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A REVIEW OF LAKE AERATION AS A TECHNIQUE FOR WATER QUALITY IMPROVEMENT

by

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SUMMARY

Aeration of lakes and reservoirs has been used for a number of years as a method of improving water quality. Aeration can be used for improvement of drinking water supplies, providing enhanced fisheries habitat and treatment of symptoms of eutrophication.

Aeration can be arbitrarily divided into two basic categories. Destratification systems, as the name implies, uses compressed air to cause vertical water movement and mixing of the lake water column. Hypolimnetic systems add oxygen to the lake without destroying the thermal stratification. Each type are appropriate in particular situations.

The largest portion of the report is a bibliography listing journal articles and reports documenting experiences with aeration projects.

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1. INTRODUCTION

A literature review on lake and reservoir aeration was originally done at the request of the Okanagan Implementation Program as part of an evaluation of the feasibility of aerating Wood Lake. This report is a compilation of that work considered in a general format so that the information could be available to those individuals and agencies for whom the information would be useful. It is not intended to be a "do-it-yourself" manual, but rather a general overview of present information and a guide to the literature on aeration.

2. AERATION SYSTEM TYPES

2.1 Historical Development

Lake aeration was first described by Scott and Foley (1919). However, little activity with regard to lake aeration is evident in the literature until a paper by Mercier and Perret (1949), brought the concept forth again. During the 1960's and 1970's numerous projects were undertaken, and the sophistication and size of many of the projects increased dramatically after that time. All of the early systems used were the destratification type where air is pumped from a shore station into the lake, through a perforated line anchored near the bottom of the lake (Figure 1). The air escaping from the hose rises through the water column, inducing vertical mixing and preventing the normal thermal stratification of the lake. The action of the rising bubbles apparently transfers very little oxygen to the water (King, 1970). Rather, the circulation pattern which is established allows gas exchange at the lake water surface and mixes this aerated water back to the bottom of the lake (Smith et al., 1975). This type of system and variations of it are considered below, while the other general category of aeration (hypolimnetic) is considered in the following section.

The thermal stratification of a lake can be destroyed without aeration. Mechanical mixing has been used successfully (Ridley 1972; Gebhart and Clady, 1977; Irwin et al., 1966) and this method is also an option for destratification.

2.2 Destratification Systems

Destratification was first used by fisheries managers to solve the problems of deoxygenation of the hypolimnion of productive lakes. Lack of oxygen in the hypolimnion during the summer restricts the habitat of fish to the epilimnion. The high surface water temperature affects the growth rates and survival of species (like trout) that prefer cool water. In winter, many productive lakes tend to 'winter kill', that is they have insufficient oxygen

