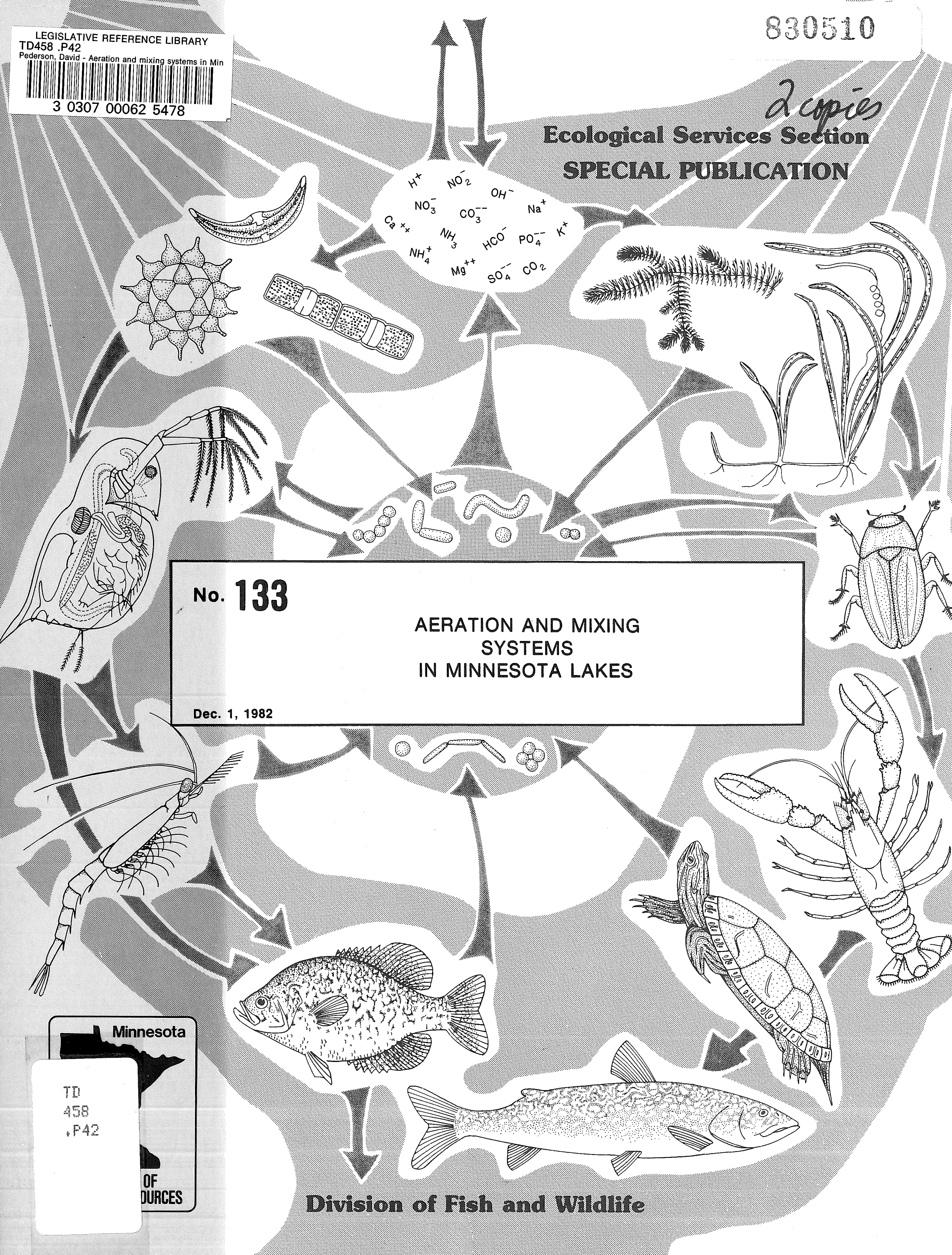

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AERATION AND MIXING SYSTEMS IN MINNESOTA LAKES

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AERATION AND MIXING SYSTEMS IN MINNESOTA LAKES

by

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ABSTRACT

With appropriate equipment technologically available, winter-kill prevention can expand Minnesota's fishing resource and, in some cases, improve water quality. Operational characteristics of high volume water pumps, sub-surface air bubblers and mechanical surface aerators, with their respective applicabilities to different lakes and conditions are presented. Average mechanical efficiencies and operating costs are estimated. Present aeration operations throughout the State are reviewed and areas needing further study are discussed.

INTRODUCTION

Lake aeration systems used to prevent winterkill of fish and improve water quality have been increasing in number in Minnesota. Technological progress, design improvements and the development of new concepts for aeration equipment used in wastewater treatment have advanced the "state of the art" in recent years. The adaptation of this equipment for use in lakes has met with success when the techniques are properly applied and an adequate sized system and design is used. Most of the aeration systems in Minnesota lakes are used to prevent winterkill though some are operated with the goal of improving summer water quality through destratification and improving the nutrient status.

The principal interest of the Department of Natural Resources (DNR) in lake aeration as a fisheries management technique is in winterkill prevention. Winterkill often results in the loss or severe reduction of angling opportunity for a period of several years. Frequent winterkills can preclude the establishment of desirable game fish populations and subsequent sport angling. Prevention of winterkill is thus desirable to insure continuous angling opportunity for preferred sizes and species of game fish.

HISTORICAL BACKGROUND

Fish winterkill, following prolonged periods of ice and snow cover, is a common problem in the shallow eutrophic lakes in Minnesota. During the past 27 winters, the number of fishing lakes which have winterkilled severely enough to cause substantial losses of their fish populations has averaged 125 and has ranged from a low of 4, during the winter of 1980-81, to a high of 308 in the winter of 1955-56 (Table 1).[1]

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[1] Based on Section of Fisheries records of lakes opened to promiscuous fishing.

