#LPL-091
(6013-01)

Beaver Dam Lake Improvement

and

Protection Project

1992 Report

Beaver Dam Lake Management District
Barron County, Wisconsin

Wisconsin Lake Management
Planning Grant Project
Account No. WR133

SEH File No. 92366

July 10, 1993

SHORT ELLIOTT HENDRICKSON INC.

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EXECUTIVE SUMMARY

The Beaver Dam Lake Improvement Project was initiated in 1992 following the receipt in late 1991 of a Wisconsin Lake Management Planning Grant of $10,000 by the Beaver Dam Lake Management District. The $14,450 project is the first phase of a three-year monitoring program to assess the water quality of Beaver Dam Lake and identify potential nutrient loading sources and their treatment. The project's specific goals are as follows:

- To acquire water quality data on Beaver Dam Lake over a series of growing seasons;
- Thorough a lake modelling effort, evaluate the water quality impact from existing development around the lakeshore and the associated land use within its drainage area;
- To evaluate the impact of the Cumberland Ditch on the water quality of Norwegian Bay of Beaver Dam Lake;
- To gather sociological information from users of the lake on recreational uses and the identify problems in need of examination; and
- To review and evaluate existing land use regulations and controls within the Beaver Dam Lake drainage area and suggest recommended changes to reduce or eliminate nonpoint source pollution.

Conclusions

Water Quality Monitoring

Water quality data was successfuly acquired from May through August on seven monitoring stations on Beaver Dam Lake and on the Cumberland Ditch during April through August in 1992.

Approximately 13 % of the volume of the hypolimnion (water column portion below the thermocline) was depleted of dissolved oxygen in upper Upper lake (C1, C2, & C2A) of Beaver Dam Lake during June, July, and August of 1992.

Approximately 86 % of the volume of the hypolimnion (water column portion below the thermocline) was depleted of dissolved oxygen in Rabbit Island Bay (C6) of Beaver Dam Lake during June, July, and August of 1992.

More than 100 % of of the volume of the hypolimnion (water column portion below the thermocline) was depleted of dissolved oxygen in Norwegian Bay (C5) of Beaver Dam Lake during June, July, and August of 1992.

Lake Trophic State

The trophic state (nutrients and algae) of the upper Upper lake is considered in good to very good condition with a recreational suitability of beautiful and a physical appearance of crystal clear. The trophic state of Library Bay is considered to have a minor aesthetic impacts due to algae but extensive emergent and submergent weed growths.

Norwegian Bay in the Lower lake is considered to be in a highly productive trophic state with a range of recreational suitability impacts of minor to swimming impaired. Cemetary Bay in the Lower lake is also considered to be in a highly productive trophic state with recreational suitability of swimming being impaired or eliminated.

Water Quality Trends

A downward trend in total phosphorus concentrations was statistically confirmed in the upper Upper lake over the period of 1975 through 1992, but may well be an artifact of changed laboratory analytical procedures and not environmental causes. A dramatic downward trend in total phosphorus concentrations was statistically confirmed in the Lower lake and has likely the resulted from the diversion of the City of Cumberland's wastewater treatment plant discharge to Cemetary Bay.

Lake Modelling

Lake modelling of the upper Upper lake confirmed the in-lake total phosphorus concentration, but does not support the contention that the nutrient loading from Rabbit Island and Library bays could be a significant source. The modelling of Library Bay indicated that urban runoff sources contribute 86 % of its annual total phosphorus loading.

Lake modelling of the Lower lake (Norwegian Bay) revealed that the Cumberland Ditch would contribute only 17 % of the phosphorus loading on an annual basis. The existing lake models used in this study are not sophisticated enough to permit an accurate simulation of Cemetary Bay's water quality.

Questionnaire Results

Of the 300 questionnaires sent out to Beaver Dam Lake Management District members, a total of 102 or 34 % were returned for analysis of results. About 48 % of lakeshore owners are year around residents with only 14 % being weekend users.

About 89 % of the respondents in Zone 1 (upper Upper lake) felt the lake's clarity was "clear to crystal clear"; conversely 55 to 66 % of the respondents in Zone 2 (Library Bay) and Zone 3 (Lower lake) believe the clarity was "cloudy to murky".

Nearly 40 % of the respondents in Zone 1 believe that the water quality has stayed the same, while 12 % felt it had gotten worse. Conversely, 55 % of the persons in Zone 2 indicated that the water quality had degraded. Most surprising and encouraging was that 42 % of the respondents in Zone 3 (Norwegian and Cemetary bays) believed that the water quality had gotten better.

Plant growth was thought to be just right for fish and wildlife by 54 % of the respondents overall, but in Zones 2 and 3, a total of 44 to 67 % felt conditions were heavy or weed choked.

Boat traffic was considered moderate by 55 % of the lakeshore owners and that little or moderate conflict had been experienced by 87 % of the respondents. Public access is considered by more than two-thirds (67 %) of the persons to be adequate for Beaver Dam Lake.

More than half (57 %) of the respondents believe that the Beaver Dam Lake Management District is most improtant in managing the lake and the development of a long-term lake management plan is the most important action by 45 % of the respondents.

A newsletter is considered by 68 % of the questionnaire respondents to be the best manner for the District to communicate with the membership.

Recommendations

1. Water quality monitoring of Beaver Dam Lake should be undertaken for one or two more growing seasons to confirm the water quality trend in the upper Upper lake and determine whether the Lower lake is reaching a steady state (leveling off in quality).

2. Serious consideration should be given to water quality and flow monitoring of selected inflows to Beaver Dam Lake to validate nutrient loading and subsequent lake modelling with BATHTUB.

3. The District should apply for an additional WDNR lake planning grant by August 1, 1993.

4. The District should approach the WDNR about participation in the U.S. Environmental Protection Agency's Clean Lakes grant program for Beaver Dam Lake in Fiscal Year 1994 (October 1, 1993) to offset the cost of a more complex monitooring and modelling effort.

5. The District should develop a newsletter for communication to its members on its actions.

Project Background

The Wisconsin Lake Management Planning Grant Program was initiated by the Legislature in 1989 and is administered by the Department of Natural Resources (WDNR). The program is laid out in the Statutes and Section 144.253, subdivision **(1m)** states:

> "The department shall develop and administer a financial assistance program to provide lake managment planning grants for projects to provide information on the quality of water in lakes, including mill ponds, in order to improve water quality assessment and planning and aid in the selection of activities to abate pollution of lakes".

The Beaver Dam Lake Improvement Project was initiated in 1992 following the receipt in late 1991 of a Wisconsin Lake Management Planning Grant of $10,000 by the Beaver Dam Lake Management District. The $14,450 project is the first phase of a three-year monitoring program to assess the water quality of Beaver Dam Lake and identify potential nutrient loading sources and their treatment. The project's specific goals are as follows:

- To acquire water quality data on Beaver Dam Lake over a series of growing seasons;
- Thorough a lake modelling effort, evaluate the water quality impact from existing development around the lakeshore and the associated land use within its drainage area;
- To evaluate the impact of the Cumberland Ditch on the water quality of Norwegian Bay of Beaver Dam Lake;
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- To review and evaluate existing land use regulations and controls within the Beaver Dam Lake drainage area and suggest recommended changes to reduce or eliminate nonpoint source pollution.

Methodology

Evaluating a lake's water quality requires establishing criteria and tasks which will result in a definitive study satisfying the District's needs and reflecting a technical content and discussion suitable for appropriate review by WDNR staff. The District's grant application outlined a five-step process by Sanders, et al. (1983) which was modified and expanded as follows:

1. Review and evaluate background lake data and watershed information, determine adequacy, and scope additional work areas;

2. Design a monitoring system;

3. Establish statistical data review and analysis procedures; and

4. Establish information reporting procedures.

A review of existing water quality data within the Beaver Dam Lake files at the WDNR, Northwest District was undertaken initially during the project. Water quality sampling and analysis of Beaver Dam Lake was conducted by WDNR in 1975, '76, '77, '78, '79, '81, '82, '83, '84, '85, '86, '87 and '89 at several stations. However, in many years only only one sample was taken from a lake station and often only during the Fall, Winter or Spring. While such data is very valuable over the long-term, a systematic sampling program throughout a growing season had not previously been implemented.

A monitoring program was designed to acquire adequate information which could be evaluated from the perspective of accurately describing the lake's condition. The program was based upon the need to answer hypotheses[1] established for Beaver Dam Lake. Ponce (1980) describes a series of statistical tests available for use in this regard. The following hypotheses were established and tested on Beaver Dam Lake:

1. The west basin of Beaver Dam is oligotrophic or meostrophic and of a high quality condition.

[1] Unproven suppositions tentatively accepted to explain certain facts or to provide a basis for further investigation.

2. The east basin of Beaver Dam Lake is eutrophic or hypereutrophic and of a poor water quality condition.

3. Internal phosphorus loading is an insignificant portion of the annual contribution to the west basin of Beaver Dam Lake.

4. Internal phosphorus loading is a significant portion of the annual contribution to the east basin of Beaver Dam Lake.

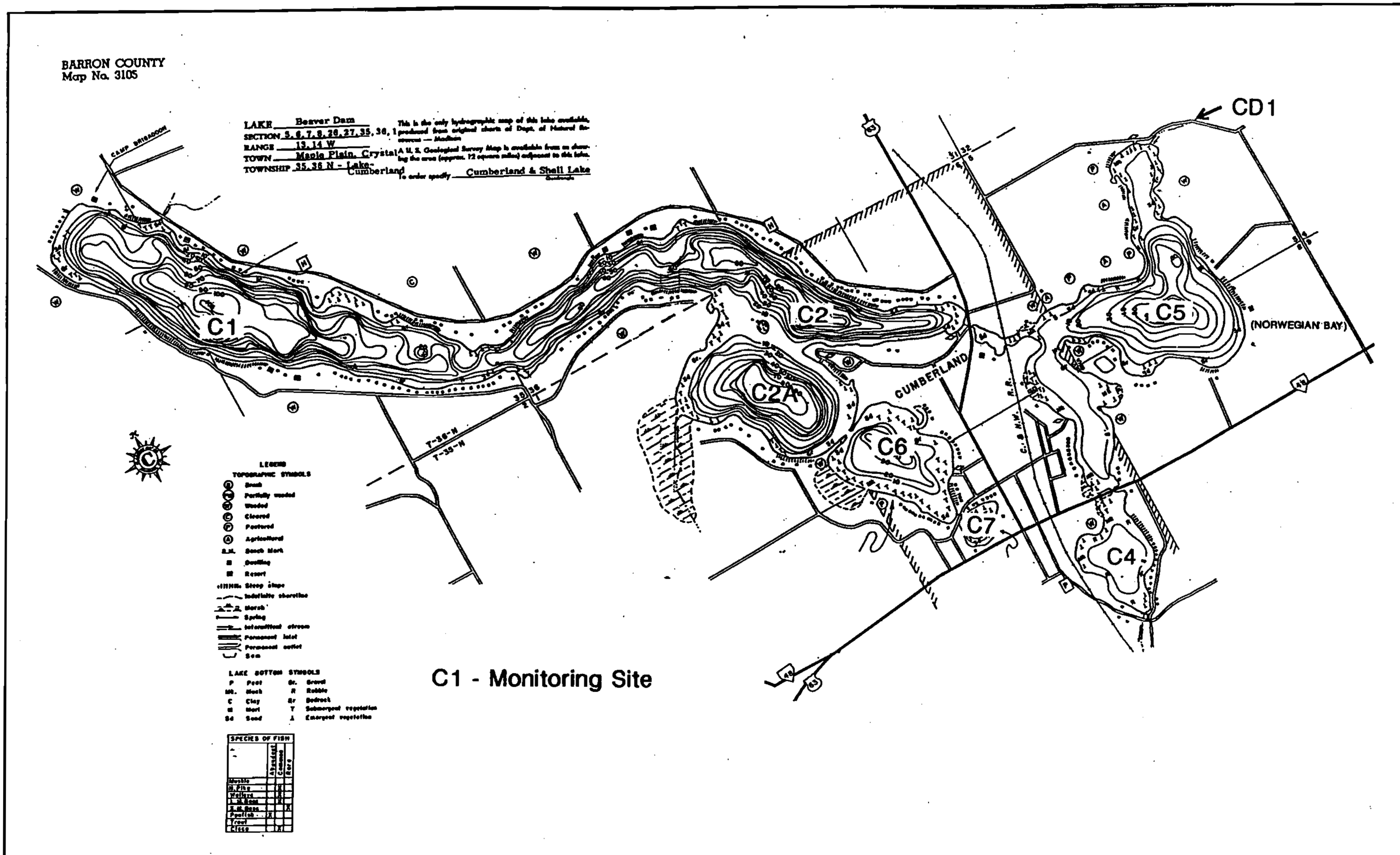
Other specific hypotheses could be tested as additional data is gathered on Beaver Dam Lake in the future.

The monitoring design involved the selection of water quality sampling sites, sample parameters, sampling frequency, and field methodology.

Sampling Sites

The location of in-lake sampling sites was made in consideration of the potential for thermal stratification, lake water circulation patterns, basin morphology, and whether a particular location had been a previous historic WDNR station. Figure 1 illustrates the sampling stations. A total of seven near surface (epilimnetic) lake stations (C1, C2, C2A, C4, C5, C6, and C7) were established in Beaver Dam Lake. Stations C1, C2, C4 and C5 were similar locations used in the WDNR lake studies. Stations C2A, C6 and C7 were newly added stations to better describe Williams Bay (C2A), Rabbit Island Bay (C6), and Library Bay (C7) areas of Beaver Dam Lake. Stations C1, C2, C5 and C6 had companion bottom water (hypolimnetic) stations to evaluate the potential magnitude of internal nutrient loading. An additional hypolimnetic sample was added to station C7 following the May 27, 1992 sampling period.

