Laminar Flow Aeration: A Sustainable Lake Improvement Option

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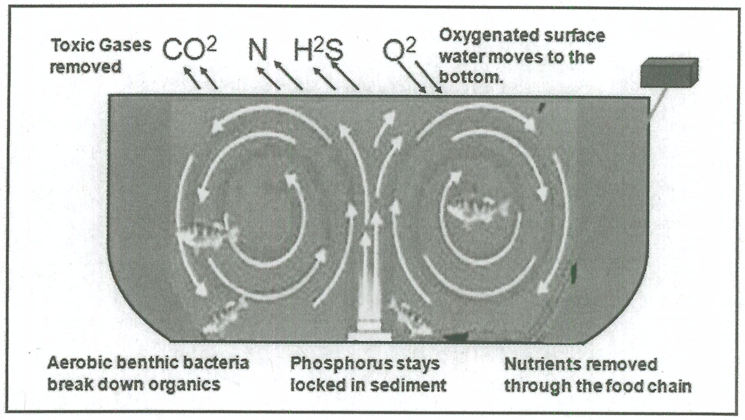

Figure 1. A Conceptual Diagram of the Laminar Flow Aeration Process (used with permission from Clean-Flo, Inc.)

Introduction and Overview of Laminar Flow Aeration:

Historically, laminar flow aeration was used in sewage treatment lagoons to increase the degradation of waste while not overwhelming the overlying water with a high biochemical oxygen demand (BOD). Only in recent times has this technology been used as a lake improvement method for the betterment of water quality within aquatic ecosystems. The laminar flow aeration system has some limitations including the inability to degrade mineral sediments, the requirement of a constant Phase I electrical energy source to power the units, and unpredictable response by various species of rooted aquatic plants.

A laminar flow aeration system utilizes diffusers that are powered by onshore air compressors. The diffusers are connected via extensive self-sinking airlines that deliver air to the diffusers which then circulate air into the overlying water column and eventually into the lake sediments (Figure 1). Laminar flow aeration utilizes systems that are retrofitted to a particular site and account for variables such as water depth and volume, contours, water flow rates, and thickness and composition of lake sediment. The systems are designed to completely mix the surrounding waters and evenly distribute dissolved oxygen throughout the lake sediments for efficient microbial utilization. In addition to the placement of the diffuser units, the concomitant use of bacteria and enzymatic treatments to facilitate the microbial breakdown of organic sedimentary constituents is also used as a component of the treatment. Organic matter in lake sediments is necessary for rooted aquatic plant growth and to support lake metabolic activities. An excessive amount of organic matter, however, leads to a decrease in lake depth and in increased rooted aquatic plant growth. Thus, laminar flow aeration has many objectives which include: 1.) Increasing the dissolved oxygen levels in the lake and lake sediments, 2.) Decreasing the thickness of the organic matter layer in lake sediments, and 3.) purging of noxious gases from the sediment pore water to the water column and eventually to the atmosphere. In order to thoroughly understand how laminar flow aeration affects changes in biological and physical and chemical water quality parameters, we must first understand the importance and functions of lake sediments, the major microbial processes that occur in lake sediments, and how the laminar flow aeration technology can be applied as a lake improvement technology.

Sediments and Their Functions within Lakes:

The majority of inland lake sediment in Michigan originates from glacial material that was deposited in lake basins nearly 8,000 years ago (Straw et al., 1978). In general, sediments in lake systems are highly heterogeneous having been derived from glacial and anthropogenic (man-induced) activities over time. Lake circulation patterns ultimately dictate the distribution of sediments in an aquatic ecosystem. In general, lake sediments with coarse particle size are associated with higher water clarity, while those with smaller particle size such as silts and clays are usually correlated with increased turbidity. Sediments with large particle size may inhibit rooted aquatic plant growth through mechanical impedance, whereas sediments with smaller particle sizes tend to favor rooted vegetation growth unless those sediments are highly flocculent and rooting is not possible. Coarse sediment particles tend to appear near shore, whereas finer particles settle out in the deeper basins of a lake.

Lake sediments provide many functions for lakes, including nutrient supplementation to rooted aquatic plants, providing a sufficient rooting medium for aquatic plants, and in regulating metabolic processes for the lake. Odum (1971) showed that lake bottom sediments regulated the metabolism of aquatic ecosystems. Sediments may also be utilized as a large source of siliceous diatoms and other macrobiota which forms the base of the food chain for higher organisms that feed on benthic biota. In addition, lake sediments are active components of the biogeochemical cycles present in aquatic ecosystems in that they recycle nutrients and organic matter via microbial metabolism. In sediments that contain low oxygen (anoxic) conditions, some rooted aquatic plants have the ability to oxidize the rhizosphere (root zone) and overcome growth limitations present in the sediment conditions. A study by Bodelier et al. (1996) determined that the emergent macrophyte, *Glyceria maxima* utilized root aerenchymatous tissue to oxidize an anoxic portion of the lake sediment which encouraged ammonia-oxidizing bacteria. In a peculiar way, this emergent aquatic plant mimics the technology of laminar flow aeration with its sediment oxidation functions.