Scidmore (1970) states that the importance of winterkill in Minnesota is not so much a matter of the number of lakes which winterkill but is rather a matter of the location of these lakes and the number and quality of other fishing lakes in the area. By far the majority of the winterkill lakes occur in the southern half of the state, an area which contains approximately 29% of the state's fishing lakes but approximately 75% of its population. By including marginal lakes (those that range from 6-20 ft deep, winterkill and frequently have nongame fish populations) with the above fish lakes in the southern half of the state, the amount of water available to anglers could be increased by a factor of 1.5 (Peterson 1971).

Many investigators have discussed the limnological conditions in ice-covered lakes which lead to winterkill since the original work of Greenbank (1945). Basically, winterkill occurs when the oxygen reserve at ice formation plus oxygen produced by photosynthesis under the ice is exceeded by the oxygen consumption rate (Patriarche and Merna 1970). As snow depth increases, light penetration and oxygen production by photosynthesis decreases. The rate of oxygen depletion is affected by factors such as mean depth (Welch et al. 1976; Barica and Mathias 1979, 1980), sediment oxygen demands (Mathias and Barica 1980) and trophic state (Welch et al. 1976; Mathias and Barica 1980).

There are two main approaches to the management of lakes that frequently winterkill. The first is to accept the limitations imposed by periodic winterkill, recognize its advantages and make maximum use of the condition through developed management practices (Johnson and Moyle 1969; Scidmore 1970; Sunde et al. 1970). The second approach is to forestall or prevent oxygen depletion by manipulation of one or more of the factors which lead to under-ice anoxic conditions.

Winterkill Prevention

Wirth (1970) describes past attempts made toward preventing winterkill as: chopping small holes in the ice to "let the air in"; pumping water onto the ice to aerate it and melt snow; removal of snow to improve light penetration and enhance photosynthesis; partial drawdown by removal of bottom waters; and augmentation with oxygenated water from upstream lakes. In addition to those described by Wirth, other methods have included removal of fish, application of alum during the growing season to reduce winter BOD, deepening of the lake by dredging or increasing water levels, control of high BOD waste effluents, artificial aeration by water pumping and artificial aeration by air pumping (Skrypek 1979). Varying levels of success have been achieved with most of these methods but their practical application has been limited for such reasons as energy and cost requirements, short-term results, improper application of the technique and undersized or inefficient equipment.

The current trend in efforts to prevent winterkill has been with the use of artificial aeration equipment. Original attempts using compressed air and perforated hoses were largely unsuccessful (Woods 1961; Patriarche 1961). In these first experiments, the air input was not sufficient to compensate for the oxygen demand. Woods (1961) felt that pumping compressed air into the water would provide an oxygenated refuge in the locality of the air distribution system but turbulence created by the bubble stream was mixed and diluted with surrounding water which prevented an increase of dissolved oxygen. Later, it was found that this circulation and mixing action can contribute to the effectiveness of aeration systems. As the air bubbles ascend, warm bottom water is entrained and brought to the surface where it melts the ice which facilitates oxygen transfer at the air-water interface. The amount of compressed air actually dissolved due to contact of rising air bubbles with the water column is inconsequential in comparison to the amount of oxygen transfer which takes place at the air-water interface when the ice cover is eliminated (Johnson 1970; Skrypek and Shodeen 1977; Toetz et al. 1972). As the warm bottom water is cooled at the surface, lateral density currents are established which together with wind and wave action, circulate the oxygenated water throughout the lake basin.

The heat budget of a lake is substantially altered as a result of aeration. Under natural conditions, very little heat loss takes place after ice formation. Warmer, denser water sinks and the lake inversely stratifies (winter stagnation). When warmer bottom water is brought to the surface through aeration and an open water area is maintained, considerable in-lake heat is rapidly lost which creates an isothermal condition causing an overall cooling of the water column (Patriarche 1961; Wirth 1970; Shodeen 1976). The significance of this situation to winterkill prevention is that cooler water temperatures mean reduced biological activity and consequent lower BOD (Shodeen 1976).

Recently, the adaptation of equipment originally designed for wastewater treatment has been shown to be successful in maintaining sufficient dissolved oxygen levels throughout the winter to prevent winterkill (Johnson and Skrypek 1975; Wirth 1970). Successful prevention of winterkill with this equipment has generated considerable interest in lake aeration which has resulted in a substantial increase in the number of systems in operation (Table 2). The locations by county of the aeration systems operating under permit during the winter 1981-82 are shown in Figure 1.

Water Quality

In addition to those aeration systems intended to prevent winterkill, some systems are run year around or only in the summer. The objective of summer aeration is to eliminate thermal stratification which tends to eliminate anoxic hypolimnetic waters. Stagnation results in hypolimnetic oxygen depletion and concentration increases of hydrogen sulfide, carbon dioxide, ammonia, iron, mangenese, phosphorus and other undesirable substances associated with anaerobic conditions.

Aeration/destratification can, in some cases, serve to improve or reverse these conditions. Hydrogen sulfide, carbon dioxide and ammonia gases can be oxidized or brought to the surface and vented through aeration and mixing. Concentrations of iron and manganese, which can only exist as free ions in near anoxic conditions, can be decreased when dissolved oxygen concentrations are increased (Toetz et al. 1972). Aerobic conditions promote the precipitation and/or sorption of phosphorus and prevent or reduce the release of phosphorus from bottom sediments (Fast 1971; Toetz et al. 1972). Other benefits of summer aeration include: prevention of summer fish kills; enhanced production of fish food organisms; increased rates of decomposition of organic matter; and expansion of fish habitat by removal of stratified thermal and chemical barriers (Toetz et al. 1972).

Results of aeration studies are not consistent and conditions can often deteriorate by improper application of these techniques. In many instances, aeration/destratification has aggravated existing problems or caused new problems because of misunderstanding the responses of physical, chemical and biological parameters to aeration. Considering the differences between aeration system types, sizes and mixing efficiencies, when coupled with the range of variability in lake basin morphometry, sediment composition, water chemistry and biological communities, it is not surprising that results are often inconsistent.