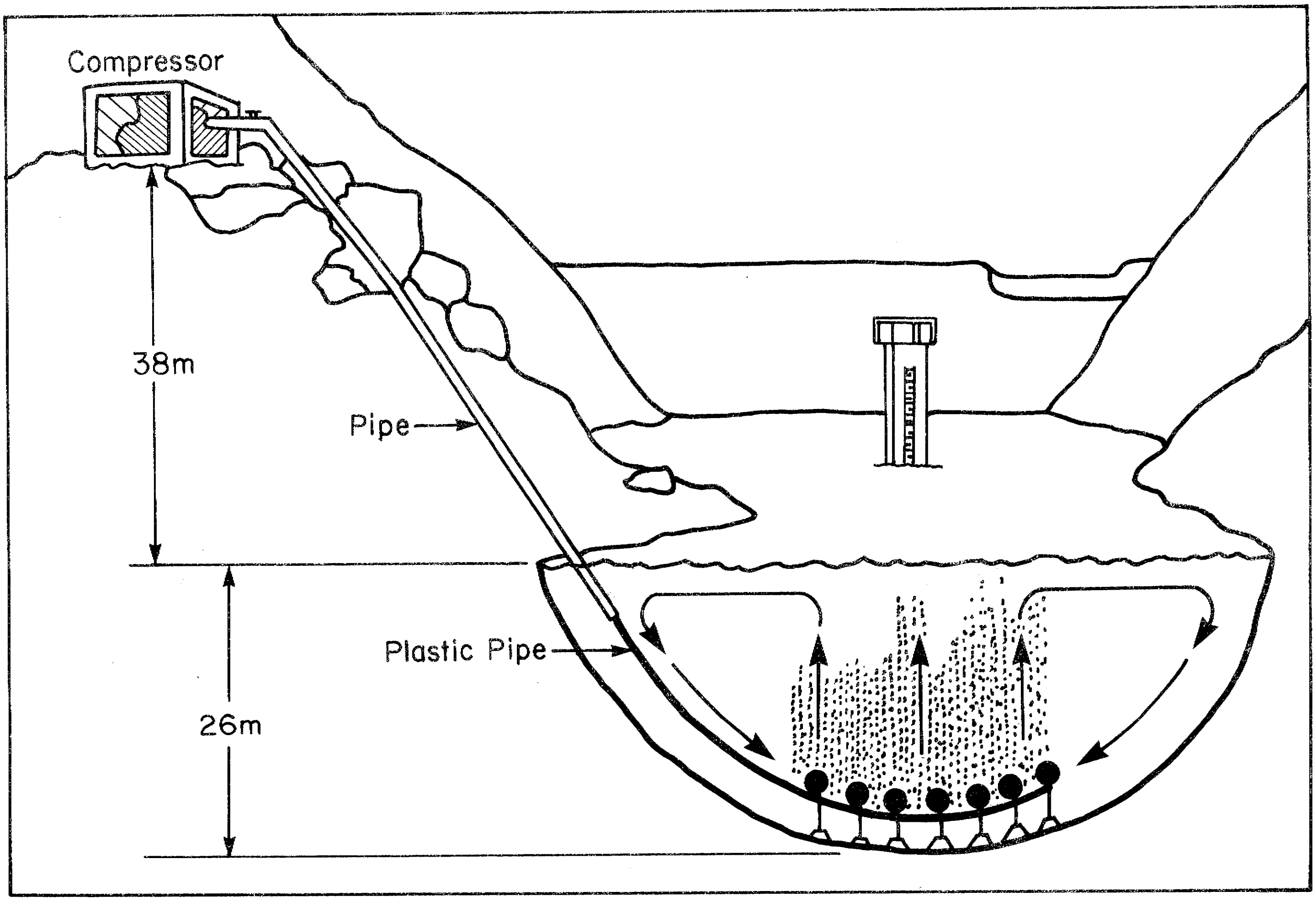


FIGURE 1: Destratification system (from Lorenzen, 1977a).

content to allow survival of fish through the entire period of ice cover. In both of these situations aeration can be a useful method of habitat improvement. Some of the early aeration projects undertaken for fisheries enhancement were in British Columbia (Halsey, 1968; and Halsey and Galbraith, 1971) as well as a variety of other locations: California (Fast, 1968); Colorado (Lackey, 1971; Lackey and Holmes, 1972); North Dakota (Tubb, 1966; Kreil, 1969 and 1971); Wyoming (Rasmussen, 1960); and Wisconsin (Wirth, 1970; Wirth and Dunst, 1967; Wirth et al., 1970). The B.C. Ministry of Environment, Fish and Wildlife Branch continues to be very active in research and application of hypolimnetic aeration systems (Ashley, 1981; and Ashley, in prep.).

Destratification by aeration provides a relatively inexpensive means of mixing the lake and destroying (or minimizing) the stratification. It can be used to accomplish a number of ends.

The use in fisheries management has been noted above. Destratification basically increases the oxygen content of an entire lake. During the summer destratification has one major disadvantage. Constant circulation of the lake may allow the heat content to increase to a point where the advantages of the increased oxygen content are overshadowed by the temperature constraints on a cold water fishery. The hypolimnetic aeration systems described below solved the problem of increased heat budget by aerating without disturbing the temperature stratification.

Destratification aeration can also be used in improvement of drinking water quality by both aerating the water column when problems of low oxygen concentrations are encountered, and controlling high algal growth. This latter aspect is one which requires a detailed evaluation of the conditions prevailing and some projections as to the effects of aeration. Destratification may reduce algal growth in three ways. First, by simply causing mixing of the algal biomass present into the entire water column, the algae are not restricted to the photic zone (Fast, 1968; Bernhardt, 1967). This does not reduce the amount of algae in the lake, it merely reduces the concentration. Second, by having the algal cells travelling vertically through the water column, part of the time they are below the photic zone and the growth rate is slowed (Lorenzen, 1977a and 1977b). A third mechanism of reduction of algal growth is by reduction of nutrients by altering the chemical nature of the water column and conditions at the sediment-water interface. Under anaerobic conditions, phosphorus particularly is mobilized from lake sediments and a flux from the sediments to the water column takes place. When the sediment is overlain with aerobic water, the phosphorus tends to be bound to iron, aluminum or manganese and remains in the sediment.

