UPPER MISSISSIPPI RIVER SYSTEM
ENVIRONMENTAL DESIGN HANDBOOK

CHAPTER 6

AERATION

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6.1. Resource Problem

Water can hold a limited amount of oxygen. That is determined by atmospheric pressure, temperature and salinity. In a natural setting, oxygen is added to water by atmospheric diffusion at the surface, by wind circulation and by photosynthesis (oxygen produced by phytoplankton or algae). Oxygen is involved in the regulation of metabolic processes of most aquatic communities and organisms, and therefore is one of the most significant chemical substances in water. The concentration of dissolved oxygen is perhaps the most important chemical quality which affects the distribution of fishes. Oxygen depletion reduces the quantity and quality of habitat for fish and fish food organisms. It causes physiological stress in fish and often leads to the development of imbalanced fish communities dominated by relatively undesirable species.

A number of conditions may develop which result in oxygen depletion. Oxygen depletions are typically associated with some of the following conditions:

Hot, cloudy, still weather is common during the summer months. High water temperature (86 degrees F or greater) reduces oxygen holding capacity. Cloud cover limits available light, slowing or halting photosynthetic oxygen production. No wind stops circulation in backwater and pond areas and restricts surface diffusion of atmospheric oxygen. Warm water increases fish consumption of oxygen by accelerating their metabolic rate. Fish are cold blooded; therefore, body temperatures and activities are regulated by water temperature. On the other extreme, however, oxygen demand is of particular concern in the winter months when primary productivity is low and re-aeration is restricted due to ice cover.

Sudden death of phytoplankton or algae bloom may result from insufficient light (e.g. cloud cover) for photosynthesis. Oxygen is consumed or depleted when dead phytoplankton/algae decay. During the nighttime hours, a dense phytoplankton bloom can remove all oxygen from the water for respiration (to breathe) alone. When a bloom crash occurs, the water appears to have become “black” or clear overnight.

Pond stratification or turnover. During summer months in deep water (8 feet or greater), the upper 4-6 feet of the water column warms quickly and becomes less dense or lighter than deep water. Because the upper layer is warmer and lighter, it does not mix with the cool deep water. The cool water near the bottom becomes stagnant; oxygen is depleted and toxic compounds may be produced by bacteria and decaying organic matter. The deep layer remains unoxygenated (anoxic) because of stratification (layering). A sudden, heavy rain (2-3 inches or greater) or a strong cold front can rapidly cool and/or mix (wind turbulence) the upper layer. Now the cooler or circulating upper layer sinks or mixes and causes the deep anoxic layer to rise above or combine with the surface water. That depletes or reduces oxygen in upper waters where fish are being cultured.

Organic waste decomposition. When fish biomass becomes large in areas, waste and organic loads (ammonia, nitrate, feces and uneaten feed) can become high. Wastes and organics will decompose. That requires oxygen, often more than is available in certain bodies of water. Also, high waste loads can stimulate an algal bloom too dense to be supported by the water body (discussed above).

These situations can occur alone or in interrelated combinations. As just discussed, conditions may develop which remove oxygen from water faster than natural processes can replace it. When they occur, emergency or supplemental aeration may be required to bring oxygen back up to tolerable or safe levels.

6.1.1. Environmental Impacts. Oxygen is vital to all metabolic processes of aquatic communities and organisms. Logically, the manipulation of the oxygen content of lakes, rivers, reservoirs and streams can have a profound effect on their chemistry and biota. Therefore, adverse or beneficial effects, other than the improvement of habitat for fishes, may result from destratification, aeration, and oxygenation management techniques.

The principal adverse effects of destratification are related to the mixing action of the technique. Destratification transforms a lake into a nearly isothermic water mass, with a temperature close to the normal surface water temperature. If the surface water temperature is too high, coldwater fishery habitat will be eliminated.

Turbulence created by the destratification processes may cause resuspension of bottom sediments. If the sediments that are resuspended exert a particularly high oxygen demand, dissolved oxygen depletion may result, especially if the destratification equipment is inefficient and cannot compensate for the increased oxygen demand. If the destratification is improperly timed in relation to algal blooms, existing oxygen deficiencies can be aggravated.

