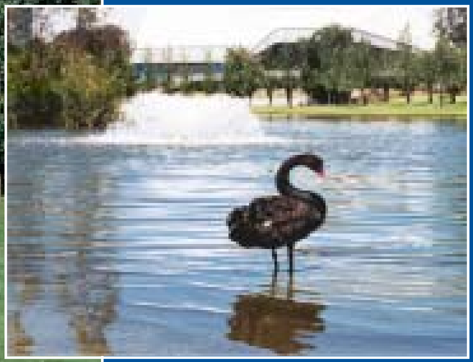
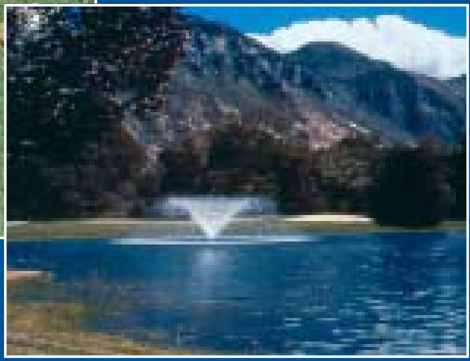
POND AND LAKE MANAGEMENT

Manual and Guide on Water Quality Management for Ponds and Lakes





Manual provided to you by Otterbine® Barebo, Inc.

Integrated Pond & Lake Management Manual & Guide

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DYNAMICS OF A LAKE

Water quality is a critical factor in the successful management of any golf course, turf, commercial or residential property. Poorly managed water will have a negative impact on the quality of the environment, turfgrass, irrigation system and the aesthetic value of the property.

Consider the negative impact of ingesting polluted water and air. These same principles hold true in the aquatic ecosystem and in managing our golf courses, landscapes and properties. Water is one of our most important and least understood natural resources.

Many of our ponds, lakes, irrigation basins, and water features are not well managed. We tend to treat the visible symptoms of poor water quality such as, algae blooms, aquatic vegetation growth, odors, clogged sprinklers, valves and pumps - rather than prevent them.

Our understanding has been superficial, leading to aspirin and band-aid type solutions that address acute problems and even appear to solve them temporarily but leave the underlying chronic causes untouched to fester and resurface time and time again.

A better understanding of the causes of these problems leads to long term, environmentally friendly, cause related solutions - which are preventative in nature.

Just as agronomists are the experts in turfgrass, ***limnologists*** are the experts in lake management. This material comes from a collection of research done by some of the world's leading limnologists located at The University of Florida and The University of Minnesota, both of which provides testing and research in the field of aeration systems oxygen transfer and circulation.

Otterbine's fifty years of practical experience in lake management is also a great source of knowledge. Our goal is to provide you with a comprehensive background of the state of the art in water quality management, as well as to create a paradigm shift.

Paradigm comes from the Greek word meaning "to design." Hopefully after reviewing this manual you will gain a better understanding of the causes of poor water quality and if necessary are able to 're-design' your approach to water quality management, allowing you to design an appropriate water quality management program that is preventative as opposed to fixative. After all you've probably heard the euphemism "An ounce of prevention is worth a pound of cure." This is especially true in regards to lake management.

"Every Lake is a Unique Ecosystem"

Imagine two lakes that are side by side, one is fresh, clean and healthy an asset to the property, while the other is dirty, weed-infested and creates odors (*Figure 1*). Why? Every lake is a unique ecosystem, and unfortunately there are no magical cures for lake problems. This is why it is essential for you to understand the causes of problems as well as the effects.

By increasing your understanding you'll be able to develop a balanced management and prevention programs for your lakes. As greens keepers or property management professionals you are well aware of our responsibilities and our ability to have significant positive impacts on the environment.

Next we'll be reviewing lake dynamics. This includes types of lakes, regions of the lake, and the importance of establishing and maintaining an ecological balance.

In order to design and put into practice preventative water quality management programs it is essential to have a firm understanding of the causes of water quality problems.

We'll review the effects of poor water quality and the related costs to the property owner or manager, as well as focusing on crafting cause-oriented solutions, designing programs to put your lakes in ecological balance and preventing nuisance problems in the future.

Knowing the type of lake you are managing will help you to establish a benchmark for the typical problems you might expect and the management programs you will be able to enact. As you review the three basic types of lakes, be sure to do a quick inventory on the lakes you manage. Which category do they fit in?

Lakes are generally classified into one of these three categories:

1. *Oligotrophic* (or new)
2. *Mesotrophic* (or middle aged)
3. *Eutrophic* (or old)

The age of the lake and the design of the lake are two critical factors we must consider.

Each lake has zones or regions and it is essential that the lake manager be aware of these zones and use them in maintaining an ecological balance in the lake. A lake that is in balance is a healthy lake, aging at a slow rate.

Oligotrophic lakes are clear, cold lakes with low nutrient levels and few macrophytes or plants. Geologically speaking, these are "new lakes." Oligotrophic or new lakes have very low levels of phosphorus, usually less than .001mg\l and there is little or no algae present.

Mesotrophic lakes tend to have intermediate levels of nutrients and macrophytes or plants and could be considered "middle aged lakes." These lakes have higher levels of phosphorus and experience some weed and algae problems.

Eutrophic lakes are characterized by high nutrient levels, turbid water, and large algae and macrophyte plant populations. Phosphorus levels can be in the range of 1mg\l. Considering that one gram of phosphorus will produce 100 grams of algal biomass, eutrophic lakes contain high algae populations.

Lakes evolve through a natural aging process. Under natural conditions this process takes hundreds, sometimes thousands of years.

Cultural eutrophication, which is the acceleration of the aging process through human inputs, speeds up this aging process at an exponential rate. These human inputs include erosion, chemicals, fertilizers, waste runoff, leaky septic systems and more. The greater the level of the input the faster the lake or pond ages.

A great majority of the lakes we manage are man-made. Many times these lakes are poorly designed, may have artificial water tables, and most are so shallow that within a few short years they pass from oligotrophic (new stage) to eutrophic (old stage).

Excessive runoff accelerates the aging process of a lake exponentially. Special attention and management programs are necessary to overcome these effects of aging and keep the lake productive and aesthetically pleasing.

Were you able to identify which categories your lakes are in? This is one of the first steps in creating a management program custom fit for your application.

We can divide the lake into regions based on location within the water body. Both the shape of the basin, ***morphometry*** *(Figure 2a)*, and the shoreline characteristics, ***morphology*** *(Figure 2b)*, have significant importance to the lake manager.

Inside these lake regions there are zones which have tremendous influence over water quality and our approach to management. These zones include the ***littoral***, ***limnetic***, ***euphotic***, and ***benthic*** zones. Let's take a closer look at these regions.

Morphometry and morphology have significant influence over mixing in the basin. Both vertical and horizontal circulation are important in creating and maintaining a balanced ecosystem.


Figure 2a

Morphometry, or lake shape, has tremendous influence over horizontal mixing. Long narrow channels or canals often experience water quality management problems. Isolated peninsulas can create physical barriers to mixing and, water quality issues can more easily occur.

Morphology, or the shoreline characteristics of a lake, has significant impact over vertical mixing and plant populations.

Different plants thrive at different depths.

For a more in-depth review of morphology we must begin by exploring specific shoreline characteristics.

First, the ***littoral zone*** *(Figure 2b)* is the region of the pond sloping from the shore out to the area of open water. It is the interface between the drainage basin and the open water, most generally the area where sunlight will penetrate to the bottom of the lake. The size of the littoral zone is dependent upon pond depth, clarity and wave action. Sunlight, wave action and the lake bottom have a great influence over this zone. Typically, this is the most challenging region of the lake to manage.

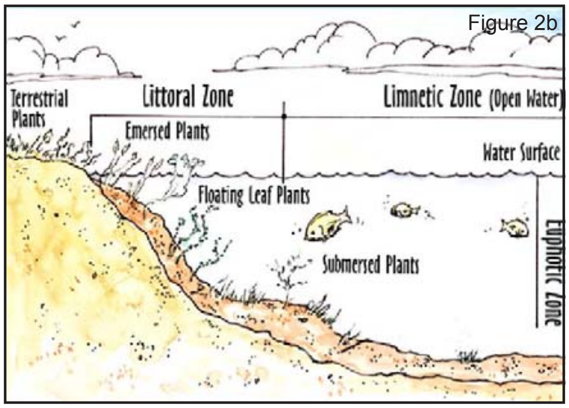

Figure 2b

You will often see a ring of plants around the shoreline in the littoral zone. The variety and type of these plants are dependent upon depth. A variety of algae, including filamentous found in the littoral zone, will typically make up 90% of the species found in the lake. Algae in the littoral zone are often attached to macrophytes, which are emergent rooted aquatic plants such as rushes and reeds, and they thrive in this zone. Algae and macrophytes make excellent habitat for natural clean up tools like micro flora and zooplankton. Zooplankton are microscopic animals like protozoan, micro crustaceans, rotifers and larger invertebrates such as: aquatic worms, crayfish, insect larvae, and fish.