Changes in algae species composition, density and productivity from aeration are equally unpredictable. Some studies have shown increases in phytoplankton (mainly blue-greens) following destratification while other studies have shown decreases (Lackey 1973). Phytoplankton with requirements unique to stratified waters, will likely be lost when mixing redistributes them throughout the water column. This may eliminate the competitive advantage of some blue-green algae which are often bouyant and found near the surface of quiescent waters (Lorenzen and Fast 1977). Changes in temperature, pH and carbon dioxide levels induced by aeration also present implications to algae composition and abundance.

A great deal remains to be learned about the effects of aeration/destratification on aquatic ecosystems. Cause-effect relationships and predictable results are difficult to establish because such a wide range of physical and chemical reactions take place quickly and simultaneously following aeration and mixing. Other changes are more subtle and continuous and still other transformations are made subsequent to and as a result of earlier reactions or changes. Comprehensive ecological monitoring and modeling will be necessary before definitive information may be obtained.

TYPES OF SYSTEMS IN USE

Several types of aeration systems are presently being used in Minnesota lakes. These include: high volume water pumps; sub-surface air bubbler systems; air injection systems; and mechanical surface aerators.

High Volume Water Pumps (Pump and Baffle)

Pump and baffle systems function through direct aeration of a significant portion of the lake volume. Large volumes of water are pumped out of the lake to the top of a chute or flume where it cascades back into the lake over a series of baffles, adding oxygen and releasing unwanted gases. Pumps for this purpose are available in a range of sizes from 1,000 to 25,000 gallons/minute (gpm). The smaller pumps can be powered by gasoline engine or electric motor while the larger pumps are typically powered by a tractor power take-off. Their portability allows them to be transported to sites on different lakes as needs arise. Another advantage of this type of operation is the ability to initiate pumping in late winter when the oxygen levels are low or beginning to rapidly decline. Because pump and baffle systems do not set up currents or circulate water to the same extent as bubbler systems, localized areas can be oxygenated rapidly to provide a refuge for fish. It has been shown that fish populations can crowd into a rather small portion of the lake in wintertime and apparently survive quite well (Johnson and Skrypek 1975). Preliminary observations indicate that these systems will work when run continuously until oxygen levels have increased sufficiently in a volume of water equivalent to 10% of the lake area to a depth of 2-3 ft; i.e. 20-30 A·ft in a 100 A lake (Skrypek and Shodeen 1977).

It is more efficient if the water intake and discharge points are well separated to prevent immediate recirculation. Shore based installations are preferable as ice cover in late winter is not adequate to support heavy equipment. The amount of open water created by a pump and baffle system is limited but still must be marked as a safety precaution.

These operations are very energy and manpower intensive which makes their cost prohibitive on lakes which suffer frequent or extended periods of oxygen depletion. For this reason and because they can be started late in the season when winterkill appears imminent, they are best suited for lakes with a low or periodic winterkill frequency.

Recently, permanent shore based pumps and flumes have been constructed on a few lakes and the results appear promising. Energy and maintenance requirements are reduced and they are much less objectionable from the standpoint of noise and appearance. Where a well is used as an alternative water source, these systems can serve the dual purpose of oxygenating and augmenting lake water levels.

Air Bubbler Systems

As mentioned earlier, air bubbler systems function as water pumps circulating oxygenated water throughout the lake basin. The air for bubbler systems is provided by high volume, low pressure blowers or by lower volume, high pressure air compressors. Blowers are normally used where the air is delivered to the lake at a depth less than 12 ft. Compressors are needed in deeper areas where greater hydrostatic pressure must be overcome.

The air is introduced at the lake bottom by various types of coarse or fine bubble diffusers or air lifts. Clustering of the diffusers or air lifts in the deepest part of the lake, preferably in wind exposed areas, appears to be the most efficient method of placement for complete circulation and maintenance of a large continuous open water area.

An advantage of bubbler systems is that there are no moving parts underwater. The only part of the system requiring general maintenance or repair is the blower or compressor which furnishes the air supply from shore. These systems also allow versatility in water depth selection for placement of the air distribution system.

Bubbler systems must be started early in the winter, when oxygen levels are high, and operated continuously until ice-out. Rapid declines in oxygen concentrations have been observed for a time following start up of aeration systems and winterkill can be accelerated or intensified as a result of upwelling and circulation of oxygen deficient bottom water and organic material having a high BOD (Patriarche 1961; Lackey and Holmes 1972). Mathias and Barica (1980) assert that if the average D.O. concentration in the water column is below 3.8 $mg \cdot l^{-1}$, mixing beneath an intact ice cover will effectively hasten the onset of anoxia. Because of the need to operate bubbler systems continuously throughout the winter, they are best suited for use in lakes having a high winterkill frequency. Shutdown periods must be avoided or open water areas will be lost. It is difficult to regain open water areas during mid-winter when air temperatures are usually coldest and water temperatures have cooled down due to operation of the system (Skrypek and Shodeen 1977).

Pontoon mounted propellor aerators which inject air just below the water surface are gaining popularity in Minnesota. Their unique design sets them apart from bubbler systems and mechanical surface aerators but because of their similarity to bubbler systems, introducing air which in turn moves large volumes of water causing substantial mixing, they will be considered here. When these aerators are placed in series, their cumulative water moving effect appears to be more than the total volume would be if the units were isolated. These aerators are portable so they can be replaced with little down-time when problems occur. Because ambient air is injected near the water surface, there is no need to compress air to overcome pressures at depth though the air delivery system (impeller) requires an amount of energy that may offset this savings. Electrical wiring to each of the units in the lake is necessary and, depending on the distance from the power source on shore, line power loss may be a factor. Like bubbler systems, these aerators should be operated continuously beginning in early winter. This type of system is also best suited for lakes which winterkill frequently.

Mechanical Surface Aerators

Various types of mechanical spray pumps and surface agitators have been used in efforts to prevent winterkill. Basically, all are floating or submersible electric pumps which agitate the surface or spray water into the air. Spray type surface aerators create a fountain-like effect wherein water is drawn upward through a draft tube and deflected outward. The sheet of water absorbs some oxygen during its brief contact with air before returning to the lake or pond. There is also oxygen transfer at the air-water interface where the droplets hit the surface. These systems are less efficient because they require more energy to pump water (rather than air) and recirculation may be rapid. Mechanical surface aerators are basically surface oxygen transfer devices. However, when used in winter surface cooling may establish temperature dependent density currents causing substantial mixing, at least to the depth of the draft tube intake (Shodeen 1976). Spray type aerators also require electrical connection to a shore based power source. These units appear to be best suited for use in ponds and small lakes.