To monitor pollutant loadings to Beaver Dam Lake requires sampling sites at all the major inlets and the outlet. Budget constraints limited a such a comprehensive effort. However, one miscellaneous stream station was located on the Cumberland Ditch (a.k.a. Dump Creek or Diversion Ditch) inlet into the east basin (Norwegian Bay) of Beaver Dam Lake so that an approximate range of nutrient concentrations with respect to water flow and potential loading could be acquired.



BEAVER DAM LAKE IMPROVEMENT AND PROTECTION PROJECT

SEH
ENGINEERS ■ ARCHITECTS ■ PLANNERS

BEAVER DAM LAKE MONITORING SITES

FILE NO. 91312

FIGURE NO. 1

The parameters selected for monitoring the water quality of Beaver Dam Lake and Dump Creek are listed in Table 1. The following is a short summary description for each parameter and its importance in water quality.

Alkalinity

Alkalinity is a measure of the water's capacity to neutralize acids with little or no change in pH. Waters with high alkalinity are effective in resisting changes in pH when acid is added. Sources of acid additions to lakes can include acid precipitation (rain or snow), acidification resulting from removal of carbon dioxide from the water column during photosynthetic growth of weeds or algae or addition of carbon dioxide from the water column during respiration of organisms. Water with an alkalinity of less than about 75 mg/L (milligrams per liter or parts per million) is considered soft; 76 to 150 mg/L moderately hard; 151 to 300 mg/L hard; and those greater than 300 mg/L very hard. Lakes with alkalinities less than 10 to 20 mg/L may be considered potentially sensitive to acid precipitation or surface runoff inputs of acidic waters.

Chloride

Chloride is a dissolved constituent which occurs in all fresh waters, but generally at low levels (less than 5-10 mg/L). Increasing chloride (as a sodium, calcium or magnesium salt) concentrations in a lake may result chloride from inputs from outside sources including subsurface seepage from septic tanks or runoff from streets receiving deicer applications. Permanent stratification of the lake's water column may occur from the increased density of chloride waters and a lack of lake flushing if concentrations in the hundreds of parts per million are observed.

Chlorophyll *a*

Chlorophyll *a* is a green pigment produced by algae to capture light energy for photosynthesis. Measurement of the concentration of chlorophyll *a* in a water sample can be used to estimate the amount or standing crop of algal populations. Except for brown stained or sediment ladened lake waters, algae most often causes the decrease in secchi disk transparency. Concentrations of chlorophyll *a* are reported in µg/L (micrograms per liter or parts per billion).

Color

Changes in the apparent color of water may be the result of natural metallic ions (iron and manganese), drainage from humus or peat materials, algae, weeds or industrial waste. The apparent color of water may also be affected by turbidity from suspended sediments such as clay. The measurement of apparent color is made in the laboratory by comparison of the sample to known platinum-cobalt solutions. The importance of apparent color in lakes is in the reduction in water transparency and the potential absence or elimination of beneficial aquatic macrophytes (submerged and emergent weeds). Non-colored lake waters typically have color values less than 15 Platinum Cobalt Units (Pt.-Co.) [Brezonik, P. 1978]. Apparent color begins to significantly affect water transparency at or above 30 Pt.-Co. units (ibid.).

Dissolved Inorganic Phosphorus

The amount of phosphorus available for aquatic plant growth is reflected as dissolved inorganic phosphorus(DIP). It is the amount of soluble phosphorus remaining following water sample filtering. Essentially, it is a measurement of ortho-phosphorus (PO_4^-) ion concentration which is readily used in the growth of microscopic algae. Below detection or very low concentrations of dissolved inorganic phosphorus translate into conditions in which the nutrient is in short supply or may be "tied-up" in organic materials. Concentrations for DIP are reported in either parts per million(mg/L) or parts per billion(µg/L).

Dissolved Oxygen

The amount of oxygen dissolved (solubility) in water increases with decreasing temperature. Lakes often have higher concentrations of dissolved oxygen near the surface because of photosynthetic algae growth. Conversely, plant matter or other organic wastes decaying through the water column and on the lake bottom coupled with the respiration of organisms, all consume oxygen. Because of temperature stratification, nutrients, oxygen and other substances present near the surface of a lake are often inaccessible to its deeper waters. Oxygen depletion in a lake's bottom region results from organism respiration and decomposition of organic matter which cannot be recharged with oxygen produced by photosynthesizing organisms at the surface. Water with an oxygen concentration less than 1 mg/L is of poor quality. Smallmouth bass require more than 6 mg/L of dissolved oxygen for optimum growth. Wisconsin Administrative Code, NR 102.04(4)(a) requires a minimum of 5.0 mg/L of dissolved oxygen for the protection of fish and aquatic life.

pH

The pH scale ranges from 0 to 14 and indicates the concentration of hydrogen ions in a liquid. A pH of 7 is considered neutral. Acidity increases as pH falls from 7 to 0, while alkalinity increases as pH falls from 7 to 14. The pH of most lakes ranges between 6.5 and 8.5. The pH of lake water can increase with photosynthetic activity. However, waters with higher alkalinity resist changes in pH with the removal of carbon dioxide(CO_2) from photosynthesis or the addition of CO_2 from respiration. Immature fish and insects are sensitive to acidity and can be affected in lakes with a pH below 5.

Secchi Disc

A secchi disc is an 8 inch in diameter black and white disk used to measure the extent to which algae, water color or other suspended and dissolved materials interfere with the penetration of light into the water. The secchi depth is a measure of the transparency of the water and can also be used to estimate the approximate density of algal populations. It is the average of the depth to which a secchi disc dissappears when lowered over the side of a boat and the depth at which it reappears upon raising it again towards the surface. Transparency values are most often reported in meters (m).

Specific Conductivity

Specific conductivity is a measurement of the reciprocal (1/x) of resistance (x). Conductance reflects the ability of water to carry an electrical current, thus loading more salts and inorganic compounds in a lake increases the specific conductivity value. Distilled water as well as soft waters have very low specific conductivities (less than 100 µmhos/cm or micromhos per centimeter). Conversely, hypereutrophic (very over-nourished) lakes have high specific conductivities (greater than 250 µmhos/cm).

Temperature

The balance of physical and chemical characteristics within a lake is governed by differences in water density which is affected by temperature. Temperature also affects the amount of oxygen dissolved in water(solubility) and the rates of chemical and biological processes such as plant photosynthesis(oxygen production) and organism growth(respiration or oxygen consumption). Temperature stratification prevents mixing of the surface and deeper waters of a lake during the summer months. Temperature is most often reported in degrees Centigrade (C).

Total Kjeldahl Nitrogen
An analytical technique and term which represents the combination of ammonia-nitrogen and organic-nitrogen. Therefore, subtracting ammonia-nitrogen from Kjeldahl nitrogen leaves organic-nitrogen. Kjeldahl nitrogen is most often reported in parts per million.

Total Nitrogen
Nitrogen is an essential nutrient for submerged/emergent plant and algal growth. It is present in the atmosphere mostly as molecular nitrogen (N_2). In lake water, it occurs in many compounds but is measured in three basic forms: first various organic compounds as organic-N, second as NH_3 or ammonia-N, and third as $NO_2^- + NO_3^-$ ions or nitrite plus nitrate-N. Total nitrogen is equal to the combination of ammonia-nitrogen and organic-nitrogen (a.k.a. kjeldahl nitrogen) with nitrate-nitrogen plus nitrite nitrogen. Natural sources of nitrogen include precipitation, atmospheric nitrogen fixation by photosynthetic plants and algae and surface and groundwater inflow. Nitrogen enrichment of lakes can occur from human sources including runoff from agricultural fields and feedlots, seepage from leaking septic tanks or properly operating drainfields, and municipal/industrial wastes.Total nitrogen is most often reported in parts per million.

Total Phosphorus
Primary productivity (algal growth) in a lake is dependent on the availability of nutrients (phosphorus, nitrogen, and other minor constituents). Total phosphorus, often the limiting nutrient in a lake, increases with lake primary productivity. Phosphorus in a lake may come from many sources both natural and cultural. Most oligotrophic (low nutrients and productivity) lakes are limited by phosphorus. Increasing lake productivity or eutrophication is caused by abundant phosphorous loading over both the short and long-term. In general, a total phosporus goal of 0.030 mg/L will avoid nuisance algal growths and impaired recreational use such as swimming.

TABLE 1

Lake and Ditch Water Quality Parameters & Monitoring Frequency

Parameter	Field/Lab (F,L)	Frequency* (MAY, JUN, JUL, AUG)	Sample Location
Secchi Disc	F	ALL	S
Dissolved Oxygen (profile)	F	ALL	S, B
Temperature (profile)	F	ALL	S, B
Dissolved inorganic phosphorus (soluble reactive phosphorus)	L	ALL	S, B, D
Total phophorus	L	ALL	S, B, D
Total Kjedahl nitrogen	L	ALL	S, B, D
Nitrite + nitrate nitrogen	L	ALL	S, B, D
Ammonia nitrogen	L	ALL	S, B, D
Total alkalinity	L	ALL	S, B, D
pH (profile)	F	ALL	S, B, D
Color	L	ALL	S, B, D
Chloride	L	ALL	S, B, D
Conductivity (profile)	F	ALL	S, B, D
Chlorophyll *a*	L	ALL	S

* Lake sampling consisted of one monthly sample during the months of May, June, July and August. Cumberland ditch samples consisted of five (5) samples collected primarily during Spring runoff period and to coincide with the lake sampling periods.

S - Lake surface sample, B - Lake bottom water, D - Cumberland Ditch

Sampling Frequency

The seven sites on Beaver Dam Lake were sampled on four occasions (27 May, 24 June, 14 July and 11 August) in 1992. The sampling of the Cumberland Ditch was to have been completed by WDNR staff, but because of workload constraints this effort was assumed by SEH, Inc. A total of six (6) samples were acquired from the the Ditch over the period of mid-April through mid-August (15 April, 27 May, 24 June, 14 July and 11 August).

Field Methods

Sample sites in each particular basin were located in the field using a portable sonar. The lake sites are often the deepest portion of a given basin. Water transparency was measured with a standard secchi disk. Profiles (surface to near bottom) were undertaken at each site for temperature, dissolved oxygen concentration, percent saturation of dissolved oxygen, total dissolved solids (TDS) concentration, specific conductivity, pH and redox (oxidation-reduction). Profiles at the sites were acquired using a Hydrolab Multiparameter Water Quality Monitor. Readings from the Hydrolab were recorded on field data sheets as the instrument was lowered at increments of one meter from the surface through the thermocline followed by every three meters to near bottom.

Water samples were retrieved from the surface and near bottom at each site, except C2A and C4 which included only surface samples. All samples were collected in bottles supplied by the WDNR. The bottles were rinsed several times with surface water before a sample was collected at the one-half meter depth. Near bottom samples were retrieved using a two-liter alpha bottle (Wildco) lowered to a depth, one meter above the lake bottom. The collected water was transferred into sample bottles provided by the WDNR after rinsing the bottles several times with water obtained from the alpha bottle. Water samples to be analyzed for nitrogen and total phosphorus compounds were preserved with sulfuric acid.

Chlorophyll *a* samples were collected with a two-meter depth integrated sampler designed to retrieve a two-liter volume. The depth integrated samples were bottled and immediately placed in a dark cooler until they were filtered. Sample preparation consisted of vacuum filtration of 300 to 600 milliliters of water through a 0.45µ (micron) glass fiber filter with a hand-operated pump. Approximately 2 milliliters of magnesium carbonate suspension were applied to the filter to stablilize the pH and minimize pheophytin production (degradation product of chlorophyll *a*.). This practice was discontinued in August, upon recommendation from Wisconsin Lab of Hygiene staff. The filter was immediately rolled-up and placed within a centrifuge tube, label attached with filtrate amount noted and placed into the shipping container.

All collected samples were packed with ice in styrofoam mailing containers provided by the WDNR. The mailers were sent via priority mail to the State Laboratory of Hygiene in Madison, Wisconsin for analyses.

Results

The project results are presented in four areas: Physical Characteristics; Temperature and Dissolved Oxygen; Nutrients; and Productivity and Transparency. All of these characteristics are interrelated in every lake and they reflect the its ecological classification and potential recreational uses.

Physical Characteristics

Beaver Dam Lake is a 1,112 acre soft water seepage lake (Sather, L. M. and C. W. Threinan, 1964). While monitoring stations were located throughout the lake's major basins, initial review of the historical and 1992 water quality data revealed chemical characteristics which effectively divided it into an upper and lower water body. For the purposes of the study report, United States Highway (U.S.H.) #63 traversing north and south through the City of Cumberland will be considered the boundary between the upper and lower lake. The upper and lower lake are further divided into several basins or bays

Upper lake

Two distinct areas will be discussed in regards to the upper lake. The first area or upper Upper lake is the largest comprising a long 6.1 kilometers (3.8 miles), "S" shaped and narrow 0.3 km (0.2 miles) portion. It includes monitoring stations C1 and C2 and Williams Bay west of the Eagle Point pennisula where station C2A is located. This portion of the upper Upper lake is the largest as shown in Table 2 at 293 hectares (723 acres) comprising about 65 percent of Beaver Dam Lake. It also contains the deepest location on the lake of 31 meters (103 feet) at the north end of this area. The volume of this area is approximately 83 percent of Beaver Dam Lake, thus making its average depth of 12.5 meters (41 feet), two and one-half times greater than Norwegion Bay in the lower lake.

The second area or the lower Upper lake includes Rabbit Island and Library bays. Monitoring station C6 is located in the portion known as Rabbit Island bay which is bounded on the south by Library Bay and on the north by an isthmus known as Beaver Dam (personal communication, C. Christianson. 1993). Rabbit Island as it is known locally is actually a pennisula surrounded by open water on the west and southeast and an adjacent wetland around the remainder of its perimeter. A man-made channel of nearly 1,000 feet in length connects the wetland area with the bay. This channel area is important because it is a source of storm water runoff from the older, developed portion of the City of Cumberland.

