Date of Report: December 30, 1993
LCMR Final Status Report - Detailed - Research

I. Project Title: Ecological Evaluation of Year Round Aeration

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A. M.L. 91 Chpt. 254, Art. 1, Sec. 14, Subd. 4(n) Appropriation: $100,000
Balance: $ 12,761

Ecological Evaluation of Year-Round Aeration: This appropriation is from the Minnesota environment and natural resources trust fund to the commissioner of natural resources to collect baseline data on aerated and non-aerated lakes and determine ecological impacts of aeration.

B. N/A

C. N/A

II. Narrative

A. An increasing number of aeration systems are being operated year-round in Minnesota lakes to mitigate water quality problems. Most of these systems operate by using bubbles to induce circulation throughout a lake's water column. The ecological impact of this practice (aeration/circulation) is poorly understood.

B. Aeration is a well accepted fisheries management tool to reduce the potential for winterkill. Claims have been made that year-round aeration will also mitigate a variety of water quality problems. These claims need to be evaluated to insure that the ecological effects of year-round aeration are consistent with the state's water quality and fisheries management goals.

C. Over 200 aeration permits for "protected" waters are issued in Minnesota annually, though the majority involve only wintertime use. Approximately twenty-five permits were issued last year for year-round use where water quality improvement was one of the stated goals. The prevalence of year-round aeration in "nonprotected" waters of the state is unknown by the program manager.

III. Objectives

A. Assess how aeration alters important physical and chemical gradients in lakes, especially those gradients of biological significance.

A.1. Narrative: Physical and chemical gradients normally occur in most Minnesota lakes due to seasonal changes in temperature. The location, amplitude, and duration of these vertical gradients is very important in determining a lake's water quality and fisheries management potential. Aeration technologies currently in use in Minnesota

are most commonly designed to eliminate or minimize existing gradients. The focus of this objective is to detail, in a comparable cross section of aerated and non-aerated lakes, the extent to which important gradients are being altered. The impact of this alteration on algal abundance and biological oxygen demand (BOD) will be specifically assessed. Algal abundance is being assessed because it represents the most direct water quality indicator (with respect to recreational use). BOD is being assessed because of its importance to fisheries management. High BOD coupled with low in-lake oxygen concentrations can lead to a fish kill.

A.2. Procedures: Ten lakes (five that are currently aerated year-round and five that are not) will be chosen for study. To the extent possible, the lakes will be paired so that each aerated basin is matched with a non-aerated lake similar in size, mean depth, watershed area, and land use. This selection process will be facilitated by cooperation with the Metropolitan Council (which has detailed information on over 120 lakes in the Metropolitan area), the Minnesota Pollution Control Agency, and fisheries personnel. The select pairs will also be reasonably close geographically (i.e. study lakes will likely all be with greater metropolitan area) to minimize climatic differences.

The sampling program was developed after extensive consultation with other local limnologists (including those at the University of Minnesota, Minnesota Pollution Control Agency, Metropolitan Council) and is designed to complement existing data bases and sampling programs.

Because most lakes that are aerated year-round are small (typically less than 100 acres) and because the goal of aeration is to completely mix the basin, a single sampling site will be adequate. Each lake will be sampled approximately 18 times over the course of one year (from Oct. '91 through Oct. '92). The sample frequency will be once per month in the winter (when access is safe) and twice per month during the open water period. The following parameters will be measured at the mid-lake station:

Parameter	Samples	Frequency
Temperature	Water Column at 0.5m intervals	Every trip
Oxygen	Water Column at 0.5m intervals	Every trip
Secchi Disk Depth		Open Water only
Underwater Illuminance	0.5m intervals	Open Water only
Total Phosphorus	Integrated epilimnetic additional at 4 meter intervals	Every trip
Total Kjeldahl Nitrogen	Integrated epilimnetic	Every trip
pH	Same depths as TP	Every trip
Alkalinity	Integrated epilimnetic	Once a month
Ortho-Phosphate	Integrated epilimnetic	Open Water only
Nitrate/Nitrite-Nitrogen	Integrated epilimnetic	Open Water only
Chlorophyll <u>a</u>	Integrated epilimnetic	Once a month

The four major goals of this sampling program will be to: 1) evaluate the physical effectiveness of the aeration systems; 2) characterize the water quality of the lakes' surface layer; 3) detail the annual nutrient dynamics; and 4) evaluate fish habitat.

The measurement of temperature and oxygen profiles will be used to ascertain the extent to which vertical gradients have been eliminated by aeration (goal 1). Measurement of most water quality parameters (goal 2) will be restricted to an epilimnetic sample. This restriction (epilimnetic only) is reasonable in this study because public use of and management efforts are focused on a lake's surface layer. The exceptions to this approach are for phosphorus, pH, and BOD. As a rule, phosphorus availability limits primary production in metropolitan lakes and additional phosphorus samples (at 3-4m intervals) will be collected so that annual nutrient dynamics can be estimated (goal 3). Oxygen and BOD profiles will be examined to determine if aeration has improved the habitat for fish or increased the potential for a summerkill occurrence (goal 4).

Approximately 10% of the field samples will be duplicated as part of our quality assurance program. Paired comparisons (aerated vs non-aerated pairs) will be the basis for evaluation.

A.3. Budget:

	LCMR Funds
a. Amount Budgeted:	$ 39,500
b. Balance:	$ 11,823

A.4. Timeline for Products:

	7/91	1/92	6/92	1/93	6/93
Select study lakes	******				
Collect field data	*********************				
Analyze data			***************		
Consult with fisheries managers				*******	
Final evaluation of results				*****************	

A.5. Status: The study lakes (5 aerated and 6 non-aerated, reference, basins) were selected after consultation with Metro DNR Fisheries, MPCA, the Metropolitan Council, lake aeration reports in the DNR, other local units of government, lake associations, aeration suppliers, and the major cooperators. All eleven lakes are located in the metropolitan counties of Dakota (Farquar), Hennepin (Arrowhead, Indianhead, Crystal, Gleason, Holy Name, Hadley, Wolsfeld, and Twin), Carver (Susan), and Ramsey (Josephine) and represent the range of aerated lake types.

Collection of field data was initiated in October 1991 and completed in October 1992. During the 1991/1992 hydrologic year (10/91-10/92), sixteen sampling trips to each lake were conducted. Collection and analysis of all physical and chemical parameters listed under Objective A were completed as planned. The data was entered into spreadsheet format (LOTUS 123). Primary data analysis was conducted

by Robert Beduhn (Barr Engineering) as a partial requirement for a Masters Degree in Professional Engineering (under the direction of Dr. John Gulliver, University of Minnesota).

The study lakes were found to represent three different lake types: 1) dimictic lakes-those that normal stratify (form a warm surface and cold bottom layer) during the summer; 2) polymictic lakes that typically do not stratify and mix repeating throughout the summer; and 3) an intermediate group. For lakes in the dimictic group, aeration/circulation altered most of the paramaters evaluated in Objective A and markedly changed in-lake conditions. At the other extreme, no response to aeration/circulation was seen in the polymictic group. This response was not unexpected since polymictic lakes are normally completely circulated by the wind. The intermediate group also showed chemical/physical changes associated with aeration.

For lakes in the dimictic and intermediate groups, the following general conclusions were reached:

1) aeration was generally effective at circulating the lake;
2) aeration did not improve the water quality of the lake's surface layer and, in some cases, water quality declined;
3) aeration increased nutrient availability in the lake's surface layer which promoted increased algal growth; and
4) the amount of fish habitat expanded with aeration.

These results are discussed in more detail in the attached summary report (Chapter I).

A.6. Benefits: Most aeration systems currently operating in Minnesota are designed to eliminate the normal stratification patterns that exist in lakes. This objective will determine whether this practice improves water quality and/or the fisheries habitat. The data collected in this objective will also be valuable for the interpretation of Objectives B-E.