Hypolimnetic aeration is more limited in controlling algal blooms than those realized by whole lake mixing, but the risk of adverse effects is less. Provided that the equipment used is properly designed, possible nitrogen supersaturation and resuspension of toxic contaminates are the only potential adverse effects that may result from hypolimnetic aeration.

Some physical hazards to humans may be associated with aeration efforts. Extensive open-water areas that result from winterkill prevention techniques create a danger, especially to snowmobilers. Mechanical aeration devices can be a hazard to swimmers and boaters. The impellers on mechanical agitators can severely injure swimmers, and the presence of such devices can obstruct navigational lanes.

6.2. Design Methodology and Criteria

6.2.1. Aeration Techniques. Artificial aeration and oxygenation techniques have been developed to help alleviate dissolved oxygen depletions in lakes and streams. Such techniques can be used in a variety of situations to improve conditions in aquatic habitats. The application of aeration techniques increases dissolved oxygen concentrations that have become unacceptably low. It is important to keep in mind that most artificial aeration techniques can only be applied to limited areas due to cost and scaling issues.

Aeration techniques can be divided into three major categories: destratification (whole-lake aeration); aeration of the anoxic lower stratum (hypolimnetic aeration); and supplemental stream aeration. Aeration techniques are used to alleviate fishery problems associated with anoxic or near anoxic conditions in bottom waters or under ice. Aeration affects the biological, chemical, and physical characteristics of a lake or stream and thus many management implications.

Of the many aeration techniques, supplemental instream aeration and winterkill prevention may be those most immediately applicable in the Upper Mississippi River System. Supplemental instream aeration may be a particularly important management alternative if significant increases in organic loading occur within the Upper Mississippi River basin. Winterkill techniques can be put to immediate use.

Destratification and hypolimnetic aeration may have limited value on the Upper Mississippi River System. However, if hydroelectric facilities are developed at the navigational dams, or if modifications of dams are made in conjunction with the development of a deeper navigational channel, the river system might be altered to the point that some degree of thermally induced density stratification occurs. If oxygen depletion results, the use of remedial destratification or hypolimnetic aeration systems may be required.

6.2.1.1. Destratification. Destratification can be achieved through air-lift circulation or pumping. This technique is used in fishery management as a method for restoring habitat losses caused by anoxic conditions in the hypolimnion of eutrophic, stratified lakes and reservoirs and to prevent winterkills.

Treatment of winterkill lakes by destratification techniques can be approached by two methods: Destratification can be implemented before ice formation to increase the lake's oxygen reserve and reduce the amount of an oxygen consuming, decomposable organic matter; or a destratification apparatus can be used during ice formation with the intent of maintaining large holes in the ice that will facilitate surface aeration and provide strong mixing currents that will circulate oxygen throughout the water mass.

Diffused –air mixing, or fine bubble aeration, is the most popular method used to disrupt destratification. Ease of installation and simplicity of operation are the principal advantages over mechanical mixing. Aeration of the water column (in addition to turbulence-induced aeration at the air-water interface) is a further beneficial feature of this technique.

A number of designs for diffused-air mixers have been developed. The systems pipe compressed air to a release apparatus located near the lake bottom in the area of greatest depth. Some of the release apparatus designs used are perforated pipes, diffuser stones or air cannons.

Diffused-air mixing aeration equipment requires electricity or fuel powered engines to operate. Therefore, this type of aeration is usually not practical in a river or backwater environment.

6.2.1.2. Hypolimnetic Aeration and Oxygenation. Hypolimnetic aeration and oxygenation is a method of adding dissolved air and oxygen to the hypolimnion of a water body without disturbing the thermal stratification. The process differs substantially from aeration by destratification and is used when maintenance of cold oxygenated hypolimnetic water is desired.

Air injection systems can be categorized as full air-lift or partial air-lift designs. In full air-lift systems, air is injected near the bottom of the aerator. As the air rises to the surface, it lifts water with it. The air and water then separate and the water returns to the hypolimnion. Partial air-lift designs operate similarly, except that the air and water are allowed to separate below the surface of the water. Water is allowed to return to the hypolimnion and air is released through a vent pipe.