Sediment Dynamics and Laminar Flow Aeration:

The laminar flow aeration process effectively purges noxious gases such as carbon dioxide (CO_2), hydrogen sulfide (H_2S), and nitrogen (N_2) from the lake sediments. Benthic CO_2 is a primary byproduct of microbial metabolism. Some studies have shown that particular species of aquatic plants obtain critical amounts of CO_2 from lake sediments. Hydrogen sulfide is produced from anaerobic bacteria and creates a pungent "rotten-egg" odor in the sediments. Beutel (2006) found that lake oxygenation eliminates release of ammonia (NH_3^+) from sediments through oxygenation of the sediment-water interface. Allen (2009) demonstrated that NH_3^+ oxidation in aerated sediments was significantly higher than that of control mesocosms with a relative mean

Figure 2. Collins Lake, New York, USA, before implementation of laminar flow aeration. Photo used with permission from Lake Savers, Inc.

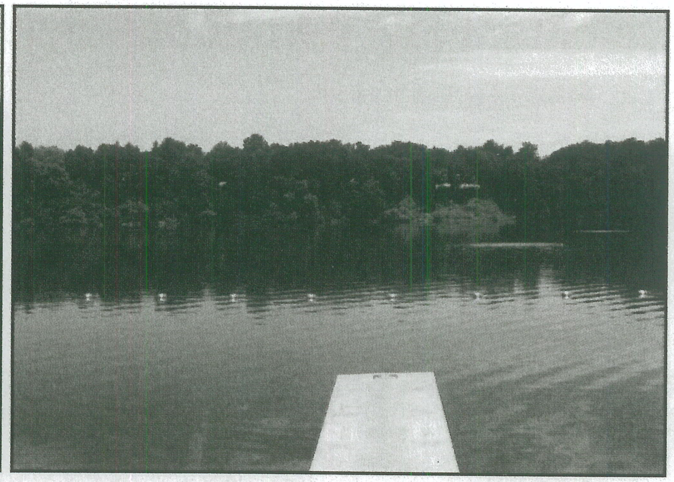

Figure 3. Collins Lake, New York, USA, after implementation of laminar flow aeration. Note the diffuser rings in the background (at upper right in photo). Photo used with permission from Lake Savers, Inc.

of 2.6 ± 0.80 mg N g dry wt day^{-1} for aerated mesocosms and 0.48 ± 0.20 mg N g dry wt day^{-1} in controls.

In contrast to the gases which are purged out of sediments, phosphorus tends to remain in the sediment during the laminar flow aeration process. Phosphorus (P) is the primary nutrient necessary for abundant algae and aquatic plant growth. The total P concentrations in lake sediments are often up to several times higher than those in the water column since P tends to adsorb onto sediment particles and sediments thus act as a "sink" or reservoir of nutrients. Phosphorus concentrations are usually higher at increased depths due to higher release rates by lake sediments under low oxygen (anoxic) conditions. Thus, with an aerated sediment pore water layer, release of P into the water column is unlikely.

Many forms of nitrogen (N) are present in lake sediments and include ammonia (NH_3^+), nitrate (NO_3^-), nitrite (NO_2^-) and organic nitrogen. These values are usually highly variable in lake sediments due to high rates of microbial activity which rapidly converts the forms of N in sediments. Much N (amino acids and proteins) also comprises the bulk of living organisms in an aquatic ecosystem. Nitrogen originates from atmospheric inputs (i.e. burning of fossil fuels), wastewater sources from developed areas (i.e. runoff from fertilized lawns), agricultural lands, septic systems, and from waterfowl droppings. It also enters lakes through groundwater or surface drainage, drainage from marshes and wetlands, or from precipitation (Wetzel, 2001).

Organic matter (OM) contains a high amount of carbon which is derived from biota such as decayed plant and animal matter. Detritus is the term for all dead organic matter which is different than living organic and inorganic matter. OM may be autochthonous or allochthonous in nature where it originates from within the system or external to the system, respectively. Many factors affect the degradation of organic matter including basin size, water temperature, thermal stratification, dissolved oxygen concentrations, particle size, and quantity and type of organic matter present. There are two major biochemical pathways for the reduction of organic matter to forms which may be purged as waste. First, the conversion of carbohydrates and lipids via hydrolysis are converted to simple sugars or fatty acids and then ferment to alcohol, CO_2, or methane (CH_4). Second, proteins may be proteolyzed to amino acids, deaminated to NH_3+, nitrified to nitrite (NO_2-) or nitrate (NO_3-), and denitrified to N_2 gas.

