED FROM STREAM SAMPLING =				90

TABLE 5.5

LAND USE AND OTHER PHOSPHORUS SOURCES FOR STREAM SAMPLING SITE SPR-5.

AREA UPSTREAM OF SUGAR LAKE AND UNNAMED LAKES.

LAND USE	AREA ACRES	AREA HECTARES	TP EXPORT RATE (KG/HA/YR)	TP EXPORT (KG/YR)
WOODS	218.7	88.5	0.19	16.8
WETLAND	7.8	3.2	0.39	1.2
PASTURE	204.9	82.9	0.44	36.5
CORN	50	20.2	1.09	22
HAY	119	48.2	0.39	18.8
FALLOW	30	12.1	0.29	3.5
RESIDENTIAL	4	1.6	0.59	0.9
FARMSTEAD	2	0.8	0.89	0.7
		LAND USE SUBTOTAL =		100.4
OTHER TP SOURCES				
BARNYARDS				13.4
			TOTAL =	113.8

AREA DOWNSTREAM OF SUGAR LAKE AND UNNAMED LAKES

LAND USE	AREA ACRES	AREA HECTARES	TP EXPORT RATE (KG/HA/YR)	TP EXPORT (KG/YR)
WOODS	195.5	79.1	0.19	15
WETLAND	134	54.2	0.39	21.1
PASTURE	25	10.1	0.44	4.4
CORN	0	0	1.09	0
HAY	21	8.5	0.39	3.3
FALLOW	0	0	0.29	0
RESIDENTIAL	0	0	0.59	0
FARMSTEAD	0	0	0.89	0
		LAND USE SUBTOTAL =		43.8
OTHER TP SOURCES				
LAKE OUTFLOW*				56.9
GROUNDWATER FROM INTERNALLY DRAINED AREA**				24

TOTAL =	124.7
TP EXPORT ESTIMATED FROM STREAM SAMPLING =	145

*ASSUMED TO BE 1/2 OF TP EXPORT FROM AREAS UPSTREAM OF LAKES

**BASED ON 84.8 ACRE AREA WHICH IS 60% WETLAND AND 40% UPLAND.
GROUNDWATER TP CONCENTRATION = 275.2 UG/L

TABLE 5.6

LAND USE AND OTHER PHOSPHORUS SOURCES FOR STREAM SAMPLING SITE CTD-6.

LAND USE	AREA ACRES	AREA HECTARES	TP EXPORT RATE (KG/HA/YR)	TP EXPORT (KG/YR)
WOODS	498.8	201.9	0.19	38.4
WETLAND	128.1	51.8	0.39	20.2
PASTURE	213.4	86.4	0.44	38
CORN	50.5	20.4	1.09	22.2
HAY	137.7	55.7	0.39	21.7
FALLOW	15.1	6.1	0.29	1.8
RESIDENTIAL	9	3.6	0.59	2.1
FARMSTEAD	0	0	0.89	0
			LAND USE SUBTOTAL =	144.4
OTHER TP SOURCES				
BEAR LAKE INTERNALLY DRAINED AREA*				22.2
			TOTAL =	166.6
TP EXPORT ESTIMATED FROM STREAM SAMPLING =				53**

*BASED ON A 203.4 ACRE UPLAND AREA WITH A GROUNDWATER TP CONCENTRATION OF 106 UG/L.

**STREAM SAMPLING SITE CTD-6 IS THE OUTLET OF LAKE FOUR. PORTIONS OF TP EXPORT FROM SUBWATERSHED CTD-6 PASS THROUGH LAKE ONE, LAKE TWO, LAKE THREE, AND LAKE FOUR. A COMPARISON OF THE STREAM SAMPLING ESTIMATE TO THE LAND USE EXPORT ESTIMATE INDICATES THIS LAKE SYSTEM IS CAPTURING 68% OF THE TP EXPORT FROM THE SUBWATERSHED. THIS IS A REASONABLE CAPTURE RATE FOR THESE LAKES, AND SO THE LAND USE TP EXPORT ESTIMATE AND THE STREAM SAMPLING TP EXPORT ESTIMATE ARE IN REASONABLE AGREEMENT.

TABLE 5.7

LAND USE AND OTHER PHOSPHORUS SOURCES FOR STREAM SAMPLING SITE CTF-7.