Other Systems

In addition to those systems described above and used in Minnesota lakes, other aeration design concepts have been tried elsewhere and may merit evaluation in lakes here. One technique has involved the use of axial flow pumps for both winterkill prevention and summer destratification (Garton el al. 1978; Summerfelt et al. 1980; McWilliams 1980). Another method has involved the use of hypolimnetic aerators to oxygenate bottom waters in stratified lakes without significantly disrupting the metalimnion (Fast 1971; Smith et al. 1975; Lorenzen and Fast 1977).

An axial flow pump is a floating apparatus designed like a ventilation fan except that it moves water instead of air (Summerfelt et al. 1980). The unit is a high-volume, low-head pump powered by an electric motor which turns a propellor (seven bladed aluminum crop drying fan). The propellor can be installed to direct the water upward, drawing oxygen deficient water to the surface or downward, pushing oxygenated surface water to the bottom. This type of system may have an advantage over other air bubble and mechanical pumping systems because of the larger pumping capacity relative to energy requirements (Summerfelt et al. 1980).

Hypolimnetic aeration may be desirable in lakes where the temperature regime below the metalimnion is suitable but summer anoxia precludes the establishment of a coldwater fishery. Several types of hypolimnetic aerators have been tried including air injection, liquid (or pure) oxygen injection and mechanical agitation systems (Lorenzen and Fast 1977). Air injection systems utilizing full air lifts appear to hold the most promise (Smith et al. 1975; Lorenzen and Fast 1977). A full air lift design involves introducing compressed air at the lake bottom at the base of an inflow tube which extends to the lake surface. Hypolimnetic water is drawn up the tube where it enters a separation box or degassing chamber on the surface. The hydraulic head in the separation box created by the air lift pump then forces the oxygenated water back into the hypolimnion via downflow tubes. Consequently, hypolimnetic water is aerated but not significantly heated or or mixed with epilimnetic or metalimnetic water. Hypolimnetic aeration has also been tried unsuccessfully in ice covered lakes where it was hoped that the open water hazard associated with winter aeration could be prevented (Smith et al. 1975).

System Size and Design

The size of the system employed is obviously of critical importance in effectively preventing winterkill or in improving water quality. However, there are no simple guidelines for estimating this need. Different designs and efficiencies of the available systems coupled with the range of variability in physical, chemical and biological characteristics of lakes, makes correct sizing of such systems an elusive quantity. Wirth (1970) observed that the amount of air delivered to lakes where Polcon Corp. "Helixor" systems have been successful in preventing winterkill has ranged from 30-86 ft^3 air/A·ft/da.

Certain costs such as equipment, manpower and electricity can be estimated but comparing operational efficiencies of equipment represents a problem. Oxygen transfer testing is commonly used to determine the efficiency of absorption of a particular aerator under a specific set of conditions (Conway and Kumke 1966; Carr and Martin 1978). Results are usually expressed as either a percentage of oxygen dissolved or the quantity of oxygen transferred per horsepower-hour (lbs. O_2/HP·hr). Conversion of these values to *in situ* conditions is difficult and results can be inconsistent. Furthermore, these methods seem to favor fine bubble systems as test conditions are affected by bubble number, size and retention time.

As stated earlier, the amount of oxygen transfer which takes place at the surface is much more important than that which occurs in the rising bubble stream. The effectiveness of circulation and turbulence in maintaining open water and the degree of basin cooling are more significant criteria in evaluating aerator performance in lakes. Further study is needed in this area in order to estimate minimum size requirements with confidence.

PRESENT STATUS OF SYSTEMS IN MINNESOTA

During the winter of 1981-82, permits were in effect for aeration operations in 68 lakes throughout Minnesota. Table 2 shows 71 permits for this season but 4 permits were only for summer use.

At the close of the winter aeration season, questionnaires (Fig. 2) were mailed to all permittees. Table 3 summarizes information on winter aeration operations in 1981-82 obtained from these questionnaires and permit files.

In the 1981-82 winter, 186 lakes suffered from winterkill compared to an average of 125 (Table 1) with winterkills being reported in five aerated lakes. The failure of at least three of these systems in preventing winterkill can be attributed to undersized or inefficient equipment and late starting dates. A $\frac{1}{4}$ hp Kembro bubbler in Cable Lake, Polk County (144 A) was not turned on until 9 February and three $\frac{1}{2}$ hp spray pumps in Lake Fremont, Sherburne County (489 A) were not started until 1 February. Eight wind-powered mixing devices (Wadler Pondmaster) were deemed to be totally ineffective in preventing winterkill in Yankton Lake, Lyon County. In addition to these, West Graham Lake in Nobles County and Sarah Lake in Murray County sustained partial winterkills following aeration efforts with larger Helixor systems. In both cases, it is likely that fish losses would have been more extensive without aeration.

Table 4 illustrates the operational characteristics of the different types of aeration systems as best they could be determined from information on the questionnaires. General comparisons between these systems may reveal differences in mechanical efficiency and economy; however, the relevance of these differences to effectiveness in preventing winterkill is not established.

Estimates of the size of open water area at midwinter from the questionnaires were judged to be too subjective to be used for comparison of aeration devices. Estimates were made by as many different individuals as there were respondents and interpretation of "midwinter" is also subject to variation. Actual measurements of open water areas created, made over a period of time, are needed for future comparisons.

PROGRAM ADMINISTRATION

Permits are presently required for aeration systems larger than the minimum size adequate to keep dock piers or mooring areas free of ice. The number of aeration systems authorized by permit from the DNR has grown from 3 in 1974 to 71 in the winter 1981-82 (Table 2). This increase has been accompanied by growth and changes in administration of the permit program.

