Southeast Wisconsin's
Pewaukee Lake
Biological Evaluation 2000

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Prepared by
Angela L. Schmoldt
Robert C. Anderson, PhD

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Introduction

Pewaukee Lake in Waukesha County, Wisconsin is an urban lake that is a very important recreational source to the area. The valley that Pewaukee Lake fills was deepened by a glacier and then blocked off in the west end to form a basin. This initial lake was known as Snail Lake (Fennelman 1910). Then, around 1838, a dam was built in the only outlet, Pewaukee River, and the present lake was formed. The dam raised the water level approximately six feet, which caused the previously swampy east basin of the lake to flood (SEWRPC 1984). The building of the dam caused Pewaukee Lake to become the popular recreational lake that it is today.

Pewaukee Lake has four inlet sources, Zion Creek, Audley Creek, and two unnamed tributaries (SEWRPC 1984). It is also fed by springs, especially along the north side (Fennelman 1910). The lake covers 2,446 acres and has a volume of 34,552 acre-feet. Approximately 15 percent of the lake area is less that five feet deep, 60 percent of the lake area is between five and 20 feet deep, and 25 percent has a depth of more that 20 feet. The mean depth is 15 feet and the maximum depth is 45 feet. Pewaukee Lake is 1.4 miles wide at its widest point and is 4.5 miles long. The west basin is considerably deeper than the east basin. Muck is the predominant bottom sediment type, covering approximately 83 percent of the lake bottom. The remainder is 11 percent sand and gravel and 6 percent silt and rubble (SEWRPC 1984).

The area of land that drains directly into Pewaukee Lake is 14,817 acres. This land is becoming increasingly populated and has been an urban area since 1930. Projections (SEWRPC 1996) indicate by 2010, 53.5 percent of the watershed will be urban land use and the remaining rural land use (mainly agriculture). The lake is almost completely surrounded by residential development.

Pewaukee Lake was studied and classified as a eutrophic lake by Aqua Tech, Inc. in 1972 and by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) in 1984. The purpose of this study is to determine the present state of Pewaukee Lake and to initiate an annual monitoring program of Pewaukee Lake. To determine the present trophic status of Pewaukee Lake, benthic macroinvertebrate populations, zooplankton populations, and water chemistry were evaluated.

Benthic macroinvertebrates can be used as water quality indicators since they are continually exposed to changes in both oxygen levels and nutrient levels (Saether 1979). Benthic macroinvertebrate populations are a result of what has already happened to the lake because they cannot easily move to a better environment if the conditions are not favorable. The current populations will reflect conditions that have existed in the lake for some time. According to the EPA (1999), benthic macroinvertebrate community structure will respond to dissolved oxygen levels and organic enrichment, both of which are characteristics used to measure trophic levels of a lake.

Zooplankton populations can also be used to indicate water quality and reflect past problems of the lake. Zooplankton levels are controlled by both higher and lower trophic levels. This means zooplankton levels reflect fish predation (high trophic levels) and nutrient levels which effect algae growth (low trophic levels). If there are low numbers of large zooplankton, it indicates predation of zooplankton by planktivorous forage fish. If there are high numbers of zooplankton, it indicates an unlimited food supply, which could be caused by high nutrient levels in the lake. If both situations are found, few large zooplankton and many small zooplankton, then both extensive fish predation and high nutrient levels may be influencing the zooplankton population (EPA 1999). Zooplankton species composition has also been found to indicate the condition of lakes. For example, an increase in cladoceran populations may indicate an increase in eutrophication (Harman *et al.* 1997).

Chemical and physical parameters measured in this study included dissolved oxygen, water clarity, conductivity, pH, temperature, reactive phosphorous, nitrate, chloride, and ammonia. These measurements allow determination of the trophic status of the lake and help predict future problems. They also will help determine if the lake is capable of supporting a normal aquatic community. The dissolved oxygen readings are especially important in determining the future of a lake by indicating how much life the lake can sustain. Chloride and ammonia levels can indicate pollution from surface water runoff. Phosphorous and nitrogen forecast potential plant and algae growth (Kevern *et al.* 1996).

Through evaluation of the biological and chemical parameters described above, an overall assessment of the conditions of Pewaukee Lake was determined. It is hoped that this information will be used in future lake management decisions and in establishing an annual monitoring program.

Methods

Benthic macroinvertebrates, zooplankton, and water chemistry samples were collected from various sites in Pewaukee Lake during the summer of 2000. The nine sample stations chosen represent three main parts of the lake (Figure 1).

Benthic macroinvertebrate samples were collected at each site in June, July, and August of 2000. Samples were taken with a standard Eckman Dredge (150mm x 150mm). Three grabs were done at each site. The contents of the dredge were emptied into Standard Mesh SS screen #30 (541 μm) bottomed bucket. This was used to filter out all the fine sediment and retain the organisms. The remaining sediment and the organisms were poured into a white basin so that all the organisms could be removed using forceps. Benthic macroinvertebrates were preserved in 90% ethanol and taken to the laboratory to be counted and identified. Edmondson (1959), Merrit and Cummins (1978), and Pennek (1953) keys were used in identification. Finally, the number of benthic macroinvertebrates per square meter of sediment was calculated.

Zooplankton were sampled at three sites during July and August of 2000. Samples were taken at sites W2, M2 and E2 (figure 1) between 10:00 am and 12:00 pm to avoid variation due to vertical migration patterns of zooplankton. Two replicate samples of water were pumped through a 153 μm zooplankton net from the surface, mid-depth, and near the bottom of sites W2 and E2. At site M2, samples were taken from the surface, half the distance to the thermocline, at the thermocline, half the distance to the bottom from the thermocline, and at the bottom and filtered through the same net. The duration of pumping was timed so that the equivalent of 5 gallons of water was pumped at each depth. After the zooplankton were collected, club soda was administered to relax them prior to preservation in 80% ethanol.

Three 1 ml subsamples were taken from each zooplankton sample jar and placed in a Sedgwick-Rafter cell for identification and enumeration. The contents of the sample jars were stirred during subsampling to insure a homogenous distribution of zooplankton in the sample. Edmondson (1959) and Pennak (1953) were used for identification. Finally, an estimate of the number of zooplankton in 1 liter of water was calculated.

The water chemistry of Pewaukee Lake was also evaluated during the second and fourth weeks in July and the second week in August of 2000. Measurements were taken at the same sites and depths as the zooplankton. Chloride, nitrate, ammonia, and reactive phosphorus were measured using the Hach Drel 2000 Basic Water Quality Laboratory. Dissolved oxygen and water temperature were measured at half-meter increments from the surface to the bottom each time zooplankton or benthic macroinvertebrates were collected using the Data Sonde 4 Hydrolab. Water clarity was measured with a Secchi disc. Time, weather, and lake conditions were also recorded.

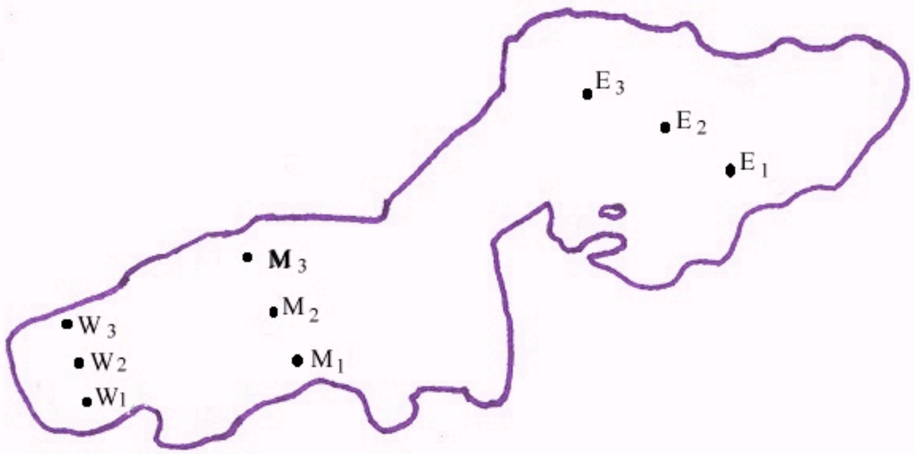

Figure 1: Pewaukee Lake, Waukesha County, Wisconsin sampling locations.

Results

In June, July, and August of 2000, a total of 544 benthic macroinvertebrates were collected from Pewaukee Lake. Analysis of the sample revealed 18 different types of organisms ranging from scuds to mayfly nymphs to midge larvae. The most common macroinvertebrate was *Prodiamesa* in the family Chironomidae (non-biting midges), which were found throughout the lake each month. Amphipoda, Emphemenoptera, and Megaloptera larvae were mostly found in the west and east ends of the lake. Leaches were found mainly in the east end of the lake, and *Chaoborus* larvae were found only in the deepest part of the lake where oxygen levels are low (Tables 1, 2, and 3).