TABLE 2
Physical Characteristics of Beaver Dam Lake

Upper lake

upper Upper lake	Area	Volume	Average Depth	Tributary Area
Stations C1, C2, C2A	723 acres (293 ha)	29,765 ac-ft ($3.66 \times 10^7 m^3$)	41.2 ft (12.5 m)	3,110 acres (1,259 ha)
lower Upper lake				
Rabbit Island Bay				
Station C6	92 acres (37 ha)	1,309 ac-ft ($1.61 \times 10^6 m^3$)	14.2 ft (4.3 m)	158 acres (64 ha)
Library Bay				
Station C7	13 acres (5 ha)	72 ac-ft ($8.86 \times 10^4 m^3$)	5.5 ft (1.7 m)	33 acres (13 ha)
SUBTOTAL:	828 acres (335 ha)	31,146 ac-ft ($3.83 \times 10^7 m^3$)	37.6 ft (11.5 m)	

Lower lake

Cemetary Bay	Surface Area	Lake Volume	Average Depth	Tributary Area
Station C4	52 acres (21 ha)	181 ac-ft. ($2.22 \times 10^5 m^3$)	3.5 ft (1.1 m)	185 acres (75 ha)
Norwegian Bay				
Station C5	288 acres (116 ha)	4,494 ac-ft ($5.53 \times 10^5 m^3$)	15.6 ft. (4.8 m)	806 acres (326 ha)
SUBTOTAL:	340 acres (138 ha)	4,675 ac-ft ($5.38 \times 10^6 m^3$)	13.7 ft (4.2 m)	
Beaver Dam Lake				
TOTAL:	1,168 acres (473 ha)	35,821 ac-ft ($4.41 \times 10^7 m^3$)	30.7 ft (9.3 m)	4,292 acres (1,737 ha)

The other portion of the *lower* upper lake is known as Library Bay (a.k.a. Library Lake) and contains monitoring station C7. This small, 5.3 hectare (13 acres) bay is bounded on the south by U.S.H. #63 and Grove Street on the north. It's shallow with a maximum depth of 5.5 m (18 feet) and an average depth of 1.7 m (5.5 feet). Water flow was observed to the north from the Bay's outlet at the Grove Street culvert crossing north into Rabbit Island Bay during April and May, 1992. The surface area of Library Bay was apparently much larger historically and extended south into the Elm Street (U.S.H. #63), Webb and Donatelle streets area (personal communication, C. Christianson, 1993).

In summary, the upper lake comprises 71 percent of the surface area and 87 percent of Beaver Dam Lake's volume. Outflow from the upper lake into the lower lake occurs through the culvert crossing at Superior Avenue (a.k.a. U.S.H. #63).

Lower lake

The lower lake comprises two principal areas: Norwegian and Cemetary bays. Norwegian Bay is the larger of the two at 116 hectares (288 acres) and deeper, average depth: 4.8 m (15.6 ft.). The Cumberland Ditch enters Norwegian Bay at its northeast corner while the channel from the upper lake is located at the northwest end. The bay's outflow is normally south into Cemetary Bay. Norwegian Bay is slightly more than three times the area of Rabbit Island Bay in the upper lake, however, it is similar with respect to average depth at 4.8 meters versus 4.3 meters in the latter.

In contrast, Cemetary Bay is only 21 hectares (52 acres) and is the shallowest area of the entire lake with an average depth of only 1.1 m (3.5 ft.). For many years, Cemetary Bay was the recipient of the City of Cumberland's wastewater treatment works (WWTW) discharge. Construction of a new plant resulted in a diversion of the discharge in 1983. In general, water flow into Cemetary Bay occurs from Nowegian Bay and the upper lake. However, it is well known in the Cumberland area that there were periods prior to the diversion of the WWTW discharge in which Cemetary Bay "backed into" Norwegian Bay. A hypothetical scenario in which seepage and surface evaporation during the growing season in the much larger Norwegian Bay could have resulted in an elevation differential with respect to Cemetary Bay, thus causing the constant WWTW discharge flow to impact the former. The historically poor quality of Norwegian Bay, discussed later, appears to support this hypothesis and potential longevity of this occurence. The bay's outlet is to south and into a tributary of the Hay River.

In summary, the Lower lake is much smaller, 138 hectares (340 acres) and shallower 4.2 m (13.75 ft.) with respect to the Upper lake.

Temperature and Dissolved Oxygen

Appendix A contains a summary of a portion of the historic data collected on Beaver Dam Lake by WDNR as well as SEH, Inc. in 1992. Appendix B contains monitoring data for stations C2A, C6, and C7 collected by SEH, Inc.

Upper lake

As discussed in the previous section, the upper portion contains the majority of the lake's volume. From a thermal standpoint, this portion of the lake is dimictic, meaning that it "turns over" twice per year in the Spring and Fall. The lake begins to thermally stratify during late April to mid May (pp. A-1, A-2, and B-1). A thermocline[2] develops at 20 to 25 feet (6-8 m) and is maintained until September when average outdoor temperatures begin to cool. This lower portion of the lake is known as the hypolimnion. By late October, the lake surface has cooled to the point where it has become more dense than the hypolimnion and turnover again occurs. As shown in Figures 2, 3 and 4, nearly identical thermal regimes were observed at stations C1, C2 and C2A during each of the sampling periods.

[2] The zone where the maximum rate of temperature decrease with respect to depth occurs (Wetzel, R.J. 1983).

Figure 2

BEAVER DAM LAKE SAMPLING SITE C1

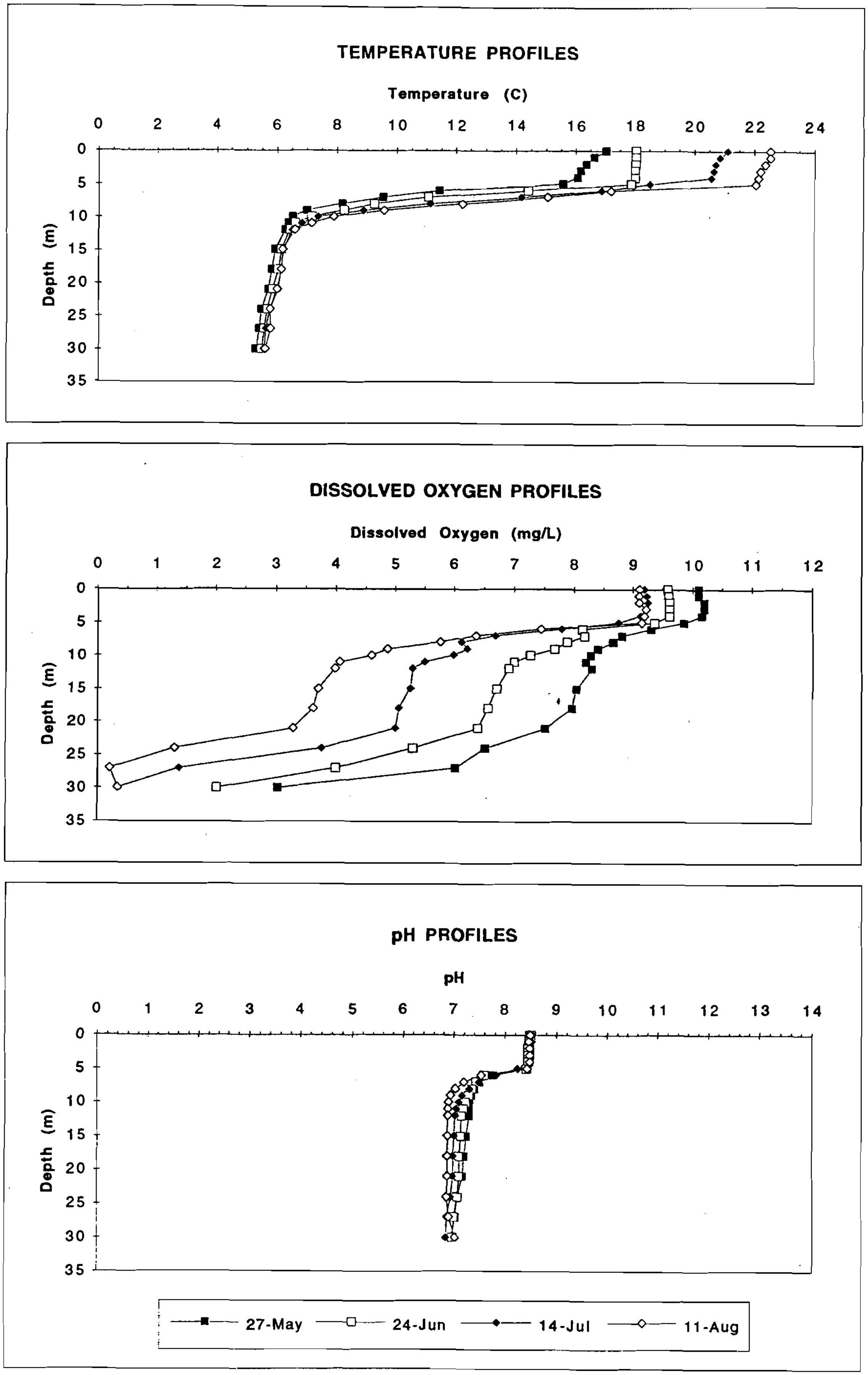


Figure 3

BEAVER DAM LAKE SAMPLING SITE C2

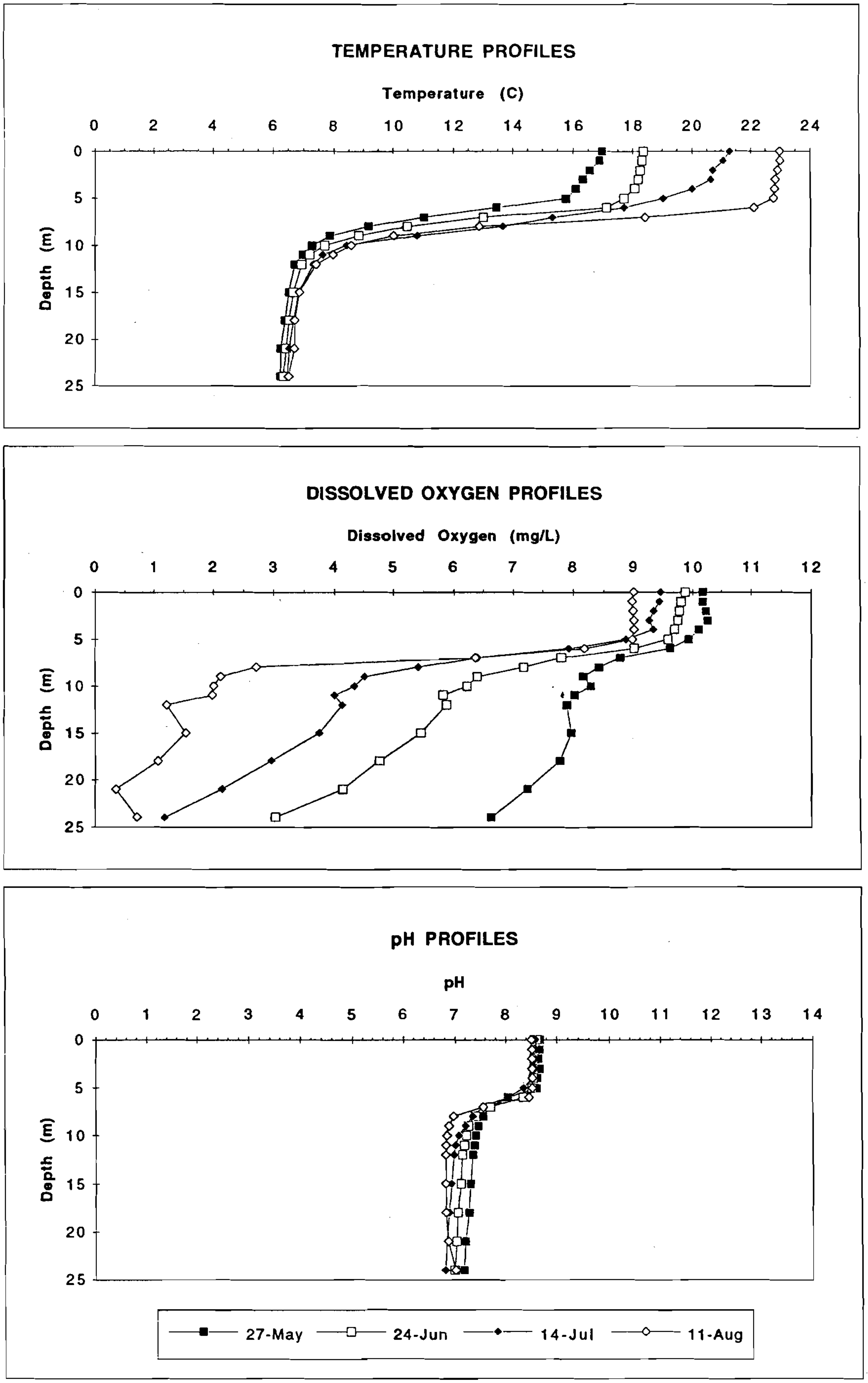
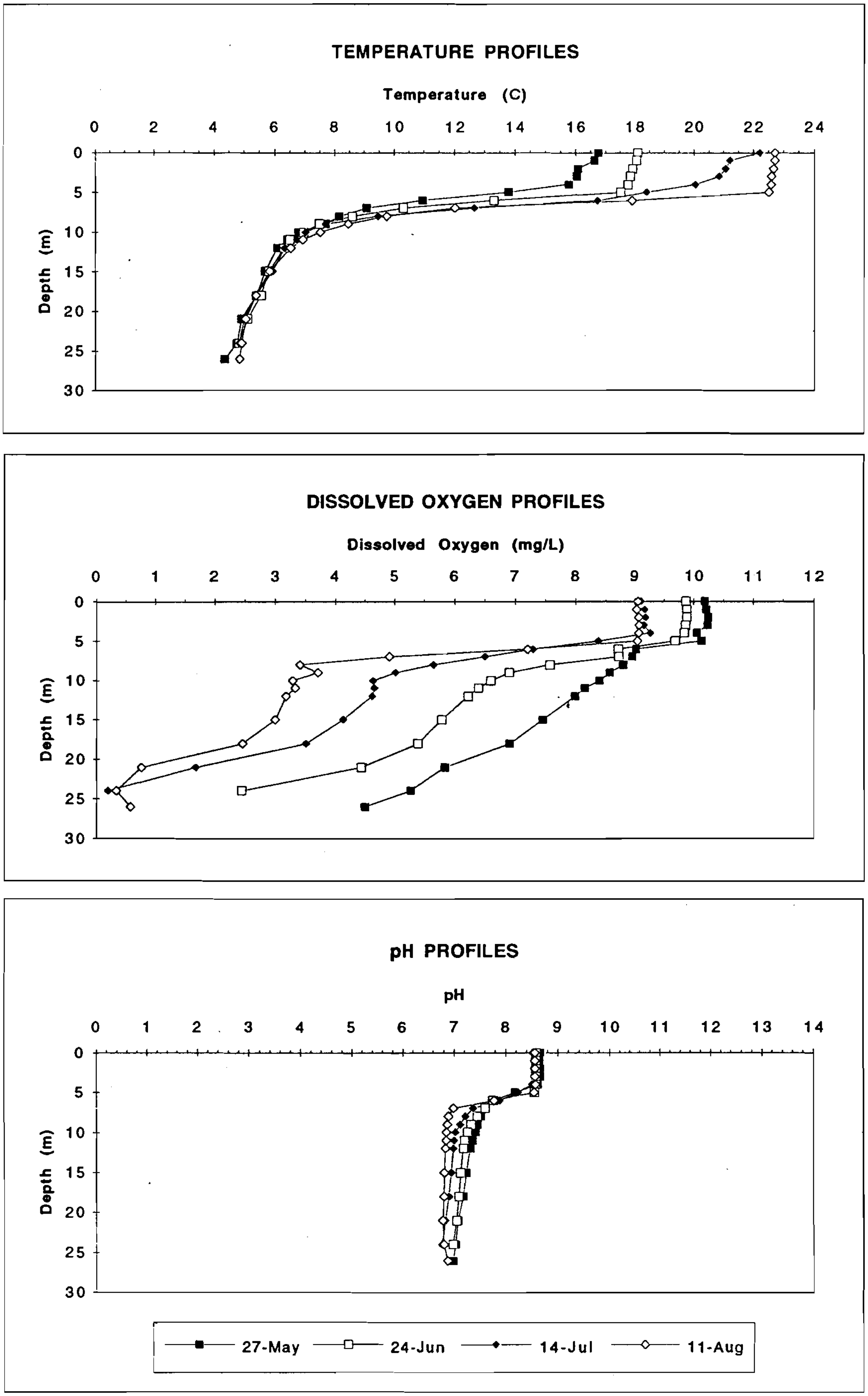