The second region of review is the ***limnetic zone***, or open water zone *(Figure 2b)*. This is the area in the lake that starts at the intersection of the littoral zone and extends out into open areas of the pond. Shore and bottom lake areas will tend to have less influence in this lake region. Planktonic algae, water lilies, submerged pondweed, zooplankton, invertebrates and fish are commonly found in the open water zone. This lake region is typically easier to manage.

The third region for review is the upper, well illuminated layer of the water - or ***epilimnion*** *(Figure 2c)*. This is the area where photosynthesis by algae and other aquatic plants occurs.

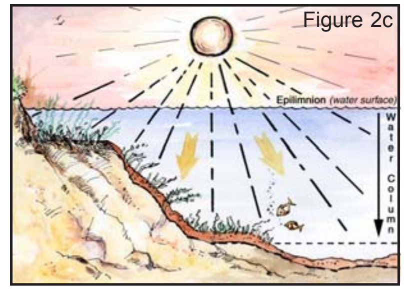

Figure 2c

The water column is the vertical column of water contained in the pond. This term is often used when discussing lake characteristics such as oxygen levels, temperature and nutrient content.

The fourth region for review is the ***euphotic zone*** or ***photozone*** area *(Figure 2d)*. This is the upper layer of the pond where sunlight can penetrate to promote the growth of green plants. We'll review the importance of light to the aquatic ecosystem in just a short while.

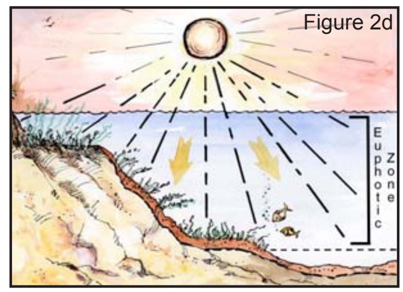

Figure 2d

Finally, the ***benthic zone*** is the area at the bottom of a pond or lake *(Figure 2e)*. The benthic zone is comprised of sediment and soil and usually has a high demand for dissolved oxygen.

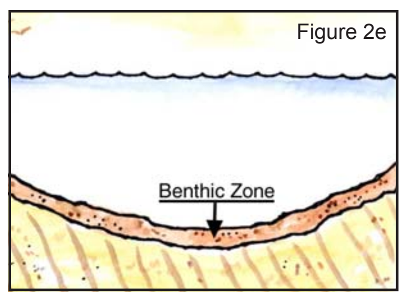

Figure 2e

Let's put it all together...

(Figure 3) The littoral zone is the shoreline area where nutrients will runoff into the water. The shallow nature of this zone and the fact that most nutrients will enter the basin through the littoral zone make it the most difficult area in the lake to manage. The limnetic or open water zone is deeper and easier to manage, while the euphotic zone is the region of the water column that is lit by the sun. Depending on turbidity, most of the lakes we encounter have euphotic zones that extend anywhere from 80% to 100% of the water column. And the benthic zone is the nutrient enriched, oxygen starved bottom layer of the lake.

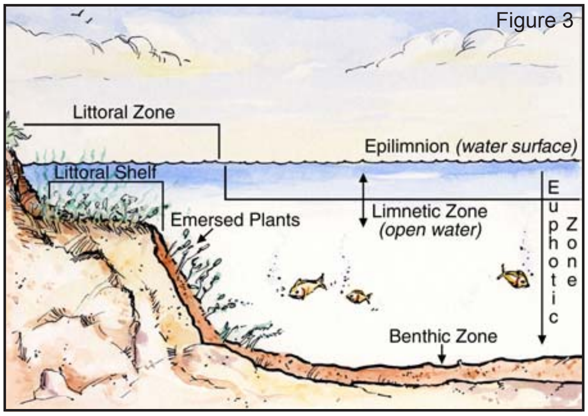

Figure 3

A balanced lake management program will take all of these zones and regions into account and use each to help achieve ecological balance.

A lake in ecological balance is a healthy, dynamic ecosystem that is aging at a very slow rate where fish and other forms of aquatic wildlife are present, and there is an absence of foul odors and algae blooms. As nutrients enter the ecosystem they are either absorbed by the aquatic plants or metabolized by ***aerobic bacteria***. There are safe levels of oxygen present in all regions of the lake with a minimum of 4 PPM or mg\l. Oxygen is added to the lake from wave and wind action, the light side of the photosynthesis process, and rain. It's a healthy, balanced ecosystem. Mother Nature has provided the necessary clean up mechanisms to keep the lake in balance.

However, this balance is a delicate one. Typically there is an influx of nutrients, as aerobic bacteria respire and consume oxygen they will metabolize nutrients. This process keeps the available nutrients at a healthy level and everything is fine until a hot, humid, cloudy day occurs when the planktonic algae doesn't photosynthesize and create oxygen or the first long, hot night when oxygen demand soars.

In these scenarios there are no oxygen producers but there are many oxygen consumers, especially in stratified waters where all the demand for oxygen can't be met. We experience an oxygen stress and in turn a fish kill where the lake then turns ***anoxic*** or ***anaerobic***. The limiting factor is oxygen, while the fish kill isn't the first indicator that there is a problem it's usually the most dramatic and understandable one.

CAUSES OF WATER QUALITY PROBLEMS

As managers, it's important that we understand the factors that impact this delicate balance. The three most significant factors to the lake manager are:

1. *Light and Temperature*
2. *Nutrients*
3. *Oxygen*

Sunlight is of major significance to lake dynamics as it's the primary source of energy. Most of the energy that controls the metabolism of a lake comes directly from the solar energy utilized in photosynthesis. Photosynthesis will occur only in the euphotic zone *(Figure 3)* or upper layer of the pond, this is the area in the water column that sunlight is able to penetrate. Shallow bodies of water less than 9ft/3m in depth more commonly experience problems such as bottom-rooted weeds or benthic algae.

Thermal Stratification is a term meaning temperature layering. As the sun shines on a pond it warms the surface water, this water becomes lighter than the cooler, denser waters which are trapped at the pond's bottom. As the hot summer season progresses the difference in temperature between the warm surface waters and the colder bottom waters grows. As a result the water becomes stratified or separated into layers with the top and bottom layers of the lake do not mix with each other. The area between the warm and cold layers, called the ***thermocline*** or ***metalimnion*** *(Figure 4)*, can act as a physical barrier preventing any vertical mixing in the lake. And, remember warm surface waters encourage algae growth.

Have you ever experienced this phenomenon when diving into a pool or lake and noticed that the water is colder at the bottom than on the surface?

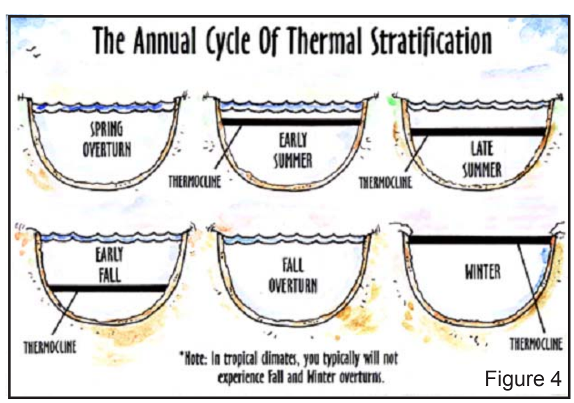

Figure 4

Thermal stratification impacts the water quality in a lake primarily because of its effect on dissolved oxygen levels, the way we measure how water holds oxygen *(Figure 5)*. Warm water has a diminished capacity to hold oxygen, in fact water at 52 degrees Fahrenheit or 11 degrees Celsius can hold over 40% more oxygen than water at 80 degrees Fahrenheit or 27 degrees Celsius. *As water temperature increases, the water's capacity to hold oxygen decreases.*

Dissolved oxygen in a lake comes primarily from photosynthesis and wave/wind action. During stratification, bottom waters are removed from both of these sources and an anoxic or no oxygen condition occurs. Aquatic organisms require oxygen to survive, in its absence organisms must move from the anoxic area or die. Anoxic bottom waters lose most if not all of the zooplankton and aerobic bacteria necessary for efficient and effective digestion, while less effective more pollutant tolerant forms of anaerobic bacteria will develop.