Laminar Flow Aeration in the Field:

Although this is a relatively new area of research, recent case studies have shown promise on the positive impacts of laminar flow aeration systems on aquatic ecosystem management with respect to organic matter degradation and resultant increase in water depth, and rooted aquatic plant management in eutrophic ecosystems (Lakeshore Environmental, Inc., 2010-2011, peer reviewed publication in progress).

There is also evidence that laminar flow aeration creates a favorable change in planktonic algal communities. Toetz (1981) found evidence of a decline in Microcystis algae (a toxin-producing blue-green algae) in Arbuckle Lake in Oklahoma. Other studies (Weiss and Breedlove, 1973; Malueg et al., 1973) have also shown declines in overall algal biomass.

Conversely, a study by Engstrom and Wright (2002) found no significant differences between aerated and non-aerated lakes with respect to reduction in organic sediments. This study was however limited to one sediment core per lake and given the high degree of heterogeneous sediments in inland lakes may not have accurately represented the conditions present throughout much of the lake bottom. The science behind the laminar flow aeration system encourages a measurable reduction in the organic matter layer of the sediment so that a significant amount of organic nutrient is removed from the sediments and excessive sediments are reduced to yield a greater water depth. This process also tends to cause a decline in some nuisance aquatic vegetation growth and leaves nutrients in the sediment which are unavailable for algae.

Ongoing research is being conducted on many lakes in Michigan, including Maple Lake (Van Buren County, MI), Sherman Lake (Kalamazoo County, MI), Chippewa Lake (Mecosta County, MI), Wing Lake (Oakland County, MI), Keeler Lake (Van Buren County, MI), and Indian Lake (Cass County, MI). Other states in the U.S. have also implemented the laminar flow technology with excellent results. Collins Lake in

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New York State discovered a substantial reduction in both nuisance rooted aquatic plant growth and dense filamentous algae growth in one season (Figures 2 and 3).

Concluding Remarks:

What defines a "sustainable" lake improvement strategy? Ultimately, sustainability of an improvement program may be dependent upon the length of the program given the existing stock of useful resources (Munasinghe and Shearer, 1995). Laminar flow aeration provides a constant stock of supplied air to the lake bottom during a given season of operation. Efforts to increase sustainability through more ecologically friendly power sources are currently underway. Orr (2003) warns us that a program with excessive economic, technological, and financial complexities is unsustainable due to a limited capacity for management. The laminar flow system is affordable, typically declines in cost with time, is technologically simple, and usually requires little maintenance. While many of the lakes in Michigan are limited in their capacities to be managed, the laminar flow aeration technology offers a self-cleansing approach to holistic lake improvement without chemicals and mechanical methods. Laminar flow aeration is not a panacea but seems to be improving inland lakes in a consistent and sustainable manner.

References Cited:

Allen, J. 2009. Ammonia oxidation potential and microbial diversity in sediments from experimental bench-scale oxygen-activated nitrification wetlands. MS thesis, Washington State University, Department of Civil and Environmental Engineering.

Beutel, M.W. 2006. Inhibition of ammonia release from anoxic profundel sediments in lakes using hypolimnetic oxygenation. Ecological Engineering 28(3): 271-279.

Bodelier, J.A., J.A. Libochant, C. Blom, and H.J. Laanbroek. 1996. Dynamics of nitrification and denitrification in root-oxygenated sediments and adaptation of ammonia-oxidizing bacteria to low-oxygen or anoxic habitats. Applied Environmental Microbiology 62(11): 4100-4107.

Engstrom, D.R., and D.I. Wright. 2002. Sedimentological effects of aeration-induced lake circulation. Lake and Reservoir Management, 18(3):201-214.

Malueg, K., J. Tilstra, D. Schults, and C. Powers. Effect of induced aeration upon stratification and eutrophication processes in an Oregon farm pond. Geophysical Monograph Series, 17: 578-587. American Geophysical Union. Washington DC.

Munasinghe, M., and W. Shearer. 1995. Defining and measuring sustainability: The biogeophysical foundations, Washington DC: World Bank and United Nations University.

Odum, E. 1971. Fundamentals of Ecology. W.B. Saunders Co., New York. 574 pp.

Orr, D.W. 2003. Four challenges of sustainability, School of Natural Resources-The University of Vermont. Spring Seminar Series-Ecological Economics.

Straw, W.T., J.S. Wood, W.B. French, T.A. Silverman, D.L. White, and W.T. Williams, 1978. Austin Lake: July 1977-January 1978—A Status Report, Institute of Public Affairs, Western Michigan University, Kalamazoo County, Michigan, 37 pp.

Toetz, D.W., 1981. Effects of whole lake mixing on water quality and phytoplankton. Water Research, 15: 1205-1210.

Weiss, C., and B. Breedlove. 1973. Water quality changes in an impoundment as a consequence of artificial destratification. 216 pp. Water Resources Research Institute. University of North Carolina. Raleigh.

Wetzel, R. G. 2001. Limnology: Lake and River Ecosystems. Third Edition. Academic Press, 1006 pgs.