Figure 4

BEAVER DAM LAKE SAMPLING SITE C2A



The dissolved oxygen regime of the Upper lake's hypolimnion is of considerable interest. At station C1, anoxia or complete loss of oxygen was observed in the bottom 10 feet (3 m) of the lake on August 11, 1992 (pp. A-3 and A-4). However, a similar zone of anoxia was observed from 65 ft (20 m) to the bottom on October 28, 1987 (p. A-4) and from 80 ft to the bottom on November 8, 1982 and August 16, 1983 during WDNR lake surveys. From an areal and volumetric perspective, the zone of anoxia is about 20 % of the upper Upper lake's area, but only 10 % of its volume.

At station C2 subtle differences in the lake's hypolimnion were observed. Dissolved oxygen concentrations were nearly identical to station C1 during the May 27, 1992 sampling period. However, the June, July and August, 1992 periods indicated levels at the same depths which were consistently 1-2 parts per million lower than C1 (pp. A-4 and A-8; Figures 2 & 3). A similar observation was made during the August 16, 1983 sampling period of the WDNR (pp. A-3 and A-8) for stations C1 and C2.

The addition of the Williams Bay monitoring station (C2A) confirmed nearly identical temperature and dissolved oxygen regimes as observed at the previously discussed station C2, east of Eagle Point pennisula. The C2A station was not monitored in the past by WDNR.

Rabbit Island Bay in the lower Upper lake is signficantly more shallow than the upper Upper lake. The Station C6 data (Appendix B, p. B-2) showed a nearly identical thermal regime on all four sampling periods (Figure 5) when compared to the upper Upper lake stations. In contrast, dissolved oxygen depletion below 20 ft (6 m) occurs much sooner (May) and was more pronounced in the hypolimnion during all four dates than the upper Upper lake stations. From an areal and volumetric perspective, the zone of anoxia is 28 % of Rabbit Bay's area and 24 % of its volume.

Library bay, or station C7 is much shallower than Rabbit Island bay. Its thermal regime is very similar to the other stations observed (Figure 6). Dissolved oxygen concentrations when compared with C6 reveal that the onset of anoxia is more rapid in the Spring and extensive from an areal perspective over the four dates. In fact, complete oxygen depletion was observed at 13 ft (4 m) during the June, July and August dates (Appendix B, p. B-3). From an areal and volumetric perspective, the zone of anoxia is only 12 % of Library Bay's area and 6 % of its volume.

Figure 5

BEAVER DAM LAKE SAMPLING SITE C6

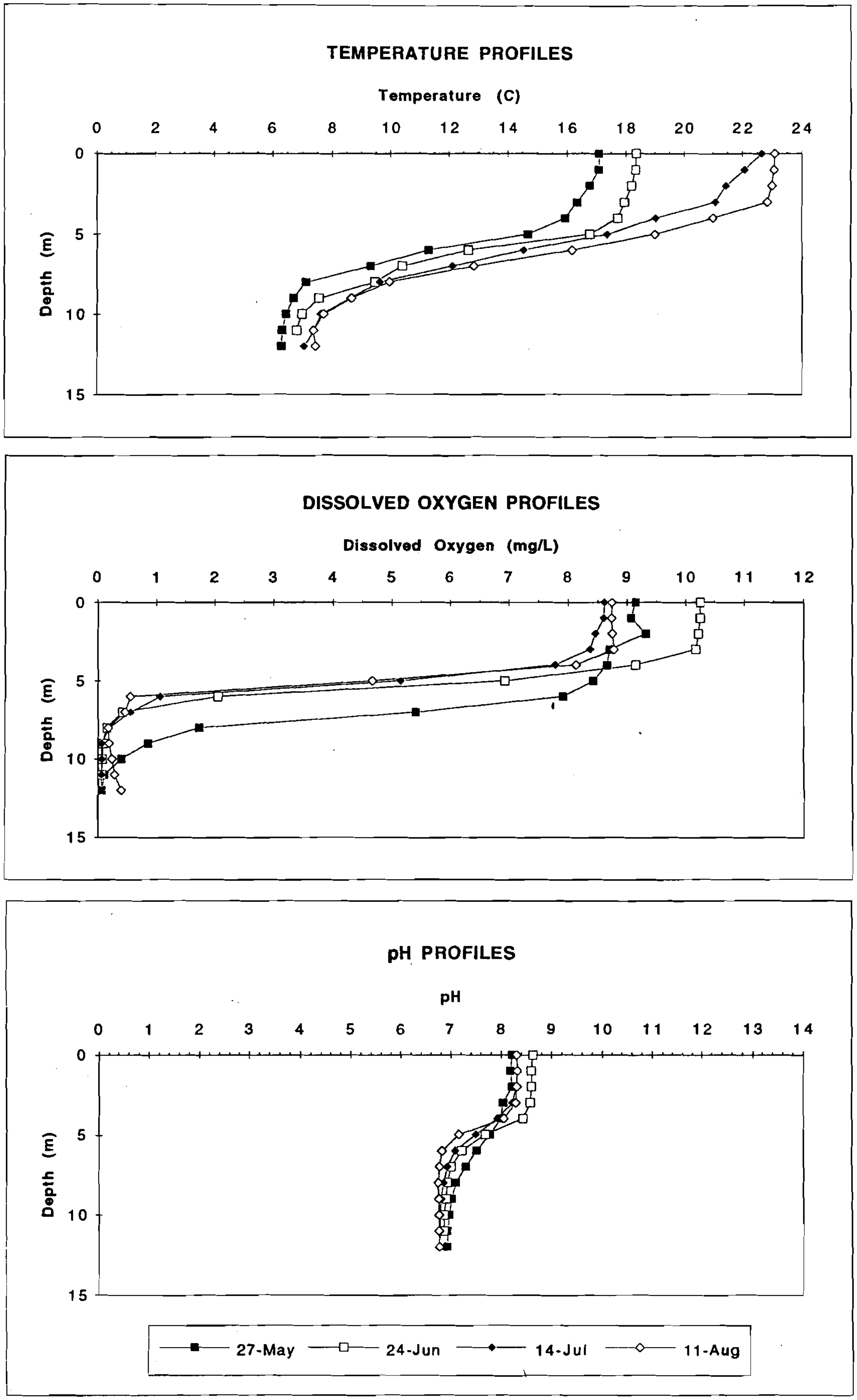
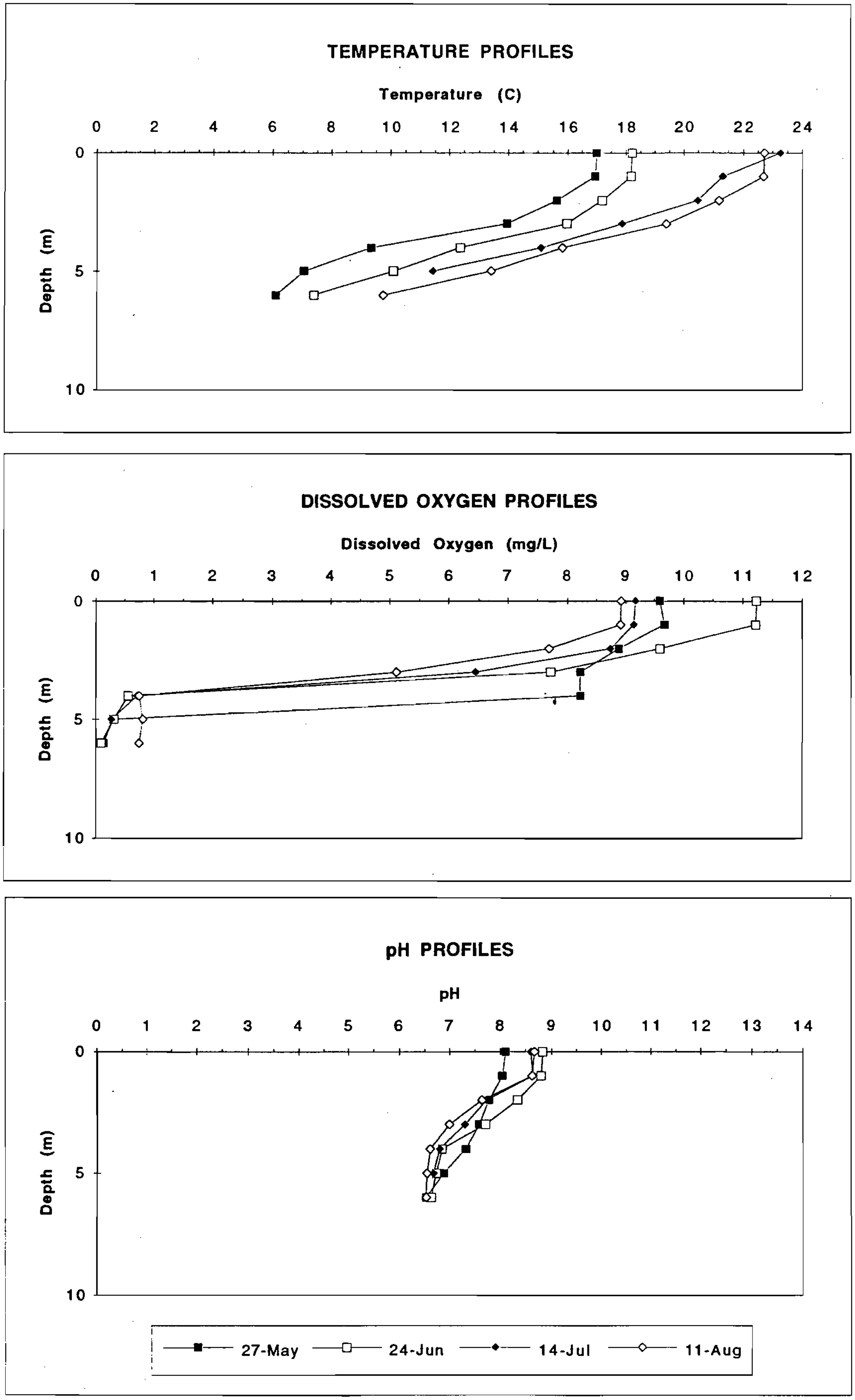


Figure 6

BEAVER DAM LAKE SAMPLING SITE C7



Lower lake

The lower lake is dominated by Norwegian Bay. As discussed previously, Norwegian Bay shares a similarity with Rabbit Island Bay with respect to its average or mean depth. The thermal stratification monitored at station C5 (Appendix A, p. A-11 and A-12) was nearly identical to station C6 with setup beginning in late April to mid-May. The thermocline is well developed at 20 to 25 feet (6 - 8 m). Dissolved oxygen concentrations (p. A-13 and A-14) throughout the water column are similar to Rabbit Island and Library bays in the lower Upper lake (Figure 7). Oxygen depletion in the hypolimnion was nearly complete below 16 to 20 feet (5 - 6 m) after the July and August sampling periods in 1992. Similar conditions were observed by WDNR on July 27, 1978 and August 16, 1983. From an areal and volumetric perspective, the zone of anoxia is 29 % of Norwegian Bay's area, but 35 % of its volume.