ABOVE BUCK LAKE AND UNNAMED LAKE

LAND USE	AREA ACRES	AREA HECTARES	TP EXPORT RATE (KG/HA/YR)	TP EXPORT (KG/YR)
WOODS	50	20.2	0.19	3.8
WETLAND	30	12.1	0.39	4.7
PASTURE	0	0	0.44	0
CORN	0	0	1.09	0
HAY	3	1.2	0.39	0.5
FALLOW	8	3.2	0.29	0.9
RESIDENTIAL	6	2.4	0.59	1.4
FARMSTEAD	0	0	0.89	0
		LAND USE SUBTOTAL =		11.3
OTHER TP SOURCES				
NONE				0
			TOTAL =	11.3

BELOW BUCK LAKE AND UNNAMED LAKE

LAND USE	AREA ACRES	AREA HECTARES	TP EXPORT RATE (KG/HA/YR)	TP EXPORT (KG/YR)
WOODS	301	121.8	0.19	23.1
WETLAND	17	6.9	0.39	2.7
PASTURE	100	40.5	0.44	17.8
CORN	3	1.2	1.09	1.3
HAY	2	0.8	0.39	0.3
FALLOW	35	14.2	0.29	4.1
RESIDENTIAL	2	0.8	0.59	0.5
FARMSTEAD	2	0.8	0.89	0.7
		LAND USE SUBTOTAL =		50.5
OTHER TP SOURCES				
BARNYARDS				4.1
LAKE OUTFLOW*				5.6
			TOTAL =	60.2

TP EXPORT ESTIMATED FROM STREAM SAMPLING = 72

TABLE 5.8

LAND USE AND OTHER PHOSPHORUS SOURCES FOR SUB-WATERSHED NPB-8. THIS IS THE IMMEDIATE DRAINAGE AREA AROUND THE NORTH BASIN OF POTATO LAKE AND INCLUDES EWET-1 AND SWET-2.

LAND USE	AREA ACRES	AREA HECTARES	TP EXPORT RATE (KG/HA/YR)	TP EXPORT (KG/YR)
WOODS	898	363.4	0.19	69
WETLAND	280.3	113.4	0.39	44.2
PASTURE	16	6.5	0.44	2.9
CORN	33.9	13.7	1.09	14.9
HAY	41.8	16.9	0.39	6.6
FALLOW	14.9	6	0.29	1.7
RESIDENTIAL	81	32.8	0.59	19.4
FARMSTEAD	1	0.4	0.89	0.4
		LAND USE SUBTOTAL =		159.1
OTHER TP SOURCES				
LAKESHORE SEPTIC SYSTEMS*				18.8
INTERNALLY DRAINED AREA E. OF NORTH BASIN**				26.6
			TOTAL =	204.5

TP EXPORT ESTIMATED FROM STREAM SAMPLING = NO SAMPLING SITE

*BASED ON THE FOLLOWING ASSUMPTIONS: 36 YEAR-ROUND RESIDENCES, 71 SEASONAL RESIDENCES, 4 MONTH OCCUPANCY OF SEASONAL RESIDENCES, 3.5 PERSONS PER RESIDENCE, 0.6 KG TP PER PERSON PER YEAR, 85% TP CAPTURE BY SOIL.

**BASED ON AN 88.1 ACRE AREA WHICH IS 2/3 WETLAND AND 1/3 UPLAND WITH A GROUNDWATER TP CONCENTRATION OF 294 UG/L.

TABLE 5.9

LAND USE AND OTHER PHOSPHORUS SOURCES FOR SUB-WATERSHED SPB-9. THIS IS THE IMMEDIATE DRAINAGE AREA FOR THE SOUTH BASIN OF POTATO LAKE

LAND USE	AREA ACRES	AREA HECTARES	TP EXPORT RATE (KG/HA/YR)	TP EXPORT (KG/YR)
WOODS	134.8	54.6	0.19	10.4
WETLAND	63	25.5	0.39	9.9
PASTURE	0	0	0.44	0
CORN	0	0	1.09	0
HAY	0	0	0.39	0
FALLOW	0	0	0.29	0
RESIDENTIAL	15	6.1	0.59	3.6
FARMSTEAD	0	0	0.89	0
			LAND USE SUBTOTAL =	23.9
OTHER TP SOURCES				
WHIPLASH L. INTERNALLY DRAINED AREA*				15.1
INTERNALLY DRAINED AREA E. OF SOUTH BASIN**				20.8
LAKESHORE SEPTIC SYSTEMS***				4.1
			TOTAL =	63.9

TP EXPORT ESTIMATED FROM STREAM SAMPLING = NO SAMPLING SITE

*BASED ON AN AREA OF 139 ACRES WHICH IS 100% UPLAND WITH A GROUNDWATER TP CONCENTRATION OF 106 UG/L.