It has also been reported that aeration can cause changes in the composition of phytoplankton in a lake or reservoir, from blue-green algae which are particularly undesirable in terms of aesthetics, taste and odour and toxicity, to less objectionable green algae (Shapiro et al., 1977; and Malueg et al., 1971). Taste and odour problems can also be overcome to some extent by aeration (Shuler, 1972) through oxidation of reduced organic and inorganic compounds.

However, destratification can act to maintain or even increase algal growth under some circumstances. Destratification aeration tends to slow the normal sedimentation processes by which algal cells sink from the surface waters to the sediment and are lost, more or less permanently, from the lake. Also, if a destratification system is started up after lake stratification has been established, the consequences can be overwhelmingly negative. Circulation of high concentrations of nutrients into the surface waters have, in a number of cases, caused algal blooms (Brown et al., 1971; Knoppert et al., 1970). If the hypolimnetic water has a high oxygen demand because of dissolved or suspended oxygen consuming materials (hydrogen sulphide or ammonia), a kill of fish and perhaps other components of the biota (zooplankton, benthos) could result from the rapid loss of oxygen from the lake. Lastly, if a lake is shallow, destratification may not reduce algal growth (Bryan, 1964; Malueg et al., 1971; and Knoppert et al., 1970). Brown et al., (1971) noted algal growth in Buchanan Lake (Ontario) increased following destratification. In all these cases the lake's maximum depth was less than 13 m. Consequently, the success of destratification in reducing algal growth may be restricted by the depth of the lake. Lorenzen and Mitchell (1973, and

1975), and Lorenzen (1977a, and 1977b) outline the conditions where destratification can be used to control algal growth.

It is prudent to start operation of a destratification system in the spring or fall while the water column is isothermal. The system can be installed at any time of the year although it may be advantageous to use warm summer weather to uncoil and install diffuser tubing. Start-up during isothermal conditions allows the aeration system to maintain aerobic conditions, and prevent the build-up of ammonia and hydrogen sulphide in the hypolimnion and disruption of the oxidized film on the sediment surface which prevents release of phosphorus from the sediments into the water column. For prevention of winterkill this also is the best strategy (Lackey and Holmes, 1972). Beginning operation of a destratification system before spring and winter stratification is the most efficient use of energy since little power is required to circulate an isothermal water column and keep it circulating. However, to destratify an existing, well established thermal stratification requires a larger input of energy and is more difficult to accomplish.

There are also a variety of other precautions required in system design. For instance, the perforated air supply line must be elevated above the bottom to preclude suspension of fine sediments into the water column (Barica, 1974; Haynes, 1973 and 1975).

Excellent reviews of the parameters which are required prior to consideration of a destratification system are contained in Lorenzen (1977a and 1977b), Fast (1979), Lorenzen and Fast (1977), Toetz et al., (1972) and Lorenzen and Mitchell (1975). Information and results of selected destratification projects are summarized in Table 1.

There are a variety of other uses for destratification systems: aeration of waste water lagoons, prevention of ice formation around structures in lakes and reservoirs, and containing oil spills. These uses have extensive literature which can be referred to, but have not been considered in this report.