Thermal Stratification Effects on Dissolved Oxygen

Degrees Celcius	Degrees Fahrenheit	Oxygen Saturation
11°C	52°F	11 PPM
17°C	62°F	10 PPM
22°C	72°F	9 PPM
27°C	80°F	8 PPM

Figure 5

The lack of dissolved oxygen sets in motion a series of chemical reactions that further reduce water quality: sulfide is converted to hydrogen sulfide, insoluble iron is converted to soluble forms, suspended solids increase and a severe decrease in the decomposition of waste materials on the pond bottom will occurs.

Thermal stratification occurs in a seasonal cycle with the thermocline becoming more severe in late summer and late winter. Lakes and ponds in warmer weather regions experience a shorter annual cycle spending more time in late Summer and early Fall conditions.

Shallow lakes offer the water manager an even greater challenge. Shallow ponds less than 6ft/2m in depth tend to be very warm allowing for the entire water column to be productive with weed and algae growth. These types of lakes need extra consideration when determining the correct water management solution.

The second essential factor in our lake management discussion is the impact of nutrients on the aquatic ecosystem. There is a direct correlation in the level of available nutrients and the populations of algae and aquatic weeds.

To gain a deeper knowledge it is important to understand the sources of nutrients, how the nutrients are absorbed and broken down, and the impact nutrients can have on water chemistry. In fact a diagnosis of a lake's chemical make up can help you design a preventative program for a problem lake.

We need to consider the way that organic nutrients are accumulated and digested in the lake. An organic nutrient is a carbon based compound essential to the life of a plant. In lake ecology the macro nutrients we specifically talk of are phosphorus and nitrogen. In fact, phosphorus has been identified as the single greatest contributor to aquatic plant growth, remember that one gram of phosphorous will produce one hundred grams of algal biomass. As the nutrient level in the water increases so does aquatic plant and weed growth, this leads to severe problems from an environmental and aesthetic viewpoint.

It is beneficial to try to identify the sources of nutrient coming into the pond. The three most common sources are bottom silt and dead vegetation in the lake, runoff water from surrounding turf areas, and the sources of incoming water.

Vegetative life in the lake and sediment at the lake bottom are the primary sources of nutrient. Although they only have a two-week life cycle, blue-green algae can experience cell division and double their population as often as every 20 minutes. At the end of the cycle, the plants simply die and begin to sink to the lake's bottom, adding to the biomass, or total amount of biological material in the pond *(Figure 6)*. This adds to the "aquatic compost pile" at the benthic zone or bottom. The layer of dead plant material acts as nutrient for future algae and aquatic weed blooms, a phenomena called ***nutrient cycling***. Nutrient cycling creates additional demands on the

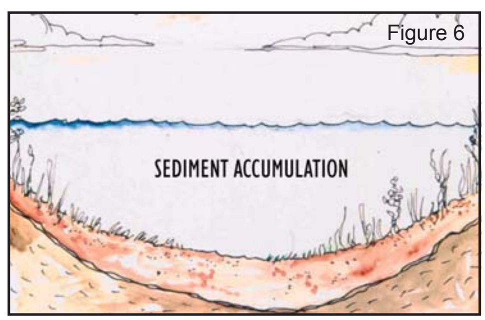

Figure 6

available oxygen in the hypolimnion, or bottom, and creates a stress situation.

Studies at the University of Florida indicate that sediment or *sludge build up can accumulate at a rate of 1 to 5 inches or 2.5 to 12cm per year* in temperate climates. While in tropical climates the rate increases to 3 to 8 inches, or 6 to 16 cm per year all depending on the level of nutrient loading.

At a mid point accumulation rate of 3 inches or 7cm per year, a one surface acre or a 4000 square meter lake will lose 80,000 gallons or 300 cubic meters of water storage capacity in a single year. Imagine the impact on an irrigation storage basin over the course of ten, twenty or fifty years. Sludge build up can gradually occur, robbing any lake or irrigation basin of it's capacity to store water.

The second most common source of nutrients is runoff from surrounding turf areas as well as roads, farms and other outlying areas *(Figure 7)*. The USGA reports that up to 4% of the fertilizers applied to areas adjacent to ponds and lakes may eventually runoff into the lakes, this runoff of fertilizers into lakes is known as ***nutrient loading***. Consider that a golf course may apply up to sixteen tons of fertilizer in a year the possibility for a half ton of fertilizer to runoff into the lakes or drainage basins exists. Leaves, grass clippings, and other materials will also runoff into the lakes, placing additional burdens on the lake's natural clean up processes. Ponds and lakes often act as Mother Nature's "garbage cans."

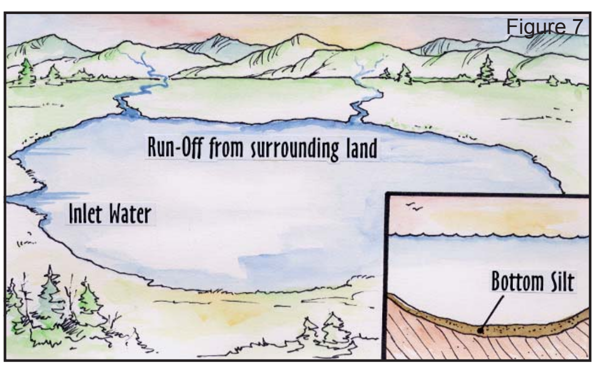

Figure 7

Nutrient loading can be very high in waters adjacent to green areas or turf grass. As the nutrient levels in the pond increase, the rate of plant growth will increase as well. The following chart shows the impact that nutrient levels can have on aquatic plants and algae.

A case study presented by the North American Lake Management Society (NALMS) suggests that the algae can absorb over 1mg\L of phosphorus and over 2.5mg\L of nitrogen *(Figure 8)*. Nutrients do have a significant impact on algae and aquatic weed growth, increased nutrient levels usually mean increased plant levels.

Nutrient is also added to our lakes and ponds through inlet waters. This inlet water can come from effluent sewage, wastewater treatment plants and leeching from septic systems. Often inlet waters have minimal oxygen and are loaded with phosphorus, an indication of excess phosphorus is foaming water.

Nutrient Loading: NALMS Case Study

	Total Nitrogen	Total Phosphorus	Algae/ Weed
Incoming	3.22 mg\l	1.7 mg\l	< 1%
Water at Lake Center	.50 mg\l	.62 mg\l	> 40% Algae Covered

Figure 8

The third essential factor in lake and pond ecology is the role oxygen plays. Oxygen is important to all forms of life in the lake, after all how long can we live without air? Oxygen supports the food chain in a lake or pond, a healthy ecosystem in a lake contains a wide variety of plants and animals including a natural mechanism to biodegrade organic nutrients. The bottom of the food chain consists of microscopic algae which are consumed by slightly larger zooplankton. Each level of consumer transfers a small fraction of the energy the lake receives up the food chain to the next level of consumer. This means that a few sport fish depend on a much larger supply of smaller fish, and in turn the smaller fish depend on a large base of plants and algae. This large mass of plants and algae require an even larger amount of nutrient to grow, a healthy food chain can pull a tremendous amount of nutrient out of the water. Oxygen supports this entire system.

Natural decomposition processes in the aquatic ecosystem are oxygen dependent. Aerobic digestion is a fast and efficient way of breaking down nutrients. Moreover, an abundant supply of dissolved oxygen supports the oxidation and other chemical processes that help keep the lake in ecological balance.

How is a lake supplied with oxygen? From several sources but primarily through photosynthesis, wave and wind action. Aquatic plants and algae produce large amounts of oxygen through the light process of photosynthesis. This is an important source of oxygen in most lakes especially older, eutrophic lakes. At night plants become oxygen consumers in the dark process of photosynthesis and produce carbon dioxide. The other significant oxygen producer is the oxygen transfer created by wave and wind action. The surface area of the lake is increased by surface waves or ripples caused by wind or other means, this wave action created by the wind creates additional circulation and partially breaks down thermal stratification. Surface waters that have direct contact with the air will be oxygenated through diffusion. And finally, as the rain passes through the atmosphere it picks up free oxygen and deposits it in a dissolved state when it strikes the surface waters of the lake.