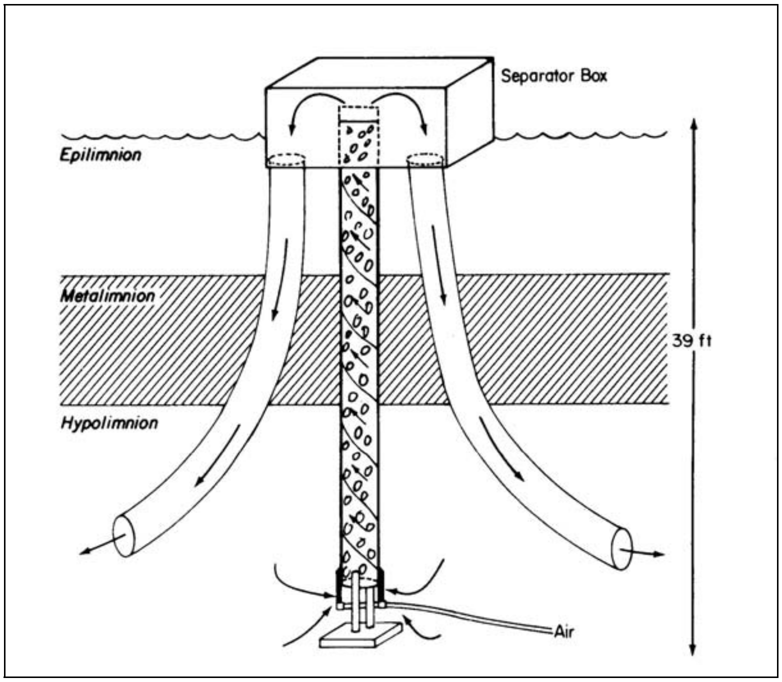

Figure 6.5. Hypolimnetic Aerator Design

6.2.1.3. Supplemental Instream Aeration. Supplemental instream aeration is the addition of air to a flowing stream to maintain the dissolved oxygen content of the water at an acceptable level. Supplemental instream aeration can be provided by using any of several devices and techniques. Mechanical and diffuser aerators are two designs that have been used for instream aeration.

The mechanical surface aerators most commonly used have an impeller that draws water to the surface and casts it out by centrifugal force. A zone of intense turbulence is created to entrain and absorb air.

Diffuser aerators are similar to those used in destratification assemblies. The headers are usually perforated pipes placed parallel to each other in the stream bed or perpendicular to the flow. The size of the device needed depends on the concentration of oxygen-demanding waste in the stream and the characteristics of the site.

Since mechanical and diffuser aerators both require some type of synthetic power supply, supplemental instream aeration may not be practical in a river or backwater environment.

6.2.2. Aeration Costs. The major capital costs associated with a destratification system and hypolimnetic aeration systems are air compressors, supply lines, and diffusers. Operating costs will be primarily for electricity, making wind-powered aeration systems much more economical. Figure 6.2 outlines the selection process for determining the best type of aeration system to be used.