TABLE 1

SUMMARY OF SOME INFORMATION FOR SELECTED DESTRATIFICATION PROJECTS

Destratification Systems

Lake	Location	Reference	Diffuser Depth (m)	Air Flow (CF/M)	Pump Power (HP)	Surface Area (ha)	Lake Volume (dam^3)	Max Depth (m)	Mean Depth (m)	Qa*/V**	Qa/A***	Comments or Observations
Blelham Tarn	U.K.	Bryan, 1964				10.9		13.4				Decreased iron, phosphorus, and manganese; algae crop was not reduced by mixing.
Buchanan Lake	Ontario Canada	Brown *et al.*, 1971	13	10	2	8.9	435	13	4.9	0.67	10.8	Total Phosphorus decreased greatly although algal crop increased 500-600%. Water clarity decreased by 50%. Zooplankton increased 4 x.
Casitas Reservoir	California U.S.A.	Fast, 1968	42.7	630	150	1063	294,792	64	27.7			Reduction in algal blooms. Oxidation of manganese (implies oxidation of phosphorus). pH lowered 0.5 relative units.
Clines Pond	Oregon U.S.A.	Malueg *et al.*, 1971	4.6	1	1/4	0.14	2.7	4.9	1.95	10	65.3	Aeration reduced phosphorus, and produced a shift away from blue green algae. No concentration change in chlorophyll.
El Capitan	California U.S.A.	Lorenzen, 1977	28.4	215	50 elec.	186	17,984	62	9.5	0.30	9.0	Total phosphorus reduced after aeration.
Kezar Lake	New. Hamp. U.S.A.	Haynes, 1973, and 1975	7.6	105		71	2,159	8.2	3.04	1.3	13.8	Phosphorus was not reduced as suspended P and was stirred up. Blue green algae were reduced. Green algae became dominant.
Wahnbach Reservoir	West Germany	Bernhardt, 1967	42.7	210	68	215	41,625	43	19.2	0.14	9.1	*Oscillatoria rubesens* was hindered and manganese and phosphorus were reduced (oxidized)
Cox Hollow	Wisconsin U.S.A.	Brezonik *et al.*, 1969	8.8	72	7.5	39	1,480		3.8	1.4	17.2	Marked decrease in manganese concentrations.
Lake Maarsseveen	Netherlands	Knoppert *et al.*, 1970	19.2	88		60.7	8,017	30	14	0.31	13.5	Single diffuser not as effective as distribution network. Also smaller air holes will give best results when used at a minimum overpressure.
Zeevws-Vlaanderen Reservoir #2	Netherlands	Knoppert *et al.*, 1970	9.5	71		25.5	2,405	10.7	9.5	0.84	26.3	Algal growth was promoted by aeration when the reservoir level fell below 6.6 m. Algal blooms are better controlled in deep reservoirs.

* Qa = Air flow in cubic feet/minute.
** V = Volume of lake expressed as V x 10^6 cubic feet.
*** A = Area of lake expressed as A x 10^6 square feet.

2.3 Hypolimnetic Systems

Hypolimnetic aeration is a more recent development than destratification systems. The first major projects were carried out in the late 1940's on Lake Bret, Switzerland (Mercier and Perret, 1949), and in the mid 1960's on Wahnbach Reservoir in Germany (Bernhardt, 1967). With destratification systems the design is more or less simple. However with hypolimnetic systems, a large number of variations in the design of systems exist (Figures 2 and 3). Most use compressed air, although pure oxygen has been used (Fast *et al.*, 1975; and Speece, 1973a and 1973b) (Figure 3(b)).

Hypolimnetic aeration was developed in an attempt to solve some of the problems inherent in destratification systems, particularly to maintain the cold water layer at the bottom of a lake or reservoir. The technique introduces oxygen to the water at the bottom of the lake without disrupting the thermocline. This is important for consideration of fisheries habitat and drinking water supplies, and where maintenance of a warm epilimnion is important (e.g., for swimming) or where mixing of nutrients from the hypolimnion into the epilimnion is important (e.g., for algal bloom control). There are a few disadvantages when compared with destratification systems. The supply of oxygen to the hypolimnion is relatively slow because of the small surface area available in the aeration apparatus across which the oxygen transfer is made. Hypolimnetic currents or any induced circulation from the aeration apparatus can be significant because of the relative thermal homogeneity and low resistance to water movement. The limiting factor appears to be the supply of oxygen. For water bodies with large hypolimnia or large surface areas, several units must be considered.

With hypolimnetic aeration with compressed air, nitrogen supersaturation can occur. Fast (1975) notes nitrogen supersaturation is of concern for reservoirs capable of releasing water containing above normal nitrogen gas concentrations on a downstream fishery. Because of these design limitations, most hypolimnetic aerators tend to be more complex and hence more expensive than destratification aerators.

