#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;

- 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.

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.

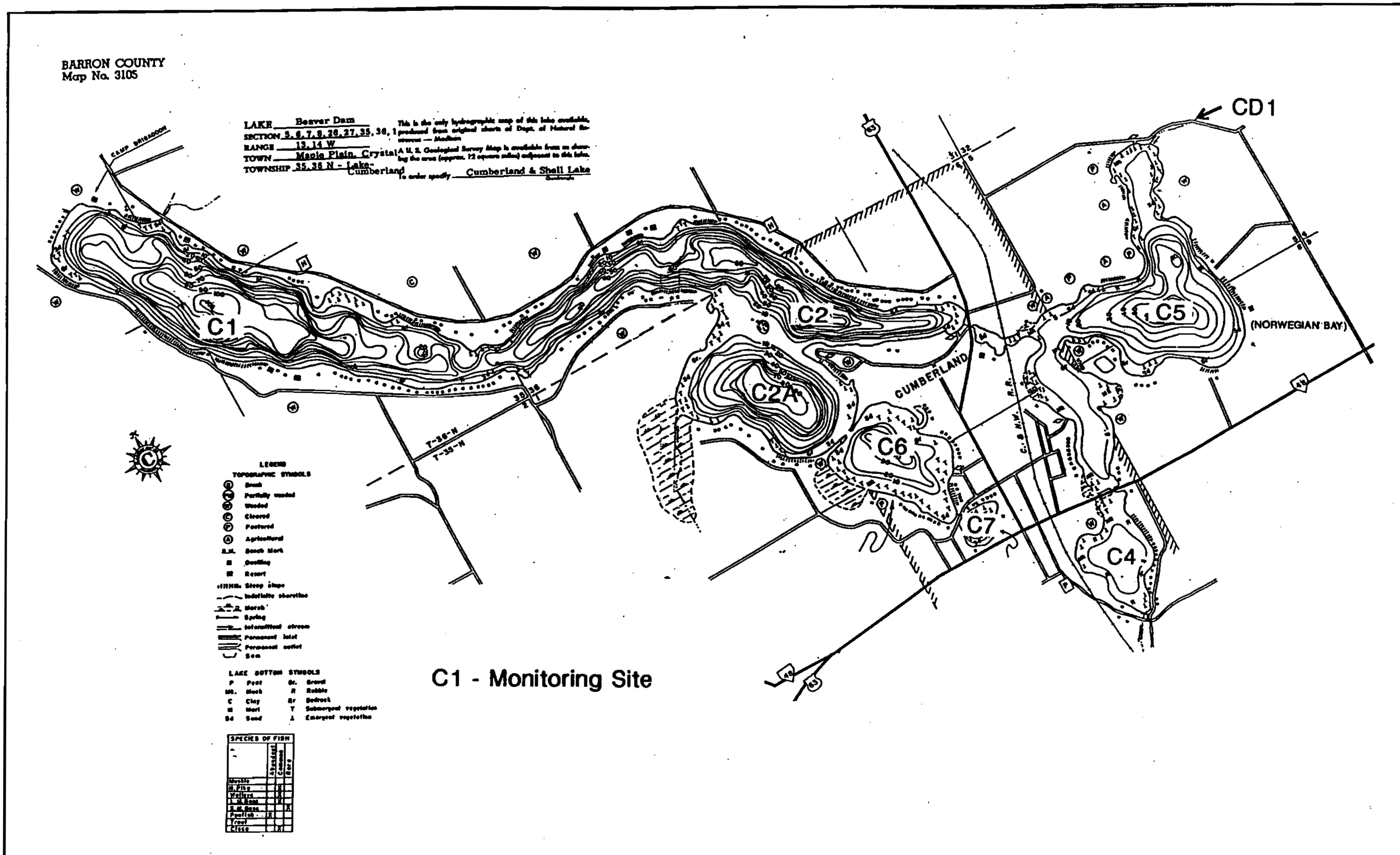
Other specific hypotheses could be tested as additional data is gathered on Beaver Dam Lake in the future.