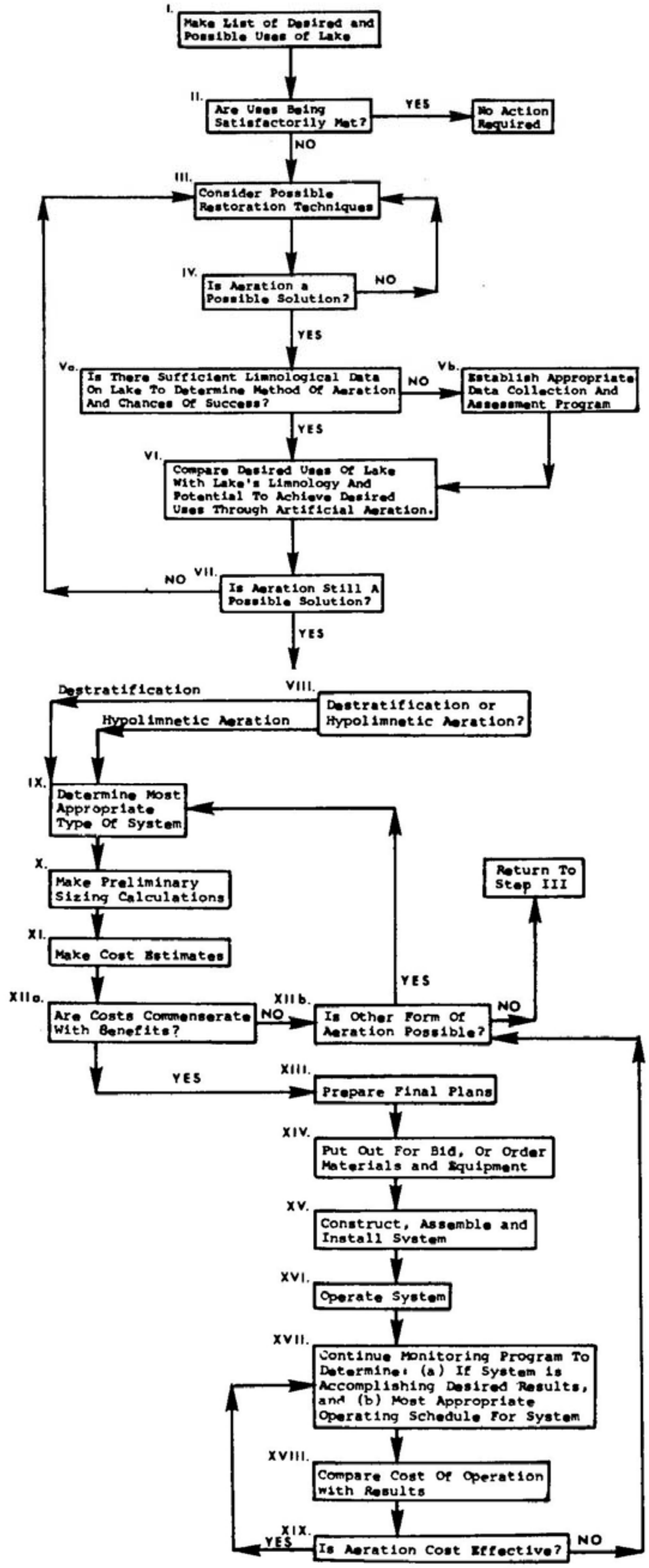

Figure 6.6. Aeration Cost Diagram

6.2.3. Aerators. Aerators work by increasing the area of contact between air and water. Aerators also circulate water so fish can find areas with higher oxygen concentrations. Circulation reduces water layering from stratification and increases oxygen transfer efficiency by moving oxygenated water away from the aerator.

Electric or mechanical aeration is used to place as much oxygen into contact with water as economically practical. That is normally accomplished by mixing large quantities of water (both volume and total surface area) with atmospheric oxygen.

Surface spray or vertical pump aerators have a submersible motor which rotates an impeller to pump surface water into the air as a spray. They float, are lightweight, portable and electrically powered. They are usually of little use in large bodies of water because of relatively low oxygen transfer rates and their inability to create an adequately large area of oxygenated water.

Pump sprayer aerators are found on many fish farms. Most are powered by a tractor power takeoff or electricity. Pump sprayer aerators are equipped with either an impeller suction pump, an impeller lift pump, or a turbine pump. Most discharge directly through a manifold which has discharge slits on top and outlets at each end. Water is sprayed vertically through the discharge slits and from each end of the manifold. This type directs oxygenated water along a bank line where distressed fish often go. Pump sprayers typically have no gear reduction which reduces mechanical failure and maintenance.

Fountain aerators are a popular choice when a decorative aerator is desired. Fountains splash the surface of the water and help control surface algae and weeds but do not aerate down to the bottom in deep waters (figure 6.3).

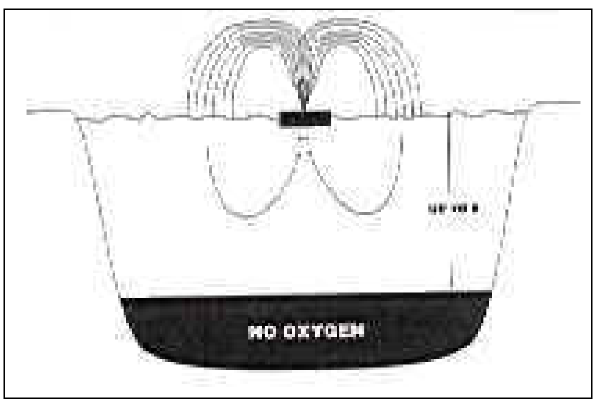

Figure 6.7. Fountain Aerator

Paddlewheel aerators are typically used on farm ponds and made from truck differentials and vary with drum size and configuration, shape, number and length of paddles. Units are powered by power takeoffs or driven by self-contained diesel engines. The self-contained units are usually on floats and attached to the pond bank or held in place by steel bars secured in the bank or pond bottom. Some paddlewheel units are electrically powered as well.