B. Assess impact of aeration on seasonal distribution and abundance of algae, particularly bluegreen algae.

B.1. Narrative: Bluegreen algae, particularly taxa which produce large "scum-forming" colonies, represent a major water quality problem in Minnesota. The scientific literature suggests that reduction in bluegreen abundance is one of the water quality improvements most often associated with whole lake aeration (circulation). The focus of this objective will be to evaluate in what lake types aeration reduces overall bluegreen abundance and/or the frequency of algal scums and thereby im[illegible]es recreational [illegible]ability.

B.2. Procedure: Epilimnetic water samples collected for chlorophyll a analysis (see Objective A) will be subsampled for phytoplankton identification and quantification. The quantification process will be an adaptation of the Rapid Assessment Procedure used by the Minnesota Pollution Control Agency. The goal of that procedure is to identify the predominant taxa present and subjectively estimate their relative proportion (based on volume) in the community. As such, numerical counts are not reported (only a series of percentages). The analyst is free to make numerical counts, measure cell volumes, or some combination, depending on the actual composition of the sample in question. (All samples will be provided at once, with replicates, in coded bottles to minimize bias). This procedure has the advantage that it is much faster than the normal procedure (where hundreds of cells/colonies are individually counted and measured) and has a resolution appropriate for our objective - are there major changes in the abundance or seasonal distribution of bluegreen algae? Paired treatment (aerated) and control (non-aerated) lakes will be the basis for making comparisons.

A field assessment of recreational suitability will be conducted using the Lake UserSurvey Form (Minnesota Pollution Control Agency). This assessment technique will be used by project personnel each time a lake is visited during the open water period. The survey allows water conditions (e.g. algal scums) which reduce recreational suitability to be quantified. Research has indicated that this is an effective way to evaluate how water quality changes affect the lake user.

B.3. Budget:

	LCMR Funds
a. Amount Budgeted:	$ 6,000
b. Balance:	$ 0

B.4. Timeline for Products:

	7/91	1/92	6/92	1/93	6/93
Collect algal samples	*	*************			
Make field observations	*	*************			
Apportion algae into taxa				*********	
Final evaluation of results					*********

B.5. Status: Epilimnetic algal samples were collected from each of the study lakes in October 1991 and during the ice-free study period in 1992 (April-October). In total, thirteen samples from each lake were collected and preserved (a total of 156 samples were collected counting duplicates). These samples were enumerated en masse, the algae present apportioned into species, and the results interpreted. Duplicate samples were compared to estimate the uncertainty associated with the results. Dr. Lloyd Ohl, an algal taxonomist with the University of Wisconsin, Eau Claire, enumerated the collected samples.

The response of the algal community to aeration also varied as a function of lake type. Lakes in the dimictic or intermediate class showed a seasonal pattern of algal composition that differed from the non-aerated reference lakes. In general, bluegreen algae were less abundant in the dimictic/intermediate lakes that had an aeration system. This difference was not very pronounced for Crystal Lake (in comparison to Twin and Josephine) but was very pronounced for Hadley and Gleason Lakes (in comparison to Wolsfeld and Susan, respectively). The increased mixing depth and lower pH in the aerated lakes may have been less favorable conditions for bluegreen algae growth. In contrast, aeration had no discernible impact on bluegreen algae abundance or algal community composition for lakes in the shallow, polymictic class.

See attached summary report for a more detailed description of the seasonal changes in algal composition (Chapter I).

Recreational suitability assessments were also conducted in October 1991 and throughout the ice-free study period in 1992. A total of thirteen assessments was completed for each study lake as well. Aeration/circulation was not found to alter recreational suitability in any of the lake types. This result was surprising since other trophic state parameters (e.g. total phosphorus, chlorophyll a, bluegreen algae composition, Secchi disk depth) did show consistent patterns associated with aeration, at least in the deeper lakes. We believe this lack of response reflects the complex nature of what a lake user perceives as water quality. As previously discussed in Objective A.5., phosphorus concentrations and algal abundance increased in lakes in the dimictic and intermediate classes when they were aerated/circulated. This increase in algal abundance would be expected to reduce recreational suitability. However, aeration also reduced bluegreen algae abundance (see above) which may improve recreational suitability. These two processes appear to have counteracted each other so that no measurable change in recreational suitability was observed. In the shallow/polymictic lakes, no change in recreational suitability was observed. This result was consistent with the other physical and chemical parameters measured which also did not change.

B.6. Benefits: Severe water quality degradation has been associated with the presence of certain colony-forming bluegreen algae (e.g. Aphanizomenon, Anabaena, and Microcystis). This objective will evaluate whether aeration alters the seasonal distribution or abundance of bluegreen algae in the surface water or the extent of surface scums.

C. Assess impact of aeration on sediment deposition rates and characteristics.

C.1. Narrative: High deposition rates of organic sediments is a problem which plagues many lakes in Minnesota. These sediments may eliminate oxygen necessary for desirable fish species and other aquatic life, support heavy aquatic weed growth, add nutrients to the overlying water column, and accelerate the loss of lake volume.

Year-round aeration has been proposed as a solution which would reduce the rate of deposition as well as the organic content of the sediment. The effectiveness of this approach will be evaluated using the historical record in lake sediments.

C.2. Procedures: The organic content and accumulation rate of sediment will be determined for all 10 lakes included in Objective A. The basin pairs (one aerated and one control) will range in depth from shallow to deep and the range of basin types currently being aerated within the state. Only lakes that have been aerated for a minimum of five years (to insure an adequate sedimentary signal) will be selected. One sediment core will initially be obtained from the profundal (deep water) area of each lake and sectioned for detailed analysis. The sections will be dated (using ^{210}Pb) and their organic/inorganic content will be determined. Based on the observed sedimentation rate, 2-4 additional, less detailed, cores per lake will be obtained to characterize within lake variability. Each pair will then be examined to determine if sedimentation rate and/or organic content of the sediment changed with the <u>onset</u> of aeration (the control lake will provide the historical reference for evaluating change).

C.3. Budget:

	LCMR Funds
a. Amount Budgeted:	$ 36,000
b. Balance:	$ 0

C.4. Timeline for Products:

	7/91	1/92	6/92	1/93	6/93
Select lake to be cored	**				
Obtain and analyze cores		****************			
Final report of analysis				************	

C.5. Status: This task was completed by the major cooperator responsible for Objective C (Dr. Dan Engstrom, University of Minnesota). Ten lakes located within the metro-area counties (ten of the eleven lakes in Objective A) were selected for study, based on their recent history of human impact. Half of the lakes had been aerated for most of the last decade if not longer, the other five lakes, selected as reference basins, had not been aerated. In mid-October, 1991, a single sediment core was collected from the deepest location within each basin (the "central core"). These central cores were 1.2-1.4 meters in length, except at two sites where peat was encountered beneath a surficial deposit of lake sediment; somewhat shorter sections were recovered from these lakes. The cores were sectioned in the field in 1-2 cm increments from the upper 20-40 cm and in 4-cm increments below that. Preliminary dating for Hadley and Wolsfeld lakes shows unexpectedly high sedimentation rates such that the initial central cores appeared too short to encompass pre-settlement conditions; similar conclusions based on loss-on-ignition data were also reached for Crystal, Gleason, and Josephine lakes. Deeper core sections were obtained at these latter five sites in July 1992.

Loss-on-ignition analysis and lead-210 dating was completed for the detailed central core from each of the ten study lakes. These analyses include the cores collected in October 1991 as well as longer core sections obtained from the central core-sites in Crystal, Gleason, Hadley, Woldsfeld, and Josephine in July 1992. Two additional cores were collected from each lake during the fall of 1992. These secondary coring sites were widely spaced from one another and from the central cores so as to encompass a range of depositional environments in each lake. The new cores were sectioned into 6-8 coarse intervals based on results from the detailed cores and other stratigraphic markers evident in the field. Loss-on-ignition determination of organic and carbonate content and lead-210 dating was completed for all 20 of these profiles.