Hypolimnetic aerators can be further distinguished into two basic groups: full lift and partial lift, and the two have different potentials in terms of nitrogen supersaturation. Full lift systems transfer water from the hypolimnion to the surface and consequently back to the hypolimnium (Figures 2(d), 3(a)). These systems tend to be less prone to causing nitrogen supersaturation in the hypolimnion than the submerged, partial lift systems (Figures 2(a)(b)(c)). This can be an important aspect when fisheries may be affected. Supersaturation to 140-150% have been reported (Fast et al., 1975, Fast 1979).

Hypolimnetic aeration can be used for many of the same purposes as destratification aerators. These include correction of summerkill or winterkill conditions for fisheries, reduction of concentrations of hydrogen sulphide and other reduced compounds which can impart unacceptable taste and odours to drinking water supplies, and improvement of the overall water quality of lakes by reducing the supply of nutrients which are released from the sediments particularly during periods of low oxygen concentration (Bengtsson and Gelin, 1975). The supply of nutrients from sediments ("internal loading") can form a significant portion of the phosphorus supply to the lake under certain conditions. In these situations, aeration can be an effective method to reduce the nutrient concentrations of the lake and improve the overall water quality. A fairly detailed nutrient budget is required before aeration is considered as a possible treatment in order to insure that the sediments are a significant source of nutrients.

Table 2 summarizes information and the results of some hypolimnetic aeration projects.

TABLE 2

SUMMARY OF SOME INFORMATION FOR SELECTED HYPOLIMNETIC PROJECTS

Hypolimnetic Systems

Lake	Location	Reference	Diffuser Depth (m)	Air Flow (CF/M)	Pump Power (HP)	Surface Area (ha)	Lake Volume (dam^3)	Max Depth (m)	Mean Depth (m)	Qa*/V**	Qa/A***	Comments or Observations
Lake Grebiner	West Germany	Dunst et al., 1975				50		25				Total phosphorus and primary production decreased. There was an increase in clarity and hypolimnetic oxygen.
Hemlock Lake	Michigan U.S.A.	Fast, 1971a & 1975				1.8		18.6				Reduction in pH. Problems with aeration tower. Nutrients leaked to epilimnion. Phytoplankton increased.
Lake Jarlasjon	Sweden	Bengtsson and Gelin, 1975				84		24				Oxidation of sediments eliminated internal phosphorus recycling.
Mirror Lake	Wisconsin U.S.A.	Smith et al., 1974		17		4.5		13				Aeration did not raise hypolimnetic O_2 above 0.5 mg/L but phosphorus levels declined. Phosphorus levels in hypolimnion rose again after aeration stopped.
Wahnbach Reservoir	West Germany	Bernhardt, 1967	18	142	50	215	41,625	43	19.2			Cool oxygenated water was available for drinking. Phosphorus was not released from the sediments during aerobic periods.

* Qa = Air flow in cubic feet/minute.
** V = Volume of lake expressed as V x 10^6 cubic feet.
*** A = Area of lake expressed as A x 10^6 square feet.