The west end and the middle sites had about the same number of benthic macroinvertebrates, while the eastern sites were considerably lower in numbers per square meter. And even though the number of macroinvertebrates per square meter at each location seems to have no consistent pattern (Figures 2, 3, and 4), the average number of organisms found per square meter in each part of the lake decreased as the summer progressed (Figure 5).

Table 1 : Estimated number of benthic macroinvertebrates per square meter in Pewaukee Lake, based on Echman dredge samples taken in June,2000.

	W1	W2	W3	M1	M2	M3	E1	E2	E3	**Total**
Order: Amphipoda										
Gammaridae	4.9									4.9
Haustoriidae										
Order: Emphemenoptera										
Caenidae	9.9									9.9
Ephemeridae										
Order: Megaloptera										
Sialidae										
Ceratopogonidae	4.9								4.9	9.8
Family: Chironomidae										
Prodiamesa	49.4	24.7	19.8		24.7	74.1	14.8	19.8	64.2	291.5
Chironomus	59.3	34.6	4.9	39.5			4.9		19.8	163
Procladius	9.9	34.6		69.1	4.9	4.9				123.4
Paratendipes	9.9	237	34.6	14.8				9.9		306.2
Corynoneura				4.9		4.9				9.8
Pentaneura									14.8	14.8
Anatopynia										
Trissocladius										
Coeloanypus										
Family: Hirudinea							4.9			4.9
Order: Oligocheate										
Tubificidae				4.9						4.9
Family: Culicidae										
Chaoborus					251.9					251.9
Total	148.2	330.9	59.3	133.2	281.5	83.9	24.6	29.7	103.7	1195

Table 2 : Estimated number of benthic macroinvertebrates per square meter in Pewaukee Lake, based on Echman dredge samples taken in July,2000.

	W1	W2	W3	M1	M2	M3	E1	E2	E3	**Total**
Order: Amphipoda										
Gammaridae										
Haustoriidae										
Order: Emphemenoptera										
Caenidae										
Ephemeridae						4.9				4.9
Order: Megaloptera										
Sialidae			4.9							4.9
Ceratopogonidae										
Family: Chironomidae										
Prodiamesa	84	88.9	133.3	64.2	9.9	29.6	54.3	4.9		469.1
Chironomus								9.9	39.5	49.4
Procladius	9.9		59.3	44.4		34.6	4.9	4.9	4.9	162.9
Paratendipes	9.9	19.8	19.8	14.8						64.3
Corynoneura						19.8		4.9		24.7
Pentaneura	14.8	9.9				14.8		4.9		44.4
Anatopynia	14.8									14.8
Trissocladius						4.9				4.9
Coeloanypus									4.9	4.9
Family: Hirudinea										
Order: Oligocheate										
Tubificidae				14.8		4.9				19.7
Family: Culicidae										
Chaoborus					88.9					88.9
Total	133.4	118.6	217.3	138.2	98.8	113.5	59.2	29.5	49.3	957.8

Table 3 : Estimated number of benthic macroinvertebrates per square meter in Pewaukee Lake, based on Eckman dredge samples taken in August,2000.

	W1	W2	W3	M1	M2	M3	E1	E2	E3	**Total**
Order: Amphipoda										
Gammaridae										
Haustoriidae		4.9						4.9		9.8
Order: Emphemenoptera										
Caenidae			9.9							9.9
Ephemeridae								4.9		4.9
Order: Megaloptera										
Sialidae									4.9	4.9
Ceratopogonidae										
Family: Chironomidae										
Prodiamesa	29.6	19.8	24.7	44.4	4.9	14.8	4.9		14.8	157.9
Chironomus										
Procladius	24.7	4.9		4.9		4.9		9.9	9.9	59.2
Paratendipes			9.9	59.3	4.9	79				153.1
Corynoneura			4.9							4.9
Pentaneura	4.9			4.9		19.8		4.9		34.5
Anatopynia										
Trissocladius										
Coeloanypus										
Family: Hirudinea	4.9						34.6			39.5
Order: Oligocheate										
Tubificidae				34.6		9.9	4.9			49.4
Family: Culicidae										
Chaoborus					19.8					19.8
Total	64.1	29.6	49.4	148.1	29.6	128.4	44.4	24.6	29.6	547.8

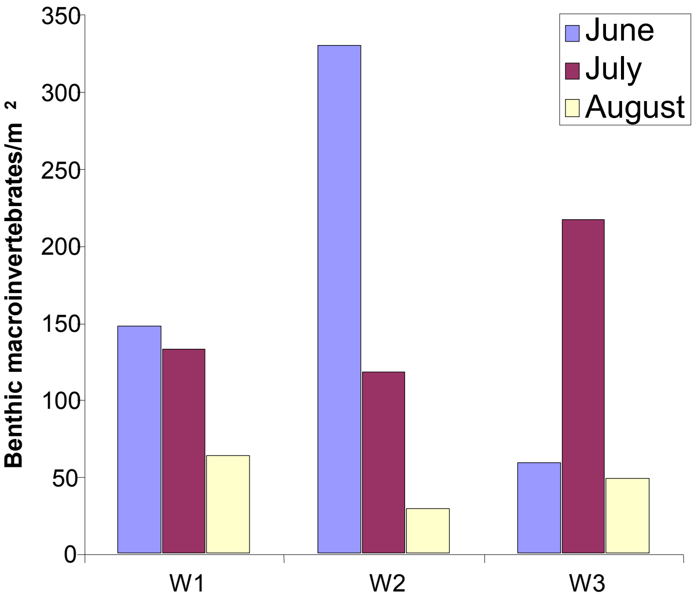

Figure 2: Estimated number of benthic macroinvertebrates per square meter in the west end of Pewaukee Lake, based on Eckman dredge samples taken in June, July, and August of 2000.

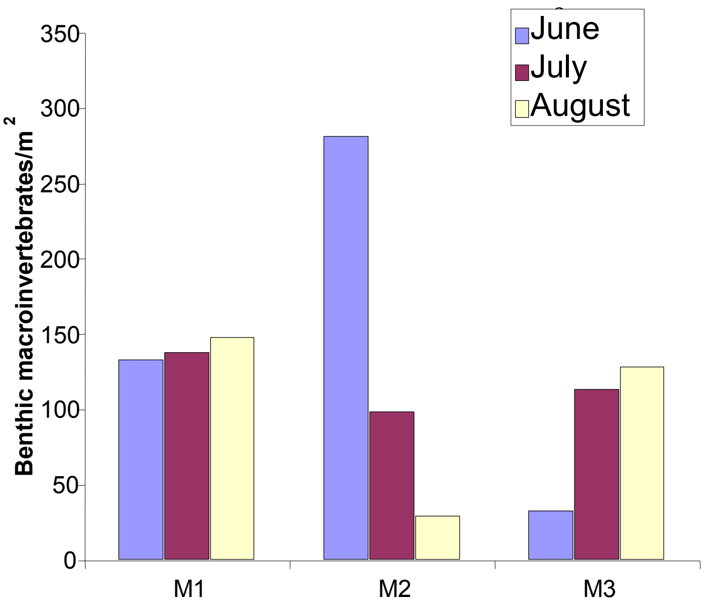

Figure 3: Estimated number of benthic macroinvertebrates per square meter in the middle of Pewaukee Lake, based on Eckman dredge samples taken in June, July, and August of 2000

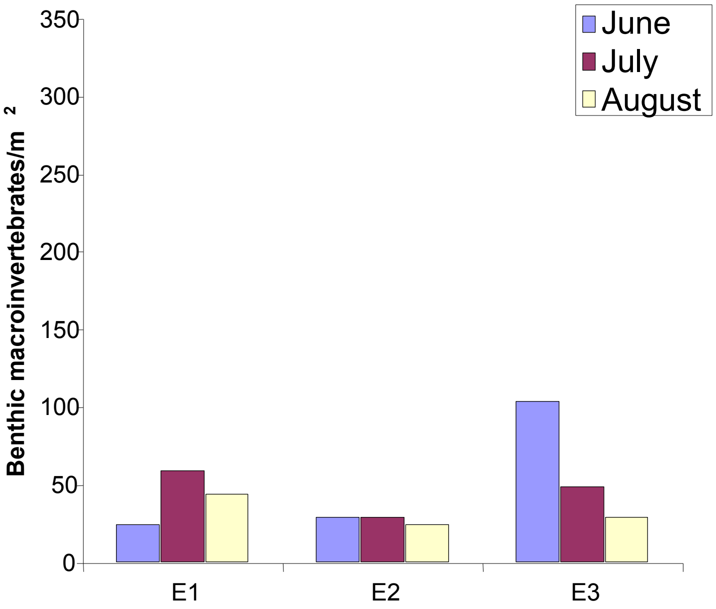

Figure 4: Estimated number of benthic macroinvertebrates per square meter in the east end of Pewaukee Lake, based on Eckman dredge samples taken in June, July, and August of 2000.