Our results indicate that aeration has not altered the rate of accumulation or the organic content of sediments in the study lakes. This result was consistent across all lake types (see Obj. A) examined and between the three cores collected within each lake. In addition, there was no indication that aeration enhanced the redistribution of sediments from littoral areas to deeper sites within a lake. Rates of sediment accumulation in these lakes have increased since European settlement of the region (c. 1870). The magnitude of increase was 2-8x pre-settlement rates. Sediment composition also changed in most lakes over the same period. The organic content decreased by 25-70% due to increased inputs of silts and clays from erosion. Historic patterns of sediment accumulation and composition in the aerated lakes, however, were not different from those observed in the non-aerated reference lakes. We concluded that aeration had no discernable impact on lake sediments and that accumulation rates and organic content were not altered. Dr. Engstrom's complete findings are included in the attached summary report (Chapter II).

C.6. Benefits: Accumulation of highly organic sediments has detrimental impacts on public use, water quality, and fisheries management in many Minnesota lakes. Year-round aeration has been advocated as a method to reduce and potentially reverse the accumulation of these sediments. This objective will critically evaluate whether these benefits (lower sediment accumulation rates and/or reduced organic content) are observed.

D. Assess impact of aeration on macrophyte community composition and distribution.

D.1. Narrative: Aquatic macrophytes (large, primarily rooted, plants) constitute a large and very valuable component of many Minnesota lake ecosystems. The plants provide food and habitat for many species of fish and wildlife, as well as reducing the erosion of shoreline areas. Heavy macrophyte growth, however, may restrict use of the lake by swimmers, boaters, and anglers (particularly in shallow areas with organically rich sediments). Operation of aeration systems during the open-water period can alter the distribution and abundance of aquatic macrophytes. Changes in water transparency (see Objective A), in sediment deposition patterns (see Objective C), or water current velocities could affect the composition, abundance, distribution of the aquatic plants. The focus of this objective is to determine: 1) whether the onset of aeration changed the historical distribution of aquatic plants in selected lakes; and 2) whether the composition and distribution of macrophytes differs systematically in aerated and non-aerated lakes.

D.2. Procedures: The composition and distribution of the macrophyte community will be mapped once or twice during the summer (late June and, if needed, again in early August) of 1992. Data will be collected on the same 10 lakes used in Objective A. Knowledge of important physical, chemical, and biological conditions will facilitate interpretation of differences in distribution or composition that exist between lakes or lake types (aerated vs non-aerated). The mapping procedure (using stratified random transects) will focus on determining the community composition and depth distribution of the various stands. Plant density will not be measured.

Historical changes in macrophyte distribution will be assessed by examining air photos. Various air photos of the study area have been taken in the last two decades by a variety of organizations (Army Corps of Engineers, Agricultural Stabilization and Conservation Service, Soil Conservation Service, Metropolitan Council, U.S. Forest Service) and include two complete sets of color IR (the preferred film) photos taken in the summer of 1978, and 1985. Additional summer photos of the study area may exist as well. This photographic record will be examined to determine whether the apparent distribution of macrophytes has changed since the onset of aeration (various dates between 1973-1990). The amount of change apparent in the non-aerated lakes will serve as the "control" baseline.

Interpretation of the historical photos will be enhanced by contracting for a current set (summer 1992) of color IR photographs for the 10 study lakes. Current photos will also allow evaluation of lakes where aeration has been implemented since 1985.

D.3. Budget:

	LCMR Funds
a. Amount Budgeted:	$ 8,500
b. Balance:	$ 938

D.4. Timeline for Products:

	7/91	1/92	6/92	1/93	6/93
Select lakes	*****				
Assess macrophyte communities			**		
Obtain and analyze historical air photos		******************************			
Shoot current air photos			***		
Final reports of analysis					*******

D.5. Status: Ten study lakes (5 aerated and 5 control basins) were selected for macrophyte assessment and represent 10 of the 11 lakes identified in Objective A. Observations during early summer 1992 indicated that two mappings of the macrophyte community would be needed for an accurate assessment. The initial mapping was completed between June 29 and July 2, 1992, while the second mapping was conducted between August 14 and September 14, 1992. Mapping the two smallest lakes (Indianhead and Arrowhead) was problematic. Heavy macrophyte control efforts in both lakes confounded attempts to assess the community. Neither lake was sampled during the initial assessment. An assessment was completed on both lakes but it was delayed until early fall of 1992.

Aerial photos of all study lakes were taken in July 1992 by Forest Inventory (MDNR, Grand Rapids). Both infrared and panchromatic (regular visible) color slides were taken (8"x11" color prints were also produced in both formats). The combination of film types was used to see which format best delineated submerged vegetation.

Our study found no indication that multiple years of aeration has reduced the distribution or abundance of the macrophyte community in the study lakes. Survey work conducted in 1992 indicated that the macrophyte community was at least as diverse, as abundant, and as extensive in its distribution in the aerated lakes as in the historical records that were available. Historical records in the MN DNR Fisheries files were used exclusively because historical aerial photos in panchromatic color format (the format we found was better for seeing submerged vegetation) do not exist. These results are tempered by the fact that a comprehensive historical record was not available and year-to-year variation within lakes appears large.

Consistent differences in the composition of aquatic macrophytes were found between aerated and non-aerated lakes in 1992. Specifically, Ceratophyllum demersum, Chara/Nitella, Elodea canadensis, Nelumbo lutea, and Potamogeton foliosus were more abundant in non-aerated lakes, while Najas flexilis, Potamogeton crispus, and Potamogeton zosteriformis were more abundant in lakes with aeration systems. Whether the differences represent an effect of aeration or underlying differences in lake type was not clear.

A more detailed description of the macrophyte assessment is included in the attached summary report (Chapter III).

D.6. Benefits: Aquatic macrophyte stands are an integral part of lake communities, but their over-abundant growth is a nuisance. Analysis will indicate whether year-round aeration systematically alters the composition or distribution of those stands.

E. Assess trophic (nutrient) response of lakes to aeration.

E.1. Narrative: Each of the preceding objectives was focused on one limited portion of the project's goal. None by itself provides a complete picture of the ecological impacts of aeration. The focus of this objective is to provide a more comprehensive view. This objective will be met by examining historical changes in the diatom community preserved in the sediment of aerated lakes vs non-aerated lakes. The community composition of diatoms (a particular group of algae) is very sensitive to water quality changes (e.g. water clarity, nutrient concentrations, mixing regimes) and the ecological preferences of most species are known. Change in community composition therefore can be used to reconstruct the water quality changes that occurred in previous years. This objective will use diatom remains to examine how a lake's trophic (nutrient) state changed in response to aeration. The magnitude and direction of changed observed in aerated lakes will be assessed and compared to the amount of change observed in the control lake's diatom community.

E.2. Procedure: All aerated and control lakes cored in Objective C will be used for diatom reconstruction. Each core will be sectioned into slices representing five years accumulation of sediment before and five years accumulation of sediment after the initiation of aeration. ^{210}Pb dating allows the appropriate thickness to be determined even if aeration has altered the rate of sediment deposition. Control lakes will be sectioned over the same time period to minimize interannual climatic variation. The pre-aeration community will then be compared to the post-aeration community and any changes evaluated. The magnitude and direction of change will be assessed by using canonical correspondence analysis to summarize the community change. This technique allows the difference between two communities to be represented in two dimensions. The change observed in the control community will then be plotted on the same areas. This will allow the magnitude of community change to be directly compared between aerated and non-aerated lakes. The direction of change will also be interpreted based on knowledge of diatom specific ecology preferences and the water quality variables measured in Objective A. For example, if aeration has decreased nutrient availability and increased water transparency, shifts in the species composition of diatoms will change in predictable ways.