Oxygen depletion or stress situations occur for different reasons. Whenever oxygen levels fall below 3 to 4 PPM or mg\L an oxygen stress will occur. Typical situations when this will happen are:

- Late at night and just before dawn
- Cloudy and still days
- Hot and humid days
- When the lakes nutrient content is high
- After a chemical application

The most immediate reactions to oxygen depletion would be fish kills or odors. Long term issues include nutrient build up, sludge accumulation, and a chemical imbalance in the lake.

Nature has provided a clean up process that will metabolize or decompose excess nutrients. This process is called ***organic digestion***. Two types of naturally occurring bacteria are present in all lakes and ponds, ***aerobic*** and ***anaerobic***. The bacteria in the water will work to break down the nutrient load by feeding on the organic nutrients and digesting it into non-organic compounds that algae and aquatic plants can not readily use for food.

The most effective of these bacteria are ***aerobic bacteria***. Aerobic bacteria only live in the presence of oxygen and they metabolize or break down nutrients respiring or consuming oxygen in the process. They are very efficient, breaking down organic nutrients, carbon dioxide and other materials and are roughly seven times faster in organic digestion than anaerobic bacteria.

Anaerobic bacteria also break down organic nutrient and exists in pond water and soils that are oxygen deficient. They are not as effective as aerobic bacteria in the digestion of organic wastes and allow soluble organic nutrients to re-cycle into the water column. Noxious by-products such as methane, ammonia and hydrogen sulfide are created by anaerobic decomposition. In general, any foul smelling waters can be assumed to be anoxic or oxygen deficient.

Oxidation is a chemical process that is dependent on oxygen. Oxygen has a positive molecular charge, as an oxygen molecule affixes itself to a particle in the water it then starts to oxidize or break down the molecular bonds which hold the particle together. In addition, the positive molecular charge of the oxygen molecule will create an attraction and pull several small particles together, a process known as ***coagulation***. These heavier, coagulated particles now precipitate, or fall out of suspension. In this process soluble substances like phosphorus and iron become insoluble and unavailable for use by aquatic vegetation. A balanced aquatic ecosystem contains a fairly low population of algae and aquatic weeds as well as other forms of nutrient. Aerobic bacteria feed on the organic nutrients and digest it into non-organic compounds that algae and aquatic plants can not use as readily for food.

Simple water quality tests will indicate the nutrient levels and other valuable information in regards to lakes and ponds *(Figure 9)*. These tests typically monitor dissolved oxygen, biological oxygen demand, alkalinity, pH, phosphorus, nitrogen, and fecal coliform in some situations. Dissolved oxygen is described in either parts per million or milligrams per liter. Biological Oxygen Demand is referred to as BOD. The chart indicates the appropriate levels for lakes and ponds. This testing can be completed by most water testing laboratories and water testing is important for a complete understanding of the water you are trying to manage.

Let's put it all together...

Let's take a look at how all of these mechanisms interact to make the lake behave the way it does. As a lake ages the level of nutrient rises, this is due to an increase in runoff, organic bottom sediment, or fertilizer used in the surrounding area, and in the amount of algae and aquatic weed growth. As these weeds grow and die they sink to the bottom of the pond to decompose, this will result in a sudden increase in the activity and population of aerobic bacteria due to the large food supply. The depth of the lake will decrease as the biomass at the lake bottom accumulates. Aerobic bacteria will use a large amount of oxygen as they digest organic waste, with primary source of oxygen in the pond coming through surface contact, rainfall and plant photosynthesis.

Water Quality Tests: Appropriate Levels

Dissolved Oxygen	>4 mg/l *(check before sunrise)*
BOD	<5 mg\l
pH	6 to 9 *(7-8 are neutral)*
Alkalinity	>50 mg\l *(well buffered)*
Chlorophyll	<2 mg\l
Suspended Solids	<5 mg\l
Fecal Coliform	<200 per 100 ml *(no human contact if >400)*
Total Nitrogen	<5 mg\l
Total Phosphorus	>.05 mg\l *(considered high)* <.1 mg\l *(will experience algae blooms)*

Figure 9

Due to thermal stratification the top and bottom layers of the pond will not mix and the needed oxygen can not get down to the lake bottom to support aerobic digestion. This will cause an oxygen depletion problem in the lower layers of the lake and may result in nutrient cycling, fish kills and foul odors caused by anaerobic digestion. The problem is caused by poor water quality, that is excessive nutrient levels, poor circulation and low oxygen levels.

Balance is critical to the aquatic ecosystem. A healthy lake contains balanced amounts of oxygen, nutrients, and temperature.

RESULTS OF POOR WATER QUALITY

Now that we have a deeper understanding of the actual causes of water quality problems, let's identify the effects or symptoms. This includes algae, weeds and odors. Associated with these effects are the costs of fixative programs. It is important that you understand the high cost of not acting, once a lake has lost its ecological balance and goes into crisis the costs of restoring the lake increase dramatically.

Many people view algae as the lake management problem but the true problem is poor water quality, a lake that is out of ecological balance. Algae and aquatic weeds are some of the first visual indications of poor water quality. Algae is better viewed as a symptom, blooms of microscopic and filamentous algae can be unsightly and can disrupt full enjoyment of the lake or pond. Planktonic algae are single or multiple cell plants found near the surface or epilimnion, they often are a light green in color and can create a "pea-soup" appearance to your lake. A lake with an abundance of Planktonic algae runs the risk of causing an oxygen depletion or stress emergency. Often during a cloudy, hot, summer day or late at night these algae can consume all the available oxygen in the water. When this happens we will see a fish kill or a mass algae die-off. An algae die-off can occur for a variety of reasons, a cold snap, lack of light, or a chemical application. The lake will change from a light green to a brown color overnight. The dead algae will produce additional demands on the available oxygen creating a negative visual aspect and odors to the environment.

Benthic or filamentous algae is a very difficult type of algae to control. These plants grow from the bottom of the lake or benthic zone, break loose and float to the surface. They will only grow in conditions where the depth and turbidity of the water allow sunlight to reach the lake bottom. These algae are often called moss or cotton algae, some species have small air bladders that float the algae to the surface. Once at the surface, this algae becomes an ideal habitat for mosquitoes and other insects.

Probably the most difficult type of weed to eradicate are bottom rooted vascular plants. These plants often have small air sacks or bladders attached permitting them to float and to keep them in suspension. Bottom rooted, vascular weeds will only grow where the sunlight penetrates to the pond bottom. All of these weeds and algae have one common benefit... they help reduce the available nutrients in the lake.

What are the impacts that algae and aquatic weeds create for the lake or property manager?

- Increased nutrient/biomass levels in water causing sludge build-up
- Oxygen depletion issues such as odors and fish kills

For the property manager the negative effects and costs of poor water quality are very real and can impact the property both in aesthetic and functional ways. Clogged irrigation valves can create havoc on the turf while sediment build-up reduces storage capacity in water basins and aesthetic appeal is lost through odors, fish kills and algae.

If a vertical turbine pump becomes fouled it will be necessary to bring a diver to the site. Commercial divers are usually not immediately available nor are they always conveniently located, this may lead to delayed repairs due to logistical concerns during which the turfgrass receives no irrigation. Once the diver arrives at the site, the pump intakes can be cleared in four to eight hours. Costs to the manager are in the $500 to $1000 range and this cost does not include travel time or damage done to the turf.

If a valve or sprinkler fouls, the problem is smaller in scope but still serious. It may take several days to identify that a sprinkler or valve is clogged. In the interim the turfgrass can either burn out due to lack of water or become saturated with excess water *(Figure 10)*. This repair is fairly simple and it normally takes two to four hours, however it can be especially difficult on a golf course where ground under repair can interfere with normal play. The costs to fix a valve or sprinkler ranges from $120 and upward.

Remember sediment increases the lake's oxygen demand and makes additional nutrients available for aquatic plant growth. Under certain conditions it is possible for the sediments to pass through the irrigation system out onto the turfgrass, this can happen when rain or wind mixes sediment back up into suspension. The intake for the irrigation pumping system's intake is near the bottom of the lake where the sediments can block pumps, pipes, valves, and sprinklers. Costs can become excessive, for instance at El Dorado CC in Texas costs of $7,500 per year were incurred to repair damage to the pumps, while at Great Hills Golf Course in Texas annual costs exceeding $20,000 per year are spent to clear blocked pipes, valves, and sprinklers.


Figure 10

If the pumping system passes the sediment out onto the turfgrass or golf course a new set of problems arise. The sediment at the bottom of the lake will often contain heavy metals, anaerobic bacteria, and partially decomposed organic material

When this sediment is applied to the turfgrass it can create a "***black layer***" in the grass root zone. This layer will effectively seal the turf and not allow oxygen, water, or nutrients to percolate down to the roots of the turfgrass, creating disease or even death of the grass.