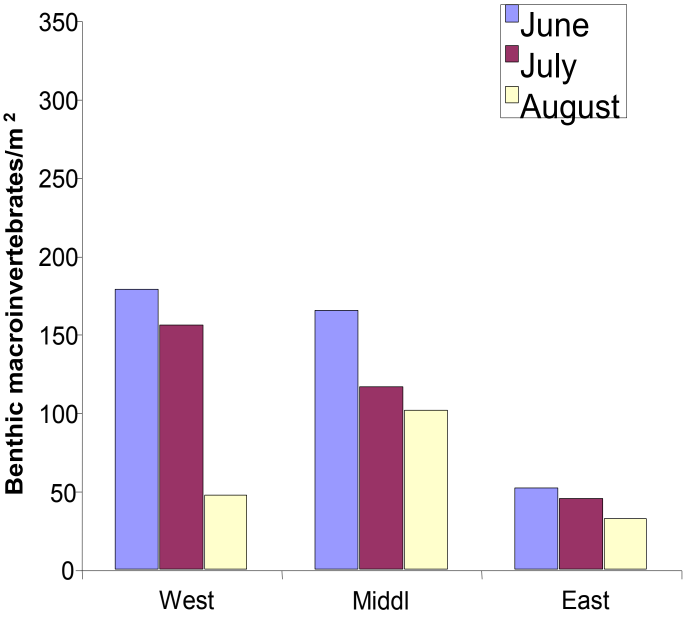

Figure 5: Average number of benthic macroinvertebrates per square meter in the west, middle, and east sections of Pewaukee Lake during June, July, and August of 2000.

A total of 1,990 zooplankton were identified and enumerated in July and August of 2000 with 14 different types found. The most common zooplankton was the cyclopoid copepod which was found throughout the lake except in the waters that had very little dissolved oxygen. There were consistently more copepods than cladocerans found throughout the lake and throughout the summer. A variety of *Daphnia* species were found mainly in the shallow middle waters of Pewaukee Lake in July, and *Diaphanosoma birgi* were found only in August. Nearly no zooplankton were found below the thermocline in the middle of the lake (Tables 4, 5, and 6). In July, at the west end, the zooplankton density was greatest near the bottom of the water column while in August the density was greatest near the surface (Figure 6). In the east end, the zooplankton density was greatest near the bottom of the water column in July and August (Figure 8). In the middle of Pewaukee Lake, the greatest concentration of zooplankton was found in the surface waters and near the thermocline (Figure 7). Just as the number of benthic macroinvertebrates per square meter decreased throughout the summer, the number of zooplankton per liter also decreased at each site throughout the lake as the summer progressed as shown in Figure 9.

Table 4 : Estimated number of zooplankton per liter of water from Pewaukee Lake in July, 2000.

	WEST			MIDDLE		EAST			
	Surface	Mid-depth	Bottom	Surface	Mid-deph	Surface	Mid-depth	Bottom	**Total**
Copepoda Cyclopoida	30.9	40.4	29.3	24.6	16.6	61	50.7	107	360.5
Copepoda Calanoid	4	3.2	4.8	6.3	14.3	14.3	13.5	6.3	66.7
Naulpii	1.6	13.5	12.7	9.5	7.1	7.1	23	71.3	145.8
Allona costa			2.4						2.4
Chydorus sphaericus		3.2	2.4	4.6	1.6	2.4	7.1	18.2	39.5
Eubosmina coregoni			2.4			5.5	7.1	2.4	17.4
Bosmina longirostris			1.6			13.5	3.2		18.3
Ceriodaphnia sp.		1.6	5.5	3.2	0.8	130.8	141.1	140.3	423.3
Daphnia pulicaria			3.2						3.2
Daphnia pulex			0.8	15.1	3.2				19.1
Daphnia longiremis				2.4					2.4
Daphnia longispina				5.5					5.5
Daphnia magna				0.8					0.8
Diaphanosoma birgi									0
Copepoda Total	36.5	57.1	46.8	40.4	38	82.4	87.2	184.6	573
Cladocera Total		4.8	18.3	31.6	5.6	152.2	158.5	160.9	531.9
Total	36.5	61.9	65.1	72	43.6	234.6	245.7	345.5	1104.9

Table 5 : Estimated number of zooplankton per liter of water from Pewaukee Lake in August, 2000.

	WEST			MIDDLE		EAST			
	Surface	Mid-depth	Bottom	Surface	Mid-depth	Surface	Mid-depth	Bottom	**Total**
Copepoda Cyclopoida	10.3	7.1	6.3	19.8	11.9	26.4	34.1	34.9	150.8
Copepoda Calanoid	0.8	7.1	3.2	4	4	7.1	8.7	0.8	35.7
Naulpii	11.1	0.8	4	0.8	3.2	3.2	4.8	9.5	37.4
Allona costa									0
Chydorus sphaericus						0.8		1.6	2.4
Eubosmina coregoni						0.8	0.8		1.6
Bosmina longirostris						4	2.4		6.4
Ceriodaphnia sp.	0.8					3.2	16.6	107.8	128.4
Daphnia pulicaria									0
Daphnia pulex									0
Daphnia longiremis									0
Daphnia longispina			0.8						0.8
Daphnia magna									0
Diaphanosoma birgi		0.8	1.6	0.8	0.8	3.2	20.6	20.6	48.4
Copepoda Total	22.2	15.1	13.5	24.6	19.1	37.2	47.6	45.2	224.5
Cladocera Total	0.8	0.8	2.4	0.8	0.8	12	40.4	130	188
Total	23	15.9	15.9	25.4	19.9	49.2	88	175.2	824.4

Table 6 : Estimated number of zooplankton per liter of water from the middle of Pewaukee Lake in July and August, 2000.

	JULY					AUGUST				
	Surface	3.75m	7.75m	11.75m	14.25	Surface	4m	8m	11.5m	13.5m
Copepoda Cyclopoida	24.6	13.6	38	0.8		19.8	11.9			
Copepoda Calanoid	6.3	14.3	1.6	0.8		4	4			
Naulpii	9.5	7.1	2.4			0.8	3.2			
Allona costa					0.8					
Chydorus sphaericus	4.8	1.6		0.8						
Eubosmina coregoni					0.8					
Bosmina longirostris										
Ceriodaphnia sp.	3.2	0.8								
Daphnia pulicaria										
Daphnia pulex	15.1	3.2	8.7	0.8						0.8
Daphnia longiremis	2.4									
Daphnia longispina	5.5		1.6		0.8					
Daphnia magna	0.8									
Diaphanosoma birgi						0.8	0.8			
Copepoda Total	40.4	35	42	1.6	0	24.6	19.1	0	0	0
Cladocera Total	31.8	5.6	10.3	1.6	2.4	0.8	0.8	0	0	0.8
Total	72.2	40.6	52.3	3.2	2.4	25.4	19.9	0	0	0.8

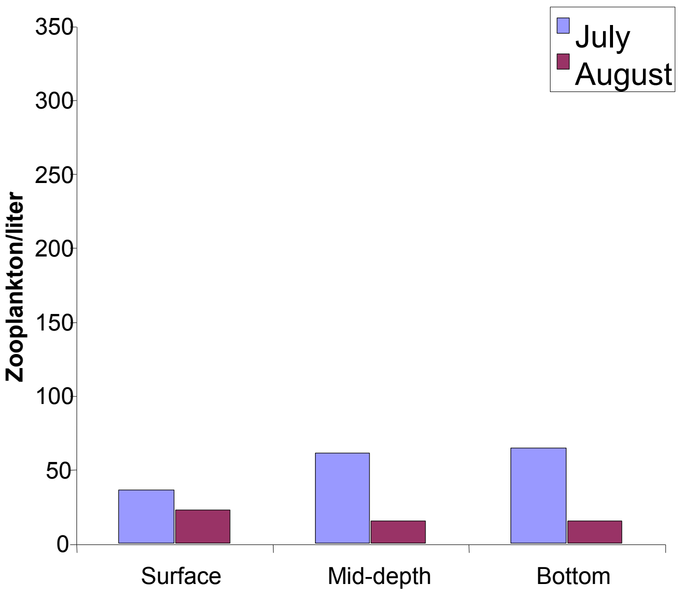

Figure 6: Estimated number of zooplankton per liter of water in the west end of Pewaukee Lake in July and August of 2000.