Previous to 1978, the DNR Division of Waters issued permits to install aeration devices under the authority of Minn. Statutes, Section 105.42 which requires permits for activities which ". . . change or diminish the course, current or cross-section of any public waters. . . by any means, including . . . placing of any materials in or on the beds of public waters."

By 1977, concerns about the effects of lake aeration systems on fish and hazards created by thin ice or open water were sufficient to bring about a formal permit system which addressed these concerns. In May 1978, Commissioner's Order No. 1996 (superseded by C.O. 2083 and 2114) was written establishing permit requirements for the installation and operation of aeration systems. At this time, the permit authority was transferred from the DNR Division of Waters to the Division of Fish and Wildlife. Transfer of the permit authority was deemed appropriate because of the potential for impact on the aquatic environment which aeration presents and the need for direct consultation between applicants, resource managers and biologists. Presently, Fish and Wildlife personnel accept applications for aeration projects and evaluate these proposals for their merit and compatibility with resource management objectives.

Applicants are required to show that they are properly equipped and organized to accomplish their stated goals. When systems are to be operated during periods of ice cover, applicants must demonstrate proof of financial responsibility which would meet any liability that may arise in the event of an accident at the system site. Posting of signs around the area of open water and at points of access to the aerated lake is also required for wintertime operation. Permits issued by the Department require that the permittee take all reasonable precautions to guard against injury to persons or property resulting from the installation, operation or maintenance of the permitted equipment and that the permittee comply with all applicable statutes, ordinances and regulations. The 1981 Minnesota Legislature passed a law (Minnesota Statutes, Section 378.22) relaxing the sign posting requirements previously established by Commissioner's Order No. 2083 and requiring that public notice be given in a local newspaper prior to the start of winter operations.

Local ordinances or resolutions are encouraged which restrict the use of motor vehicles at night on the ice surface of lakes where aeration systems are in use. Such ordinances are possible under provisions of Minnesota Statutes, Section 378.32 and are subject to approval by the Commissioner of Natural Resources prior to adoption.

Two types of permits are issued for aeration systems. Where the permittee is an individual, sportsmens group, lakeshore association or other private interest, an annually renewable permit is issued. An open-ended permit with no expiration date is issued when the permittee is a unit of government such as a county, municipality, watershed district or other entity whose long-term existence is assured. Aeration projects require a substantial commitment of manpower and money for effective operation and it is felt that units of government are more capable of meeting this commitment perennially, without review.

Conflicts in Use

Classification of lake type and management objectives are important considerations in the decision to install an aeration system. In general, lake basins assigned a game lake classification (shallow lakes) should not be aerated until the implications to wildlife management are evaluated. The detrimental effects of carp and bullheads on waterfowl lakes are well known. Attempts to prevent winterkill through aeration in these lakes may likely result in only a marginal improvement of the fishery resource and loss or degradation of important waterfowl sources.

In addition to those lakes assigned a game lake classification based on previous investigations or surveys, a formal procedure exists for reserving, designating and managing certain waters for their primary wildlife use and benefit. These designations are made by Commissioner's Order following published notices and public hearings. Aeration system permits will not be granted in designated waterfowl lakes unless benefits can be attributed to wildlife.

If game lakes are excluded from consideration, this leaves marginal lake types which are too deep for waterfowl but too shallow to over-winter a fish population. In considering benefits to fish populations which might be gained through winterkill prevention, it should be pointed out that a high proportion of the marginal lake types which are prone to winterkill are lakes that would contain fish populations dominated by bullheads or carp even if no winterkill occurred (Scidmore 1970). Unless accompanied by other efforts such as nongame fish removal, chemical rehabilitation and/or barrier construction, improvements from aeration efforts may not justify the expenditure.

Skrypek (1976) outlined the following factors which should be considered before aerating a marginal lake: frequency of winterkill, proximity of permanent fish lakes in the area, type of fish population the lake could be expected to support with aeration, importance of the lake to a local community or resort establishments, cost of restocking fish without aeration, cost of installation and operation of the aeration system, proximity of intensive use areas on shore such as public parks, cost of increased nongame fish control programs which may be necessary with aeration, whether contract nongame fish removal is feasible on the aerated lake and possible conflict of open water areas and thin ice with wintertime recreational activity.

The issue is complex and a determination of the appropriateness of aeration requires consideration of economic and social values as well as biological factors. With proper planning and analysis, the potential for enhancement of our states fishing resource by aeration is substantial.

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Table 1. Number of winterkill lakes in Minnesota, 1955-1982.

Winter season	Number of lakes	Winter season	Number of lakes
1955 - 1956	308	1969 - 1970	204
1956 - 1957	24	1970 - 1971	133
1957 - 1958	5	1971 - 1972	132
1958 - 1959	77	1972 - 1973	40
1959 - 1960	171	1973 - 1974	62
1960 - 1961	48	1974 - 1975	206
1961 - 1962	212	1975 - 1976	59
1962 - 1963	38	1976 - 1977	268
1963 - 1964	76	1977 - 1978	128
1964 - 1965	270	1978 - 1979	236
1965 - 1966	75	1979 - 1980	8
1966 - 1967	188	1980 - 1981	4
1967 - 1968	28	1981 - 1982	186
1968 - 1969	185	Avg. 1955 - 1982	124.9

Table 2. Aeration permits issued by year.

Year	Number of systems under permit
1974	3
1975	7
1976	13
1977	25
1978	28
1978 - 79[a]	20
1979 - 80	34
1980 - 81	45
1981 - 82	71

[a]Fish and Wildlife Division began issuing permits in 1978-79. Decline in number of permits issued that year is likely the result of confusion over where permits were to be obtained following transfer of permit authority.

Table 3. Aeration systems 1981-82.