**BASED ON AN AREA OF 61 ACRES WHICH IS 80% WETLAND AND 20% UPLAND WITH A GROUNDWATER TP CONCENTRATION OF 331.6 UG/L.

***BASED ON THE FOLLOWING ASSUMPTIONS: 8 YEAR-ROUND RESIDENCES, 15 SEASONAL RESIDENCES, 4 MONTH OCCUPANCY OF SEASONAL RESIDENCES, 3.5 PERSONS PER RESIDENCE, 0.6 KG TP PER PERSON PER YEAR, 85% CAPTURE OF TP BY SOIL.

TABLE 6.

COMPARISON OF TP LOADS ESTIMATED FROM STREAM MONITORING TO TP LOADS ESTIMATED FROM LAND USE EXPORT RATES

STREAM MONITORING SITE AND SUBWATERSHED	STREAM MONITORING* ESTIMATED TP LOAD (KG)	LAND USE** ESTIMATED TP LOAD (KG)	PERCENT DIFFERENCE
MCD-1	776	785	+12
MCU-2	314	362	+15
HLR-3	36	31	-14
BLR-4	90	166	+85
SPR-5	145	125	-14
CTD-6	53	53	0***
CTF-7	72	60	-16
(SITES MONITORING DIRECT INFLOW TO NORTH BASIN)****			
MCD-1	776	785	
SPR-5	145	125	
CTF-7	72	60	
	SUBTOTAL 993	SUBTOTAL 970	-2

* Estimated from flow-weighted TP concentrations and a 10"/unit area stream discharge.

** Includes BARNY estimates for barnyards, groundwater estimates for internally drained areas, and small lake TP retention effects.

*** These two estimates have been matched by assuming a TP retention of 68% by the lake cluster present.

**** These are sites at the most downstream ends of monitored tributaries. Site MCD-1 monitors the composited flows from several upstream subwatersheds.

There are several small lakes in the watershed that have surface outlets and that can capture phosphorus from upgradient portions of the subwatersheds in which they are located. Lakes capture phosphorus by sedimentation. Common capture rates are in the 50 to 75% range. Sugar Lake (subwatershed SPR-5) and Buck Lake (subwatershed CTF-7) were assumed to capture 50% of the phosphorus from upgradient sources. The lake complex including Lakes One, Two, Three, and Four was assumed to capture 68% of the phosphorus from upgradient sources as suggested by the comparison of estimated TP inputs to measured TP outflow.

The watershed map (figure 2) shows a large area of impounded water on McDermott Creek. This impoundment was created by beaver dams in the past and was not present at the time of this study.

South basin outflow

The south basin of Potato Lake flows into the north basin and so is another TP source for the north basin. This source was estimated to be 48.3 kg by using the average measured epilimnetic TP concentration in the south basin (28.8 ug/l) and the modeled annual water discharge (1.42×10^3 acre-feet).

Barnyard runoff

TP export for barnyard runoff was estimated by Rusk County LCD staff using the BARNY model. Estimates for the four barnyards are listed below:

Location	Annual TP Export (kg)	No. of Cattle
T33N, R8W, Sec.6, NW1/4	49.8	70
T33N, R9W, Sec.22, NW ¼	13.4	78
T33N, R9W, Sec.10, SE1/4	48.1	30
T33N, R9W, Sec.15, NE1/4	4.1	10

Lakeshore septic systems

For septic systems, residences within 400 feet of the lakeshore were counted on the 1972 USGS quad map. These counts were increased by 30% to account for additional construction. The following assumptions were applied:

- 1/3 of residences are year-round
- 2/3 of residences are seasonal with four month occupancy
- 3 1/2 persons per residence
- An additional 20 seasonal residents are present at the camp on the south shore of the north basin
- TP input to septic systems is 0.6 kg per capita year
- TP retention by soils is 85%

For the north basin, this indicates 215.5 capita years, and that septic systems contribute 19.4 kg/yr to the lake. For the south basin, this indicates 45.5 capita years, and that septic systems contribute 4.1 kg/yr to the lake. A capita year is one person living along the lakeshore for 365 days.

Carp

A significant carp population is present in the north basin of Potato Lake. Carp are bottom feeders that release substantial amounts of dissolved phosphorus to the water through their digestive processes. A study of carp influence on lake TP concentrations (Sorge and Engel, 1989) found carp contribute TP at a rate of 0.0048 kg/acre/yr/lb of carp. The carp population in the north basin of Potato Lake is estimated to be 30 lb/acre (Lealos, 2000) or a total of 13,500 pounds. Carp removal efforts by netting during the 1980's removed 2,000 to 3,000 pounds of carp per year. This removal rate is about 19% of the total estimated population, which seems like a reasonable capture rate and so helps validate the total population estimate. The TP contribution to the north basin from carp is estimated to be 64.8 kg/yr. The carp population in the south basin was assumed to be insignificant.