Should this happen, it will be necessary to replace the greens or core out and install new USGA mix in the turf. The costs here can be staggering. Coring out and installing new USGA mix costs $10,000 to $15,000 per green. The cost to rebuild and reshape a green can range from $35,000 to $45,000 per green or a possible total cost of $850,000. Mr. Jim Moore, Director of Education for the USGA states, "This is a lot bigger problem than most people realized. It's destroyed a lot of greens, clubs are faced with the reconstruction of greens and tees built within the last ten years because of lousy water quality."

Sludge build up (eutrophication) as stated earlier impacts the manager in different ways. With the reduction in the basin's capability to store water, it has severe impact if the lake is an irrigation storage basin or a storm water retention pond. In either instance, the lake has been designed to hold a given capacity of water which have now been diminished *(Figures 11a & 11b)*.

Oxygen depletion can lead to fish kills and odors. Warm water fish require roughly 4 PPM (parts per million) of dissolved oxygen and cold-water fish require 5 PPM of dissolved oxygen. As

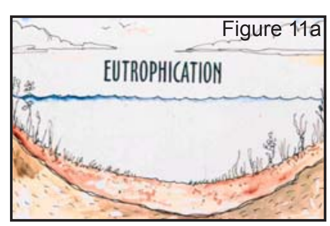

Figure 11a

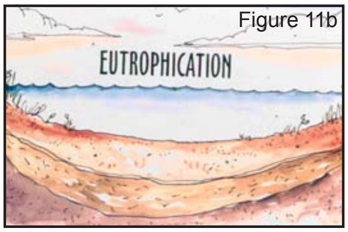

Figure 11b

mentioned before when oxygen levels in a pond drop one of the first indicators is a fish kill. When fish go into an oxygen stress you will typically see them at the surface where a minimal oxygen transfer occurs through oxygen diffusion.

Odor problems in ponds are generally traced to four causes:

1. *Algae*
2. *Chemical pollution*
3. *Geological conditions*
4. *Low oxygen levels resulting in an anaerobic condition*

By increasing oxygen levels and circulating oxygen rich water throughout the pond, anaerobic conditions can be minimized while odorous gases can be stripped out of the water. These conditions are generally treatable through filtering or aeration.

Therefore, problems associated with poor water quality such as: excessive weed and algae growth, clogged sprinkler heads, valves and pumps, sludge build up and reduction of storage capacity, black layers under turf, as well as unpleasant odors, diminished aesthetics and insect problems are avoidable if the lake manager puts a proactive, preventative lake management program into place.

PREVENTATIVE PRACTICES

The lake manager has many water quality management tools available. The art of lake management lies in the design of an integrated lake management program properly aligning the best solution with the chronic causes of quality issues. The manager should strive to create an environmentally friendly program which is preventative in nature. Proactive management means preventative management, keeping the lake in ecological balance by design. Reactive management typically means crisis management, where the lake manager waits until the lake is thrown out of ecological balance and a crisis occurs. Reactive solutions tend to be less friendly to the environment and more costly to implement.

In order to identify the proper preventative practice it is important to identify the true causes of the problem. How does the problem relate to the three factors that have the most impact on water quality management: sun light and temperature, nutrients and oxygen? With the growing awareness of the importance of water quality and its impact on the environment, preventative practices revolve around these issues and offer the most acceptable solutions as these solutions are directed at the causes.

Many lake management issues are related to light and the heat generated by the sun. Shallow lakes with a severe benthic or filamentous algae problem would be in this category. To attack the causes of excess solar radiation we need to look at the basin configuration and the use of lake dyes to block U.V. penetration.

Proper lake design or configuration is the first step towards sound water quality and will minimize many of the inevitable management issues that arise as the lake ages. Many of the lakes we encounter are man-made, so when designing a lake it is critical that the designer keep the biological factors in mind as morphometry and morphology play important roles in the dynamics of the lake. Unfortunately there are many times lakes are designed too shallow, creating unnecessary problems that could have easily been avoided in the initial stages of development. Proper lake design is the first step towards sound water quality and will minimize many of the inevitable management issues that arise as the lake ages.

In regards to the shape of the lake (morphometry) long isolated peninsulas or fingers of land that interfere with circulation should be avoided. The shoreline of the lake (morphology) should allow for a littoral shelf where nutrients can be buffered or absorbed by plants before reaching the limnetic zone (*Figure 12a & 12b*). A minimum of 9ft/3m is suggested for the depth of the basin. This depth will allow for sunlight and provide an area that should not experience bottom rooted plants and have cooler waters to mix with surface waters. ***Shallow, warm ponds can be the lake manager's greatest challenge.*** By allowing for reasonable depths it will help minimize the impact of solar radiation and the related heat on the lake.


Figure 12a

There are also a lot of times the lake or water feature is constructed as an artificial water table in a place where a lake or pond would not occur naturally. In many cases the soil on the site is not suitable to hold water, while in some areas environmental concerns dictate that drainage water from the site does not make contact with underground water tables. All of these factors have resulted in the greater use of lake-liners (*Figure 13*).


Figure 12b

When using a lake-liner, subgrade preparation is an important factor to a successful project. The site manager should take groundwater into account and if present they should develop a french drain system that will allow water to flow laterally under the lining depositing the drainage water in a gravel sump. This under drain will prevent the liner from floating due to ground water or gas build up under the liner. The lakebed should be well prepared before the liner is laid down making sure that it is smooth and well manicured to insure an easy and successful installation. Lake-liners can be a tremendous asset to the property manager.

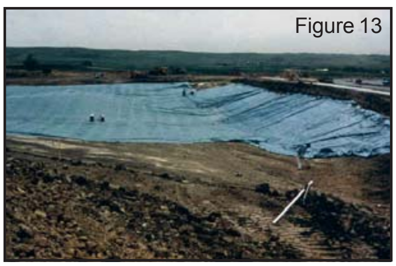
Figure 13

While there are different types of materials available PVC remains the most commonly specified choice. As UV rays will degrade PVC it is necessary to place a minimum of 1ft/30cm of topsoil over the liner once installed. Another material, reinforced polypropylene, is not affected by light and can be successfully installed without the use of topsoil to cover the liner. Traditionally clay or bentonite have been used as a liners, however they tend to crack and are not as widely used as they were once before.

Lastly, it is highly recommended that a provision for electrical supply be made to each and every lake. This is very inexpensive in the construction phases of the project and makes provision for supplemental aeration systems or other electrical needs later on down the road.

Lake dyes are an important proactive management tool for use in shallow lakes. These products can help offset the lack of depth by reducing the UV energy absorbed by the lake. A lake dye is a photosynthesis inhibitor, it blocks the penetration of sunlight into the lake, thus slowing the growth of aquatic plants. Lake dyes will also improve the appearance of lakes by masking or covering improving clarity or color problems.

Lake dyes are available in liquid or powder form and contain an inert form of powder similar to blue food colorant #5, be sure to choose a dye that is government or EPA approved. Use the dye in lakes or ponds that have no outlets or streams and it can help give your lake additional aesthetic appeal by enhancing the coloring of the water to a deep blue (*Figure 14*). Most lake dye will last an average of 6-8 weeks and will not harm fish or stain waterfowl. Nutrient sources include inorganic and organic matter already existing in the lake, nutrients which runoff or leach into the lake, and the source of the water itself. The manager has a great degree of control over the nutrients that may runoff into the lake. Our goal should be to prevent as much nutrient as possible from reaching the water.

How can we best achieve this? One of the simplest ways lies in fertilization and mowing practices. You can create a “no fertilizer” zone in the immediate perimeter of any lake, we recommend a band of 30 feet or 10 meters if possible, this will help eliminate chemical runoff to enter the pond or lake. The use of slow release fertilizers will also help minimize fertilizer run off, as well as letting the turf grass grow longer in the turf grass-lake interface zone. Finally, a slight geological relief such as a swale or berm will help prevent organic nutrients and fertilizers from running directly into the water.


Figure 14

Another preventative, biological control method is the introduction of wetlands at the areas where water or runoff flows into the lake. The wetland area can perform two functions: slow the progress of water into the lake, reducing erosion and flooding problems, and secondly the intensive plant growth in a wetland area acts as a nutrient sink for the nutrient enriched waters flowing into the basin. The plants in the wetland will actually absorb nutrient before it has a chance to enter the lake. This can result in higher water quality due to lower organic nutrient levels.