Lake (ID #)	County	Lake area (A)	Sponsor	System description	Electrical consumption (KWH)	Electrical costs	Number months operated
BUBBLER SYSTEMS				Polcon Helixor			
Clear (32-22)	Jackson	415	Jackson County Conservation League	Two 5 hp. motors, 6 Helixor diffusers	16,890	$681.50	3
Allie (65-6)	Renville	451	Buffalo Lake Rod & Gun Club	One 7½ hp. motor, 6 Helixor diffusers	11,980	$786.26	3
Elysian (81-95)	Waseca	1,902	Smiths Mill-Janesville Sportsmen Club	Three 7½ hp. motors, 15 Helixor diffusers	42,000	$3,195.00	3
Okabena (53-28)	Nobles	783	City of Worthington	Two 7½ hp. motors, 9 Helixor diffusers	22,097	$881.10	2.5
Swan (43-41)	McLeod	343	Silver Lake Sportsmens Club	One 5 hp. motor, 3 Helixor diffusers	9,000	$585.00	2.5
Lura (7-79)	Blue Earth	1,223	Lura Lake Aeration Corporation	One 10 hp. motor, 6 Helixor diffusers	NI[a]	NI	4.5
Split Rock (59-1)	Pipestone	60	Pipestone County	One 7½ hp. motor, 3 Helixor diffusers	13,120	$558.35	3
Sleepy Eye (8-45)	Brown	425	City of Sleepy Eye	Two 5 hp. motors, 9 Helixor diffusers	20,158	$998.99	3.25
Fountain (24-18)	Freeborn	534	City of Albert Lea	Two 7½ hp. motors, 6 Helixor diffusers	31,200	$2,131.00	4
Benton (41-43)	Lincoln	2,857	Lincoln County	Two 7½ hp. motors, 12 Helixor diffusers	32,670	$1,625.81	3.75
West Graham (53-21)	Nobles	602	Nobles County	Two 7½ hp. motors, 6 Helixor diffusers	NI	Approx. $800.00	3
South (First) Fulda (51-21)	Murray	118	Murray County	Two 7½ hp. motors, 4 Helixor diffusers	9,330	$478.16	3

Table 3. Continued.

Lake (ID #)	County	Lake area (A)	Sponsor	System description	Electrical consumption (KWH)	Electrical costs	Number months operated
BUBBLER SYSTEMS				Polcon Helixor			
Sarah (51-63)	Murray	1,173	Murray County	One 7½ hp. motor, 4 Helixor diffusers	12,670	$386.82	3
Shetek (51-46)	Murray	3,705	Murray County	Three 7½ hp. motors, 12 Helixor diffusers	25,841	$966.11	3
Round (32-69)	Jackson	995	Round Lake Sportsmens Club	Two 7½ hp. motors, 9 Helixor diffusers	21,930	$937.12	3.75
Long (34-66)	Kandiyohi	286	Kandiyohi County/ West Central Aeration	Two 10 hp. motors, 12 Helixor diffusers	49,640	$2,000.00	3.5
				Clean-Flo			
Crystal (27-34)	Hennepin	78	City of Robbinsdale	Two ½ hp. compressors, 3 Clean-Flo ceramic diffusers	16,366	$975.00	12
Swimming Pool Pond (27-28)	Hennepin	48	City of Edina	One ½ hp. compressor, 3 Clean-Flo ceramic diffusers	NI	NI	Continuous
Tadd (No ID #)	Kandiyohi	NI	City of Atwater	Two ½ hp. compressors, 4 Clean-Flo ceramic diffusers	NI	$45.00/mo	Continuous
Bennett (62-48)	Ramsey	41	City of Roseville	Three ½ hp. compressors, 6 Clean-Flo ceramic diffusers	NI	$45.00/mo	Continuous
Twin (No ID #)	Hennepin	NI	Twin Lakes Association	Two ½ hp. compressors, 5 Clean-Flo ceramic diffusers	NI	≈$350.00	Continuous
Indianhead (27-44)	Hennepin	15	City of Edina	Four ½ hp. compressors, 4 Clean-Flo ceramic diffusers	NI	$45.00/mo	Continuous
Simon (80-3)	Wadena	103	Water Environmental Control Corp.	Twelve ½ hp. compressors, 24 Clean-Flo ceramic diffusers	54,612	$3,061.68	Continuous

Table 3. Continued.

Lake (ID #)	County	Lake area (A)	Sponsor	System description	Electrical consumption (KWH)	Electrical costs	Number months operated
BUBBLER SYSTEMS				Kembro			
Loon (11-226)	Cass	237	Loon Lake Property Owners, Inc.	Five ¼ hp. Kembro compressors 5 diffusers	5,300	$424.28	4.5
Cable (60-293)	Polk	144	Cable Lake Association	One ¼ hp. Kembro compressor 1 diffuser	NI	$14.00	1.25
Stocking (80-37)	Wadena	356	Stocking Lake Booster's Club	Five ¼ hp. compressors, 5 diffusers	NI	NI	Continuous
				Other Air Bubble Systems			
Cloverdale (82-9)	Washington	35	Cloverdale Farms	Three ½ hp. compressors, 3 venturi type diffusers	3,850	$225.00	4
Marion (43-84)	McLeod	594	Brownton Rod & Gun Club	One 5 hp. motor, seven MAT air lifts	9,310	$610.15	3.25
Ann (71-69)	Sherburne	184	Ann Lake Improvement Club	Two ½ hp. compressors, two open-ended hoses	1,849	$114.63	2.5
				Aeration Industries			
Eagle (10-121)	Carver	233	Carver County	Two 2 hp. Aire-O_2 propellor aspirators	17,150	$1,176.00	3.25
Currant (51-82)	Murray	377	Murray County	Four 2 hp. Aire-O_2 propellor aspirators	19,500	$795.82	3
Bass (27-98)	Hennepin	173	Bass Lake Improvement Association	Two 2 hp. Aire-O_2 propellor aspirators	2,576	$150.10	2.75
Cedar (70-91)	Scott	780	New Prague Sportsmens Club	Six 2 hp. Aire-O_2 propellor aspirators	33,740	$2,229.37	3.25
Shaokatan (41-89)	Lincoln	995	Lincoln County/ Shaokatan Sportsmens Club	Two 2 hp. Aire-O_2 propellor aspirators	4,677	$252.27	1.5

Table 3. Continued.