E.3. Budget:

	LCMR Funds
a. Amount Budgeted:	$ 10,000
b. Balance:	$ 0

E.4. Timeline for Products:

	7/91	1/92	6/92	1/93	6/93
Collect and date cores	******************				
Section cores and identify diatoms		***************			
Perform C.C. analysis and evaluate community changes				********	
Final report of analysis					******

E.5. Status: This task was completed by the major cooperate responsible for Objective E (Dr. Sheri Fritz, University of Minnesota). The 10 study lakes selected for a comprehensive historical evaluation using diatom community structure were the same lakes from which sediment cores were obtained (see Obj. C). Four time periods were selected for analysis in each lake. For the aerated lakes, two samples were chosen before, and two samples after, the onset of aeration. Samples were chosen to bracket the onset of aeration as closely as possible. Samples representing comparable time periods were chosen for the reference lakes.

Dramatic changes in the diatom community were not found in any of the lake cores sampled. This lack of dramatic change suggests that none of the lakes, aerated or reference basins, had experienced major changes in their physical or chemical conditions over the period of record. Some of the aerated lakes did show small changes in diatom community composition associated with the onset of aeration. An increase in abundance of various species of the genus Aulacoseira was observed in a number of lakes. Aulacoseira, a genus which reaches maximum abundance during periods when waters are cold and well mixed, would be expected to increase in response to year-round aeration/circulation.

Dr. Fritz's complete findings are included in the attached summary report (Chapter IV).

E.6. Benefits: Year-round aeration alters many physical and chemical parameters in lakes. The diatom record should provide specific detail on whether the diatom community responded to those changes in predictable ways. If consistent patterns emerge, the diatom community changes can be used to historically reconstruct the magnitude of physical/chemical change associated with year-round aeration.

IV. Evaluation:

The project can be evaluated by its ability to demonstrate ecological differences (or lack thereof) between aerated and non-aerated lakes. We know that aeration will alter important physical and chemical gradients that naturally exist in lakes. This project will evaluate whether other ecological parameters (1) phytoplankton abundance and blue-green algae composition; (2) sediment accumulation and organic content; (3) macrophyte distribution and composition; and (4) overall trophic state are changed as well. The data generated will allow year-round aeration to be evaluated based on its anticipated water quality and fisheries management impacts.

The "behavior" of lakes reflects many factors (climatic, hydrologic, historic, biologic, human perturbation, etc.) and, as such, an evaluation based on one year's data (even with 5 replicates) would appear to contain unacceptable levels of uncertainty. Three factors significantly reduce the uncertainty involved. First, a large water quality data base exists on Metropolitan Lakes which will provide a frame of reference for interpreting observed differences. Second, land use practices in the metropolitan area have not changed dramatically in the last 10 years around most aerated lakes or the amount of change can be quantified. Finally, the historical approaches proposed will add a time element not available within the LCMR project period.

V. Context:

A. Numerous studies have been conducted on the aeration of a specific lake or summarizing the results of various aeration projects. These studies have produced conflicting results which do not provide an adequate basis for evaluating the ecological impacts of year-round aeration (circulation) in Minnesota. In addition, previous studies have focused on modern data (collected in one or a series of years). This approach makes it difficult to separate natural historical change from aeration-induced changes.

B. The proposed study will supplement existing work in three ways.

1. It will survey multiple lakes in one project so that the differences between lakes vs those between study designs can more easily be evaluated.

2. It will include modern data and historical reconstructions so that aeration-induced changes can be better separated from natural historical change.

3. It will provide a comprehensive data set of aerated lakes in this geographical area.

C. The program manager participated in an LCMR funded research project (1985 Biennium "Development of biological approaches to lake restoration") that examined the ecological impacts of summer aeration. That project focused on a different aeration technology (not the bubbler systems that will be examined in this study) and was restricted to a single lake. An extensive literature review of aeration design and aeration-induced ecological impacts was accomplished as part of that project. This current project is designed as a one-time evaluation of bubbler type aeration systems. The data collected will be valuable in future assessment of specific aeration projects, but this project is not designed as the first in a series of studies.

D. N/A

E. Biennial Budget System Title and Budget: N/A

IV. Qualifications:

1. Program Manager:

Dr. David I. Wright
Research Scientist
Ecological Services Section
Minnesota Department of Natural Resources
Ph.D. Aquatic Ecology, University of Kansas, 1981

The program manager has worked professionally as an aquatic ecologist since 1981. During that period, he has been employed by the University of Minnesota (as Research

Associate and as an Instructor), as a private consultant, and by the Minnesota Department of Natural Resources (since 4/88). His research interests include evaluating the impacts of perturbations on lake communities (e.g. fish kills, aeration, lime application). His experience includes participating in an LCMR funded research project (1985 Biennium - "Development of biological approaches to lake restoration") that developed and field tested a new type of aeration system. Dr. Wright's primary role will be as program coordinator and to oversee work conducted under Objectives A, B, and D.

Relevant Publications:

Wright, D.I. 1984. Bush Lake Diagnostic Study. Prepared for Barr Engineering Company. Shapiro, J. and Wright, D. 1984. Lake restoration by biomanipulation: Round Lake, Minnesota, the first two years. Freshwater Biol. 14:371-383.

Stefan, H.G., Bander, M.D., Shapiro, J., and D.I. Wright. 1987. Hydrodynamic design of a metalimnetic lake aerator. J. Env. Eng. 113:1249-1264.

2. Major Cooperators:

A. Dr. Daniel Engstrom
Research Associate, University of Minnesota
Ph.D. Ecology and Behavioral Biology, University of Minnesota, 1983
M.S. Zoology, University of Minnesota Duluth, 1975

Dr. Engstrom's research interests are in the areas of geological and chemical limnology and include a strong emphasis on lake history, sediment dating, and sediment geochemistry. A major aspect of his work involves the study of long-term human impacts on lakes, including current investigations of mercury deposition in Minnesota lakes and the history of phosphorus inputs to Lake Okeechobee, Florida. He has established an active program in ^{210}Pb sediment-dating at the University of Minnesota and is an associate editor of the Journal of Paleolimnology, an international scientific journal. Dr. Engstrom's primary role will be to coordinate the collection, dating, analysis, and evaluation of sediment cores (Objective C).

B. Dr. Sherilyn C. Fritz

Research Associate, University of Minnesota
Ph.D. Ecology, University of Minnesota, 1985
M.S. Biology, Kent State University, 1979

Dr. Fritz's research involves the use of diatoms in lake sediments to study historical changes in the aquatic environment. She has studied diatom communities in a wide variety of aquatic systems in both North America and Europe, ranging from oligotrophic to hypereutrophic and including both freshwater and inland saline lakes. Much of Dr. Fritz's research has focused on human impact on lakes. She is currently directing a project for the Michigan DNR, involving the reconstruction of water quality in 3 oligotrophic lakes in northern Michigan. Dr. Fritz's primary role will be to identify and evaluate the diatom community changes in sediment cores (Objective E).

Publications:

Fritz, S.C. 1989. Lake development and limnological response to prehistoric and historic land-use in Diss. Norfolk, U.K. Journal of Ecology 77:182-202.

Fritz, S.C., A.C. Stevenson, S.T. Patrick, P.G. Appleby, F. Oldfield, B. Rippey, J. Natkanski & R.W. Battarbee. 1989. Paleolimnological evidence for the recent acidification of Llyn Hir, Dyfed, Wales. Journal of Paleolimnology 2:245-262.

Fritz, S.C. 1990. Twentieth-century salinity and water-level fluctuations in Devils Lake, North Dakota: test of a diatom-based transfer function. Limnology and Oceanography (in press).