Atmospheric deposition

Atmospheric deposition which includes rain, snow, and dry fallout falling directly on the lake surface was estimated to be 0.35 kg TP/ha/yr, based on literature values.

Summaries of the TP sources for the north and south basin are provided in tables 7 and 8.

LAKE TP MODELS

The Wisconsin Lake Model Spreadsheet (WILMS), version 2.00, was used to model the north and south basin of Potato Lake using the TP input loads described above. Vollenweider's 1975 lake model (contained in WILMS) was used to predict spring TP concentrations. The models are shown in appendix B.

The models for each basin contain a "point source" phosphorus term which includes sources that can't be expressed as land use export terms. The 328.3 kg listed for the north basin includes:

- 108.7 kg from barnyards
- 55.9 kg from the outflow from Sugar and Buck Lakes
- 48.3 kg from the outflow of the south basin
- 64.8 kg from carp
- 50.6 kg from groundwater from internally drained areas

No "point source" water loading was added for the south basin outflow, since the tributary drainage area for the north basin includes the combined areas for the north and south basins.

TABLE 7.

TP SOURCES FOR THE NORTH BASIN OF POTATO LAKE

DIRECTLY DRAINED LAND USE AREA	ACRES	TP LOAD (KG)	% OF TOTAL TP LOAD
WOODS	3984	306	22.6
WETLAND	698	110	8.1
PASTURE	1154	206	15.2
CORN FIELD	301	133	9.8
HAY FIELD	819	129	9.5
FALLOW	232	27.3	2
RESIDENTIAL	112	26.6	2
FARMSTEAD	8.1	2.9	0.2
OTHER SOURCES			
ATMOSPHERIC DEPOSITION	450	63.8	4.7
GROUNDWATER FROM INTERNALLY DRAINED AREAS*		50.6	3.7
OUTFLOW FROM SUGAR AND BUCK LAKE*		55.9	4.1
OUTFLOW FROM THE SOUTH BASIN OF POTATO LAKE*		48.3	3.6
BARNYARD RUNOFF*		109	8.1
LAKESHORE SEPTIC SYSTEMS		19.4	1.4
CARP*		64.8	4.8
TOTAL		1,353	99.8

*Entered in WILMS spreadsheet as point sources.

TABLE 8.

TP SOURCES FOR THE SOUTH BASIN OF POTATO LAKE

DIRECTLY DRAINED LAND USE AREA	ACRES	TP LOAD (KG)	% OF TOTAL TP LOAD
WOODS	135	10.4	8.0
WETLAND	63	9.9	7.7
RESIDENTIAL	15	3.6	2.8
OTHER SOURCES			
ATMOSPHERIC DEPOSITION	87.2	12.4	9.6
GROUNDWATER FROM INTERNALLY DRAINED AREAS*		35.9	27.8
OUTFLOW FROM LAKE FOUR*		53	41.0
LAKESHORE SEPTIC SYSTEMS		4.1	3.2
TOTAL		129.3	100.1

*Entered in WILMS spreadsheet as point sources.

The 88.9 kg listed as a "point source" phosphorus term for the south basin includes 53 kg from the outflow of Lake Four and 35.9 kg from groundwater from internally drained areas.

For the north basin a spring TP concentration of 47 ug/l is predicted. The two years with measured values show a range from 33 to 86 ug/l, with a mean of 59.5 ug/l. The predicted value falls within the measured range.

For the south basin, a spring TP concentration of 24 ug/l is predicted. This is very similar to the value of 26 ug/l measured in the spring of 1999.

The models were also used to predict what the natural state of the two basins was prior to development of the watershed (appendix C). Wetland and woodland land uses were maintained and all other land uses were converted to woodland. TP loads from barnyards, septic systems and carp were removed. Under these conditions, the spring TP concentration for the north basin was predicted to be 28 ug/l. This suggests the basin's TP concentration has increased 68% as a result of watershed development and carp introduction. However, the natural state concentration of 28 ug/l is still a moderately eutrophic value.

The spring TP concentration for the south basin was predicted to be 19 ug/l, which suggests the basin's TP concentration has increased 26% as a result of watershed development. The natural state value of 19 ug/l is marginally eutrophic.