A very effective form of biological control is using vascular, rooted plants as a buffer. This technique was pioneered over a decade ago by Dr. Bob Blackburn from Auburn University. He believes this technique to be the lake manager's "first line of defense." By planting these plants in the littoral zone they absorb the nutrients before they reach the water, helping to lower the nutrients available for algae, aquatic weeds, and bacteria.

The following chart (*Figure 15*) indicates which plants are suitable for different depths. We recommend that the seedlings or roots be planted 1ft/25cm apart.

Note: The choice of plants is related to depth, contact your local Department of Natural Resources or Conservation for more details on these plants. The scientific name may be useful in sourcing the less common plants. Like the wetland plants, these species will provide a wonderful habitat for fish and waterfowl as well as provide beautiful foliage.

AQUASCAPING: SUGGESTED PLANTINGS

Depth	Plant Types
0-1 ft 0-25 cm	Burred, Three Square Rush, Smartweed, Cattails
0-1.5 ft 0-40 cm	Wild Rice, Arrowhead, Bulrush, Pickerel
0-2 ft 0-50 cm	Deep Water Arrowhead, Water Lilies
1-5 ft 25-125 cm	Sago Pondweed, Water Celery

Figure 15

FOUNTAINS AND AERATORS

There is a significant difference between fountains and aerators. The primary function of an aerator is to add oxygen and induce circulation in the water. The primary function of a fountain is to create an aesthetic effect. For aeration purposes look for Oxygen Transfer Rates (OTR) in excess of 1lb/5kg per horse power per hour and pumps in excess of 300 GPM or 1200 LP per horsepower. Depending on site conditions we recommend 1HP to 3HP aerating units per surface acre or 4000 square meters.

Aeration, by definition, is the addition of oxygen into the water, the second component of aeration is circulation and destratification. Aeration is a scientific discipline first used to treat wastewater during the industrial revolution and continues to play an important role in the treatment of industrial and domestic waste. Aeration can also make significant improvements to effluent waters that are being used for turf irrigation, similar to creating a mini-treatment plant in your lake. Aeration is a holistic, preventative tool that will prolong the useful life of a lake.

How does an aerator improve water quality and control algae growth?

By impacting the three factors; oxygen, nutrients, and temperature. By putting large amounts of oxygen into the water, an aerator encourages a strong colony of aerobic bacteria which, in turn, works to clean the lake of organic nutrients and waste. Lastly, a properly sized aeration system will create circulation breaking down thermal stratification and lowering surface temperatures while adding dissolved oxygen to the lower regions of the lake (*Figure 16*).

The introduction of dissolved oxygen to the lake's bottom will inhibit phosphorus to release from sediments, curtailing this internal nutrient source. In fact, by adding oxygen to the lower levels of the lake a chemical reaction occurs which converts soluble forms of phosphorus and iron into non-soluble forms that can not be used by plants.

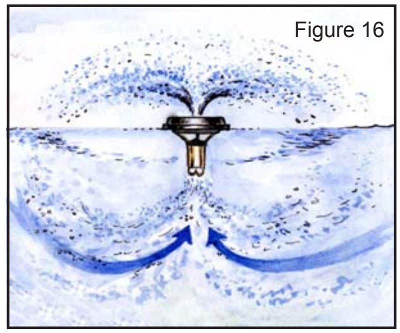
Figure 16

In addition to the problems related to growing turf grass in high iron conditions, iron in irrigation waters can cause staining of cart paths and buildings. The Water

Figure 17

Pollution Control Federation tells us that iron staining starts at .3 PPM or mg\l.

An aeration system, if properly sized, can lower iron concentrations to .1 PPM or mg\l. At a case study in Western Australia, iron levels in the irrigation lakes were wreaking havoc on the turf grass (*Figure 17*). After proper aeration and minimal recon-figuration of the basin's design iron was reduced over 15mg\l from 17 PPM to .02 PPM (mg\l).

Scientific evidence indicates that aeration can help soften hard water and even lower high pH levels. This is due in part to mixing carbon dioxide enriched waters from the lake bottom up into the water column.

The high pumping rate or circulation rate of an aerator breaks down thermal stratification, mixing denser bottom waters with warmer surface water, distributing oxygen to all parts of the lake. By pulling cool bottom water up to the surface, the surface layers are cooled and the growth of algae is slowed. Single cell algae are mixed to the lake bottom increasing the cells time in darkness and slowing growth and reproduction. As you can see aeration effectively deals with the three factors of poor water quality: temperature, nutrients and oxygen keeping them all in balance.

By improving water quality we lower aquatic weed and algae growth, bottom sludge build up, odors, and insect infestation. In turn this has a positive impact on the irrigation and pumping system efficiencies, the environment, and aesthetics. Aeration attacks the source of the problem, poor water quality, and is an economical and on-going method of lake management. It has no harmful side effects and supports the natural ecosystem. By addressing the causes of poor water quality it is preventative and proactive in nature, an old saying goes, "An ounce of prevention is worth a pond of cure," nothing could be more true in the water quality management field.

AERATOR SELECTION

There are three basic types of pond aerators: Surface Spray, Horizontal Aspirators, and Air Diffusion Systems.

Each type is best suited for specific applications. The different types can be used in conjunction to treat several different types of problems in the same lake or on their own, depending on the situation.

Surface Spray Aerators provide the best vertical circulation in lakes less than 15ft or 5m deep, while Horizontal Aspirators are the choice for lakes between 3ft/1m and 12ft/4m deep that will benefit from a strong directional flow. Air Diffusion Systems are the most unobtrusive aerators and are most effective in water that is 15ft or 5m deep or deeper.

Figure 18a

Let's take a closer look at each system and their respective strengths.

Surface Spray (*Figure 18a*) type aerators provide the best vertical circulation in lakes less than 15ft or 5m deep. They lift bottom water up to the top and spread it out over the surface waters to aerate it and create convection currents. While they provide an attractive display, independent research indicates that these systems add 2mg per liter of dissolved oxygen at 10ft/ 3m in depth. The wave action caused by the spray pattern is excellent at breaking up algae mats and discouraging mosquito breeding.

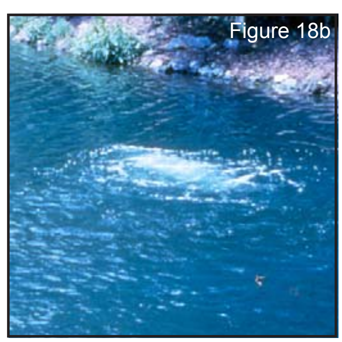

Figure 18b

Horizontal Aspirators (*Figure 18b*) are the choice for lakes between 3ft/1m and 12ft/4m deep that will benefit from a strong directional flow. A good choice for applications where a spray pattern is not wanted or desired, these units are used to create artificial currents in long narrow ponds or canals and will also break up algae mats in stagnant waters.

Air Diffusion Systems (*Figure 18c*) are the most unobtrusive aerators. They are most effective in water that is 15ft/5m deep or deeper but can work in waters as shallow as four feet (*Figure 19a*). As the air bubbles will rise to the surface at 1ft/30cm per second, the system's efficiency is directly related to depth. At 9ft/3m in depth these systems operate at roughly 25% efficiency. As you can see the depth must be sufficient to allow for the rising air bubbles to entrain water towards the surface providing circulation and to transfer into the water column providing aeration.


Figure 18c

The way the system works is that a shore mounted air compressor forces a large volume of air through a supply hose to the diffuser located at the bottom of the pond. The diffuser emits the air in the form of thousands of small bubbles that capture or entrain the bottom water and carry it to the surface. Air diffusion systems have no surface presence other than a boil of bubbles which creates surface water movement that breaks up algae mats and discourages insect breeding, at the same time it provides excellent bottom to top mixing breaking up the thermacline. Air diffusion systems are economical to operate and can be used in conjunction with other types of aerators.

Air Diffuser Efficiency at Depth

Depth	Oxygen Transfer Rate per HP/Hr	Efficiency
15ft or 5m	4.4 lb or 2 kg	100%
12ft or 4m	2.2 lb or 1 kg	50%
9ft or 3m	1.1 lb or .5 kg	25%
6ft or 2m	.5 lb or .25 kg	12%
3ft or 1m	.25 lb or .12 kg	6%

Figure 19a

Be careful to choose the proper type of diffusers. Research indicates that the bubble size and density will effect oxygen transfer rates (OTR) and circulation rates. The following chart shows the efficiency of various systems at 6ft/2m in depth (*Figure 19b*). The test clearly shows that the aeration tubing is 24% less efficient than the synergistic air lift.