VI. Reporting Requirements:

Semiannual status reports will be submitted not later than January 1, 1992, July 1, 1992, January 1, 1993, and a final status report by June 30, 1993.

I. Project Title: Ecological Evaluation of Year Round Aeration

Program Manager: David Wright
Agency Affiliation: Minnesota Department of Natural Resources
Division of Fish and Wildlife
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A. M.L. 91 Chpt. 254, Art. 1, Sec. 14, Subd. 4(n) Appropriation: $100,000
Balance: $ 12,761

Ecological Evaluation of Year-Round Aeration: This appropriation is from the Minnesota environment and natural resources trust fund to the commissioner of natural resources to collect baseline data on aerated and non-aerated lakes and determine ecological impacts of aeration.

B. N/A

C. N/A

II. Narrative

A. An increasing number of aeration systems are being operated year-round in Minnesota lakes to mitigate water quality problems. Most of these systems operate by using bubbles to induce circulation throughout a lake's water column. The ecological impact of this practice (aeration/circulation) is poorly understood.

B. Aeration is a well accepted fisheries management tool to reduce the potential for winterkill. Claims have been made that year-round aeration will also mitigate a variety of water quality problems. These claims need to be evaluated to insure that the ecological effects of year-round aeration are consistent with the state's water quality and fisheries management goals.

C. Over 200 aeration permits for "protected" waters are issued in Minnesota annually, though the majority involve only wintertime use. Approximately twenty-five permits were issued last year for year-round use where water quality improvement was one of the stated goals. The prevalence of year-round aeration in "nonprotected" waters of the state is unknown by the program manager.

III. Objectives

A. Assess how aeration alters important physical and chemical gradients in lakes, especially those gradients of biological significance.

A.1. Narrative: Physical and chemical gradients normally occur in most Minnesota lakes due to seasonal changes in temperature. The location, amplitude, and duration of these vertical gradients is very important in determining a lake's water quality and fisheries management potential. Aeration technologies currently in use in Minnesota

are most commonly designed to eliminate or minimize existing gradients. The focus of this objective is to detail, in a comparable cross section of aerated and non-aerated lakes, the extent to which important gradients are being altered. The impact of this alteration on algal abundance and biological oxygen demand (BOD) will be specifically assessed. Algal abundance is being assessed because it represents the most direct water quality indicator (with respect to recreational use). BOD is being assessed because of its importance to fisheries management. High BOD coupled with low in-lake oxygen concentrations can lead to a fish kill.

A.2. Procedures: Ten lakes (five that are currently aerated year-round and five that are not) will be chosen for study. To the extent possible, the lakes will be paired so that each aerated basin is matched with a non-aerated lake similar in size, mean depth, watershed area, and land use. This selection process will be facilitated by cooperation with the Metropolitan Council (which has detailed information on over 120 lakes in the Metropolitan area), the Minnesota Pollution Control Agency, and fisheries personnel. The select pairs will also be reasonably close geographically (i.e. study lakes will likely all be with greater metropolitan area) to minimize climatic differences.

The sampling program was developed after extensive consultation with other local limnologists (including those at the University of Minnesota, Minnesota Pollution Control Agency, Metropolitan Council) and is designed to complement existing data bases and sampling programs.

Because most lakes that are aerated year-round are small (typically less than 100 acres) and because the goal of aeration is to completely mix the basin, a single sampling site will be adequate. Each lake will be sampled approximately 18 times over the course of one year (from Oct. '91 through Oct. '92). The sample frequency will be once per month in the winter (when access is safe) and twice per month during the open water period. The following parameters will be measured at the mid-lake station:

Parameter	Samples	Frequency
Temperature	Water Column at 0.5m intervals	Every trip
Oxygen	Water Column at 0.5m intervals	Every trip
Secchi Disk Depth		Open Water only
Underwater Illuminance	0.5m intervals	Open Water only
Total Phosphorus	Integrated epilimnetic additional at 4 meter intervals	Every trip
Total Kjeldahl Nitrogen	Integrated epilimnetic	Every trip
pH	Same depths as TP	Every trip
Alkalinity	Integrated epilimnetic	Once a month
Ortho-Phosphate	Integrated epilimnetic	Open Water only
Nitrate/Nitrite-Nitrogen	Integrated epilimnetic	Open Water only
Chlorophyll a	Integrated epilimnetic	Once a month

The four major goals of this sampling program will be to: 1) evaluate the physical effectiveness of the aeration systems; 2) characterize the water quality of the lakes' surface layer; 3) detail the annual nutrient dynamics; and 4) evaluate fish habitat. The measurement of temperature and oxygen profiles will be used to ascertain the extent to which vertical gradients have been eliminated by aeration (goal 1). Measurement of most water quality parameters (goal 2) will be restricted to an epilimnetic sample. This restriction (epilimnetic only) is reasonable in this study because public use of and management efforts are focused on a lake's surface layer. The exceptions to this approach are for phosphorus, pH, and BOD. As a rule, phosphorus availability limits primary production in metropolitan lakes and additional phosphorus samples (at 3-4m intervals) will be collected so that annual nutrient dynamics can be estimated (goal 3). Oxygen and BOD profiles will be examined to determine if aeration has improved the habitat for fish or increased the potential for a summerkill occurrence (goal 4).

Approximately 10% of the field samples will be duplicated as part of our quality assurance program. Paired comparisons (aerated vs non-aerated pairs) will be the basis for evaluation.

A.3. Budget:

	LCMR Funds
a. Amount Budgeted:	$ 39,500
b. Balance:	$ 11,823

A.4. Timeline for Products:

	7/91	1/92	6/92	1/93	6/93
Select study lakes	******				
Collect field data	*********************				
Analyze data			***************		
Consult with fisheries managers				*******	
Final evaluation of results				*****************	

A.5. Status: The study lakes (5 aerated and 6 non-aerated, reference, basins) were selected after consultation with Metro DNR Fisheries, MPCA, the Metropolitan Council, lake aeration reports in the DNR, other local units of government, lake associations, aeration suppliers, and the major cooperators. All eleven lakes are located in the metropolitan counties of Dakota (Farquar), Hennepin (Arrowhead, Indianhead, Crystal, Gleason, Holy Name, Hadley, Wolsfeld, and Twin), Carver (Susan), and Ramsey (Josephine) and represent the range of aerated lake types.

Collection of field data was initiated in October 1991 and completed in October 1992. During the 1991/1992 hydrologic year (10/91-10/92), sixteen sampling trips to each lake were conducted. Collection and analysis of all physical and chemical parameters listed under Objective A were completed as planned. The data was entered into spreadsheet format (LOTUS 123). Primary data analysis was conducted by Robert Beduhn (Barr Engineering) as a partial requirement for a Masters Degree in Professional Engineering (under the direction of Dr. John Gulliver, University of Minnesota).

The study lakes were found to represent three different lake types: 1) dimictic lakes- those that normal stratify (form a warm surface and cold bottom layer) during the summer; 2) polymictic lakes that typically do not stratify and mix repeating throughout the summer; and 3) an intermediate group. For lakes in the dimictic

group, aeration/circulation altered most of the paramaters evaluated in Objective A and markedly changed in-lake conditions. At the other extreme, no response to aeration/circulation was seen in the polymictic group. This response was not unexpected since polymictic lakes are normally completely circulated by the wind. The intermediate group also showed chemical/physical changes associated with aeration.

For lakes in the dimictic and intermediate groups, the following general conclusions were reached:

1) aeration was generally effective at circulating the lake;
2) aeration did not improve the water quality of the lake's surface layer and, in some cases, water quality declined;
3) aeration increased nutrient availability in the lake's surface layer which promoted increased algal growth; and
4) the amount of fish habitat expanded with aeration.