Lake (ID #)	County	Lake area (A)	Sponsor	System description	Electrical consumption (KWH)	Electrical costs	Number months operated
BUBBLER SYSTEMS				Aeration Industries			
Hendricks (41-110)	Lincoln	1,560 (665 in Minn.)	Lincoln County/ Lake Hendricks Imp. Association	Three 2 hp. Aire-O_2 propellor aspirators	10,505	$652.92	2.75
Rebecca (27-192)	Hennepin	198	Henn. Co. Park Reserve District	Three 2 hp. Aire-O_2 propellor aspirators	8,980	$687.46	2
O'Dowd (70-95)	Scott	258	O'Dowd Lakes Chain Association, Inc.	Three 2 hp. Aire-O_2 propellor aspirators	8,890	$461.52	2
Horseshoe (77-128)	Todd	118	Browerville Sportsmens Club	One 2 hp. Aire-O_2 propellor aspirator	2,844	$156.63	1.75
SPRAY PUMPS							
Gorman (40-32)	LeSueur	499	Izaak Walton League LeCenter Chapter	Seven ½ hp. spray pumps	7,540	$483.88	1.5
Fish (46-145)	Martin	174	Odin Sportsmens Club	Four 1 hp. Zoeller spray pumps	5,283	$280.00	3.25
Buffalo (46-44)	Martin	262	Odin Sportsmens Club	Three 1 hp. Zoeller spray pumps	3,584	$190.00	2.5
Cross (60-27)	Polk	328	Fosston Community Sportsmens Club	Two 1 hp. spray pumps and two 3/4 hp. distributor pumps	7,200	$330.00	2.5
Turtle (60-32)	Polk	581	Fosston Community Sportsmens Club	Two 1 hp. spray pumps and two 3/4 hp. distributor pumps	7,200	$330.00	2.25
Sandhill (60-69)	Polk-Mahnomen	510	Fosston Community Sportsmens Club	Two 1 hp. spray pumps and two 3/4 hp. distributor pumps	4,000	$184.00	1.75
Maple (60-305)	Polk	1,477	Maple Lake Improvement Association	Seven 1½ hp. spray pumps and seven 3/4 hp. distributor pumps (minosavor)	32,000	$1,750.00	2

Table 3. Continued.

Lake (ID #)	County	Lake area (A)	Sponsor	System description	Electrical consumption (KWH)	Electrical costs	Number months operated
SPRAY PUMPS							
Crystal (7-98)	Blue Earth	396	Crystal & Loon Lake Recreation, Inc.	Six 3/4 hp. spray pumps	4,640	$340.00	1
Loon (7-96)	Blue Earth	754	Crystal & Loon Lake Recreation, Inc.	Six 3/4 hp. spray pumps	3,906	$278.07	.75
Island (62-75)	Ramsey	57	Ramsey County Public Works Dept.	One 5 hp. Welles Aqualator spray pump	4,104	$164.46	2.25
PUMP & BAFFLE							
Hyland (27-48)	Hennepin	67	Hennepin Co. Park Reserve District	350 gpm pump & baffle permanent shore installation (electric)	NI	NI	Continuous
Lower Penn (27-4)	Hennepin	31	City of Bloomington	Permanent shore based pump & baffle (electric)	NI	NI	Continuous
Pine (15-149)	Clearwater	1,188	Red Lake Watershed District	100 hp. tractor driven 16" Crisafulli pump (est. 5,000 gpm)	NI	$298.38[b]	76.5 hrs
Kansas (83-36)	Watonwan	398	Odin Sportsmens Club	Two 12" high volume water pumps	NI	$1,100.00[c]	192 hrs
Silver (62-1)	Ramsey	72.1	Ramsey County Public Works Dept.	50 hp. electric mobile pump & baffle, 12", 3,800 gpm	8,020	$337.50	336 hrs

[a]No information

[b]Diesel fuel

[c]Diesel Fuel & LP gas

Table 4. Operational characteristics of aeration systems, winter 1981-82.

BUBBLER SYSTEMS		hp/A	$/A/mo	$/hp/mo	KWH/hp/mo	KWH/hp/A
Helixor	Range	0.005-0.127	$0.09-3.10	$10.63-47.33	207.3-720.0	0.31-29.16
	Mean	0.033	$0.80	$26.69	541.6	5.10
	n	16	15	15	14	14
Clean-Flo	Range	0.010-0.133	$1.04-3.00	$22.50-45.00	785.5	88.37
	Mean	0.059	$1.91	$33.84	785.5	88.37
	n	4	4	5	1	1
Kembro	Range	0.002-0.005	$0.08-0.40	$44.80-75.43	408.9	17.89
	Mean	0.004	$0.24	$60.11	408.9	17.89
	n	3	2	2	1	1
Aeration Industries	Range	0.004-0.30	$0.15-1.74	$13.65-90.46	234.2-1319.2	1.12-18.40
	Mean	0.017	$0.80	$46.28	793.8	6.65
	n	9	9	9	9	9
SPRAY PUMPS Zoeller, Mino-Saver, Aqualator, etc.	Range	0.006-0.088	$0.21-1.28	$14.62-92.17	364.8-1436.2	1.15-14.4
	Mean	0.018	$0.55	$47.68	828.0	7.80
	n	10	10	10	10	10

Figure 1. Distribution of aeration systems authorized by permit for for operation in 1981-82.