Diffuser aerators operate by low pressure air blowers or compressors forcing air through weighted aeration lines or diffuser stones releasing air bubbles at the water's bottom or several feet below the water surface. Efficiency of oxygen transfer is related to the size of air bubbles released and water depth. The smaller the bubble and the deeper it is released, the more efficient this type of aerator becomes (figure 6.4).

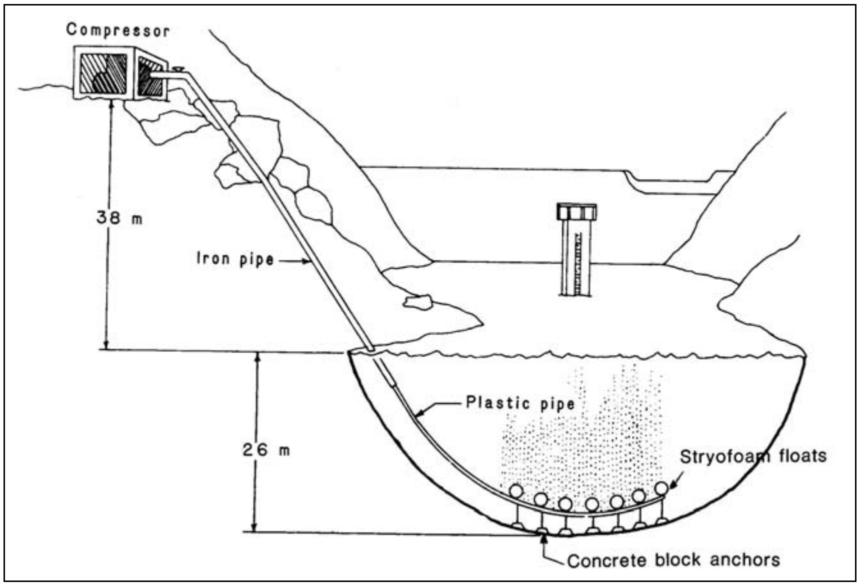

Figure 6.8. Diffuser Aerator

Propeller-aspirator aerators consist of a rotating, hollow shaft attached to a motor shaft. The submerged end of the rotating, hollow shaft is fitted with an impeller which accelerates the water to a velocity high enough to cause a drop in pressure over the diffusing surface which pulls air down the hollow shaft. Air passes through a diffuser and enters the water as fine bubbles that are mixed into the water by the turbulence created by the propeller. These types of aerators are electrically powered.

Wind-powered aeration devices may be a viable alternative if oxygen depleted water masses are in remote areas where electrical and gasoline power sources are unavailable or where their installation is uneconomical. However, wind-powered, artificial aeration system must possess certain basic qualities. The system must be relatively cheap. In order for wind-power to be an economical energy alternative, the system must be available at a low price. The design must also be simple and it must be constructed out of inexpensive and readily available components. Since the system will be installed at remote sites, it must be easy to transport and easy to erect. This means that the system must be simple to assemble and disassemble. The system must also be structurally and mechanically able to withstand high winds and extreme temperatures with only a minimum of maintenance.

Supplemental in-stream aeration. There are physical ways to circulate waters with low flow by placing alternating structures within the stream to increase the atmospheric processes of aeration.

Other aeration techniques are available without the introduction of pumps or other apparatuses to a body of water. Deeper water and improved flows reduce the dissolved oxygen problems that reduce habitat quality. Through dredging, increases in flows improve oxygen exchange between the spring-fed areas and main water bodies. Deepwater areas improve overall aquatic habitat quality and provide ingress and egress to oxygen deficient-prone areas. Flow increase in side channel dredge areas increases the introduction and mixing of more oxygen-rich water into low-velocity areas. By providing entrance and exit channels for fish, trapping and winter/summer kill potential can be significantly reduced in nonflowing water bodies.