Diffuser Efficiencies at 6 Ft (2m)

Type of System	OTR per HP/Hr	Percent Differ-ence
Ceramic Diffusers (6 Diffusers in a 2' x 2' or 50cm x 50cm grid)	.4868 lb	--
Aeration Tubing (72in or 22m)	.37 lb	-24%
Flexible Membrane Diffusers	.2843 lb	-43%

Figure 19b

While waterfalls offer some aeration benefit they are not an effective replacement for an aeration system (*Figure 20*). The average waterfall will use a 5 HP to 25 HP pump to move roughly 1000 GPM or 3700 LPM over a 10ft/3m wall. This approach does not have appropriate oxygen transfer rates or the necessary circulation capabilities for true water quality management.


Figure 20

In order to be effective an aerator must have a very high pumping rate. As mentioned previously, look for a unit that pumps or moves at least 300 gallons per minute or 1.5m^3\minute per horsepower. Aerators are rated by their oxygen transfer rate, a good spray type or aspirating aerator will put 2 to 3 pounds or 1 to 1.3 kilos of oxygen into the water each hour for each horsepower, while an air diffusion system will do slightly more or less depending on the depth of the pond. Try to look for an aerator that has had independent oxygen transfer testing, the measurement with the most importance is S.A.E. or *Standard Aeration Efficiency*. This is the method approved by the American Society of Civil Engineers and rates the oxygen transfer by actual horsepower created.

Safety testing is very important, as most aerators are electrical appliances operating in water. Look for system-wide testing and approval by CE, C.S.A., ETL, or UL. Testing of individual components of a system without system-wide testing does not guarantee that the unit is assembled safely or that all of the components are properly sized or suited for your application.

Proper sizing and placement is the key to a successful installation, the best equipment will not be effective if it is used inappropriately (*Figure 21*). For Surface Spray and Aspirator units you will want to use 2 horsepower per surface acre or 4,000 square meters of water. Add more horsepower if the lake is less than 6ft/2m in depth, if there is evidence of high nutrient levels or if it is an older lake with a heavy organic sludge layer. Air Diffusion systems use approximately one diffuser for each 1.5 acres or 6,000 square meters of water assuming the depth is at least 15ft/5m. In shallower lakes significantly more diffusers will be required.


Figure 21

In larger or irregularly shaped lakes several smaller units will be more effective than one large unit. In a round, square or oval lake, place a spray type unit or an air diffuser in the center of the lake or over the deepest area, while an aspirator placed near the edge of the lake would generate circular flow. In long, thin lakes use multiple units or diffusers to generate circulation throughout the lake. If you are using a single unit, place it in the area that will give you the greatest amount of circulation, aerators in irregularly shaped lakes should be placed where they will generate maximum circulation. Use the appropriate unit for the appropriate area of the lake, streams and canals can best be aerated by using the horizontal aspirator.

ALTERNATIVE SOLUTIONS

Ozone is a powerful oxidant and disinfectant, the concept is in its relative infancy as far as lake management is concerned. At this time there is little or no university based data regarding ozone in our field and the International Ozone Association have no studies regarding ozone use for lake management. However it is possible to extrapolate data from the water treatment and wastewater industries and apply it to our industry.

Ozone is a highly unstable form of oxygen, its chemical sign is O_3 and is created when an oxygen molecule is split from O_2 to two O_1. These oxygen radicals are highly unstable and quickly attach to surrounding oxygen molecules to create O_3 the unstable ozone molecules will quickly revert back to oxygen soon after. The half-life of ozone in water is roughly 20 to 30 minutes and will last in water up to one hour depending on temperature and oxygen demand.

Ozone is created by either corona discharge or by ultraviolet light generators. Corona discharge is the method used for wastewater and water treatment and is able to produce an ozone/air mixture that ranges from 2 to 4% ozone, consuming 6 to 8 kilowatt hours to produce one kilogram of ozone. Ultraviolet light generators can produce an ozone/air mixture that is roughly .1% ozone, consuming 40 kilowatt hours to produce one kilogram of ozone. When comparing the systems, both capital and operational costs must be considered. From a practical view, consider the capital cost in terms of grams of ozone created per dollar, from an operational viewpoint consider energy costs to produce one kilogram of ozone.

Ozone's ability to oxide is tremendous. It is five times stronger than oxygen and over 50% more powerful than chlorine. As such, it has significant potential in lake management. Ozone is a strong disinfectant it's able to kill bacterial cells by piercing the cell wall and bursting the cell in a process known as ***lysing***. Ozone is over 3,000 times faster and 50% stronger than chlorine as a disinfectant, and reverts to harmless oxygen in short order.

In lake management we can look to ozone to provide solutions in the following scenarios: Algae control, Clarity enhancements, Effluent.

In one situation the clarity was 8in/20cm, after a week of corona discharge ozone treatment the clarity in the same lake exceeded 3ft/1m.

Ozone demand in the water is extremely high. Research indicates that with the small generators currently used in the market (<40 grams of ozone/hour), it is virtually impossible to sterilize a lake by putting in too much ozone. When sizing a system it is important to know the volume of the lake, source of the water, shape of the basin, and any other related detail. It's important to remember that the basin should be turned or mixed over 4 to 7 times per day.

Follow the following dosage levels to achieve satisfactory results:

Standard algae, odor, or clarity problems
1.8 grams/hour per 1,234 m^3 or acre foot

Moderate algae, odor, or clarity problems
2.57 grams/hour per 1,234 m^3 or acre foot

Effluent & severe problems
3.85 grams/hour per 1,234 m^3 or acre foot

Another form of biological control is the introduction of additional bacteria into the pond, otherwise known as ***bioaugmentation***. This is a very important tool for helping lower nutrient counts especially in effluent waters. Several companies commercially produce bacteria and they can be applied in either liquid or powder form. These aerobic bacteria consume oxygen and help speed the breakdown of nutrients. Studies have shown that by using aeration and bacteria in conjunction 1 to 6 inches or 2 to 15 cm of bottom sediment can be reduced in a single year. However pH and the chemical make up of your lake will determine if this approach is effective for you.

These products have been used for decades in wastewater treatment facilities and fish farms. In turf related lakes, the objectives are to reduce algae, improve clarity, eliminate odors and to break down the organic material in the sludge bed. This is partially achieved by lowering nutrients and suspended solids in the water column. Algae blooms are reduced through the redirection of nutrients. Phosphorus is absorbed into the bacteria's cell wall making it unavailable to algae, nitrogen is taken from the water through the nitrification cycle, while ammonia and nitrates are oxidized by dissolved oxygen. Basically the bacteria competes for the same nutrient needed by the algae and wins!

While visible results take several weeks, a 50% reduction in phosphorus and nitrogen occur within 1 to 2 days. In 3 to 4 days there is a significant reduction of odors and in 14 days clarity enhancements are noticeable. Algae should either be harvested or chemically treated before the addition of bacteria, if chemicals are used wait at least 48 hours before using bioaugmentation products (*Figure 22*).

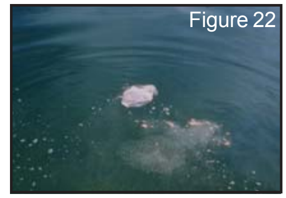
Figure 22

Initial doses are required with lighter maintenance doses following periodically. The limiting factors with this approach are pH, temperature and dissolved oxygen. The pH should be between 6 and 9, while the water temperature should be between 55 to 100° F (12 to 40° C). The bacteria's metabolic rate falls with temperature and optimum results are achieved when the water temperature nears 86° F/30° C. Dissolved oxygen levels are critical to any aerobic bacteria activity, and this is especially the case when the bacterial population is artificially increased. *Aeration is a must if one is to see results from bioaugmentation.*


Figure 23a

Another proactive, preventative measure is the introduction of weed eating fish or grass carp such as the White Amur or Triploid Grass Carp (*Figure 23a*). These fish can be quite effective in keeping excessive weed growth under control. They are inexpensive over the long term and require no labor or upkeep once they are in the water. They can eat 2 to 3 times their body weight in a day, unfortunately they assimilate only a fraction of what they eat doubling their body weight in a year. The rest of the weed matter is returned to the lake as waste.