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.

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[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

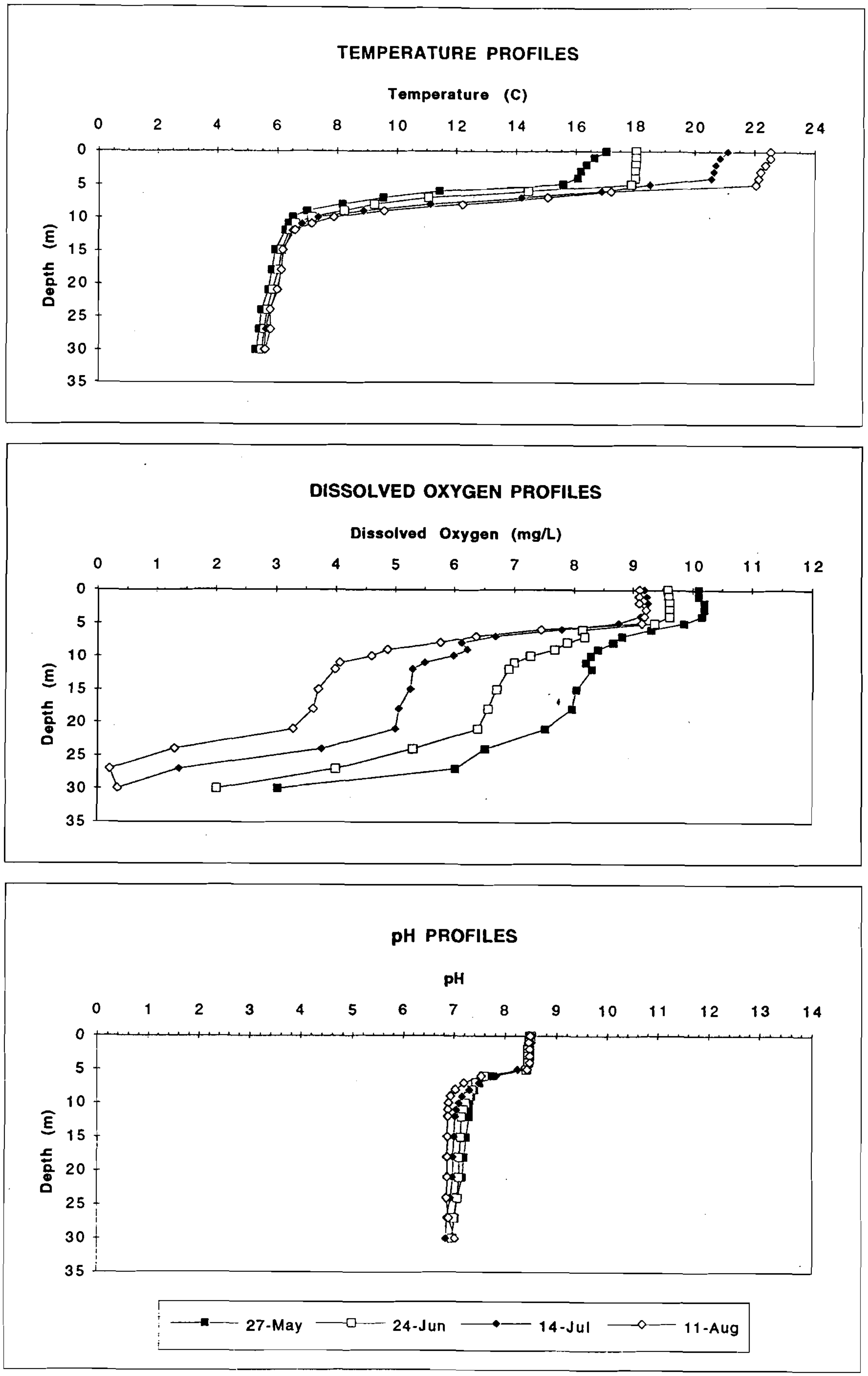

Figure 3

BEAVER DAM LAKE SAMPLING SITE C2

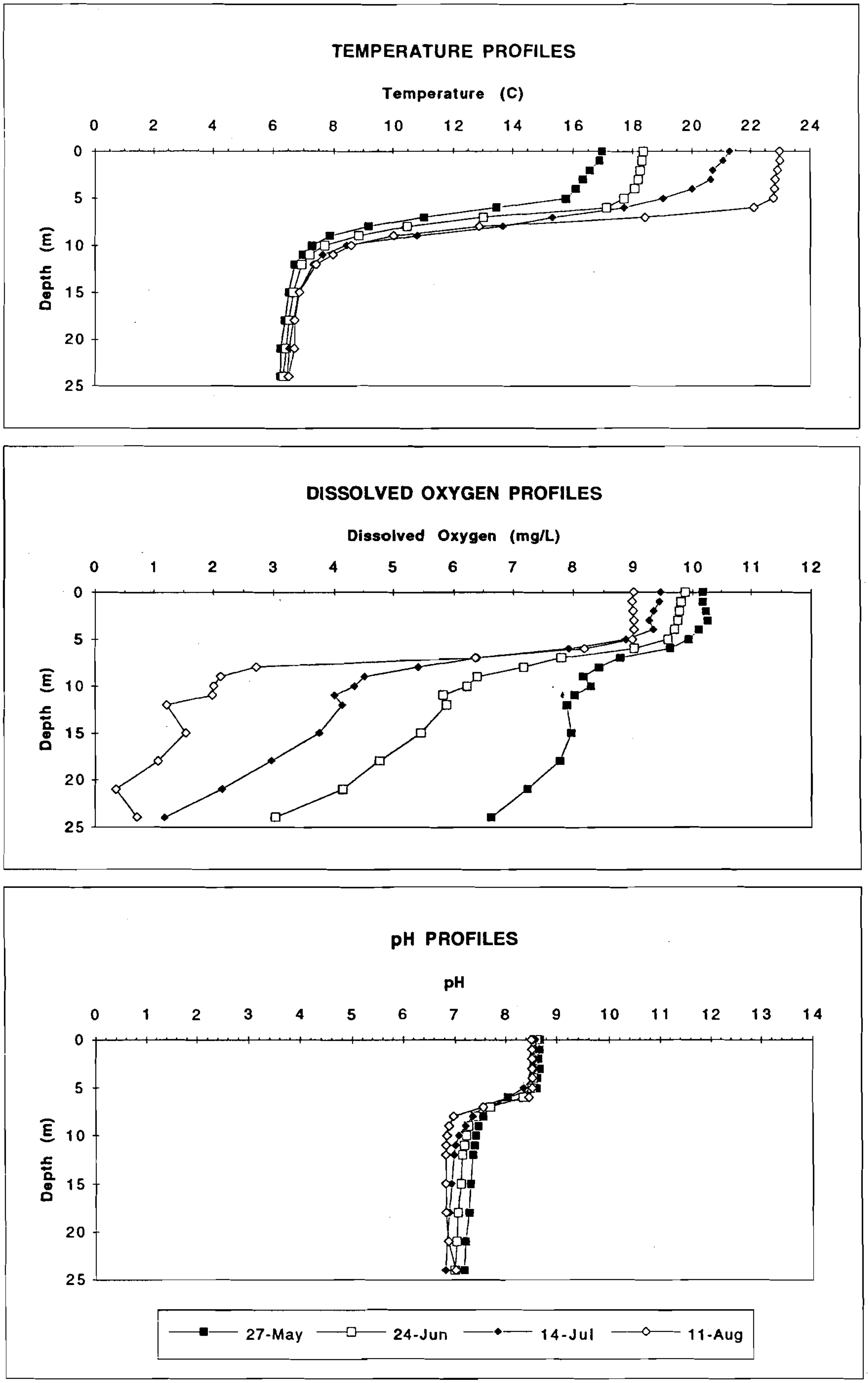

Figure 4

BEAVER DAM LAKE SAMPLING SITE C2A