Cemetary Bay is the shallowest in the Lower lake as well as the entire lake. Thermally it is polymictic[3] as shown in Figure 8 (Appendix B, p. B-4). Dissolved oxygen concentrations in the water column show only a small decrease between 3 and 5 feet (1 - 1.5 m).

[3] Continuous or frequent mixing due to shallow depth or a combination of shallow depth with a large surface area (Wetzel, R.J. 1983).

Figure 7

BEAVER DAM LAKE SAMPLING SITE C5

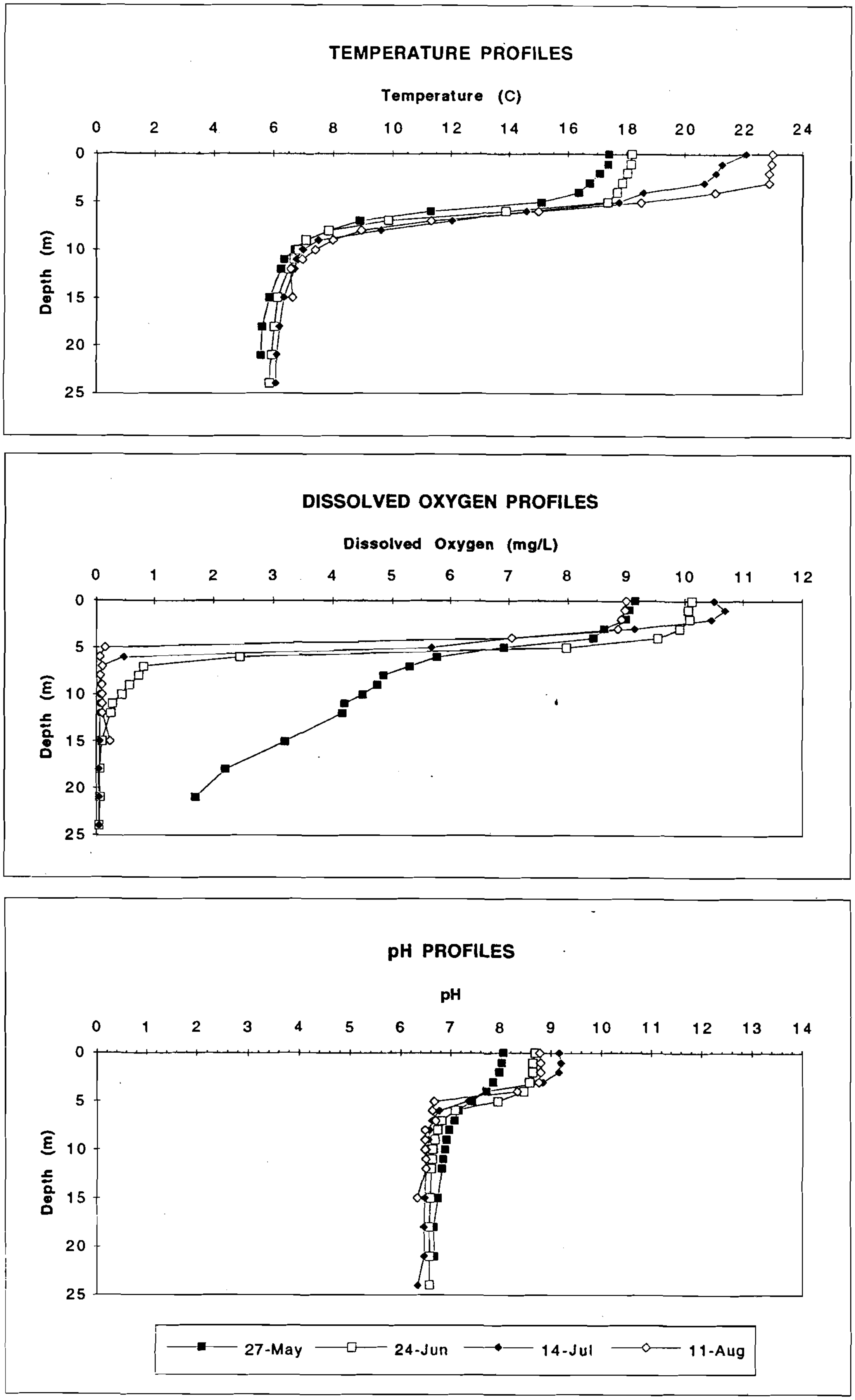
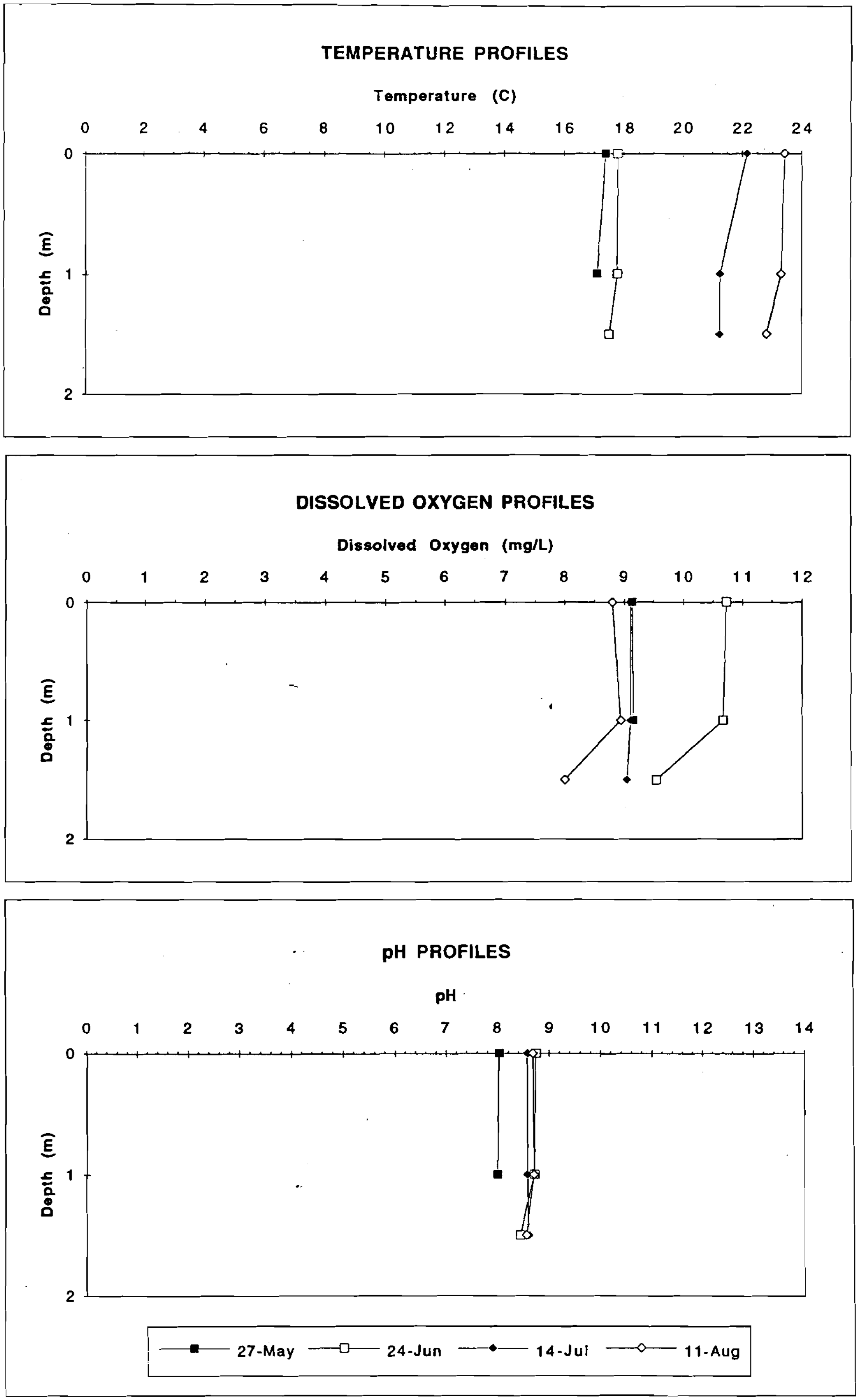


Figure 8

BEAVER DAM LAKE SAMPLING SITE C4



Discussion

Beaver Dam Lake exhibits a variety of thermal and dissolved oxygen regimes worthy of discussion. Very strong thermal stability is seen at stations C1, C2, and C2A in the upper Upper lake versus the absence of such in Cemetary Bay. While Cemetary Bay has a very shallow depth, it is also subject to easy wind mixing. In contrast, the north end of the upper Upper lake is very deep and therefore more resistant to wind mixing. The other bays except for Library bay also have fairly strong thermal stratification. The importance of thermal stability relates to the ability of nutrients to be contributed to the photic zone of the lake. For example, the recycling of nutrients would be readily apparent in Cemetary Bay versus the upper Upper lake because of its lack of thermal stratification.

Another issue of note is the degree to which the hypoliminetic oxygen deficit may slowly be increasing in the upper Upper lake. Wetzel (1983) has noted along with many others that hypolimnetic oxygen deficits are positively related to increasing algae populations, higher total phosphorus concentrations, and inversely porportional to secchi disc transparency. In the case of Beaver Dam Lake, significant zones of oxygen depletion were noted in Rabbit Island, Library and Norwegian bays. The impact of this zones of depletion (anoxia) on each of the bays is shown more dramatically in the following short table:

	Hypolimnion Volume	Anoxic Volume	Percent
upper Upper lake (C1, C2, C2A)			
Thermocline at 20 ft. D.O. anoxia from 70 - 100 ft.	17,765 ac-ft	2,357 ac-ft	13 %
Rabbit Island Bay (C6)			
Thermocline at 20 ft. D.O. anoxia from 23 - 50 ft.	321 ac-ft	275 ac-ft	86 %
Norwegian Bay (C5)			
Thermocline at 20 ft. D.O. anoxia from 18 - 90 ft.	2,905 ac-ft	3,000 ac-ft	100 %

It should be stressed that the hypolimnion volume is a nearly indentical in percentage (60 - 65 %) of the whole for both the upper Upper lake and Norwegian Bay.

The higher quality of the upper Upper lake is best observed at station C1. The subtle decreasing hypolimnetic dissolved oxygen concentrations at stations C2 and C2A may be related to contributions of nutrients from Rabbit Island and Library bays or the direct tributary drainage area (see Modelling section). However, this supposition should be viewed with caution in the absence of monitoring data on nutrient runoff, hydraulics, and further analyses of hypolimnetic temperatures and thicknesses for the Upper lake. It should be noted, however, that small changes in hypolimnetic oxygen concentrations such as discussed above can occur over many years as shown in work on Douglas Lake, Michigan (Bazin and Saunders, 1971; Lind, 1978).

Nutrients, Productivity, and Transparency

The growth of algae in a lake is most often limited by the supply of phosphorus. Increasing or decreasing the mass of phosphorus discharged into the lake over an annual or seasonal time scale will increase or decrease the average concentrations of phosphorus and algae in the lake. In other words, Beaver Dam Lake's condition depends upon how much phosphorus it receives from both internal and external sources. Algal growth or primary productivity is usually expressed in terms of mean (average), growing season chlorophyll *a* in the lake's near surface water. Because the amount of chlorophyll *a* in a lake is most often directly related to the amount of phosphorus, long term monitoring of this nutrient is an important factor in assessing Beaver Dam's trophic state.

Transparency or secchi disc measurements are undertaken to measure the light entering the lake which is scattered often due to suspended algae or otehr matter. Secchi disc level is directly related in an inverse manner with chlorophyll *a* ; that is the greater the transparency the lower the amount of primary productivity. Transparency is important in reflecting the degree to which a lake may support various uses such as drinking water, swimming, boating and fishing.

Upper lake

Similar to the discussion about temperature and dissolved oxygen, the trophic characteristics of Beaver Dam Lake as measured by total phosphorus, chlorophyll *a* and secchi disc transparency reflect considerable variation. Table 3 depicts the average values for these three parameters based upon the four sampling periods in 1992. The upper Upper lake exhibited the lowest average nutrient phosphorus and primary productivity levels for the entire lake. Following each average value in Table 3 is the standard deviation of the data set preceeded by plus(+) and minus(-) signs. Small standard deviations reflect little variation in the data set at each sampling station. Little variation in the nutrient and chlorophyll *a* data is indicative of a more stable condition and consistent quality. The transparency of the upper Upper lake was not as high on average as observed in Rabbit Island bay, however, there was less variation among the twelve values.

In contrast, the lower Upper lake reflects a subtle increase in nutrients and primary productivity similar to the discussion involving hypolimnetic dissolved oxygen. Rabbit Island bay shows slightly higher nutrient phosphorus and primary productivity than the upper Upper lake. The same conclusion can be made with respect to Library bay in comparison to Rabbit Island bay. The raw data within Appendices A and B show good internal consistency among the stations.

TABLE 3

Trophic Characteristics of Beaver Dam Lake
1992

Upper lake

upper Upper lake	TPHOS[3]	CHL *a*[4]	Secchi Depth[5]
Stations C1, C2, C2A	7 ppb ± 2	4 ppb ± .7	10.8 ft ± 1 (3.1 m)
lower Upper lake			
Rabbit Island Bay			
Station C6	11 ppb ± 2	5 ppb ± 3	12.1 ft ± 2 (3.7 m)
Library Bay			
Station C7	17 ppb ± 2	6 ppb ± 1	10.1 ft ± 1 (3.1 m)

Lower lake

Cemetary Bay	TPHOS	CHL *a*	Secchi Depth
Station C4	38 ppb ± 18	23 ppb ± 16	4 ft ± 2 (1.2 m)
Norwegian Bay			
Station C5	20 ppb ± 3	16 ppb ± 9	6.8 ft. ± 2 (2.1 m)

---

3 Average total phosphorus (TPHOS) in parts per billion with data variation by one standard deviation shown.
4 Average chlorophyll *a* (CHL *a*) in parts per billion with data variation by one standard deviation shown.
5 Average secchi disc transparency with data variation by one standard deviaion shown.