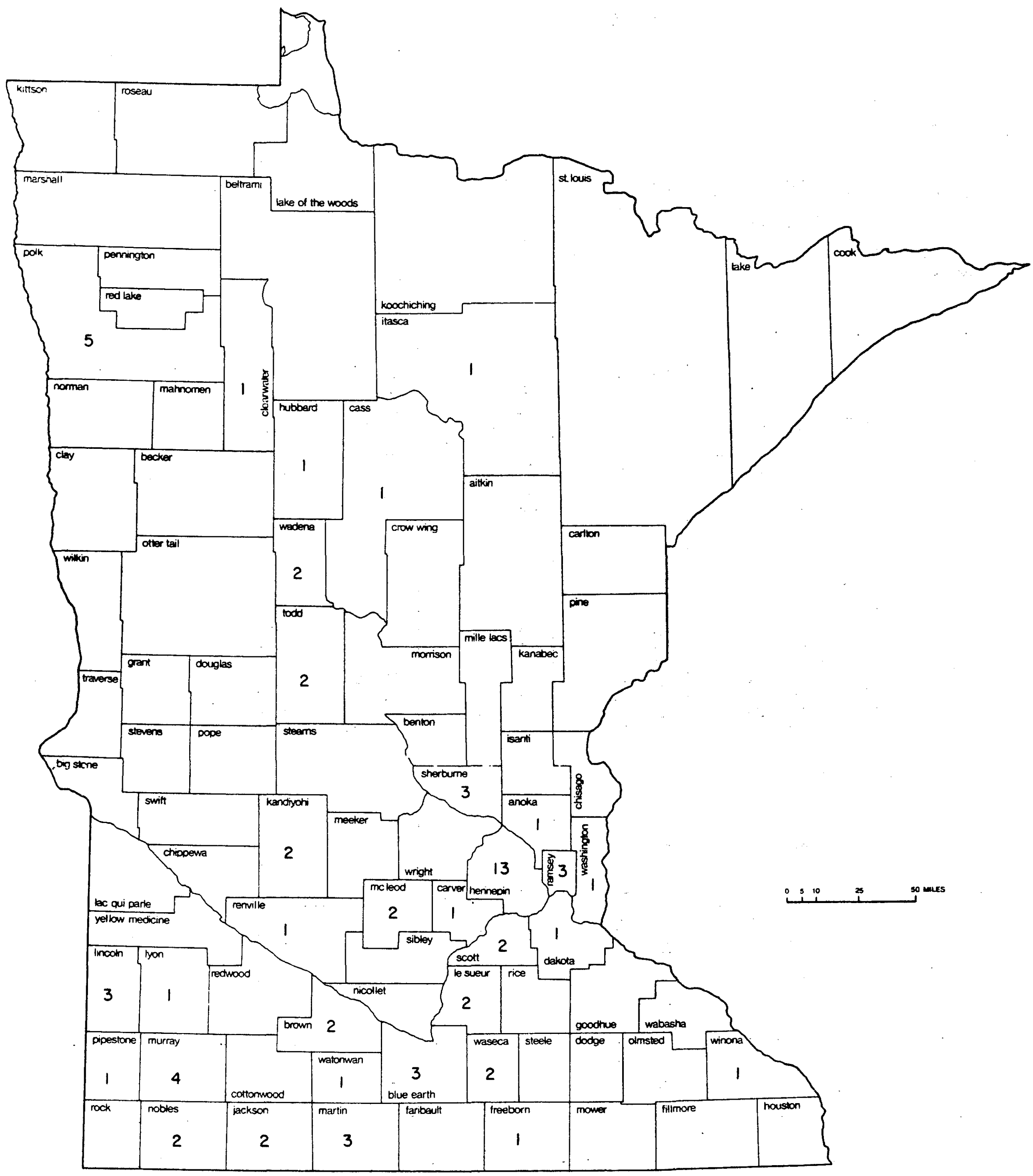

Figure 2. Questionnaires mailed to aeration system permittees.

MINNESOTA DEPARTMENT OF NATURAL RESOURCES
SECTION OF ECOLOGICAL SERVICES

Report on Operation of an Aeration System for Winterkill Prevention

1. Name of person or organization____________________ Date__________

2. Lake____________________ County____________________

3. Was the aeration system operated last winter____yes ____no (If you checked no, do not complete the balance of this form. If only part of the system authorized by your permit was used explain on the back of this form).

4. Date the system was started____________________

5. Date the system was shut off____________________

6. Dates of any extended periods of shutdown during the operating season

____

7. Electric power consumption for season in KWH____________________

8. Cost of power for season____________________

9. Approximate size of open water area at midwinter____________________

10. Was there any evidence of winterkill at ice-out? ____yes ____ no

11. Were there any safety problems due to thin ice or open water? ____yes ____no

12. If you answered yes to question 11 explain below.

____

____

____

13. Any additional comments you have about operation of the aeration system or State Administration of the program.

____

____

____

Instructions

When completed please mail this form in the enclosed envelope to:

Minnesota Department of Natural Resources
Section of Ecological Services
Box 25, Centennial Office Building
658 Cedar Street
St. Paul, Minnesota 55155-1679

SPECIAL PUBLICATIONS (1977-82)*

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No. 124	A Biological Reconnaissance of the Rum River by Thomas Kucera. March 1978.
No. 125	The Management of Lakes for Streem Trout and Salmon by Merle W. Johnson. January 1978.
No. 126	Water Quality Monitoring Program on Representative Fish Lakes 1977, by David B. Zappetillo and Howard Krosch. April 1978.
No. 127	Fish and Wildlife Resources of the St. Louis River by Arthur Peterson. May 1979.
No. 172A	Annual Report of Mercury Levels in Fish in the Mississippi, Red and St. Louis Rivers, Minnesota 1977. (Robert Glazer).
No. 128	Summary and Analysis of the Water Quality Monitoring Program from 1973 to 1978, by Arthur R. Peterson and Nancy Potthoff. October 1979.
No. 129	Fish and Wildlife Resources of the Mississippi River from Lake Itasca to Lake Winnibigoshish by Thomas Kucera and Arthur Peterson. March 1980.
No. 130	Fish and Wildlife Resources of the Roseau River, by John W. Enblom. May 1982.
No. 131	Parasites and Selected Anomalies of some fishes of the North Central United States and Canada, by Ellis J. Wyatt and Philip P. Economon. September 1981.
No. 132	Lake Management Planning Guide. December 1982.

* Complete list of all publications in the series available from Minnesota Department of Natural Resources, Division of Fisheries and Wildlife, Section of Fisheries, Box 12, 658 Cedar St., St. Paul, Minnesota 55155