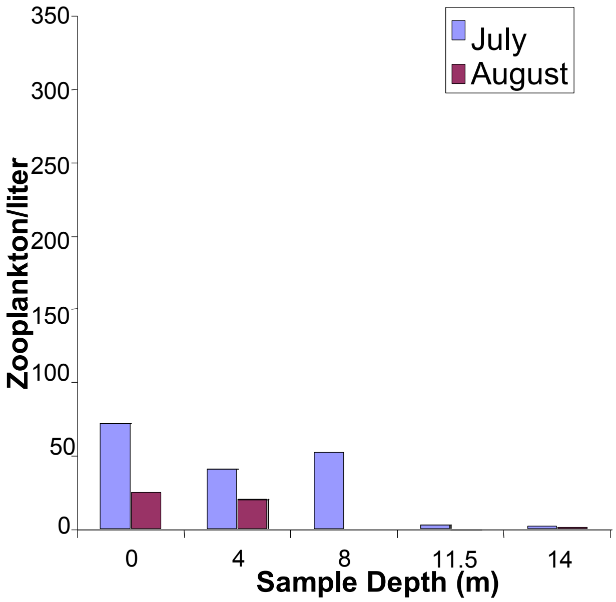

Figure 7: Estimated number of zooplankton per liter of water in the middle of Pewaukee Lake in July and August of 2000.

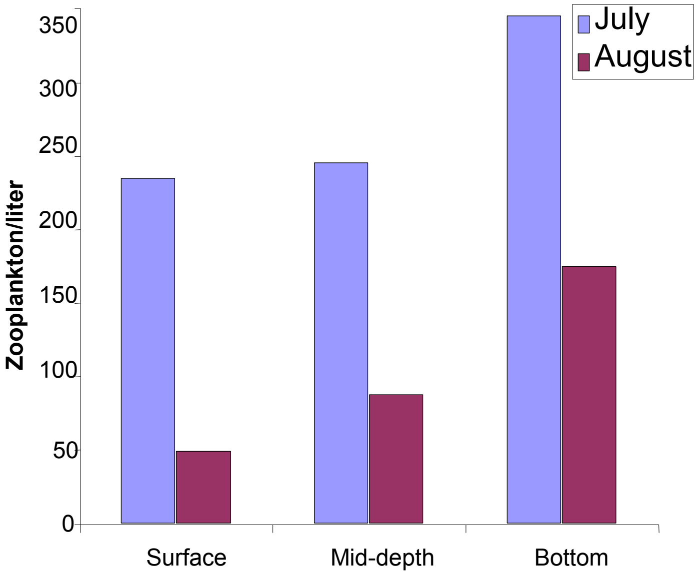

Figure 8: Estimated number of zooplankton per liter of water in the east end of Pewaukee Lake in July and August of 2000.

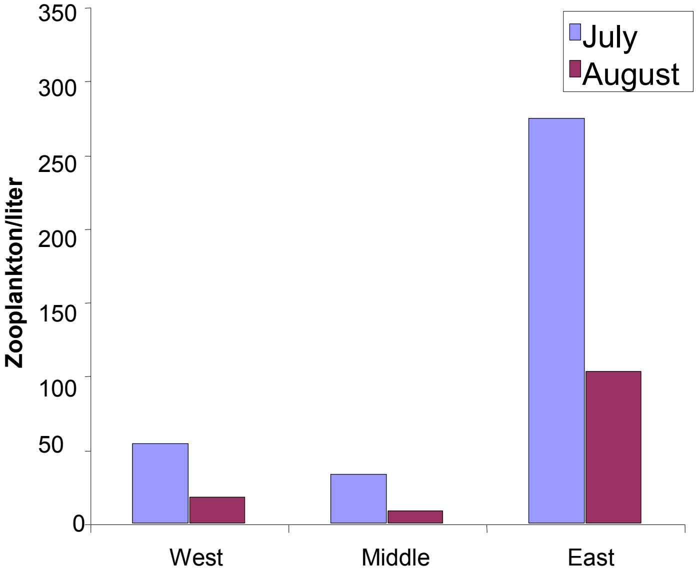

Figure 9: Average number of zooplankton per liter of water in the west, middle, and east sections of Pewaukee Lake in July and August of 2000.

Nitrate, ammonia, reactive phosphorous, and chloride levels in water samples taken at each zooplankton site were assessed. Chemical analysis of nitrates ranged from 0 to 3.4 mg/liter of water with the higher levels below the thermocline in the middle of the lake. No apparent pattern was found in the water column in the east and west ends of the lake. Ammonia ranged from 0 to 0.5 mg/liter of water, and is similar to nitrate in that the significantly higher concentrations were also measured below the thermocline. The concentrations of reactive phosphorous ranged from 0 to1.2 mg/liter of water with again the higher levels beneath the thermocline. Also, the east end had lower concentrations of phosphorus than the rest of the lake. The amount of chloride ranged from 90 to 145 mg/ liter of water. This chemical had the highest concentrations throughout the lake and was evenly distributed in the water column (Figure 10).

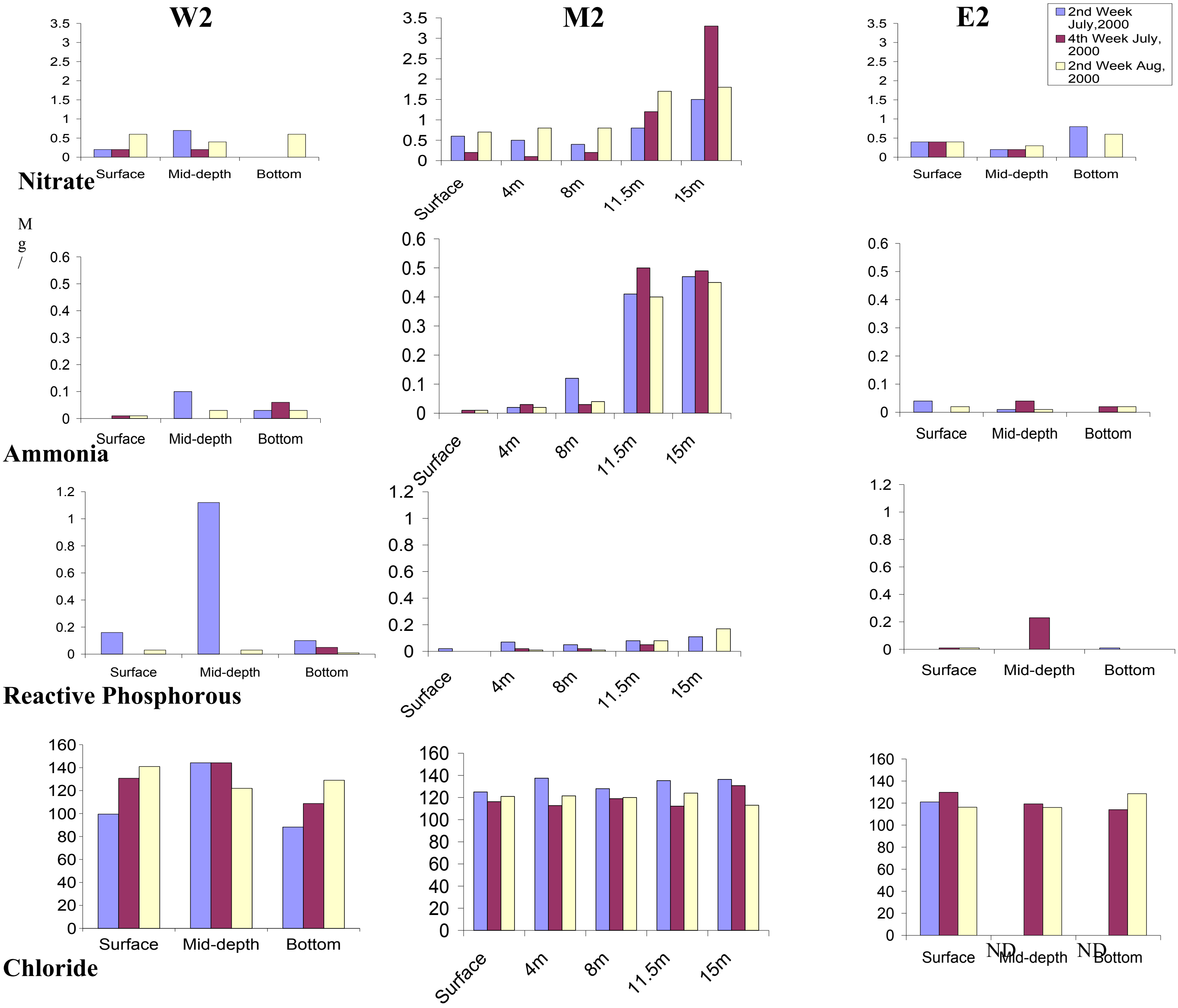

Figure 10: Levels of nitrite, ammonia, reactive phosphorous, and chloride (mg/L) at sample sites W2, M2, and E2 in Pewaukee Lake during the second and fourth weeks of July and the second week in August of 2000.