The best way to deal with low oxygen is to take action before a problem develops. Good management is vital to the overall quality of aquatic habitat.

6.2.4. Gravity Flow Aeration . Gravity flow techniques provide aerated water to downstream water bodies. These projects usually consist of a dredged channel with some type of control structure such as a gated conduit to regulate the quantity of flow that is conveyed into downstream water bodies. The size of these structures is based on the following items:

- **Water Quality Requirements in Downstream Water Bodies.** The amount of water needed must provide adequate dissolved oxygen during critical times of the year, but not reduce water temperatures to levels that are too low. Usually, a hydraulic residence time in the downstream backwater that exceeds 10 days is required.

- **Maintenance Considerations Related To Debris Plugging.** In some situations small debris can be flushed from the conduit entrance or from the outlet channel, by increasing discharge levels and velocities in the system. This usually requires a flow capacity that is significantly higher than that required for aeration.

- **Economics.** Smaller structures are generally cheaper, however unknown flow requirements in the future may require that a larger structure be constructed to cover all flow requirements.

- **Controlling and Maintaining Debris.** This is a primary consideration in designing the inlet to these structures. Trash racks, wooden piles, sheep and cattle fencing, and a number of other techniques have been used to prevent debris from plugging these structures. Debris can be large (trees and logs) or small (floating vegetation).

It is important to keep in mind however, that introducing water to an area may also introduce sediment. This may be minimized by only opening the control structure during low flow periods, winter months or when absolutely necessary for aeration.

6.3. Lessons Learned

Blackhawk Park. The ultimate purpose or goal of the Blackhawk Park project was to preserve and enhance existing fish habitat. The backwater lakes and sloughs at Blackhawk Park were identified as important fishery habitat with multi-State importance. The purpose of the project was to convert 258 acres of backwater lakes from seasonal to year-round fish habitats, annually contributing an additional

20,000 fish to the boundary waters of Wisconsin, Minnesota, and Iowa. Over the 50-year project life, an estimated 1 million fish would be produced and dispersed to the waters of the three States. Several of the side channels that historically supplied water to this backwater complex were obstructed by the construction of roads to the park and to adjacent private developments. These obstructions resulted in the loss of freshwater (well-oxygenated) flows to these backwater areas during most of the year. The lack of freshwater flow resulted in dissolved oxygen (DO) depletion problems in these backwater lakes and sloughs. Habitat restoration efforts in the Blackhawk Park area began prior to the creation of the EMP.

The USACE constructed a channel to provide fresh water to Green and Peck Lakes in the early 1980's. The Blackhawk Park habitat project under the EMP was a continuation of this effort to provide flows to the backwater complex lying east of the park boundaries. The project included the installation of three culverts in a private driveway, the construction of channels from the main channel to Long Slough, and the dredging of two sediment traps. The major action was the construction of 7,000 linear feet of channels from the main channel to the head of Long Slough. The channels provide freshwater flow to Long Slough in order to alleviate oxygen depletion problems.

The channel depth and size should have been increased to account for sediment deposition, debris, and ice blockage. Although the channels continue to provide flow to downstream backwaters, the amount of flow is marginal and can be greatly reduced by ice formation in the winter.

Big Timber. Big Timber HREP project was initiated in response to a rapid accumulation of sediment that had greatly reduced the quantity and quality of the wetland habitat in the low swales present on Big Timber Refuge and aquatic habitat in the deep areas of the interior channels. In the shallow areas of the interior channels, dissolved oxygen values had fallen to critical levels and fish species diversity had decreased.

The Big Timber HREP project was hydraulically dredged and mechanically excavated to enhance aquatic habitat. The objective was to restore both deep and shallow aquatic habitat, improve levels of dissolved oxygen during critical seasonal stress periods, and provide year-round habitat access. The Big Timber project was successful in its effort to improve levels of DO during critical seasonal stress periods. The project was highly successful in achieving this goal during the critical winter months where supersaturated conditions were often observed.