Lower lake

In general, the Lower lake is two to three times higher in total phosphorus and chlorophyll *a* concentrations in comparison to the Upper lake. Norwegian Bay is significantly higher in phosphorus and primary productivity than Library Bay. Of the two bays in the Lower lake, Cemetary has the highest levels of nutrient phosphorus and primary productivity. The range of secchi disc transparency measurements of 4 to 7 feet for the two bays in the Lower lake were 50% or less than comparable sites in the Upper lake.

Discussion

The three parameters: total phosphorus, chlorophyll *a*, and secchi disc combine to reflect the trophic state of a lake. Lake trophic states are often described by the following limnological terms and their corresponding parameter ranges.

Trophic State	Total phosphorus	Chlorophyll *a*	Secchi Depth
Oligotrophic	0 - 10 ppb	< 4 ppb	> 13 ft. (4 m)
Mesotrophic	11 - 25 ppb	4 - 10 ppb	6.6 - 13 ft.
Eutrophic	26 - 60 ppb	11 - 25 ppb	3.3 - 6.6 ft.(2 m)
Hypereutrophic	60 - 120+ ppb	> 25 ppb	< 3.3 ft. (1 m)

Source: U.S. Environmental Protection Agency, 1988.

Heiskary, et al. 1987 developed a statewide assessment methodology for lakes in Minnesota in which phosphorus impacts were related to lake conditions as measured by chlorophyll *a* and secchi disc. These parameters and respective ranges were correlated to an individual lake's uses and perceptions. The Minnesota methodology is useful in Wisconsin because of the similar geographical latitude and growing season in the Beaver Dam Lake area. The following two tables were adapted from Heiskary and Walker, 1988. Basically, the values shown represent the median (50th percentile) of the users responses and the parameters describing the lakes' trophic state.

Recreation Suitability	Total phosphorus	Chlorophyll *a*	Secchi Depth
Beautiful	< 20 ppb	< 4 ppb	> 12 ft
Minor aesthetic impact	30 ppb	8 ppb	7 ft
Swimming impaired	80 ppb	40 ppb	2.5 ft
No swimming	100 ppb	53 ppb	2.0 ft

Physical Appearance	Total phosphorus	Chlorophyll *a*	Secchi Depth
Crystal clear	< 13 ppb	< 3 ppb	> 13 ft
Some algae	24 ppb	4 ppb	9 ft
Definite algae	33 ppb	11 ppb	6 ft
High algae	87 ppb	47 ppb	2.5 ft

An additional useful table is from a WDNR publication (1990) regarding the statewide lake monitoring program.

Lake Description	Secchi Disc	
Excellent	> 20 ft.	(> 6.1 m)
Very Good	10 - 20 ft	(3 - 6.1m)
Good	6.5 - 10 ft	(2 - 3 m)
Fair	5 - 6.5 ft	(1.5 - 2 m)
Poor	3.2 - 5 ft	(1 - 1.5 m)
Very Poor	< 3.2 ft	(< 1 m)

Source: Lillie and Mason, 1983; U.S. Environmental Protection Agency, 1980.

Upper lake

In general, the Upper lake should be considered in good to very good condition. Technically, the trophic state of the upper Upper lake is oligotrophic with a recreational suitability of "Beautiful" and a physical appearance of "Crystal clear". The lower Upper lake is in good condition. Rabbit Island Bay is mesotrophic, but would be considered very similar to the upper Upper lake in terms of recreational suitability and physical appearance.

Library Bay would also be considered mesotrophic with occasional minor aesthetic impact and some algae. However, in the the case of the latter bay, the traditional trophic classification system does not address the impact of a basin with extensive submergent and emergent weed (macrophyte) populations. Very heavy weed growth was apparent to the 12 foot depth in Library Bay. Because of the macrophyte populations, Library Bay could be considered eutrophic.

The contrast between the Upper and Lower lakes is very apparent in the review of the trophic data. It is a rarity in either Wisconsin or Minnesota to be able to observe very low productivity (oligotrophy) and high productivity (eutrophy to hypereutrophy) in the same lake ! Norwegian Bay is in a transitional state (discussed later), but would likely still be considered eutrophic or highly productive. It's recreational suitability fluctuated between "minor aesthetic impacts" to "swimming impaired", to "some algae" and "definite algae". Such fluctuations are not unusual for eutrophic lakes.

Cemetary Bay is also in transition and would be considered to have a trophic state between eutrophic and hypereutrophic. Swimming may be impaired or eliminated and definite algae population growth was apparent.

In summary from a secchi disc transparency perspective, Beaver Dam Lake exhibits very good quality in the upper Upper lake and Rabbit Island Bay, good quality in Library and Norwegian bays, and poor to very poor quality in Cemetary Bay.

Trends

An important objective of a monitoring program is to detect changes or trends in pollution levels over time. Several purposes for such a program may be examined such as the detection of nonpoint pollution inputs to a lake or to determine if pollution levels have declined following the initiation of control programs. As long-term monitoring programs are implemented, large amounts of data are gathered which must be scrutinized, evaluated for representation and statistically examined for trends to determine if changes are needed in management programs. Proper long-term lake management requires that such efforts are implemented to assure that monies are not needlessly spent and that there is a proper focus on data gathering.

The statistical analysis involved two procedures. First, past lake water quality monitoring data of Beaver Dam Lake was acquired from the WDNR Northwest District office (personal communication, D. Ryan. 1991). Total phosphorus data was examined for internal consistency and loaded into a spreadsheet program along with the 1992 monitoring data. Second, a statistical analysis of the total phosphorus data was undertaken using the nonparametric Mann-Kendall (Mann, 1945; Kendall, 1975) test for trend. Test procedures followed those outlined in Gilbert, R.O. 1987. Gilbert states that this test is particularily useful because missing values are allowed and the data need not conform to any particular distribution.

In addition, data reported as less than the detection limit can be used by assigning them a common value that is smaller than the smallest measured value in the data set. In the case of the Beaver Dam Lake data set, several data points in the Upper lake were below the laboratory detection level (0.02 mg/L) and were assigned a value of 0.01 mg/L for the statistical analysis. Four stations on Beaver Dam Lake were statistically analysed: C1, C2, C4 and C5. These stations were selected because historical data from WDNR lake surveys of the mid-1970's existed. The results of the analyses are presented in tabular format in Appendix C and in a graphical and narrative discussion as follows.

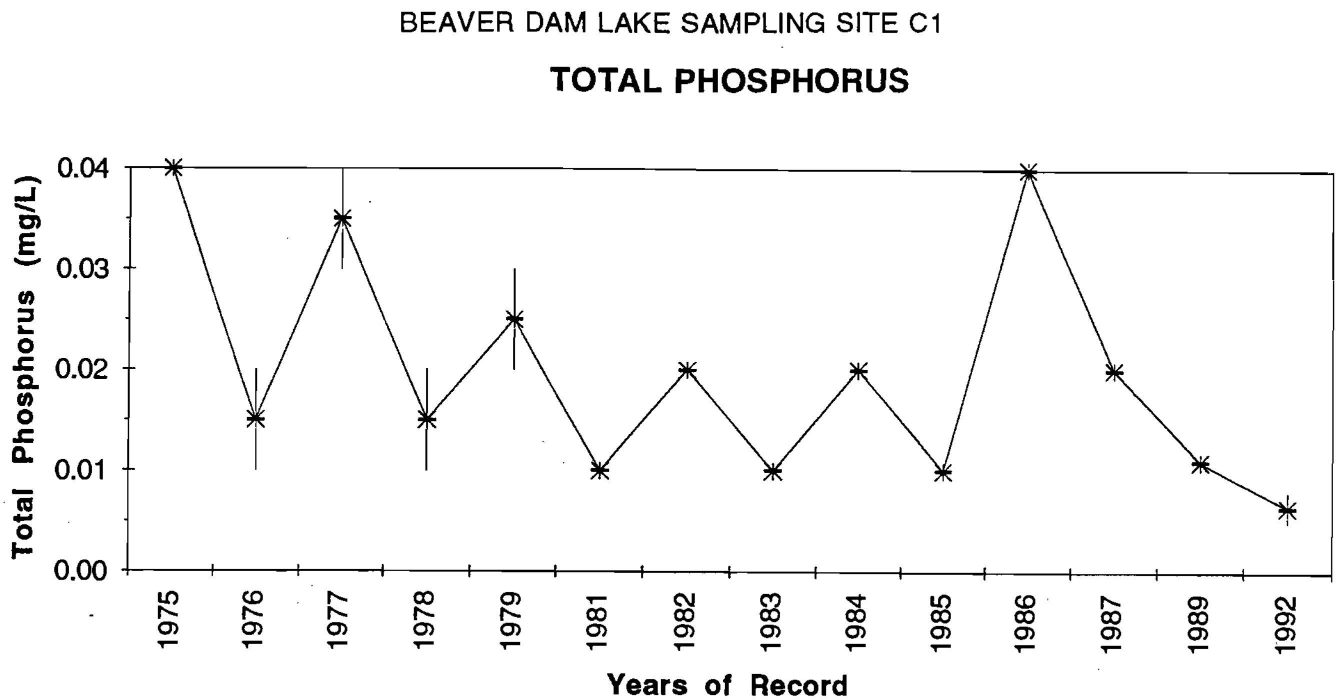
Upper lake

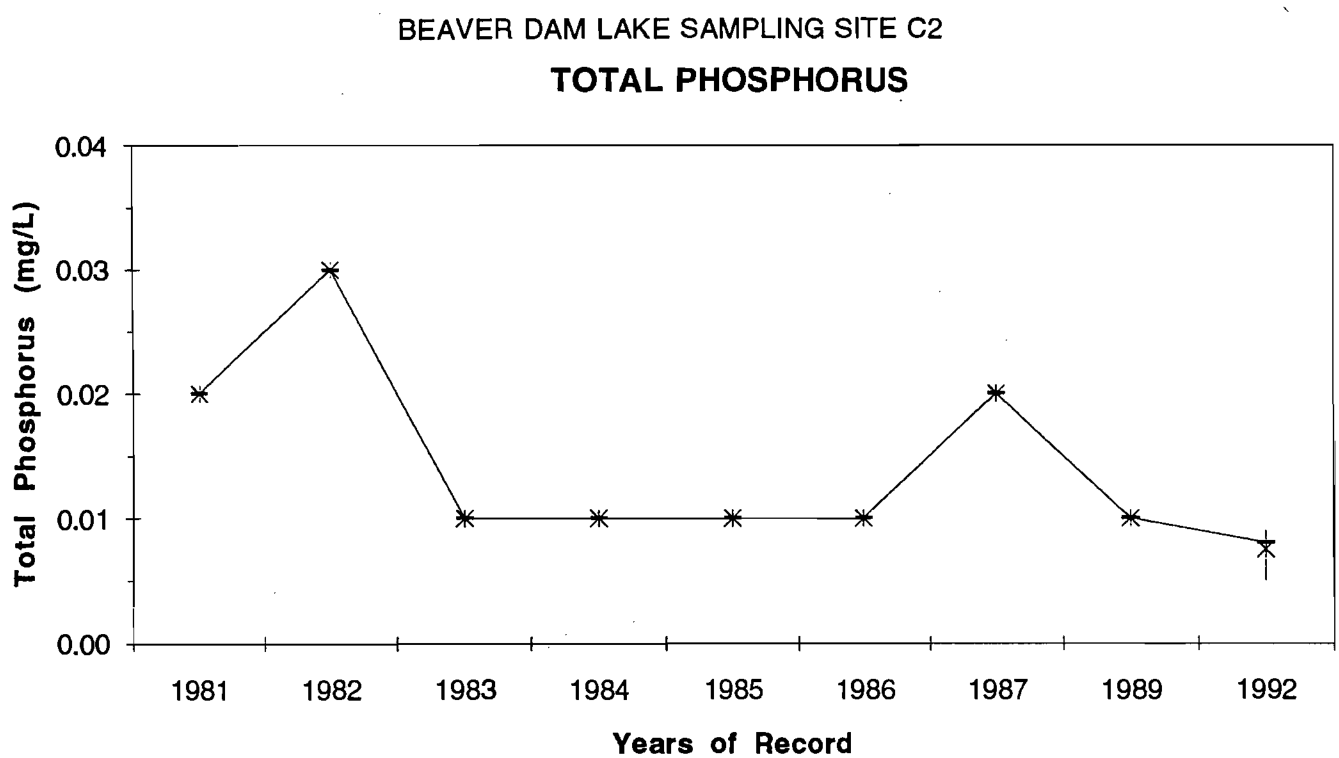
Two stations, C1 and C2 were analysed for a total phosphorus trend in the Upper lake. Fourteen (14) years of data were available from 1975 through 1992 (four years missing) at station C1 and nine (9) years of data from 1981 through 1992 (three years missing) at station C2. Figure 9 illustrates the total phosphorus data versus time for these two stations. A decreasing slope line could be drawn through the data for station C1 and quite easily for C2 without further statistical analysis. Such an effort may or may not be a correct interpretation of what appears to be a decreasing trend. Appendix C, pages C-1 through C-3 contain the output of the Mann-Kendall statistical test. In both examples, hypotheses are established (e.g. Ho = No Trend and Ha = Downward Trend) which need to be tested statistically.