The physical parameters of Pewaukee Lake changed throughout the summer. Dissolved oxygen concentrations decreased as temperature increased and water clarity decreased from June to August. The levels of dissolved oxygen were rarely low enough to impact the organisms except below the thermocline. In the west end of the lake, water temperatures ranged from 17°C in June to 24°C in August and dissolved oxygen ranged from 16 mg/liter at the surface in June to 0 mg/liter near the substrate in July (Figure 11). In the middle section of the lake, temperatures ranged from 14°C in June and 24°C in August and concentrations of dissolved oxygen went from 10 mg/liter at the surface in June to 0 mg/liter below the thermocline during June through August (Figure 12). In the east end, the temperatures ranged from 21°C in June to 25.5°C in August and dissolved oxygen ranged from 10 mg/liter near the surface in June to 3 mg/liter near the substrate in August (Figure 13). The water clarity generally decreased from June to August with the better clarity in the west and middle sections than in the east end of the lake (Figure 14).

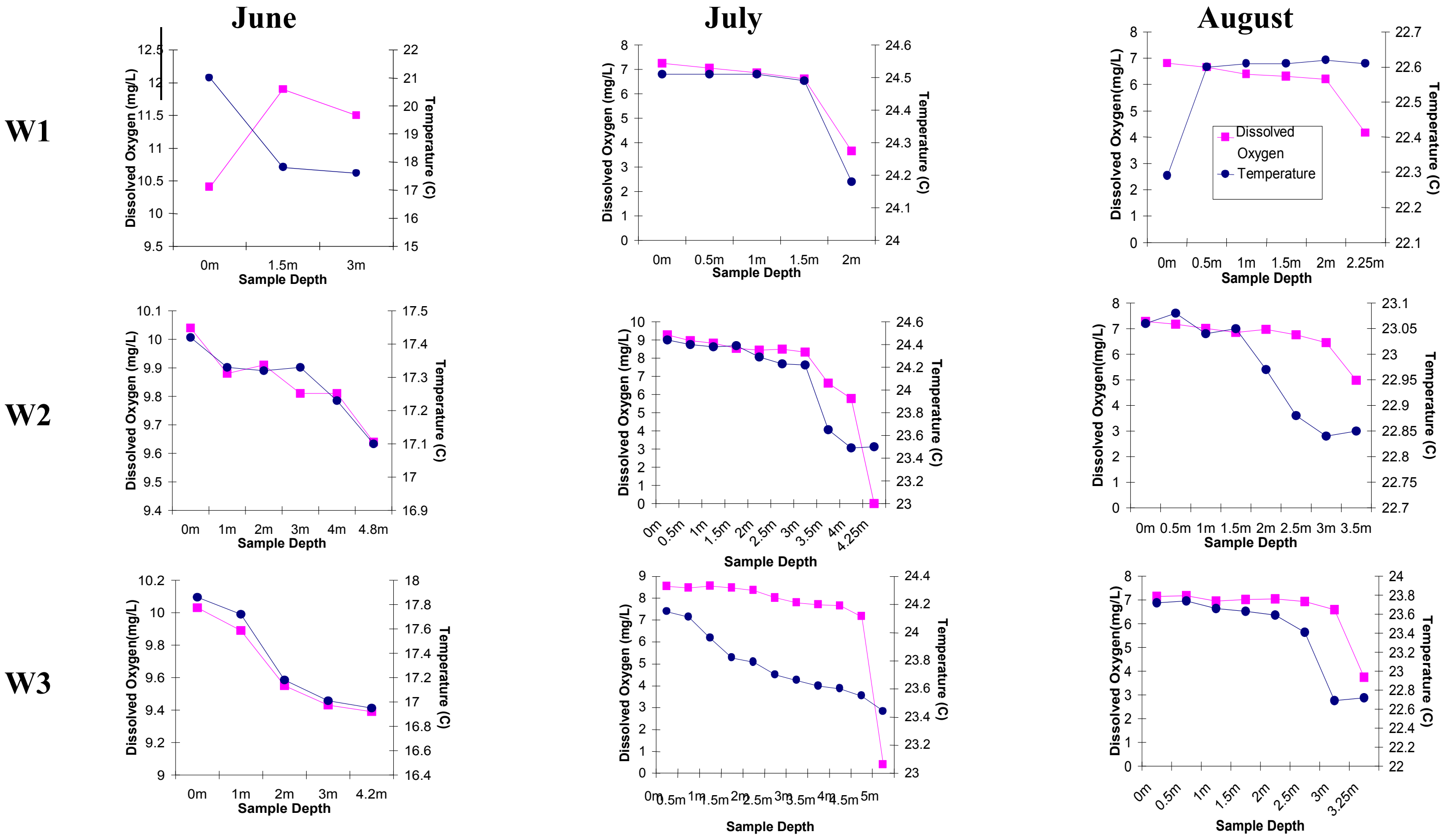

Figure 11: Dissolved oxygen (mg/L) and temperature (C) readings taken in Pewaukee Lake in June, July, and August of 2000 at sample stations W1, W2, and W3 with the Data Sonde 4 Hydrolab.

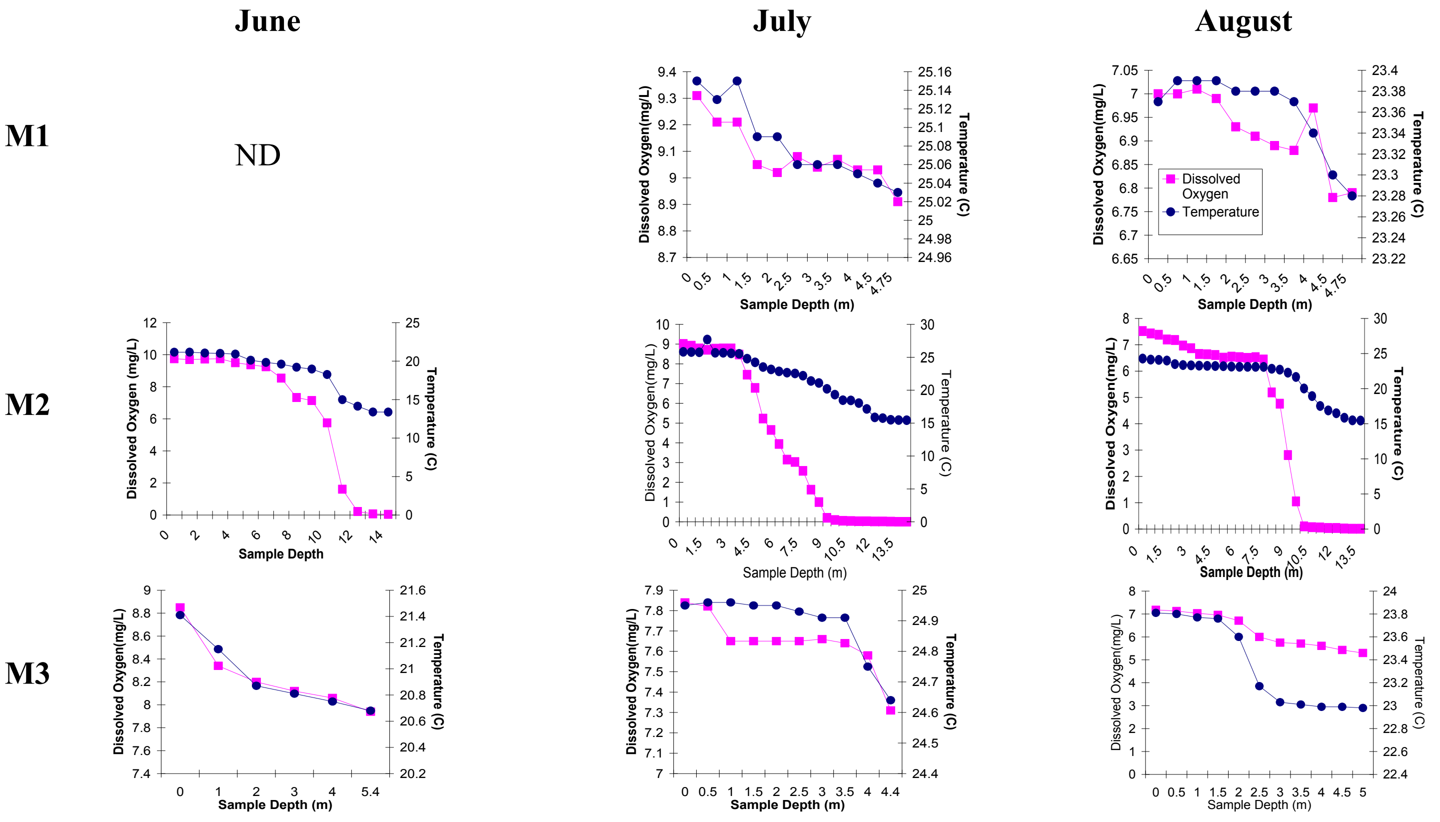

Figure 12: Dissolved oxygen (mg/L) and temperature (C) readings taken in Pewaukee Lake in June, July, and August of 2000 at sample stations M1, M2, and M3 with the Data Sonde 4 Hydrolab.