Stocking rates are twelve to sixteen 10in/20cm fish for every one surface acre or 4,000 m^2. Restocking is required every five years. They are indiscriminate feeders, growing to over 45 pounds/20 kilos (*Figure 23b*). However, be aware that their preferred foods are the most desirable aquatic plants and they will only eat algae if their preferred plants are not available. Many states regulate their use as they are a non-native species and destroy the habitat of native fish and disrupt the food chain. Also, by removing all of the aquatic plant growth in the pond a major source of oxygen is removed and odor and water quality problems can result.


Figure 23b

Barley straw has also been receiving attention as a possible cure for algae blooms. The concept requires that straw be distributed on the surface of the pond or placed in netting and then submerged (*Figure 24*). If sufficient dissolved oxygen levels are present the straw will begin to decompose, as this occurs it goes through several stages. During the final stage of decomposition the straw oxidizes to humic acids and other humic substances. It has been shown that when sunlight shines into water that contains dissolved oxygen and humic substances hydrogen peroxide is formed., low levels of peroxide are known to inhibit the growth of algae.


Figure 24

To date the only documented research has been done by Dr. Jonathan Newman, Aquatic Weed Research Unit, U.K. and the University of Florida. The study from England is written in scientific language, but several times in the report it returns to the conclusion that, *"Activity is only produced if the straw is rotting under well oxygenated conditions."* The University of Florida study produced inconclusive results that barley straw had any impact on algae. By adding straw to the water, we add more nutrient and vegetative matter that will convert to biomass, creating more oxygen demand. While there may be short term benefits in the long run the addition of more nutrient makes the lake more difficult to manage and creates additional biological imbalance.

A relatively new fad in water quality management is the burning of sulfur to treat irrigation water and lower the pH. Return water from the irrigation system is mixed in the irrigation lake where the sulfur dioxide (a cousin of sulfuric acid) will then lower the pH of some lake water 2 to 2.5pH. However the sulfur dioxide will attach to the dissolved oxygen in the pond and can lower the oxygen into crisis levels, therefore supplemental aeration must be used in conjunction with these systems. The typical system costs $50,000 and burns $7,000 worth of elemental sulfur per year and a sulfur odor smell is produced into the air when the system is operational. From a lake manager's vantage point, this tool is targeted more at a symptom, algae - than at the cause, poor water quality. The EPA is currently looking into the environmental impact of these systems.

'Reactive' means we wait for the lake to lose ecological balance before we implement a management program. Reactive management tends to be crisis driven and less environmentally friendly, not to mention they are usually more costly. However they can be a necessary and important tool for the lake manager.

When designing your lake management program be sure to align the proper management method with the ecological needs of the lake. Using a reactive tool for prevention will not achieve the desired results. Likewise, preventative tools will have less impact once the lake is in crisis.


Figure 25

The harvester is a device that removes floating weeds, algae, and debris from the lake by skimming it off the surface (*Figure 25*). This is an extremely effective tool and removes the plants and the associated nutrients from the lake permanently. However the process is expensive and short term in effect. We stated that green and blue green algae have a two-week life, thus the use of a harvester for ongoing algae control would prove cost prohibitive.

When a lake becomes eutrophic and a significant sludge/nutrient bed is established at the lake bottom, there may be no alternative but to dredge the lake. Dredges are large floating machines that must be transported across the golf course or site, where there is a risk of damage being done to the turf and greens

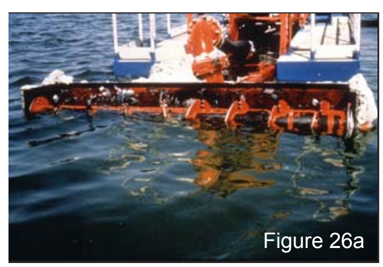
Figure 26a

The dredge employs a large auger type screw, much like a snow blower (*Figure 26a*). The screw is lowered into the water and begins to scrape up the sediment. These sediments will have a high degree of partially degraded, anoxic materials and it will prove quite odiferous. The debris material is then pumped to the shore where it must be removed from the site (*Figure 26b*), often the slurry or debris can contain heavy metals and is sometimes considered hazardous waste. The average machine can


Figure 26b

remove 3ft/1m depth of sludge material from a one acre lake\4,000m^2 in 40 hours. By removing sediments and plant material, a potential nutrient source is removed from the pond, not to mention mechanical control is expensive, labor intensive, and needs to be repeated often as plants grow back.

Chemical control is a widely used method of aquatic plant control, algaecides and herbicides are applied to the pond or lake to kill the algae and plants. The benefits of chemical control methods are that they are fairly quick and can be used to control stubborn problems or to eliminate specific types of unwanted plants. Most aquatic algaecides and herbicides are copper-based products and are available in liquid (*Figure 27a*) or granular form (*Figure 27b*). Liquid algaecides/ herbicides are used for plants throughout the entire water column, while granular forms are typically used to treat problems at the bottom.

Figure 27a

Figure 27b

Dosage levels are dependent on the alkalinity of a lake, particularly with copper based products. *Water chemistry should be tested before using any chemical.*

Chemicals may be applied by hand, however great care must be used to insure they are handled properly, in larger lakes they may be applied from a spray boat (*Figure 27c*). Many states and countries require that the applicator is licensed, as it is important to understand the desired dosage and proper application technique. Be sure to use EPA or government approved chemicals only. Many herbicides are copper based products that add heavy metals to the water table, if there is prolonged use of these chemicals there will be a toxic build up of copper in the lakes. It is essential that chemicals are only used in static lakes.

Manufacturers claim that herbicides kill a "broad range" of aquatic plants and some kill on contact. When "broad range" killers are introduced into the aquatic ecosystem beneficial plants that fix nitrogen and phosphorus may be killed with nuisance algae or weeds. Herbicides do not discriminate and beneficial bacteria and protozoa may be damaged in the process as well.


Figure 27c

There are other side effects, herbicides kill plants and algae that then sink to the pond bottom and begin to decompose creating the potential by-product of oxygen depletion, fish kills and aquatic odors. In addition, herbicides kill the beneficial bacteria which help to decompose nutrients. As these herbicides are released into the water, they accelerate oxygen consumption again creating an oxygen depletion or stress situation.

As stated earlier, it is important to hire a licensed applicator when using chemicals in a pond. Since these products are herbicides there is a risk to turf and land plants if the treated water is used to irrigate. Mechanical aeration used in conjunction with chemicals has been proven to reduce the amount of chemicals needed, moreover mechanical aeration and limited chemicals can offer a strong proactive approach with reactive measures used when necessary.

CLOSING SUMMARY

Water quality management is a science. A better understanding of the aquatic ecosystem and the causes and effects of the interrelated factors are critical to successfully manage any pond or lake. Every lake or pond is a unique ecosystem that requires the proper analysis and understanding. *NO* two lakes are the same and as such no one management program will provide the same results on two different lakes. The delicate balance between temperature, nutrients, and oxygen plays an important role in creating the management program for any lake or pond.

The fundamentals of designing great lake management programs on your properties are fairly straightforward. The first step is to identify the causes, not the symptoms of chronic lake management problems. Consider the essential factors; is your problem light, temperature, nutrient, or oxygen related? Most of the problems that lakes suffer from are a combination of all three of these factors.

Next, analyze the basin configuration. Do you have the necessary size, shape and depth to sustain a healthy ecosystem, as it's almost impossible to make up for a bad design.

After you have identified the chronic problem and the root causes, you are ready to craft a solution. Minimize light and heat issues with lake-dye and mixing. If you don't have the necessary depth it may be necessary to dredge. Nutrient related problems need to be addressed by minimizing the nutrients that runoff into the lake and by lowering nutrient levels in the lake. No fertilize zones, slow release fertilizers, swales, wetlands and buffer plants will help to reduce new loading in the lake. Aeration, bioaugmentation, and weed eating fish help lower nutrient levels in the lake itself.

Use proactive tools as your ongoing management program, reserving the reactive tools for when the lake goes into crisis. Harvesting, dredging, and chemicals are all effective but none of these are practical day-to-day solutions.

Use complimentary practices when designing your program. For instance there are cases where the use of aeration and lake-dye are able to completely solve algae problems in just six weeks. There is no single stand alone tool for lake management and a solution designed around controlling all of the essential factors will have the greatest degree of success.

Lake management is a continuum. The longer a proactive management program is in place the greater the benefit you will see. Biological solutions will garner results on a gradual, long-term basis.

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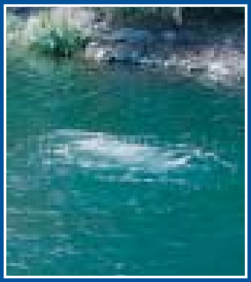

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