INTERNAL LOADING AS A TP SOURCE

As mentioned previously, internal loading of TP due to sediment TP release during the summer has a major influence on the water quality of the north basin of Potato Lake. The lake TP models that have been applied have been used to predict spring TP concentrations only.

There are various ways to evaluate the impact of internal loading. A simple, but meaningful approach is to compare the spring TP concentration to summer TP concentrations. Lakes with low levels of internal TP loading usually have stable to slightly declining epilimnetic TP concentrations from spring to summer. When a lake's epilimnetic TP concentrations increase dramatically from spring to summer, internal loading is usually the source of the increase. In 1999, north basin epilimnetic TP concentrations increased from 33 ug/l in spring to 214 ug/l in September. In 1998, north basin epilimnetic TP concentrations increased from 86 ug/l in spring to 135 ug/l in August.

Comparing the spring TP concentration to the growing season mean (GSM) TP concentration, suggests that in 1999, internal loading was the source of 71% of the TP present during the growing season, while in 1998 it was the source of 21% of the TP present, with an average of 46% for the two years. At 46%, internal loading is the source of 1,153 kg of TP annually.

TP release from the early July die back of curly-leaf pondweed is also a component of internal loading in the north basin. This source may account for about 5% of the total annual internal load based on the following assumptions:

- curly-leaf beds cover 36 acres
- average biomass density of the beds is 200 g dry weight/m2
- 0.27% of dry weight is TP
- 2/3 of the TP content ends up in the water column

Internal loading probably also influenced summer TP concentrations in the north basin in its natural state, prior to watershed development. The lake's depth and area coupled with eutrophic TP concentrations in spring would have made it prone to the sequence of thermal stratification, development of hypolimnetic anoxia, sediment TP release, and eventual transport of hypolimnetic TP to the epilimnion. However, the magnitude of internal loading in the natural state would have been lower, since lower algal abundance would have reduced the rate of hypolimnetic oxygen depletion.

In the south basin of Potato Lake, internal loading has only a minor influence. Comparing the spring TP concentration to the GSM TP concentration, suggests that in 1999, internal loading was the source of only 8% of the TP present during the growing season.

SEDIMENT ANALYSES

A sediment core was collected from the deepest spot of the north basin in August, 1999. The diatom species present at the core's surface were compared to species present at a depth of 55-57 cm. Diatoms are useful indicators of lake nutrient levels. The diatoms present at 55-57 cm were assumed to have been deposited at least 100 years ago.

The diatom species present indicate the lake has had relatively high nutrient levels both historically and currently. However, current levels are higher than historic levels (appendix E). This agrees with the lake phosphorus modeling results that indicate the lake was moderately eutrophic prior to watershed development, but currently has higher total phosphorus concentrations.

Sediment cores were also collected from two sites in the north basin in May, 2000 (appendix D). Concentrations of most heavy metals were low and unlikely to be causing any significant toxicity. Arsenic concentrations ranged from 11-12 milligrams/kilogram (mg/kg). Ontario sediment quality guidelines (Jaagumagi 1990) suggest substantial toxicity to benthic organisms can occur at these concentrations. MacDonald, et al. (2000) suggested arsenic toxicity in sediment is unlikely below 10 mg/kg and is probable above 33 mg/kg. The arsenic concentrations found in Potato Lake are fairly typical for northwestern Wisconsin lake sediment and are believed to be naturally occurring.

Total phosphorus concentrations are high and range from 1830-4230 mg/kg. Water content of the sediment is also high, ranging from 95.4-96.2%.

AQUATIC PLANT SURVEYS

Curly-leaf pondweed (*Potamogeton crispus*) is a non-native, exotic species that was first seen in Wisconsin in 1905. It is now common throughout the state. Curly-leaf sprouts in fall, continues growing under the ice in winter, and then grows rapidly in spring. It achieves peak growth in June and then dies back dramatically around the beginning of July. Decomposition of the plants at that time can contribute TP to the water column and help fuel summer algae blooms.

Its rapid spring growth helps it out-compete more desirable native vegetation. It competes especially well in lakes like the north basin of Potato Lake, where good water clarity exists in spring and very poor water clarity exists later in the summer due to severe algae blooms. Curly-leaf also has the potential to form dense surface canopies that shade other plants and can restrict boating, swimming, and fishing. A picture and additional information on curly-leaf is contained in appendix H.