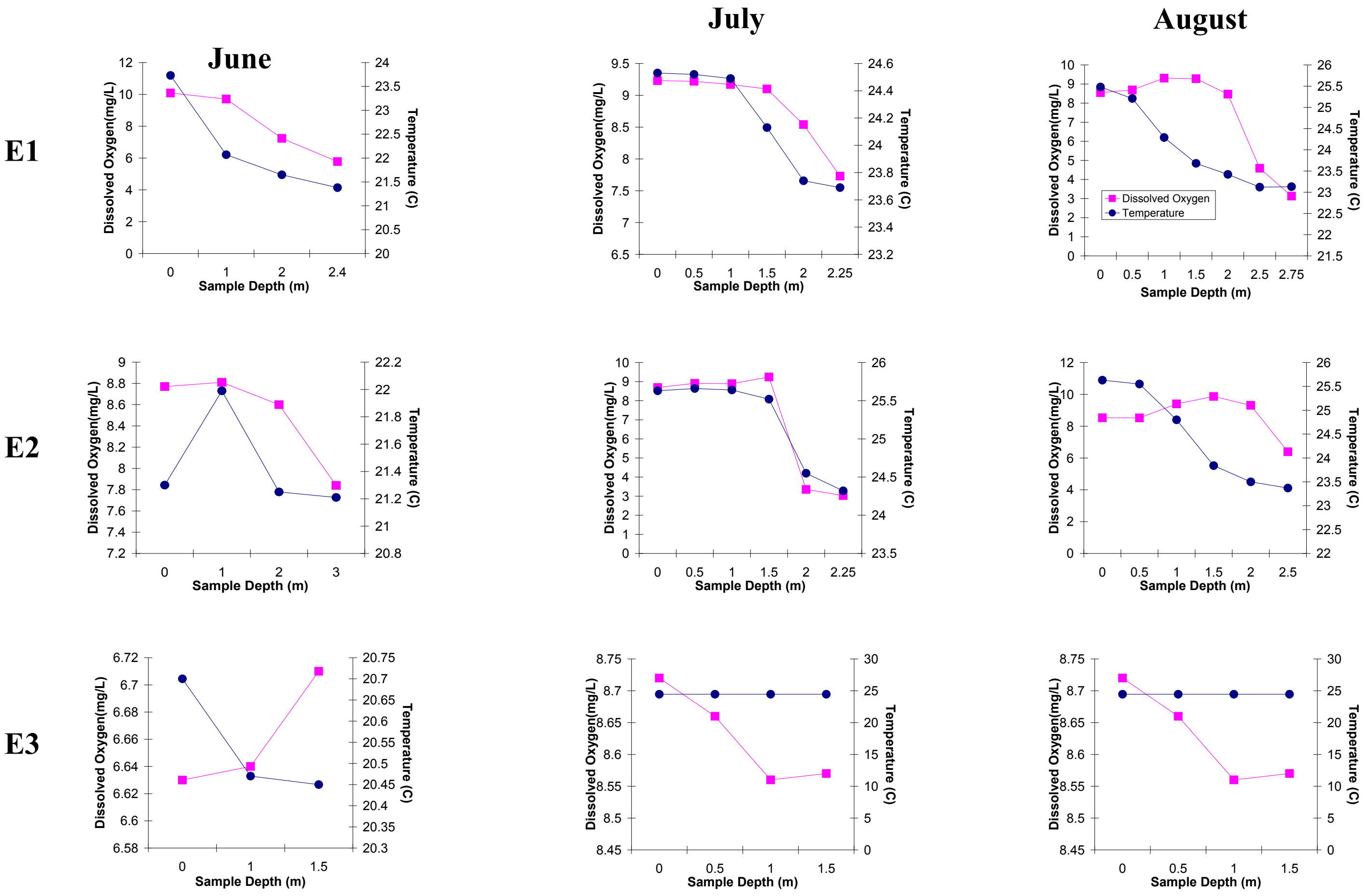

Figure 13: Dissolved oxygen (mg/L) and temperature (C) readings taken in Pewaukee Lake in June, July, and August of 2000 at sample stations E1, E2, and E3 with the Data Sonde 4 Hydrolab.

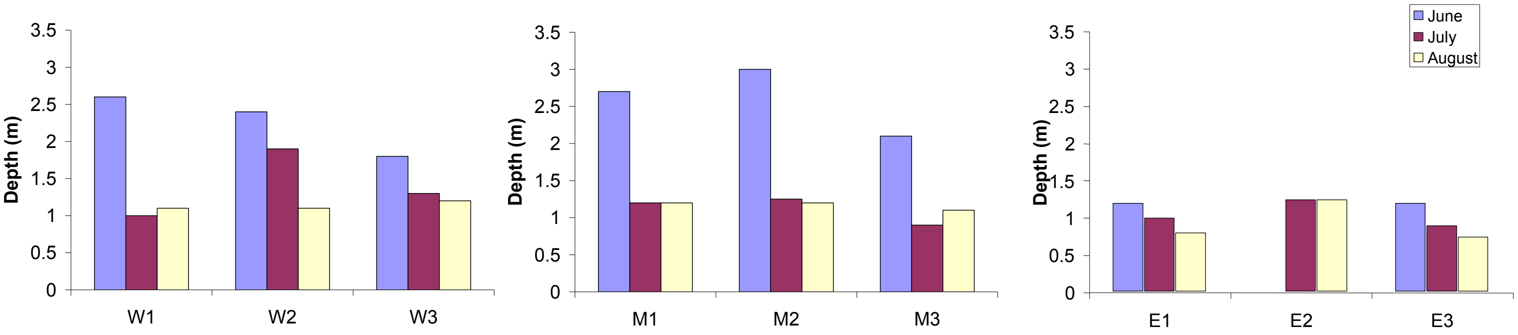

Figure 14: Average Secchi disk readings taken at each sample station in Pewaukee Lake during the summer of 2000.

Discussion

The goal of this study was to evaluate the present state of Pewaukee Lake and identify its trophic status based on benthic macroinvertebrate and zooplankton populations as well as the chemical and physical parameters of the lake. The trophic status of a lake is a function of its productivity and how it relates to and affects water clarity, dissolved oxygen, and flora/fauna populations (Harman *et al.* 1997). It is important to remember that the trophic status of a lake is not the same as the water quality of the lake (Carlson 1977). The quality of Pewaukee Lake's water may affect its trophic status and increase its rate of trophication; however, a high trophic status (i.e. eutrophic) does not necessarily indicate poor water quality.

The productivity of a lake depends on the nutrient levels of the lake. Nutrients are the substances needed by algae and aquatic plants for normal growth. The three main nutrients are carbon, phosphorous, and nitrogen. Carbon is generally not a concern for lakes; it is plentiful and non-polluting. Phosphorous is found only in small amounts in nature, so it is usually the limiting factor of plant and algae growth. Nitrogen is found naturally in organic matter. Growth of plants and algae is important because they are the primary producers of a lake system. If phosphorous and nitrogen are found in high quantities and the plant and algal growth is not limited, the lake is highly productive (Kevern *et al.* 1996).

As a lake acquires more nutrients, its trophic status increases because its productivity increases. A eutrophic lake is nutrient rich and is characterized by many biotic and abiotic factors. A eutrophic lake typically has a large phytoplankton population, which leads to poor water clarity. It also has high populations of zooplankton and planktivores. A eutrophic lake has deep muck, anoxic conditions in the deep water, shallow weed beds, and often has good fishing. Eutrophication is a natural process that normally takes thousands of years to complete. However, urbanization can hasten the eutrophication process so that it could take place in one to two human generations (Kevern *et al.* 1996). It has been determined that algal and invertebrate communities are subject to significant impacts of human land use practices (Hall *et al.* 1999). It is our concern that this is happening to Pewaukee Lake.