Without going into a great detail on the Mann-Kendall methodology, a "Z" statistic was computed from the monitoring data. A positive value of "Z" indicates an upward trend and conversely a negative value indicates a downward trend. The "Z" statistic generated for both stations C1 and C2 was negative causing the "No Trend" hypothesis to be rejected and the "Downward Trend" hypothesis to be accepted. While the downward trend is real, the basis for the trend is problematic. Gilbert, R.O. 1987 states:

> "A change of analytical laboratories or of sampling and/or analytical procedures may occur during a long-term study. Unfortunately, this may cause a shift in the mean or in the variance of the measured values. Such shifts could be incorrectly attributed to changes in the underlying natural or man-induced processes generating the pollution".

Figure 9
Total Phosphorus Trend Analysis
Stations C1 and C2





Total phosphorus levels at station C2 were at or below the laboratory detection limit of 0.020 mg/L in 1983, 1984, 1985 and 1986. The analytical technique for total phosphorus used in 1992 by the Wisconsin Lab of Hygiene had detection limit below 0.005 mg/L versus the 0.020 mg/L used in the 1980's. Total phosphorus monitoring data for station C2 indicated concentrations below 0.010 mg/L. While it cannot be positively concluded that the downward trends at both stations were due to analytical procedures, it appears to be a more likely occurrence than a change in the lake's environmental conditions.

Lower lake

The two monitoring stations C4 (Cemetary Bay) and C5 (Norwegian Bay) were also analysed for a total phosphorus trend in the Lower lake. Both of these stations were impacted in the past by the City's municipal wastewater discharge. Ten (10) years of data were available from 1974 through 1992 (seven years missing) at station C4 and thirteen (13) years of data from 1976 through 1992 (three years missing) at station C5. Figure 10 illustrates the total phosphorus data versus time for these two stations. It is quite apparent that total phosphorus has decreased in both bays over this period.

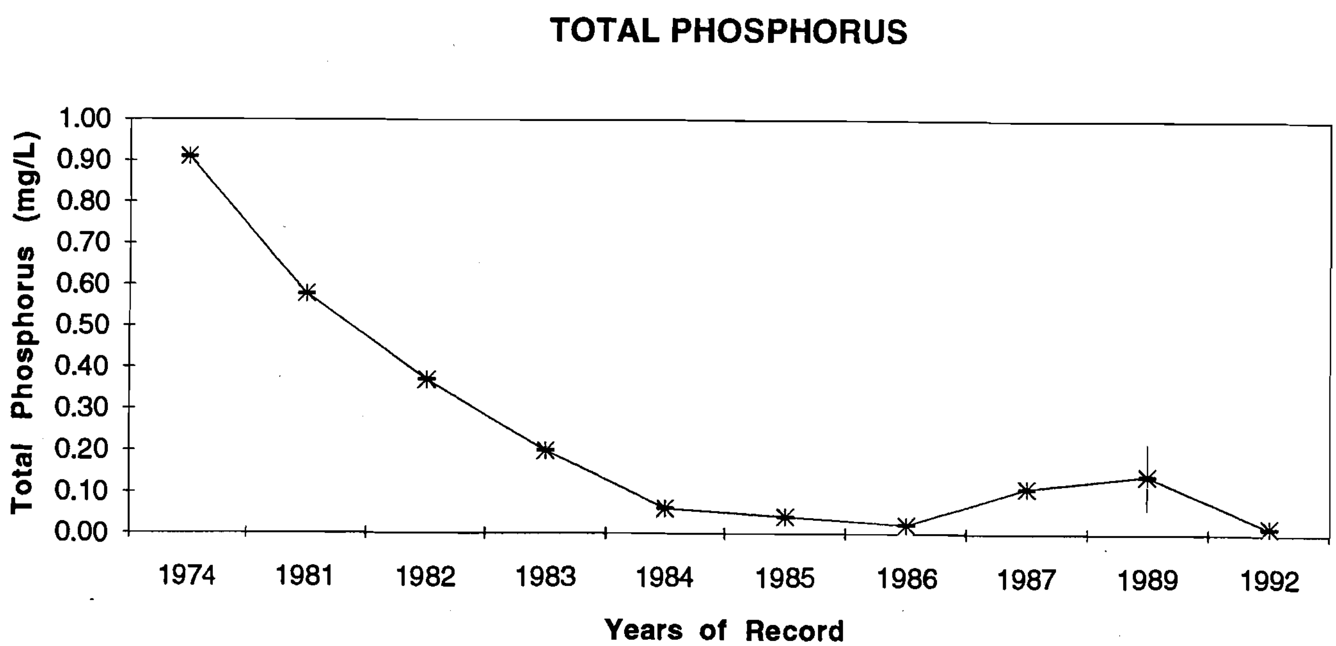
The Mann-Kendall statistical test results on both bays are in Appendix C, pages C-4 through C-7. The "Z" statistic generated for both stations C4 and C5 was negative causing the "No Trend" hypothesis to be rejected and the "Downward Trend" hypothesis to be accepted. The question of laboratory analytical procedure changes causing the downward trend does not come into issue for these two bays because the total phosphorus concentrations were an order of magnitude higher than observed in the Upper lake.

Discussion

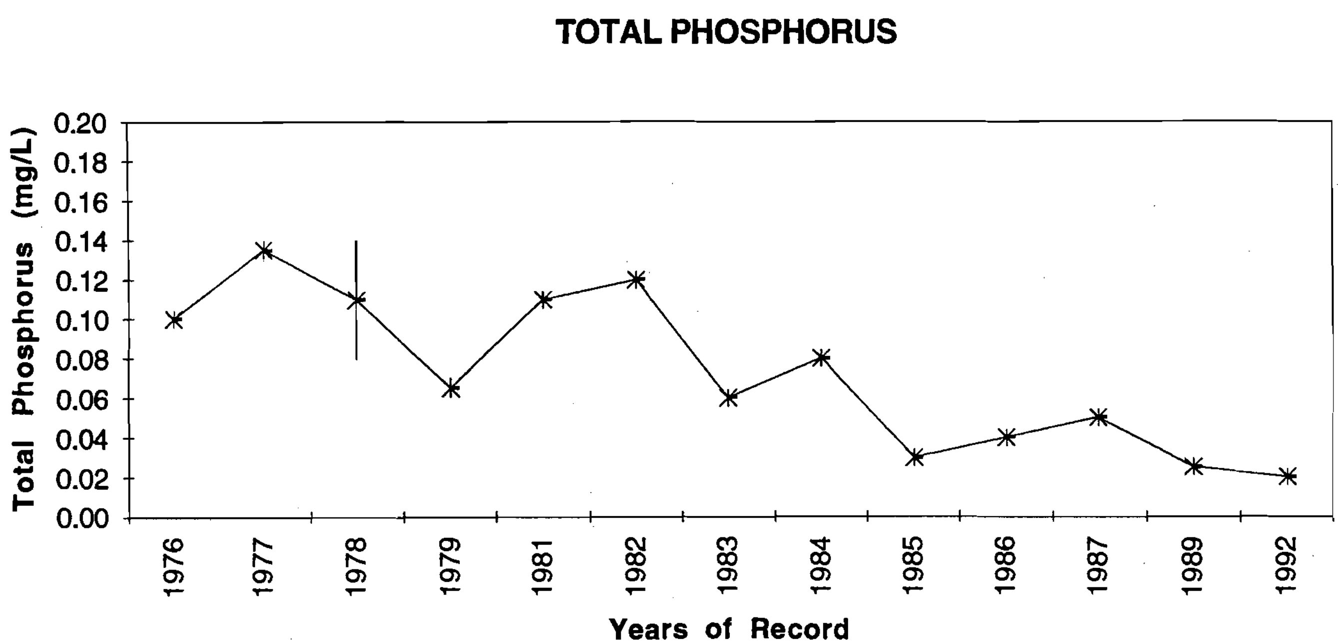
Whether the Upper lake is in a "steady state" condition where no upward or downward trend in total phosphorus is occurring cannot be conclusively determined at present. On the plus sign, laboratory detection levels for total phosphorus are at the point where a further reduction appears very unlikely. The Lower lake will likely continue to decrease in total phosphorus concentration through the flushing and sedimentation mechanisms. Continued monitoring of the Upper and Lower bays is warranted to determine at what point a "leveling off" may be reached in nutrient concentrations. This is particularily important with respect lake management alternatives which would consider the long-term impact(s) from nutrients remaining in the bottom sediments from the past wastewater discharge.

Figure 10
Total Phosphorus Trend Analysis
Stations C4 and C5

BEAVER DAM LAKE SAMPLING SITE C4



BEAVER DAM LAKE SAMPLING SITE C5



Modelling

Methodology

The computer model used was the Lake Evaluation Model Spreadsheet (LEMS), [Schilling and Panuska, 1992]. Given the complexity of Beaver Dam Lake, it would not have been appropriate to model the entire lake as one basin. Therefore, the lake was divided into five subbasins. The five subbasins and corresponding monitoring stations are as follows:

Upper lake

1. upper Upper lake (C1, C2, and C2A)
2. Rabbit Island bay (C6)
3. Library bay (C7)

Lower lake

4. Norwegian bay (C5)
5. Cemetary bay (C4)

General information on each subbasin is included in Table 1 along with the direct tributary (drainage) area for each of the bays. The LEMS requires the input of water body, watershed and annual rainfall data, along with observed in-lake spring total phosphorus concentration. The water body information was planimetrically determined from the lake bathymetric (depth contour) map for Beaver Dam Lake (No. 3105). The required watershed data includes the size of the tributary area, the phosphorus export for each landuse type within the area, runoff volume, and the subsequent loading of phosphorus from any point source discharge(s). The tributary area for each of the bays was planimetrically determined from the U.S. Geological Survey 7.5 minute quadrangle map for the area. The phosphorus export from the tributary area was estimated based upon values from Reckhow and Chapra (1983) and Mulcahy (1991). The phosphorus export values for each landuse type used in the analysis are shown in the following short table.

Phosphorus Export in kg/ha/yr by Landuse Type

Landuse Type	Low	Most Likely	High
Recreational/Residential	0.04	0.40	0.80
General Urban	0.30	0.70	3.00
Commercial/Industrial	0.10	1.50	4.30
Agricultural	0.30	0.45	1.50
Open Space/Grassland	0.04	0.34	0.63
Open Space/Wooded	0.02	0.22	0.45

kg/ha/yr is kilograms/hectare/year (x 0.892 = lbs./acre/yr)

The precipitation from the Cumberland monitoring station and the lake surface evaporation was calculated from pan evaporation values from NOAA (1982) using a pan coefficient of 0.60. The average annual runoff from each tributary drainage area was assumed to be 9 inches and was taken from U.S. Geological Survey, 1976. The only external point source flowing into the system was Cumberland ditch flowing into Norwegian Bay. An estimated annual water loading of 390 acre-feet ($4.8 \times 10^5 m^3$) was used with an annual nutrient loading of 73 lbs. (31 kg). A summary of the ditch monitoring and loading results follows in Table 4.

The point source water and nutrient loading feature of LEMS was used to connect the various bays of the lake. In order for the hydraulic and nutrient budgets to be correct for each subbasin, the hydraulic and nutrient loading for each embayment was input as a point source from the upstream embayment. The nutrient loading to a downstream basin was calculated using the runoff volume to the upstream basin multiplied by the observed spring phosphorus concentration to obtain an estimated annual nutrient loading. The upstream runoff volume was used as the annual water loading.

TABLE 4

Water Quality Monitoring Results - Cumberland Ditch

1992

Date	920415	920527	920624	920714	920811
Alkalinity	24 mg/L	27 mg/L	26 mg/L	28 mg/L	32 mg/L
Ammonia - N	0.035 mg/L	0.024 mg/L	0.031 mg/L	0.018 mg/L	0.067 mg/L
Dissolved phosphorus	0.003 mg/L	0.004 mg/L	0.002 mg/L	0.004 mg/L	0.013 mg/L
Chloride	3.0 mg/L	3.0 mg/L	3.0 mg/L	2.0 mg/L	8.0 mg/L
Color Pt.-Co	60	60	55	50	50
Specific Conductivity	62	65	63	66	73
Nitrate-nitrite - N	0.083 mg/L	not detect.	not detect.	not detect.	not detect.
Kjeldahl - N	0.600 mg/L	0.700 mg/L	0.700 mg/L	0.700 mg/L	1.300 mg/L
Total phosphorus	0.030 mg/L	0.029 mg/L	0.037 mg/L	0.026 mg/L	0.094 mg/L
Flow (cfs)	~ 10	9.9	0.9	7.05	0

Total Water Loading = 390 acre feet ($4.8 \times 10^5 m^3$)

Flow weighted mean concentration = 0.029 mg/L

Phosphorus Loading: Low = 31 lbs. (14 kg), Most Likely = 68 lbs (31 kg), High = 110 lbs. (48 kg)

Five separate but interrelated LEMS simulations were run and are included in Appendix D. A summary of the modelling results is shown in the following short table.

Subbasin	Recommended Model	Predicted Total Phosphorus	Observed Total Phosphorus
	Upper lake		
u. Upper lake	Reckhow, 1977 General Lake Model	10 μg/L	7 μg/L
l. Lower lake			
Rabbit Island Bay	Reckhow, 1979 Lake Model	10 μg/L	14 μg/L
Library Bay	Reckhow, 1979 Lake Model, 1979	10 μg/L	18 μg/L
	Lower lake		
Norwegian Bay	Canfield-Bachmann, 1981 General Lake Model	19 μg/L	16 μg/L
Cemetary Bay*	None	N.A.	30 μg/L

μg/L = micrograms per liter or parts per billion
*All models significantly under predicted the in-lake total phosphorus concentration.