A survey was conducted for curly-leaf pondweed on June 15th, 1999. The survey found curly-leaf present around nearly the entire perimeter of the north basin (figure 16). Curly-leaf grew to a maximum depth of 6.5 feet, with densest growth at depths less than 6 feet. Figure 16 depicts the generalized distribution of curly-leaf in the lake, but the areas shaded exaggerate areal coverage. The widths of individual shoreline segments were usually much narrower than shown. Appendix F provides more detailed information.

In the south basin, curly-leaf was found at depths up to 8 feet. Curly-leaf was present at very low densities at scattered locations around the basin perimeter.

A second aquatic plant survey was conducted on August 8th, 1999 to assess the remaining species in the lake.

Seventeen species were found in the north basin, with only five submersed species present (table 9). The three most abundant species were coontail (*Ceratophyllum demersum*), elodea (*Elodea canadensis*), and white water lily (*Nymphaea odorata*) (appendix G). These are all species that can tolerate poor water clarity. White water lily was found growing to depths of 6 feet at two transects. For all other transects and all other species, growth was restricted to depths of 4 feet or less.

Twenty-three species were found in the south basin, with nine submersed species present (table 9). The three most abundant species were coontail (*Ceratophyllum demersum*), northern milfoil (*Myriophyllum sp.*), and flat-stem pondweed (*Potamogeton zosteriformis*) (appendix G). Maximum depth of plant growth was 9 feet. The south basin has a more diverse plant community and in August, has greater densities of plants than the north basin. Better water clarity is probably the main reason for this. The

TABLE 9.

POTATO LAKE AQUATIC PLANT LIST

Scientific Name	Common Name	Present in: North Basin	South Basin	Species Code*
EMERGENT PLANTS – plants with leaves that extend above the water surface				
Eleocharis palustris	Creeping Spikerush	X	X	--
Equisetum fluviatilis	Water Horsetail		X	--
Pontederia cordata	Pickerelweed	X	X	--
Sagittaria latifolia	Common Arrowhead	X	X	--
Scirpus acutus	Hardstem Bulrush		X	--
Scirpus fluviatilis	River Bulrush	X	X	--
Scirpus validus	Softstem Bulrush	X		--
Sparganium eurycarpum	Common Bur-reed	X	X	--
Typha latifolia	Broad-leaved cattail	X	X	--
FREE-FLOATING PLANTS – plants that float freely on the water surface				
Lemna minor	Small Duckweed	X	X	--
Lemna trisulca	Forked Duckweed		X	--
Spirodela polyrhiza	Large Duckweed	X	X	--
Wolffia columbiana	Common Watermeal	X	X	--
FLOATING-LEAF PLANTS – plants with leaves that float on the water surface				
Nuphar variegata	Spatterdock	X	X	NUPVA
Nymphaea odorata	White Water Lily	X	X	NYMOD
SUBMERSED PLANTS – plants with most of their leaves growing below the water surface				
Ceratophyllum demersum	Coontail	X	X	CERDE
Elodea Canadensis	Common waterweed	X	X	ELOCA
Myriophyllum sp.	A Milfoil species	X	X	MYRSP
Najas flexilis	Slender Naiad		X	NAJFL
Potamogeton amplifolius	Large-Leaf Pondweed		X	POTAM
Potamogeton crispus	Curly-Leaf Pondweed	X	X	POTCR
Potamogeton pectinatus	Sago Pondweed		X	POTPE
Potamogeton zosteriformis	Flat-Stem Pondweed	X	X	POTZO
Vallisneria americana	Eel Grass		X	VALAM

* Species codes are used in the tabulated results of the aquatic plant transect survey conducted August 8, 1999. See table xx and xx.

healthy native plant community may restrict curly-leaf pondweed to only a minor presence in this basin.

Pictures and additional information on the aquatic plant species present in the lake are contained in appendix H.

LAKE MANAGEMENT OPTIONS

PHOSPHORUS LOADING REDUCTIONS

Reducing inputs (loading) of total phosphorus (TP) to a lake is a standard approach to improve water quality. For the north basin of Potato Lake, 34% of the current spring TP concentration is derived from increased TP exports via runoff from developed land. (An additional 6.2% is derived from carp (4.8%) and septic systems (1.4%)). Reducing this by about 1/3 is probably a reasonably achievable goal. A substantial watershed TP control project would be required. This would reduce spring TP concentrations by 11%. However, the source of about 46% of the GSM TP concentration is internal loading. Therefore, only a 6% reduction in GSM TP would be expected. This amount of reduction is unlikely to produce any noticeable change in lake water quality.

Dramatic improvements in lake water quality from controlling only external TP loading appear unlikely. However, it is still advisable to control TP sources where feasible to contribute to minor improvements and reduce the potential for long-term degradation of the lake. A number of source controls could be pursued.