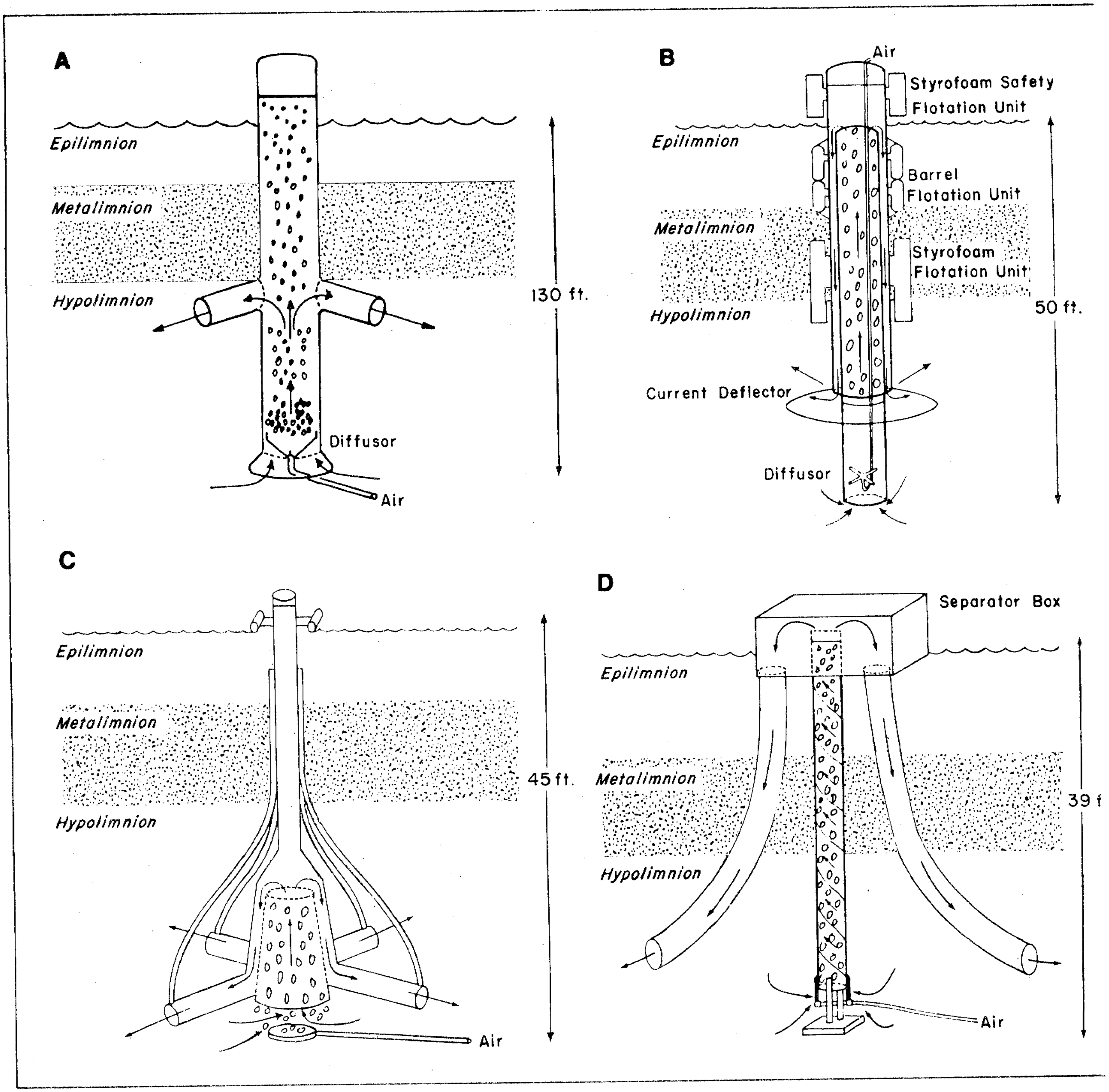
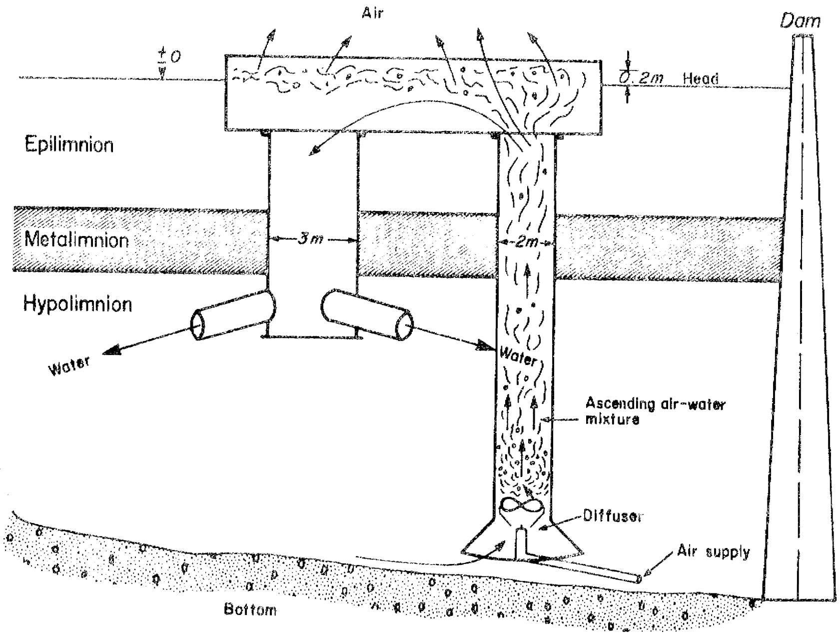


FIGURE 2: Hypolimnetic aeration units: (a) Bernhardt, 1967; (b) Fast, 1971; (c) Union Carbide, 1973; (d) Smith et al., 1975.