A.6. Benefits: Most aeration systems currently operating in Minnesota are designed to eliminate the normal stratification patterns that exist in lakes. This objective will determine whether this practice improves water quality and/or the fisheries habitat. The data collected in this objective will also be valuable for the interpretation of Objectives B-E.

B. Assess impact of aeration on seasonal distribution and abundance of algae, particularly bluegreen algae.

B.1. Narrative: Bluegreen algae, particularly taxa which produce large "scum-forming" colonies, represent a major water quality problem in Minnesota. The scientific literature suggests that reduction in bluegreen abundance is one of the water quality improvements most often associated with whole lake aeration (circulation). The focus of this objective will be to evaluate in what lake types aeration reduces overall bluegreen abundance and/or the frequency of algal scums and thereby improves recreational suitability.

B.2. Procedure: Epilimnetic water samples collected for chlorophyll a analysis (see Objective A) will be subsampled for phytoplankton identification and quantification. The quantification process will be an adaptation of the Rapid Assessment Procedure used by the Minnesota Pollution Control Agency. The goal of that procedure is to identify the predominant taxa present and subjectively estimate their relative proportion (based on volume) in the community. As such, numerical counts are not reported (only a series of percentages). The analyst is free to make numerical counts, measure cell volumes, or some combination, depending on the actual composition of the sample in question. (All samples will be provided at once, with replicates, in coded bottles to minimize bias). This procedure has the advantage that it is much faster than the normal procedure (where hundreds of cells/colonies are individually counted and measured) and has a resolution appropriate for our objective - are there major changes in the abundance or seasonal distribution of bluegreen algae? Paired treatment (aerated) and control (non-aerated) lakes will be the basis for making comparisons.

A field assessment of recreational suitability will be conducted using the [illegible] User

Survey Form (Minnesota Pollution Control Agency). This assessment technique will be used by project personnel each time a lake is visited during the open water period. The survey allows water conditions (e.g. algal scums) which reduce recreational suitability to be quantified. Research has indicated that this is an effective way to evaluate how water quality changes affect the lake user.

B.3. Budget:

	LCMR Funds
a. Amount Budgeted:	$ 6,000
b. Balance:	$ 0

B.4. Timeline for Products:

	7/91	1/92	6/92	1/93	6/93
Collect algal samples	*	*************			
Make field observations	*	*************			
Apportion algae into taxa				*********	
Final evaluation of results				*********	

B.5. Status: Epilimnetic algal samples were collected from each of the study lakes in October 1991 and during the ice-free study period in 1992 (April-October). In total, thirteen samples from each lake were collected and preserved (a total of 156 samples were collected counting duplicates). These samples were enumerated en masse, the algae present apportioned into species, and the results interpreted. Duplicate samples were compared to estimate the uncertainty associated with the results. Dr. Lloyd Ohl, an algal taxonomist with the University of Wisconsin, Eau Claire, enumerated the collected samples.

The response of the algal community to aeration also varied as a function of lake type. Lakes in the dimictic or intermediate class showed a seasonal pattern of algal composition that differed from the non-aerated reference lakes. In general, bluegreen algae were less abundant in the dimictic/intermediate lakes that had an aeration system. This difference was not very pronounced for Crystal Lake (in comparison to Twin and Josephine) but was very pronounced for Hadley and Gleason Lakes (in comparison to Wolsfeld and Susan, respectively). The increased mixing depth and lower pH in the aerated lakes may have been less favorable conditions for bluegreen algae growth. In contrast, aeration had no discernible impact on bluegreen algae abundance or algal community composition for lakes in the shallow, polymictic class.

Recreational suitability assessments were also conducted in October 1991 and throughout the ice-free study period in 1992. A total of thirteen assessments was completed for each study lake as well. Aeration/circulation was not found to alter recreational suitability in any of the lake types. This result was surprising since other trophic state parameters (e.g. total phosphorus, chlorophyll a, bluegreen algae composition, Secchi disk depth) did show consistent patterns associated with aeration, at least in the deeper lakes. We believe this lack of response reflects the complex nature of what a lake user perceives as water quality. As previously discussed in Objective A.5., phosphorus concentrations and algal abundance increased in lakes in the dimictic and intermediate classes when they were aerated/circulated. This increase in algal abundance would be expected to reduce recreational suitability. However, aeration also reduced bluegreen algae abundance (see above) which may improve recreational suitability. These two processes appear to have counteracted each other so that no measurable change in recreational suitability was observed. In the shallow/polymictic lakes, no change in recreational suitability was observed. This result was consistent with the other physical and chemical parameters measured which also did not change.

B.6. Benefits: Severe water quality degradation has been associated with the presence of certain colony-forming bluegreen algae (e.g. Aphanizomenon, Anabaena, and Microcystis). This objective will evaluate whether aeration alters the seasonal distribution or abundance of bluegreen algae in the surface water or the extent of surface scums.

C. Assess impact of aeration on sediment deposition rates and characteristics.

C.1. Narrative: High deposition rates of organic sediments is a problem which plagues many lakes in Minnesota. These sediments may eliminate oxygen necessary for desirable fish species and other aquatic life, support heavy aquatic weed growth, add nutrients to the overlying water column, and accelerate the loss of lake volume. Year-round aeration has been proposed as a solution which would reduce the rate of deposition as well as the organic content of the sediment. The effectiveness of this approach will be evaluated using the historical record in lake sediments.

C.2. Procedures: The organic content and accumulation rate of sediment will be determined for all 10 lakes included in Objective A. The basin pairs (one aerated and one control) will range in depth from shallow to deep and the range of basin types currently being aerated within the state. Only lakes that have been aerated for a minimum of five years (to insure an adequate sedimentary signal) will be selected. One sediment core will initially be obtained from the profundal (deep water) area of each lake and sectioned for detailed analysis. The sections will be dated (using ^{210}Pb) and their organic/inorganic content will be determined. Based on the observed sedimentation rate, 2-4 additional, less detailed, cores per lake will be obtained to characterize within lake variability. Each pair will then be examined to determine if sedimentation rate and/or organic content of the sediment changed with the onset of aeration (the control lake will provide the historical reference for evaluating change).

C.3. Budget:

	LCMR Funds
a. Amount Budgeted:	$ 36,000
b. Balance:	$ 0

C.4. Timeline for Products:

	7/91	1/92	6/92	1/93	6/93
Select lake to be cored	**				
Obtain and analyze cores		***************			
Final report of analysis				************	

C.5. Status: This task was completed by the major cooperator responsible for Objective C (Dr. Dan Engstrom, University of Minnesota). Ten lakes located within the metro-area counties (ten of the eleven lakes in Objective A) were selected for study, based on their recent history of human impact. Half of the lakes had been aerated for most of the last decade if not longer, the other five lakes, selected as reference basins, had not been aerated. In mid-October, 1991, a single sediment core was collected from the deepest location within each basin (the "central core"). These central cores were 1.2-1.4 meters in length, except at two sites where peat was encountered beneath a surficial deposit of lake sediment; somewhat shorter sections were recovered from these lakes. The cores were sectioned in the field in 1-2 cm increments from the upper 20-40 cm and in 4-cm increments below that. Preliminary dating for Hadley and Wolsfeld lakes shows unexpectedly high sedimentation rates such that the initial central cores appeared too short to encompass pre-settlement conditions; similar conclusions based on loss-on-ignition data were also reached for Crystal, Gleason, and Josephine lakes. Deeper core sections were obtained at these later five sites in July 1992.

Loss-on-ignition analysis and lead-210 dating was completed for the detailed central core from each of the ten study lakes. These analyses include the cores collected in October 1991 as well as longer core sections obtained from the central core-sites in Crystal, Gleason, Hadley, Woldsfeld, and Josephine in July 1992. Two additional cores were collected from each lake during the fall of 1992. These secondary coring sites were widely spaced from one another and from the central cores so as to encompass a range of depositional environments in each lake. The new cores were sectioned into 6-8 coarse intervals based on results from the detailed cores and other stratigraphic markers evident in the field. Loss-on-ignition determination of organic and carbonate content and lead-210 dating was completed for all 20 of these profiles.