Barnyards

Preliminary assessments by Rusk Co. LCD staff indicated two barnyards had high rates of TP export. One barnyard located in T33N, R8W, Sec. 6, NW1/4 was estimated to export 50 kg (110 lb) of TP per year. A second barnyard located in T33N, R9W, Sec. 10, SE 1/4 was estimated to export 48 kg (106 lb) of TP per year. These two barnyards should be reassessed and runoff control options should be explored.

Cropland nutrient management

Nutrient management plans should be encouraged for all cropland. These assure that applications of fertilizer and manure, and gains from nitrogen fixing crops are balanced to meet crop needs and avoid any excessive nutrient build-up in the soil.

Erosion control

Whenever bare soil is exposed and erosion occurs, substantial runoff of nutrients also occurs. Erosion control practices should be implemented for tilled cropland and residential and road construction sites.

Residential shoreline management

Shoreline property owners should be encouraged to maintain as much area as possible in natural vegetative cover. This reduces nutrient and sediment delivery to the lake, provides habitat, and enhances shoreline aesthetics.

Fertilizer use should be minimized and low phosphorus or no phosphorus fertilizer should be used when needed. Lawn soils are rarely found to require additional phosphorus. Soil testing can be done to verify this.

Runoff from rooftops, driveways and other impervious areas should be directed to sites where maximum ponding and/or infiltration into the soil can be achieved. This can reduce nutrient and sediment delivery to the lake.

CARP CONTROL

Carp are estimated to be the source of about 5% of the spring TP concentration in the north basin. Elimination of carp could reduce spring TP concentrations by that amount. This is not enough to produce a noticeable change in lake water quality. Also, carp removal has been found to be a very difficult task, where it has been attempted. Netting is relatively inefficient and markets for netted carp have dwindled. Carp populations reduced by netting tend to show increased reproductive rates, which minimizes removal effects.

Carp control with rotenone has been used elsewhere. The use of rotenone results in the total elimination of a lake's fish population. Restocking is necessary to restore the fishery. The limited size of the carp population and the quality of the existing sport fish population in Potato Lake make this inadvisable. Also, carp from the Chippewa River could easily re-enter the lake unless a fish barrier was created at the lake outlet. Such a barrier would also obstruct the passage of game fish between the lake and the river.

INTERNAL PHOSPHORUS LOADING REDUCTION

Since internal phosphorus loading, primarily due to sediment phosphorus release, is estimated to provide almost half of the GSM TP concentrations in the north basin, measures to control it would be necessary to achieve a substantial improvement in water quality. The two potential methods to control sediment phosphorus release are alum application or aeration.

Alum

Alum (aluminum sulfate) has been used to control sediment phosphorus release in many lakes. When added to lake water, alum forms a whitish aluminum hydroxide floc that settles to the surface of the sediment. This floc has the ability to absorb phosphorus. Phosphorus captured by the floc can no longer be released to the overlying water, and eventually becomes permanently mineralized. Alum has been well studied and has been shown to be safe and non-toxic in aquatic systems. Successful alum treatments can control sediment phosphorus release for 10-20 years.

A GSM TP concentration reduction of 39% could be achieved with an alum treatment assuming that:

- Sediment phosphorus release is the source of 46% of the GSM TP concentration, and
- An alum treatment would reduce sediment phosphorus release by 85%.

Past alum treatments have not always been successful and it can be difficult to predict outcomes. Wapogasset and Bear Trap Lakes in Polk Co., Wisconsin were treated with alum in 1999. Both lakes responded well in 2000, with greatly improved water quality. However, the treatment of Wapogasset appears to have failed after two years because the alum has sunk deeply into the sediment. In Bear Trap Lake, the alum is still at a relatively shallow depth in the sediment, although its future effectiveness is in question.

A comparison of some sediment and lake water characteristics between the north basin of Potato Lake and Wapogasset Lake is shown below. A thorough investigation would be needed before applying alum to Potato Lake.

Sediment	Potato Lake	Wapogasset Lake
% water	95-96	94-96
Al (mg/kg)	7,300-10,000	8,000-9,000
Fe (mg/kg)	20,000-25,000	36,000-44,000
TP (mg/kg)	1,830-4,230	1,260-3,000
Lake Water		
Alkalinity (mg/l as $CaCO_3$)	64-74	90-100

In the north basin, there are 213 acres with a water depth of 10 feet or more. If this area was treated with an alum dose of 40g Al/m^2, at a cost of $480/acre, the total treatment cost would be $102,240. A DNR Lake Protection Grant could potentially provide 75% of the cost of an alum treatment. External phosphorus loading must first be reduced to the extent practical before an alum treatment can be funded.