According to the EPA (1999), the benthic macroinvertebrate assemblage typically corresponds to and can be classified by the three basic habitats along the bottom of the lake: littoral, sublittoral, and profundal. The littoral habitat (sample sites W1, W3, E1, E2, and E3) should have a large, diverse population that is highly variable. The sublittoral zone (sites W2, M1, and M3) should have a less diverse population but it is also more stable. The profundal habitat (site M2) should have a population that is mostly composed of chironomids, oligocheates, and chaoborus. Our benthic macroinvertebrate samples from these three habitats in Pewaukee Lake were all similar to the typical profundal zone macroinvertebrate community. Variation from the typical macroinvertebrate assemblage in lakes is often viewed as a response to stress resulting from pollution in the watershed. The EPA (1999) has compiled a set of metrics to evaluate this stress (Table 7). Applying the EPA metrics to the benthic macroinvertebrate

Table 7: EPA benthic macroinvertebrate metrics (1999)

Metric	Response to Stress
No. of taxa	Reduced
Shanon-Weiner Index	Reduced
%contribution of dominant taxon	Elevated
% oligeocheate	Elevated under organic enrichment
% non-insect	Reduced

collections in Pewaukee Lake reveal that three of the five metrics indicate the lake is stressed. It is also noted that the number of benthic macroinvertebrate taxa has decreased over the past three decades based on comparison of results in this study to those obtained by Aqua Tech in 1972. The percent contribution of the dominant taxa has dramatically increased since 1972 and the Shannon Weiner Index of Diversity has decreased. (Table 8). The stress producing these changes is most likely related to input of excess nutrients and pollutants from the surrounding watershed as this area continues to develop.

Table 8: Pewaukee Lake macroinvertebrate metrics

Metric	1972*	1976**	1977**	2000
No. of taxa	5	5	4	3
Shanon-Weiner Index	1.532	0.463	0.605	0.382
%contribution of dominant taxon	36%	90%	84%	90%
% oligeocheate	0%	0%	0%	0%
% non-insect	64%	0%	0%	0%

*Data Source: Aqua Tech, Inc., 1972

**Data Source: SEWRPC, 1984

An interesting observation is that none of the sample sites contained live sails. Snails at one time must have been very abundant since Pewaukee Lake used to be called Snail Lake. We also noted that at some of our sample sites, the substrate was composed of almost all snail shells. Snails are intolerant to low–oxygen levels (Feltmate and Williams 1992). The decrease in dissolved oxygen levels along with copper sulfate and arsenic treatments many years ago appear to have nearly eliminated the snail population. This is yet another piece of evidence of Pewaukee Lake's decline.

However, according to the benthic macroinvertebrate population Pewaukee Lake is not as eutrophic as it could be. Wiederholm (1980) found that as a lake becomes increasingly eutrophic the chironomid portion of the benthic community decreases while the oligocheat component increases. This occurs because oligocheats are more tolerant of low oxygen conditions. This shift toward oligocheats has not occured in Pewaukee Lake, there were many more chironomids found than oligiocheates.

The results of the zooplantkon population analysis of Pewaukee Lake are not as clear in evaluating the condition of Pewaukee Lake. Gulati (1982) stated that as a lake becomes more eutrophic, calanoid copepods become less significant and cyclopoid copepods and cladocerans dominate. Cyclopoids and cladocerans have dominated Pewaukee Lake since 1971 however the ratio between the two classes improved from 1971 to 1976 and has remained the same since 1976 (Figure 15). This stable relationship

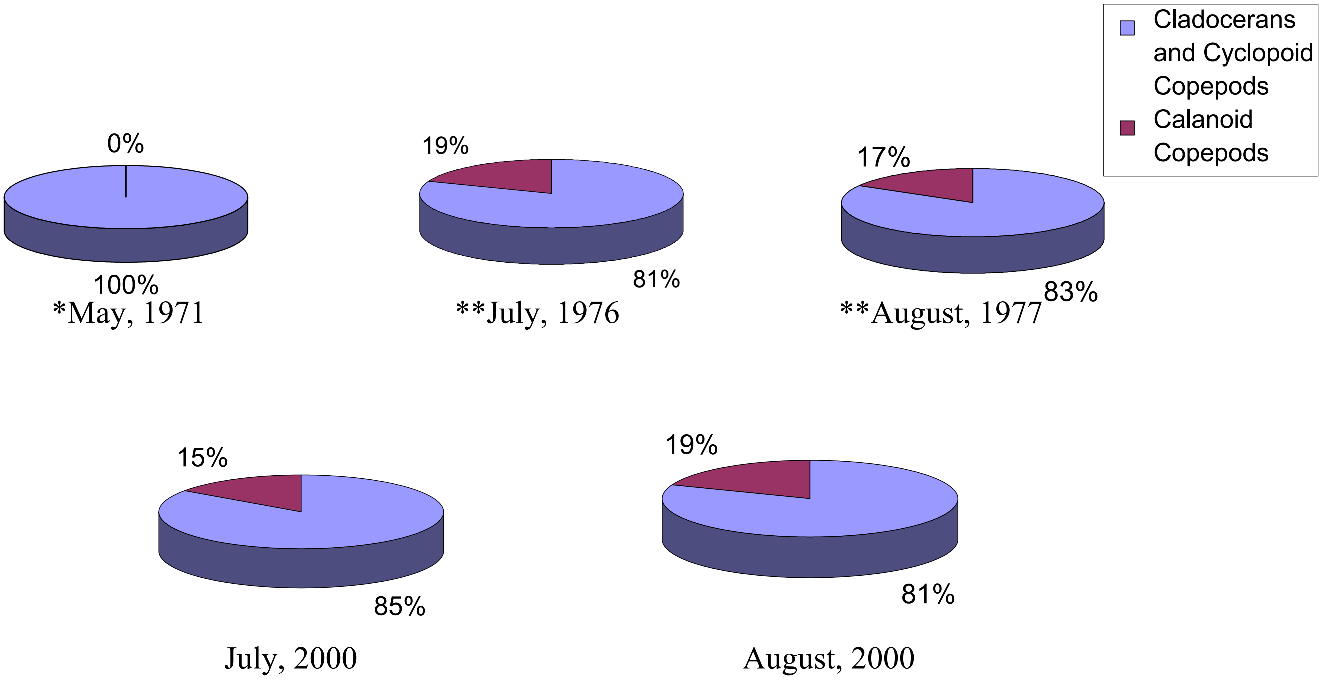

Figure 15: Percentage of total populations of Cladocerans and Cyclopoid Copepods compared to percentage of total population of Calanoid Copepods in 1971, 1976,1977, and 2000.

*Data Source: Aqua Tech, Inc., 1972
**Data Source: SEWRPC, 1984

given Gulati's hypothesis could indicate a leveling of the eutrophication process in Pewaukee Lake as a response to lake management practices such as aquatic plant harvesting. Gulati (1982) also stated that the dominance of small claderans, especially *Chydorus* , *Diaphanosoma,* and *Ceriodaphnia*, indicates the availability of nanoseston which is often found in eutrophic lakes rich in bacterial flora, fine detritus, and ultra-nanoplankton. The ratio of the small cladocera to the total population in Pewaukee Lake varied from 1976 to 2000. In July, 1976, all the cladocera were small indicating a eutrophic lake, as in July, 2000. However, in August 1977, there were smilar amounts of small cladocera and large cladocera, and in August 2000, there were more large than small. This could actualy indicate decreasing eutrophication in Pewaukee Lake. It is possible however that the dominance of small cladocerans may indicate the presence of an abundant population of planktivorous fish. Planktivorous fish filter zooplankton from the water column trapping mainly the large zooplankton. Therefore, if sampling reveals mainly small zooplankton, it is possible that they are heavily preyed on by the planktivorous fish rather than responding to eutrophication (EPA 1999). This is very likely taking place in Pewaukee Lake since it has an abundant population of planktivorous black crappie (Beyler 2000). Therefore, as was described by Vanni and Layne (1977) in Tuesay Lake in the upper peninsula of Michigan, the plankivorous fish may be controlling the zooplankton population from the top down as opposed to the nutrient levels of the lake effecting the population from the bottom up. Thus the Pewaukee Lake zooplankton community may reflect a stable fish community that includes plantivores.

The EPA (1999) also reported metrics for zooplankton populations that indicate a lake's response to stress (Table 9). Applying these metrics to the Pewaukee Lake zooplankton community as reflected in samples since 1971 provides mixed results. The percentage of large Daphnia has decreased and the percentage of the dominant species of zooplankton is high, indicating stress. However the number of taxa has increased which is a positive indication (Table 10). Also, the overall numbers of zooplankton per liter of Pewaukee Lake water has increased since 1972. This can be an indication of stress on the lake however, Gulati (1982) stated that the relationship between eutrophication and zooplankton biomass is not as simple as it may appear. Therefore, zooplankton sampling has not provided a straight forward indication of Pewaukee Lake's condition.