Our results indicate that aeration has not altered the rate of accumulation or the organic content of sediments in the study lakes. This result was consistent across all lake types (see Obj. A) examined and between the three cores collected within each lake. In addition, there was no indication that aeration enhanced the redistribution of sediments from littoral areas to deeper sites within a lake. Rates of sediment accumulation in these lakes have increased since European settlement of the region (c. 1870). The magnitude of increase was 2-8x pre-settlement rates. Sediment composition also changed in most lakes over the same period. The organic content decreased by 25-70% due to increased inputs of silts and clays from erosion. Historic patterns of sediment accumulation and composition in the aerated lakes, however, were not different from those observed in the non-aerated reference lakes. We concluded that aeration had no discernable impact on lake sediments and that accumulation rates and organic content were not altered.

C.6. Benefits: Accumulation of highly organic sediments has detrimental impacts on public use, water quality, and fisheries management in many Minnesota lakes. Year-round aeration has been advocated as a method to reduce and potentially reverse the accumulation of these sediments. This objective will critically evaluate whether these benefits (lower sediment accumulation rates and/or reduced organic content) are observed.

D. Assess impact of aeration on macrophyte community composition and distribution.

D.1. Narrative: Aquatic macrophytes (large, primarily rooted, plants) constitute a large and very valuable component of many Minnesota lake ecosystems. The plants provide food and habitat for many species of fish and wildlife, as well as reducing the erosion of shoreline areas. Heavy macrophyte growth, however, may restrict use of the lake by swimmers, boaters, and anglers (particularly in shallow areas with organically rich sediments). Operation of aeration systems during the open-water

period can alter the distribution and abundance of aquatic macrophytes. Changes in water transparency (see Objective A), in sediment deposition patterns (see Objective C), or water current velocities could affect the composition, abundance, or distribution of the aquatic plants. The focus of this objective is to determine: 1) whether the onset of aeration changed the historical distribution of aquatic plants in selected lakes; and 2) whether the composition and distribution of macrophytes differs systematically in aerated and non-aerated lakes.

D.2. Procedures: The composition and distribution of the macrophyte community will be mapped once or twice during the summer (late June and, if needed, again in early August) of 1992. Data will be collected on the same 10 lakes used in Objective A. Knowledge of important physical, chemical, and biological conditions will facilitate interpretation of differences in distribution or composition that exist between lakes or lake types (aerated vs non-aerated). The mapping procedure (using stratified random transects) will focus on determining the community composition and depth distribution of the various stands. Plant density will not be measured.

Historical changes in macrophyte distribution will be assessed by examining air photos. Various air photos of the study area have been taken in the last two decades by a variety of organizations (Army Corps of Engineers, Agricultural Stabilization and Conservation Service, Soil Conservation Service, Metropolitan Council, U.S. Forest Service) and include two complete sets of color IR (the preferred film) photos taken in the summer of 1978, and 1985. Additional summer photos of the study area may exist as well. This photographic record will be examined to determine whether the apparent distribution of macrophytes has changed since the onset of aeration (various dates between 1973-1990). The amount of change apparent in the non-aerated lakes will serve as the "control" baseline.

Interpretation of the historical photos will be enhanced by contracting for a current set (summer 1992) of color IR photographs for the 10 study lakes. Current photos will also allow evaluation of lakes where aeration has been implemented since 1985.

D.3. Budget:

	LCMR Funds
a. Amount Budgeted:	$ 8,500
b. Balance:	$ 938

D.4. Timeline for Products:

	7/91	1/92	6/92	1/93	6/93
Select lakes	*****				
Assess macrophyte communities			**		
Obtain and analyze historical air photos		**********	**********	**********	**
Shoot current air photos			***		
Final reports of analysis					*******

D.5. Status: Ten study lakes (5 aerated and 5 control basins) were selected for macrophyte assessment and represent 10 of the 11 lakes identified in Objective A. Observations during early summer 1992 indicated that two mappings of the macrophyte community would be needed for an accurate assessment. Th[illegible]tial mapping was completed between June 29 and July 2, 1992, while the second mapping was conducted between August 14 and September 14, 1992. Mapping the two smallest lakes (Indianhead and Arrowhead) was problematic. Heavy macrophyte control efforts in both lakes confounded attempts to assess the community. Neither lake was sampled during the initial assessment. An assessment was completed on both lakes but it was delayed until early fall of 1992.

Aerial photos of all study lakes were taken in July 1992 by Forest Inventory (MDNR, Grand Rapids). Both infrared and panchromatic (regular visible) color slides were taken (8"x11" color prints were also produced in both formats). The combination of film types was used to see which format best delineated submerged vegetation.

Our study found no indication that multiple years of aeration has reduced the distribution or abundance of the macrophyte community in the study lakes. Survey work conducted in 1992 indicated that the macrophyte community was at least as diverse, as abundant, and as extensive in its distribution in the aerated lakes as in the historical records that were available. Historical records in the MN DNR Fisheries files were used exclusively because historical aerial photos in panchromatic color format (the format we found was better for seeing submerged vegetation) do not exist. These results are tempered by the fact that a comprehensive historical record was not available and year-to-year variation within lakes appears large.

Consistent differences in the composition of aquatic macrophytes were found between aerated and non-aerated lakes in 1992. Specifically, Ceratophyllum demersum, Chara/Nitella, Elodea canadensis, Nelumbo lutea, and Potamogeton foliosus were more abundant in non-aerated lakes, while Najas flexilis, Potamogeton crispus, and Potamogeton zosteriformis were more abundant in lakes with aeration systems. Whether the differences represent an effect of aeration or underlying differences in lake type was not clear.

D.6. Benefits: Aquatic macrophyte stands are an integral part of lake communities, but their over-abundant growth is a nuisance. Analysis will indicate whether year-round aeration systematically alters the composition or distribution of those stands.

E. Assess trophic (nutrient) response of lakes to aeration.

E.1. Narrative: Each of the preceding objectives was focused on one limited portion of the project's goal. None by itself provides a complete picture of the ecological impacts of aeration. The focus of this objective is to provide a more comprehensive view. This objective will be met by examining historical changes in the diatom community preserved in the sediment of aerated lakes vs non-aerated lakes. The community composition of diatoms (a particular group of algae) is very sensitive to water quality changes (e.g. water clarity, nutrient concentrations, mixing regimes) and the ecological preferences of most species are known. Change in community composition therefore can be used to reconstruct the water quality changes that occurred in previous years. This objective will use diatom remains to examine how a lake's trophic (nutrient) state changed in response to aeration. The magnitude and direction of changed observed in aerated lakes will be assessed and compared to the amount of change observed in the control lake's diatom community.

E.2. Procedure: All aerated and control lakes cored in Objective C will be used for diatom reconstruction. Each core will be sectioned into slices representing five years accumulation of sediment before and five years accumulation of sediment after the initiation of aeration. ^{210}Pb dating allows the appropriate thickness to be determined even if aeration has altered the rate of sediment deposition. Control lakes will be sectioned over the same time period to minimize interannual climatic variation. The pre-aeration community will then be compared to the post-aeration community and any changes evaluated. The magnitude and direction of change will be assessed by using canonical correspondence analysis to summarize the community change. This technique allows the difference between two communities to be represented in two dimensions. The change observed in the control community will then be plotted on the same areas. This will allow the magnitude of community change to be directly compared between aerated and non-aerated lakes. The direction of change will also be interpreted based on knowledge of diatom specific ecology preferences and the water quality variables measured in Objective A. For example, if aeration has decreased nutrient availability and increased water transparency, shifts in the species composition of diatoms will change in predictable ways.