Aeration

Aeration is another potential method to reduce sediment phosphorus release. If oxygen in the water overlying the sediment remains available, the dissolution of iron-phosphorus complexes will not occur and phosphorus will not be released to the water. To achieve this, an aeration system is designed to keep the lake mixed throughout the spring and summer, and to prevent thermal stratification from occurring.

This method has not been well proven. A full lake aeration system was installed in Cedar Lake in Polk and St. Croix Co.'s, Wisconsin in 1990. Although there were some indications of water quality benefits in the first two years of operation, average TP concentrations in the years following aeration have been higher than the years prior to aeration. A system is currently being installed in Little Green Lake in Green Lake Co., Wisconsin. The performance of this system will be worth watching.

The equipment and installation cost of a full lake aeration system in the north basin is roughly estimated to be around $40,000-60,000, with annual operation costs of $4,000-8,000. A DNR Lake Protection Grant could potentially provide 75% of the cost of equipment and installation. External phosphorus loading must first be reduced to the extent practical before an aeration system can be funded.

EXTERNAL PHOSPHORUS LOADING REDUCTIONS IN COMBINATION WITH AN ALUM TREATMENT

This combination of management efforts has the best potential to substantially improve water quality in the north basin. As previously mentioned, 34% of the current spring TP concentration is derived from increased TP exports via runoff from developed land. Reducing this by 1/3 could produce an 11% reduction in spring TP concentration and a 6% reduction in GSM TP concentration. An alum treatment could reduce GSM TP concentration by an additional 39%. In combination, a 45% reduction in GSM TP concentration could be produced. This would reduce the current GSM TP concentration of 111 ug/l to 61 ug/l. The lake would still be quite eutrophic at this level. However, noticeable improvements would be expected.

Applying the same percentage reduction (45%) to the observed summer (June-August) mean TP concentration indicates a reduction from 119 ug/l to 65 ug/l would occur. Summer mean chlorophyll a concentration would decline from 78 ug/l to 30 ug/l, based on Carlson's (1977) TP – chlorophyll relationship.

Water clarity improvements are difficult to predict. The summer algae population is currently dominated by *Aphanizomenon*. This algae grows in relatively large, flake-like colonies. These larger particles scatter light less effectively than smaller algae particles. For a given chlorophyll concentration, water clarity will be greater when *Aphanizomenon* is the dominant algae. If a shift in the dominant species of algae would occur at reduced TP concentrations, the existing chlorophyll – water clarity relationship would change.

Chlorophyll (CHL) vs. Secchi depth (SD) data for the north basin was plotted and the best fitting exponential curve was determined ($CHL = 237.86e^{-1.3297(SD)}$; $r^2 = 0.96$). This relationship suggests that reducing the mean summer chlorophyll concentration to 30 ug/l would increase the mean summer Secchi depth from 3.2 feet (0.98 m) to 5.1 feet (1.55 m). However, this predicted improvement may be on the high side. Wisconsin statewide and regional relationships for comparable lakes indicate that a lake with a mean summer TP concentration of 65 ug/l and a mean summer chlorophyll concentration of 30 ug/l would typically have water clarity in the 3.3 to 4.3 feet range.

The frequency of nuisance algae blooms (>20 ug/l) would also be reduced. Under current conditions, nuisance bloom frequency is estimated at 97%. With the predicted chlorophyll reductions, nuisance bloom frequency would be reduced to 63%.

CURLY-LEAF PONDWEED CONTROL

Curly-leaf pondweed produces nuisance conditions at various locations in the north basin. The curly-leaf beds are mostly in bands along the shoreline. This distribution may make it unlikely that there will be shared interests in controlling curly-leaf at any particular location.

Harvesting and herbicide applications are the two potential control methods. Both methods need to be applied on an annual basis and generally do not provide any long-lasting benefits. However, if curly-leaf is controlled early enough, the production of turions (the plants reproductive "buds") may be reduced and growth the following season may be lessened.

Contractors who provide harvesting and herbicide application services are available. Harvesting typically costs $300-500/acre. Herbicide application typically costs $200-400/acre. Qualified lake associations interested in purchasing their own aquatic plant harvester can potentially obtain a grant from the Wisconsin Waterways Commission to cover 50% of the purchase cost. Any mechanical harvesting or herbicide application requires a permit from the DNR.

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