Table 9: EPA zooplankton metrics (1999)

Metric	Response to Stress
% Large Daphnia (>1mm)	Low
No. taxa	Reduced
% dominance	High

Table 10: Pewaukee Lake zooplankton metrics

Metric	1972*	1976**	2000
% Large Daphnia (>1mm)	50%	12%	16%
No. taxa	4	8	10
% dominance	50%	37%	45%

*Data Source: Aqua Tech, Inc., 1972

In using organisms to evaluate lake condition it is most effective to consider more than one community. The fact that low numbers of both zooplankton and macroinvertebrates were found in the deep middle section of Pewaukee Lake does indicate a eutrophic condition. Feltmate and Williams (1992) found that as a lake becomes more eutrophic, much of the fauna in the profundal zone can be eliminated. In addition to biological indicators, chemical and physical conditions of lake can also point to lake condition.

The nutrient levels of Pewaukee Lake indicate moderate eutrophication since nitrate levels have increased and reactive phosphorus has stayed the same. Nitrogen is an important nutrient for plant and algal growth. Too much nitrogen in a lake causes excessive plant growth which can clog water ways and deplete oxygen after the plants die and begin to decompose. The amount of nitrate per liter of water in Pewaukee Lake has increased dramatically since the summer of 1976 (Table 11). One cause for this may be from the rainfall. The amount of nitrogen in rainfall often exceeds 0.5 mg/l. The majority of increases in lake nitrogen levels however are typically due to local land use. Farm and lawn fertilizers, animal waste, and runoff all can contribute to an increase in nitrogen levels (WDNR 1999). Phosphorous is also an important nutrient for plants and algae. If found in high levels, it too promotes excessive plant growth. In this study, we measured the amount of reactive phosphorous found in Pewaukee Lake. Reactive phosphorous is readily available for the plants and algae to use. The level of reactive phosphorous has not increased in Pewaukee Lake (Table 11). However, this is not a measurement of the total amount of phosphorous in the lake. Phosphorous precipitates out of solution easily with calcium, iron, and aluminum. Therefore, the sediment can act as a reservoir for phosphorus keeping the aquatic plants well fertilized. A more effective evaluation of nutrients in Pewaukee Lake would involve measuring nutrient loading. Total input of nitrogen and phosphorus could be compared to the amount lost into the

Pewaukee River and through plant harvesting allowing an estimate of annual nutrient loading.

High levels of chloride were also measured in Pewaukee Lake. Even though chloride levels do not promote plant growth and are not toxic, they do indicate water pollution. Chloride in lakes is common in this area of the state due to high amounts of limestone in the soil. Therefore, levels above 10 mg/liter in surface water are expected. However, the amount of chloride in Pewaukee Lake has greatly increased since the summer of 1976. This indicates that Pewaukee Lake is becoming increasingly polluted. The excessive chloride entering Pewaukee Lake is most likely from road salt runoff (WDNR, 1999).

Table 11: Amounts (mg/l) of nitrate,ammonia, reactive phosphorous, and chloride in Pewaukee Lake in 1972, 1974, 1975, 1976, and 2000.

	Aug., 1972*	July, 1974**	June, 1975**	Summer 1976**	July, 2000***
Nitrate Nitrogen	ND	0.11	0.05	0.06	0.88
Ammonia	ND	0.4	0.37	0.18	0.2
Reactive Phophorous	0.04	0.04	0.04	0.04	0.04
Choride	ND	32.33	35.67	33	125.3

*Date Source: Aqua Tech, Inc., 1972
**Data Source: SEWRPC, 1984
*** Average amount in water column

Dissolved oxygen is critical for life in lakes. Most organisms depend on it to survive. The maximum amount of dissolved oxygen in a lake depends on the lake’s water temperature. The colder the water, the more oxygen it can hold. The distribution of oxygen depends upon the mixing of the lake by wind since oxygen can only enter at the lake’s surface and or via plant photosynthesis which only takes place in shallow waters. During the summer, many deep lakes are stratified and mixing does not take place because of the different water temperatures. Cold water is dense so it sinks to the bottom of the lake and the warm water stays on top. Because of their different densities, they do not mix. The top, warm layer is called the epiliminion, the cold, bottom layer is the hypolimnion, and the area in between is the thermocline (Lampert and Sommer 1997). The bottom cold water will not receive any oxygen until the fall turnover, when the epilimnion cools and becomes the same temperature as the hypolimnion. At this time, the two layers will mix. This occurs in Pewaukee Lake in the central basin.

Throughout the summer, when Pewaukee Lake is stratified, oxygen is still being consumed by animal respiration and bacterial decomposition in the hypolimnion and it is not being replaced. In productive lakes like Pewaukee Lake, large quantities of organic material from dead plants and animals throughout the lake settle into the hypolimnion where bacterial decomposition consumes a great deal of oxygen. This creates a greater demand for oxygen that can be supplied, and all the dissolved oxygen of the hypolimnion is used. An anoxic environment is formed in which many animals can no longer live. Pewaukee Lake is especially susceptible to this because it has a small hypolimnion that cannot hold much oxygen. Decomposition processes quickly deplete the oxygen after the thermocline is established leaving very little oxygen in the hypolimnion during the summer. This phenomenon has been occurring in Pewaukee Lake since at least 1971 (Table 12). Nevertheless, the amount of dissolved oxygen in the surface water (epilimnion) has remained at acceptable levels even during the summer. This is another indication that Pewaukee Lake is not completely eutrophic.

Table 12: Dissolved Oxygen levels in the deepest part of the lake since July of 1976 (mg/l).

	Aug., 1971*	July, 1976**	Aug., 1976**	July, 2000	Aug., 2000
Surface	7.1	8.5	5.5	9	7.5
Mid-depth	5.7	4	4	2.5	6.8
Bottom	0	0	0	0	0

*Data Source: Aqua Tech, Inc., 1972

**Data Source: SEWRPC, 1984

Secchi disk measurements are useful in determining the trophic status of a lake because as a lake becomes more eutrophic, its water clarity decreases. Water clarity is measured by a Secchi disk. The average Secchi disk reading for a eutrophic lake is 2.45 meters and the range is between 0.8 and 7.0 meters (Kevern *et al.* 1996). The average Secchi disk reading for Pewaukee Lake was 1.3 meters and the range was 1.0 to 1.9 meters. Pewaukee Lake is less clear than the average eutrophic lake and has a smaller range. Carlson (1977) developed a Trophic Status Index (TSI) based on Secchi disk readings. According to this index, for the summer of 2000, using the average Secchi disk reading stated above, Pewaukee Lake receives a rating of 56 which places Pewaukee Lake between the eutrophic and mesotropohic status. SEWRPC (1984) used this same index to determine that Pewaukee Lake was eutrophic from 1972 to 1978. SEWRPC (1984) noted that the trend in chlorophyll a levels indicated a decrease in the eutrophication rate. After 1976, the TSI improved, changing the rating from eutrophic to mesotrophic. Our TSI results fit this trend.

In conclusion, after analyzing many different parameters of Pewaukee Lake, both biotic and abiotic, Pewaukee Lake seems to be teetering between mesotrophic and eutrophic. The benthic macroinvertebrates are under stress and indicate a decline in the lake. The zooplankton offer mixed results that indicate both eutrophic and mesotrophic conditions. The water quality seems to be declining but does not indicate serious eutrophication. However, based on increasing levels of chloride, nitrogen, and ammonia, pollution seems to be increasing. Finally, the physical parameters indicate the lake's status is between eutrophic and mesotrophic. The anoxic hypolimnion indicates eutrophication while the surface levels of dissolved oxygen and TSI rating do not.

Given the current status of Pewaukee Lake and continued development in the watershed, a regular monitoring program and restoration program should be carried out. The restoration program should include projects that address the cause of eutrophication, not just the symptoms. If this is done correctly, natural healing of the lake will occur and efforts will pay off in the long run. (Williams *et al.* 1997). To prevent complete eutrophication, the nutrients entering the lake need to be controlled. For example, lawn fertilizer that could wash into the lake should not be used. An education program highlighting the benefits of natural shoreline vegetation to prevent erosion and runoff should be offered to riparians. The amount of marsh area associated with tributaries to Pewaukee Lake should be increased. A marsh can be an effective filter that will clean up runoff water before it reaches the lake, keeping unwanted nutrients out. If nutrient levels are reduced, productivity will also be reduced which slows eutrophicaton (Lampert and Sommer 1997). Also, a phosphorous budget for Pewaukee Lake should be developed. This is very important since it would allow identification of input and output levels of phosphorous which would enhance the ability to control this nutrient in Pewaukee Lake. All of these measures along with continued harvesting of macrophytes would go along way to retaining Pewaukee Lake as an outstanding resource for a wide variety of uses.

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