Finger Lakes. Design for a wide range of flow conditions. The gated conduits that were used at this site were sized to provide up to 50 cubic feet per second (cfs) to each of the downstream Finger Lakes. A Biological Response study that was conducted after the project was constructed indicated that the required winter flow was on the order of 5 cfs or less, about 1/10th the capacity of the conduits. However, recommended summer discharges are on the order of 40 cfs, which is near the maximum flow of the conduit. Furthermore, the Fish and Wildlife Service often flushes the pipes by using their full capacity to clear out small debris from the entrance and outlet channels. The important thing is that being able to provide a range of flow rates is desirable at aeration projects.

Spring Lake - Dye Dispersion and Fish Movement in Response to Increased Winter Inflow at Spring Lake. An environmental enhancement project for the lake was completed in 1999 as part of the Upper Mississippi River System Environmental Management Program. The project included construction of a gated inlet in the perimeter levee of the lake to allow for the inflow of oxygenated river water into the lake during winter periods of low dissolved oxygen to help prevent fish kills. The gates are closed during other times of the year in order to prevent sediment from entering the lake.

A fish kill occurred in both the upper and lower portions of Spring Lake during January 2001. During this time, one gate was open 15 cm (6 in) and low dissolved oxygen (DO0 concentrations were recorded by an in-situ water quality monitoring instrument deployed in the lower lake. In an effort to prevent future fish kills the following dye studies were performed.

Dye dispersion and fish movement were monitored during February 2005 by U.S. Army Corps of Engineers, Rock Island District following an increase in inflow to Spring Lake. The results from a similar dye study performed in 2002 indicated that with a 25 cm (10 inch) gate opening, reoxygenation of the lake occurs slowly, with the dispersal pattern favoring the deeper portions of the lake. The primary purpose of the present study was to determine how inflowing oxygenated water disperses, both temporally and spatially, throughout the lake during the winter under ice cover while utilizing a gate opening of 91 cm (3 feet). A single slug injection of Rhodamine WT dye was dispensed in the inlet structure and tracked over a period of thirteen days as it dispersed throughout the lake.
An additional objective of the study was to track the movement of 20 radio-tagged centrarchids in response to the increased inflow. Fish movement was determined during three tracking events over an 11-day period.

As anticipated, with the larger gate opening, the dye traveled through the lake in a shorter period of time. With a gate opening of 91 cm (3ft) in 2005, inflowing water dispersed throughout Spring Lake faster and more completely than was observed during a similar study in 2002 when the inlet structure gate was open only 25 cm (10 in). A comparison of dye analysis results from samples collected on the sixth day following injection during both studies show that the dye traveled more than twice the distance during 2005 compared to that observed in 2002. The dye traveled 1,125m (3,691 ft) in 2002, for an average velocity of .22 cm/sec while in 2005 it traveled 2,375 m (7,792 ft) for an average velocity of .46 cm/sec.

Movement of radio-tagged centrarchids (black crappies and a bluegill) indicated the fish were not adversely impacted by the increased gate opening. Initial concerns that the fish may be “flushed” from the area did not materialize. The velocity in the vicinity where most fish were located throughout the study increased from 0.16 cm/sec (prior to increasing the gate opening) to 0.45 cm/s (after increasing the gate opening). The 0.29 cm/s increase in velocity was apparently insufficient to cause the fish to disperse from the area.

Although not practical, the breach of a levee or dam is another way to introduce dissolved oxygen to an area with low levels of oxygen. For example, in 1968 Spring Lake was divided by the U.S Fish and Wildlife Service into an Upper Spring Lake and Lower Spring Lake. When the Lower Spring Lake levee was breached on the west and south sides by the 1965 flood, ingress and egress of other species from the river provided more diversity in aquatic life. This breach also provided the lake with an abundant supply of dissolved oxygen. With the repair of the levee in 1991, flow of dissolved oxygen through the Lower Lake was greatly diminished. This lack of dissolved oxygen is a limiting factor in the current fishery.

Water control structures play a role in the amount of dissolved oxygen contained in a body of water. The construction of inlet structures and gatewell structures allow for flow and dissolved oxygen dissipation. Water control structures can be used to help control and maintain water quality in backwaters and side channels.

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