E.3. Budget:

	LCMR Funds
a. Amount Budgeted:	$ 10,000
b. Balance:	$ 0

E.4. Timeline for Products:

	7/91	1/92	6/92	1/93	6/93
Collect and date cores	*****************				
Section cores and identify diatoms		**************			
Perform C.C. analysis and evaluate community changes				********	
Final report of analysis					******

E.5. Status: This task was completed by the major cooperate responsible for Objective E (Dr. Sheri Fritz, University of Minnesota). The 10 study lakes selected for a comprehensive historical evaluation using diatom community structure were the same lakes from which sediment cores were obtained (see Obj. C). Four time periods were selected for analysis in each lake. For the aerated lakes, two samples were chosen before, and two samples after, the onset of aeration. Samples were chosen to bracket the onset of aeration as closely as possible. Samples representing comparable time periods were chosen for the reference lakes.

Dramatic changes in the diatom community were not found in any of the lake cores sampled. This lack of dramatic change suggests that none of the lakes, aerated or reference basins, had experienced major changes in their physical or chemical conditions over the period of record. Some of the aerated lakes did show small changes in diatom community composition associated with the onset of aeration. An increase in abundance of various species of the genus Aulacoseira was observed in a number of lakes. Aulacoseira, a genus which reaches maximum abundance during periods when waters are cold and well mixed, would be expected to increase in response to year-round aeration/circulation.

E.6. Benefits: Year-round aeration alters many physical and chemical parameters in lakes. The diatom record should provide specific detail on whether the diatom community responded to those changes in predictable ways. If consistent patterns emerge, the diatom community changes can be used to historically reconstruct the magnitude of physical/chemical change associated with year-round aeration.

IV. Evaluation:

The project can be evaluated by its ability to demonstrate ecological differences (or lack thereof) between aerated and non-aerated lakes. We know that aeration will alter important physical and chemical gradients that naturally exist in lakes. This project will evaluate whether other ecological parameters (1) phytoplankton abundance and blue-green algae composition; (2) sediment accumulation and organic content; (3) macrophyte distribution and composition; and (4) overall trophic state are changed as well. The data generated will allow year-round aeration to be evaluated based on its anticipated water quality and fisheries management impacts.

The "behavior" of lakes reflects many factors (climatic, hydrologic, historic, biologic, human perturbation, etc.) and, as such, an evaluation based on one year's data (even with 5 replicates) would appear to contain unacceptable levels of uncertainty. Three factors significantly reduce the uncertainty involved. First, a large water quality data base exists on Metropolitan Lakes which will provide a frame of reference for interpreting observed differences. Second, land use practices in the metropolitan area have not changed dramatically in the last 10 years around most aerated lakes or the amount of change can be quantified. Finally, the historical approaches proposed will add a time element not available within the LCMR project period.

V. Context:

A. Numerous studies have been conducted on the aeration of a specific lake or summarizing the results of various aeration projects. These studies have produced conflicting results which do not provide an adequate basis for evaluating the ecological impacts of year-round aeration (circulation) in Minnesota. In addition, previous studies have focused on modern data (collected in one or a series of years). This approach makes it difficult to separate natural historical change from aeration-induced changes.

B. The proposed study will supplement existing work in three ways.

1. It will survey multiple lakes in one project so that the differences between lakes vs those between study designs can more easily be evaluated.

2. It will include modern data and historical reconstructions so that aeration-induced changes can be better separated from natural historical change.

3. It will provide a comprehensive data set of aerated lakes in this geographical area.

C. The program manager participated in an LCMR funded research project (1985 Biennium - "Development of biological approaches to lake restoration") that examined the ecological impacts of summer aeration. That project focused on a different aeration technology (not the bubbler systems that will be examined in this study) and was restricted to a single lake. An e[illegible]sive literature review of aeration design and aeration-[illegible] ecological impacts

was accomplished [illegible] part of that project. This current project is designed as a one-time evaluation of bubbler type aeration systems. The data collected will be valuable in future assessment of specific aeration projects, but this project is not designed as the first in a series of studies.

D. N/A

E. Biennial Budget System Title and Budget: N/A

IV. Qualifications:

1. Program Manager:

Dr. David I. Wright
Research Scientist
Ecological Services Section
Minnesota Department of Natural Resources
Ph.D. Aquatic Ecology, University of Kansas, 1981

The program manager has worked professionally as an aquatic ecologist since 1981. During that period, he has been employed by the University of Minnesota (as Research Associate and as an Instructor), as a private consultant, and by the Minnesota Department of Natural Resources (since 4/88). His research interests include evaluating the impacts of perturbations on lake communities (e.g. fish kills, aeration, lime application). His experience includes participating in an LCMR funded research project (1985 Biennium - "Development of biological approaches to lake restoration") that developed and field tested a new type of aeration system. Dr. Wright's primary role will be as program coordinator and to oversee work conducted under Objectives A, B, and D.

Relevant Publications:

Wright, D.I. 1984. Bush Lake Diagnostic Study. Prepared for Barr Engineering Company. Shapiro, J. and Wright, D. 1984. Lake restoration by biomanipulation: Round Lake, Minnesota, the first two years. Freshwater Biol. 14:371-383.
Stefan, H.G., Bander, M.D., Shapiro, J., and D.I. Wright. 1987. Hydrodynamic design of a metalimnetic lake aerator. J. Env. Eng. 113:1249-1264.

2. Major Cooperators:

A. Dr. Daniel Engstrom
Research Associate, University of Minnesota
Ph.D. Ecology and Behavioral Biology, University of Minnesota, 1983
M.S. Zoology, University of Minnesota Duluth, 1975

Dr. Engstrom's research interests are in the areas of geological and chemical limnology and include a strong emphasis on lake history, sediment dating, and sediment geochemistry. A major aspect of his work involves the study of long-term human impacts on lakes, including current investigations of mercury deposition in

Minnesota lakes and the history of phosphorus inputs to Lake Okeechobee, Florida. He has established an active program in ^{210}Pb sediment-dating at the University of Minnesota and is an associate editor of the Journal of Paleolimnology, an international scientific journal. Dr. Engstrom's primary role will be to coordinate the collection, dating, analysis, and evaluation of sediment cores (Objective C).

B. Dr. Sherilyn C. Fritz
Research Associate, University of Minnesota
Ph.D. Ecology, University of Minnesota, 1985
M.S. Biology, Kent State University, 1979

Dr. Fritz's research involves the use of diatoms in lake sediments to study historical changes in the aquatic environment. She has studied diatom communities in a wide variety of aquatic systems in both North America and Europe, ranging from oligotrophic to hypereutrophic and including both freshwater and inland saline lakes. Much of Dr. Fritz's research has focused on human impact on lakes. She is currently directing a project for the Michigan DNR, involving the reconstruction of water quality in 3 oligotrophic lakes in northern Michigan. Dr. Fritz's primary role will be to identify and evaluate the diatom community changes in sediment cores (Objective E).

Publications:

Fritz, S.C. 1989. Lake development and limnological response to prehistoric and historic land-use in Diss. Norfolk, U.K. Journal of Ecology 77:182-202.
Fritz, S.C., A.C. Stevenson, S.T. Patrick, P.G. Appleby, F. Oldfield, B. Rippey, J. Natkanski & R.W. Battarbee. 1989. Paleolimnological evidence for the recent acidification of Llyn Hir, Dyfed, Wales. Journal of Paleolimnology 2:245-262.
Fritz, S.C. 1990. Twentieth-century salinity and water-level fluctuations in Devils Lake, North Dakota: test of a diatom-based transfer function. Limnology and Oceanography (in press).

VI. Reporting Requirements:

Semiannual status reports will be submitted not later than January 1, 1992, July 1, 1992, January 1, 1993, and a final status report by June 30, 1993.