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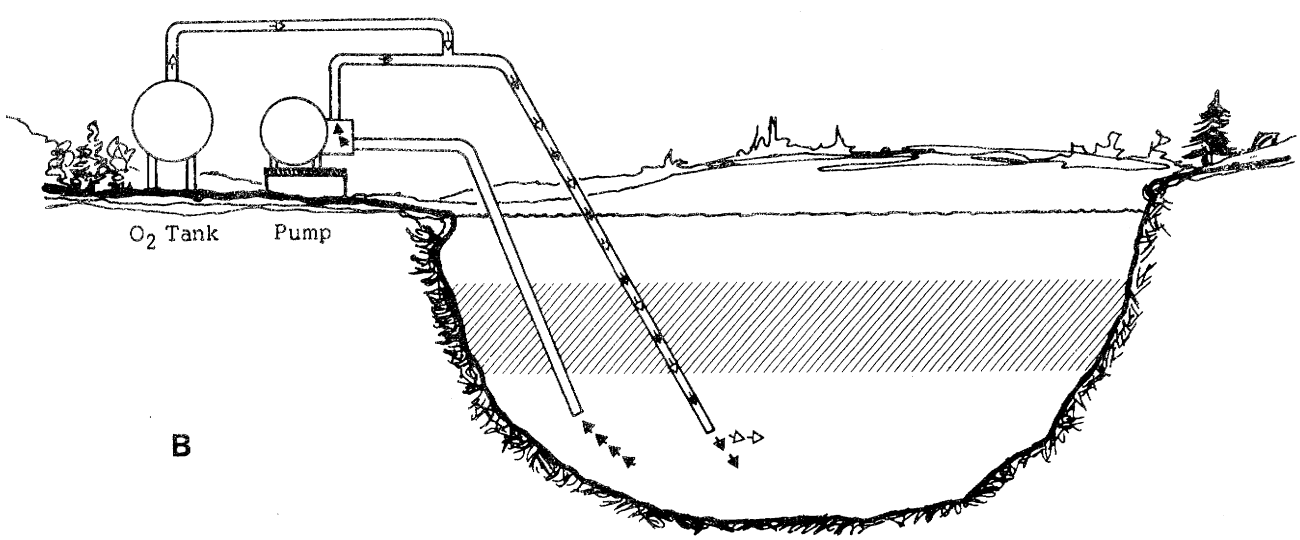

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FIGURE 3: Hypolimnetic aeration units: (a) Bernhardt 1967, (in Fast and Lorenzen, 1976); (b) Fast et al., 1975.

3. CONCLUSIONS

Aeration systems have been used to improve water quality of lakes and reservoirs. However in some cases no net benefit and even worsening of conditions have occurred because of inappropriate use of aeration systems. Because of this, a detailed evaluation of prevailing chemical and biological limnology and anticipated effects, as well as an engineering evaluation of most appropriate technology (particularly the size of the components used) is absolutely necessary. A careful scrutiny of the literature is an essential prerequisite prior to undertaking an aeration project.

Commercially manufactured systems are available from a number of companies: destratification systems from Hinde Engineering[1] ("Air Aqua"); hypolimnetic aerators from Atlas-Copco[2] and Union Carbide[3]; and wind powered destratification aerators for small lakes (Rieder, 1977) from Lake-Aid[4].

1* Hinde Engineering, 654 Deerfield Road, P.O. Box 188, Highland Park, Illinois, 60035/Hinde Manufacturing, 260 Burlington Street East, Hamilton Ont., L8L 4H4

2* Atlas Copco AB, S-105, 23 Stockholm Sweden/Atlas Copco, P.O. Box 745, Point Claire, Quebec, H9R AS8

3* Union Carbide Corp., Tarrytown, N.Y.

4* Lake Aid, Route 2, Bismarck, North Dakota, 58501

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* No endorsement is implied, only a listing of possible suppliers.

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