Upon reviewing the output within the above table, it is important to note that the recommended model may not necessarily be the model with the predicted in-lake phosphorus concentration closest to the observed, but rather the model with the closest predicted phosphorus that is valid. In order to be valid, the input parameters must fall within the range of valid parameters for the data set developed by the author(s) of a given model (e.g. Reckhow, 1979). The third page of each LEMS printout in Appendix D lists the parameters for each model. With respect to the phosphorus loading module of LEMS, it normally uses the "most likely" export or load amount to arrive at a total load for the lake and the relative percent distribution for each landuse or source(s).

Upper lake

The Reckhow, 1977 General Lake Model is recommended for the upper Upper lake. This model was developed from 95 northern temperate lake with in-lake phosphorus concentrations less than 900 μg/L and and inflow concentration of less than 1 mg/L. It should be noted that no septic tank contribution has been included in the loading module. Because there was no actual monitoring of any of the loading sources, the error may be substantial in the estimates. However, the contribution from Rabbit Island bay (identified as the point source loading at 0.5 %) is based upon an estimated water loading coupled with the 1992 flow-weighted mean lake surface phosphorus concentration. Error in the loading estimate has been reduced substantially because the phosphorus concentration is known with good precision. Therefore, even if there was a fifty percent or more error in the water loading estimate into the upper Upper lake, the loading from Rabbit Island bay to the north would remain an insignficant amount.

The Reckhow, 1979 Lake Model appears best to work for Rabbit Island and Library bays in the lower Upper lake. The Reckhow, 1979 model was developed from a data set of 47 northern temperate lakes. The phosphorus levels in these lakes range from 4 to 135 μg/L, areal phosphorus loadings from 0.070 $kg/m^2m/yr$ and an areal water loading between 0.75 and 187 m/yr. Of particular note for both bays is that the phosphorus loading contribution from urban runoff is very significant and quite likely the source of the bays' present condition. This is particularily evident for Library bay where urban runoff sources (Gen. Urban and Comm./Industrial) amounts to 85 % of the total phosphorus loading. However, again it's important to stress, in the case of Rabbit Island bay, that the amount of phosphorus loading contribution from Library bay (1.2 %) was relatively insignificant in comparison to the surrounding watershed sources.

Lower lake

For the Lower lake, the Canfield-Bachmann, 1981 General Lake Model is the best valid model for Norwegian Bay. This model was developed from a data set of 704 lakes from the United States, Canada and Northern Europe. The data set for the Canfield-Bachmann model is very large and includes a large range for input parameters. From the phosphorus loading standpoint, the impact of the Cumberland Ditch (Point Source Phos.) was only about 17 % of the annual contribution. Precipitation and open space/woods combined were the major significant sources (55.1 %) and would have to be considered uncontrollable. It should be stressed that <u>no</u> estimate has been included for the potential contribution of internal loading of phosphorus from the bottom sediments impacted in the past by the City's WWTW. Obviously, including this as a source would drop the percent contribution of the other sources.

None of the models do a very good job of predicting total phosphorus levels in Cemetary Bay. These results are not surprising considering the volume of water passing through Cemetary Bay. The LEMS indicates that Cemetary Bay flushes (complete water exchange) about 20 times per year. Since Cemetary Bay is the most downstream waterbody, any errors in runoff volume from the upstream models will be the most evident at this location. In addition, the previous discussion regarding internal phosphorus loading on Norwegian Bay is even more important on Cemetary Bay. Internal loading of phosphorus from the bottom sediments of Cemetary Bay may be as much as 50 % of its annual load.

Discussion

The models recommended in the above table are reasonable selections for use on portions of Beaver Dam Lake. Using LEMS to model Beaver Dam Lake required division of the lake into subbasins (bays). The various lake models in LEMS were developed assuming a single basin lake. Given thsi assumption, the LEMS model is not well suited for multiple subbasin or segmented systems. The complexity of Beaver Dam Lake with its many bays, demands a more sophisticated modeling approach. One lake water quality model with segmentation capability is the BATHTUB model (Walker, 1987). The level of effort required to set-up and run BATHTUB is greater than that required for LEMS. However, BATHTUB will better describe the lake's bay to bay variability and behaviors.

Questionnaire

Prior to the initial formation of the Beaver Dam Lake Management District, a series of meetings were held with University of Wisconsin - Extension staff and interested lakeshore owners to determine problems and solutions that could be solved. During the February 6, 1990 meeting of the Beaver Dam Lake Association, Board of Directors, there was a concensus that an application should be made to the WDNR for a lake planning grant. Notes from that meeting (Lowell Klessig, Ph.D., 1990) indicated that one of the important issues facing a new district was:

> "... that the planning grant include some sociological surveys of the people regarding their interest in additional lake management activities and formation of a lake district and also potentially their use patterns on the lake".

One of the requirements of the Beaver Dam Lake Improvement Project was

- To gather sociological information from users of the lake on recreational uses and the identify problems in need of examination.

Therefore, a questionnaire was prepared to determine the sociological, recreational and environmental information from district members. The questionnaire was adapted from a model survey prepared by Lowell Klessig, Ph.D. and Robert Korth, Ph.D., University of Wisconsin - Extension, Stevens Point. A total of 300 questionnaires were prepared and delivered to the District at its annual meeting on July 11, 1992. The figure of 300 questionnaires represented about ten percent of the District's membership. The questionnaire consisted of 30 multiple choice questions and two narrative questions. While the quesionnaire was somewhat lengthy, it was felt that those individuals that were sincerely interested in Beaver Dam Lake would take the time necessary to fill it out and return it to the District.

In addition, to questions about the a persons feelings about the lake and its environment, the questionnaire contained a map which divided the lake into three zones. Zone 1 included the upper Upper lake as well as Rabbit Island bay. Zone 2 included the Library Bay area and Zone 3 was the Lower lake. Because the lake was so different in quality, it was felt that it would be useful to segregate responses from these areas of the lake, narrow, and prioritize specific management issues. The questionnaires were sent out by direct mail to as many of the lakeshore owners as possible and an additional small segment of the District population.

The survey was **not** intended to be a random sample of the District's membership. The main reason for the non-random sampling was to acquire as much information as possible from those individuals that live on the lake and therefore had the greatest opportunity to observe changes and/or problems in Beaver Dam Lake.

A copy of the questionnaire is included as Appendix E.

Results

Of the 300 questionnaires sent out, a total of 102 or 34 % were returned with responses which could be tallied and analysed. A summary of the questionnaire results is presented in Table 5. The following are highlights from the some of the survey results and where appropriate a short discussion of the specific differences noted based upon the three zones. A separate report could have been prepared on only the questionnaire, so this summary raises only the major issues of importance by the respondents. Three-quarters of the responses came from Zone 1, while 9 % came from Zone 2 (Library bay) and 12 % from Zone 3 (Norwegian/Cemetary bays).

Lakeshore

The median frontage for lakeshore lots is 117 feet with 39 % of the respondents indicating that natural vegetation best describes their lakeshore.

Structures and Watercraft

About 74 % of the homes are winterized with the remainder used as summer cottages. Sheds are favored by 61 % of the respondents as accessory structures. Motor boats over 25 hp are the most popular on the lake with motor boats less than 25 hp, canoes and pontoons followed closely behind.

Residency

About 48 % of the lakeshore owners are year round residents, while only 14 % are weekend users.

Clarity and Water Quality

Three-quarters (76 %) of the respondents indicate that the water clarity is "clear or crystal clear" and 22 % as "cloudy or murky". Similarily, 69 % felt that the water quality was "good to very good" and 30 % "fair to poor". However, an overall conclusion that the lake is in clear and good condition would be very misleading. Where 89 % of the respondents in Zone 1 felt the clarity was clear to crystal clear, 55 to 66 % of the respondents in Zones 2 and 3 said the clarity was cloudy to murky. From a water quality perspective, 81 % of those in Zone 1 consider it to be good to very good while in contrast 66 to 78 % in Zones 2 and 3 believe it to be fair to poor.

Water Quality Trends

Surprising is the fact that 45 % of the respondents believe that the lake quality near their lakeshore has slightly degraded or considerably degraded and only 24 % believing its remained the same. From a zone perspective the responses are very different. Nearly 40 % of the respondents in Zone 1 believe that the water quality has stayed the same while a much smaller amount, 12 %, believe it has considerably degraded. In Zone 2 (Library Bay), 55 % indicated that the quality had slightly or considerably degraded. Most surprising and encouraging is the fact that 42 % of the respondents in Zone 3 (Norwegian and Cemetary bays) believe that the quality has gotten better. This was the only zone in which water quality was considered to have improved on Beaver Dam Lake.

Plant Growth

Plant growth was thought to be moderate and just right for fish and wildlife for 54 % of all the respondents. From a specific location, however, heavy to choked weed growth adversely impacting use of the lake was seen by 44 to 67 % of the respondents in Zones 2 and 3.

Boater Conflict and Public Access

Boat traffic was considered moderate by 55 % of the lakeshore owners and not impacting their use along with 87 % believing that little or moderate conflict had been experienced. Public access is considered by more than two-thirds (67 %) of the respondents to be adequate for Beaver Dam Lake.

Lake Management

More than half (57 %) the respondents believe that the Beaver Dam Lake Management District is most important in managing the lake. Development of a long-term lake management plan is felt to be the most important action that should be taken by 45 % of the persons. The super-majority of the respondents feel that a newsletter is best way for the District to communicate with the membership.

Conclusions

1. Water quality data was successfuly acquired from May through August on seven monitoring stations on Beaver Dam Lake and on the Cumberland Ditch during April through August in 1992.

2. Temperature profiles of Beaver Dam Lake indicated strong vertical stratification in all the bays except Cemetary due to its shallow depth.

3. Approximately 13 % of the volume of the hypolimnion (water column portion below the thermocline) was depleted of dissolved oxygen in upper Upper lake (C1, C2, & C2A) of Beaver Dam Lake during June, July, and August of 1992.

4. Approximately 86 % of the volume of the hypolimnion (water column portion below the thermocline) was depleted of dissolved oxygen in Rabbit Island Bay (C6) of Beaver Dam Lake during June, July, and August of 1992.

5. More than 100 % of of the volume of the hypolimnion (water column portion below the thermocline) was depleted of dissolved oxygen in Norwegian Bay (C5) of Beaver Dam Lake during June, July, and August of 1992.

6. The trophic state (nutrients and algae) of the upper Upper lake is considered in good to very good condition with a recreational suitability of beautiful and a physical appearance of crystal clear.

7. The trophic state of Library Bay is considered to have a minor aesthetic impacts due to algae, but extensive emergent and submergent weed growths.

8. Norwegian Bay in the Lower lake is considered to be in a highly productive trophic state with a range of recreational suitability impacts of minor to swimming impaired.

9. Cemetary Bay in the Lower lake is also considered to be in a highly productive trophic state with recreational suitability of swimming being impaired or eliminated.

10. A downward trend in total phosphorus concentrations was statistically confirmed in the upper Upper lake over the period of 1975 through 1992, but may well be an artifact of changed laboratory analytical procedures and not environmental causes.

11. A dramatic downward trend in total phosphorus concentrations was statistically confirmed in the Lower lake and has likely the resulted from the diversion of the City of Cumberland's wastewater treatment plant discharge to Cemetary Bay.

12. Lake modelling of the upper Upper lake confirmed the in-lake total phosphorus concentration, but does not support the contention that the nutrient loading from Rabbit Island and Library bays could be a significant source.

13. Lake modelling of Library Bay indicated that urban runoff sources contribute 86 % of its annual total phosphorus loading.

14. Lake modelling of the Lower lake (Norwegian Bay) revealed that the Cumberland Ditch would contribute only 17 % of the phosphorus loading on an annual basis.

15. The existing lake models used in this study are not sophisticated enough to permit an accurate simulation of Cemetary Bay's water quality.

16. Of the 300 questionnaires sent out to Beaver Dam Lake Management District members, a total of 102 or 34 % were returned for analysis of results.

17. About 48 % of lakeshore owners are year around residents with only 14 % being weekend users.

18. About 89 % of the respondents in Zone 1 (upper Upper lake) felt the lake's clarity was "clear to crystal clear"; conversely 55 to 66 % of the respondents in Zone 2 (Library Bay) and Zone 3 (Lower lake) believe the clarity was "cloudy to murky".

19. Nearly 40 % of the respondents in Zone 1 believe that the water quality has stayed the same, while 12 % felt it had gotten worse; conversely 55 % of the persons in Zone 2 indicated that the water quality had slightly or considerably degraded.

20. Most surprising and encouraging was that 42 % of the respondents in Zone 3 (Norwegian and Cemetary bays) believed that the water quality had gotten better.

21. Plant growth was thought to be just right for fish and wildlife by 54 % of the respondents overall, but in Zones 2 and 3, a total of 44 to 67 % felt conditions were heavy or weed choked.

22. Boat traffic was considered moderate by 55 % of the lakeshore owners and that little or moderate conflict had been experienced by 87 % of the respondents.

23. Public access is considered by more than two-thirds (67 %) of the persons to be adequate for Beaver Dam Lake.

24. More than half (57 %) of the respondents believe that the Beaver Dam Lake Management District is most improtant in managing the lake along with the development of a long-term lake management plan as the most important action by 45 % of the respondents.

25. A newsletter is considered by 68 % of the questionnaire respondents to be the best manner for the District to communicate with the membership.

Recommendations

1. Water quality monitoring of Beaver Dam Lake should be undertaken for one or two more growing seasons to confirm the water quality trend in the upper Upper lake and determine whether the Lower lake is reaching a steady state (leveling off in quality).

2. Serious consideration should be given to water quality and flow monitoring of selected inflows to Beaver Dam Lake to validate nutrient loading and subsequent lake modelling with BATHTUB.

3. The District should apply for an additional WDNR lake planning grant by August 1, 1993.

4. The District should approach the WDNR about participation in the U.S. Environmental Protection Agency's Clean Lakes grant program for Beaver Dam Lake in Fiscal Year 1994 (October 1, 1993) to offset the cost of a more complex monitooring and modelling effort.

5. The District should develop a newsletter for communication to its members on its actions.

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