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Lakes A to Z Help Guide

Introduction and Legalities. Below is information on key words for lakes (in alphabetical order) with the purpose to give lay people a basic understanding of lakes based on Medora's experience.

Medora is grateful to the many researchers whose papers contributed to lake science, and is sorry that the nature of this document does not allow for individual credits to be given. Please let Medora know if you would like to see terms corrected, improved, or added.

Medora's lake knowledge is based partly on study, but also strongly on field work. Since 2002, Medora's US field crews have performed more actual lake water quality tests, on thousands of water bodies, with boats and instruments, than any other organization we know of in the world.

Medora's lake machines, SolarBee° (larger, spacing to 35 acres each) and Aeration Plus° (smaller, spacing to 5 acres each), are now successful in 450 lakes, storm water ponds, reuse ponds, and other fresh water bodies in the US and various other countries. These water bodies range in size from 1- 10,000 acres, with some machines deployed for full lake treatment and others for partial lake treatment. They include an estimated 200 raw water reservoirs that supply water treatment plants, some over 40 MGD. The mechanisms for this success are shown below at the term "circulation". Medora estimates that its experience and success rate is 15X higher than any other method of lake restoration worldwide, which is usually defined as the reduction or elimination of cyanobacteria blooms, aka blue-green algae blooms, harmful algae blooms, or HABs.

Because no two water bodies are the same, Medora's lake proposals speak to "the probability of success", which is usually high, instead of "absolute success". To reduce the financial risk to the owner of a lake restoration project, Medora offers rentals that can be converted to a purchase and, also, if a purchase is made initially, a full money-back guarantee less the rental cost had the machine(s) been rented before the purchase. More information about Medora's lake products can be found at www.medoraco.com, including many short white board videos.

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303(d) List of Impaired Lakes. Each US state is required by the US EPA to periodically assess all lakes in the state to determine which lakes are "impaired" in that they cannot be used for all the purposes they logically should be useable for. After the state puts a lake on its 303(d) list, the state then performs a Total Maximum Daily Load (TMDL) study for the lake to determine the cause and best correction for the impairment. The impairment is usually associated with repeated cyanobacteria blooms, aka blue-green algae blooms, though the specific language in the 303(d) listing and TMDL study may refer to turbidity, high pH, high chlorophyll *a*, excess phosphorous, and so on. Usually the TMDL study is aimed at reducing phosphorus and nitrogen flows into the lake, and recommends some type of corrective actions be taken in the watershed. But due to high costs, the difficulty of controlling nonpoint pollution, and the fact that watershed protection has virtually never worked to control algae blooms, corrective actions are hardly ever taken or, if they are, are not measurably successful. More information is at TMDL.

Actinomycetes. Cyanobacteria, aka blue-green algae, can emit toxins, taste and odor directly into the water. But in some lakes these contaminants are caused by actinomycetes bacteria that are digesting dead cyanobacteria. Actinomycetes are aerobic bacteria, and usually with circulation the other bacteria in a lake can outcompete the actinomycetes. In one of the first SolarBee lakes, in Colorado, the taste and odor problem from actinomycetes ended shortly after the SolarBees were installed.

Activated Carbon. Activated carbon is used in drinking water plants to take out taste, odor, toxins, colors, and other contaminants. It is often made from wood-based carbon, and looks like crumbled charcoal. The two main forms are granular activated carbon (GAC) and powdered activated carbon (PAC).

Aeration. An aeration system usually is designed for "hypolimnetic aeration". It has a compressor on shore, air pipes laid in deep water at the bottom of the lake, and air-bubble outlets (diffusers) mounted on the pipes. The goal is usually to keep the lake deep water oxic in order to prevent phosphorus from being released from the sediment (internal loading).

Aeration systems appear to have been tried in perhaps 50-100 lakes in the US the 1970s-1990's, but were hardly ever successful so the concept has been mostly abandoned.

Some of the problems are (a) the difficulty of getting the oxygen to spread out evenly across an uneven lake bottom, and (b) the rising air, which is 79% insoluble nitrogen and 21% soluble oxygen, can drag deep-water nitrogen and phosphorus to the surface, making cyanobacteria blooms worse, and (c) most of the phosphorus that fuels summer algae blooms comes into the top of the lake from runoff or from nightly lateral mixing or from phosphorus releases due to high pH from attached algae growth in the shallow water, so bottom nutrients are generally not the cause of summertime blooms anyway, and (d) there can be a high energy and repair cost, and noise disturbance, due to the compressor.

Aerobic. Water that contains dissolved oxygen (DO). If there is measurable DO, that means there is enough oxygen in the water to meet all chemical and biological needs of the water, and there is still some DO left.

Akinetes. Akinetes are spores, or "daughter cells", of active vegetative cyanobacteria cells. Akinetes are inactive until they germinate and become vegetative cyanobacteria cells. Cyanobacteria "parent" cells produce an akinete an estimated 10-20% of the time, which falls to the bottom sediment and usually survives over winter. Then, the next season something, nobody is sure what that is, causes a whole mass of akinetes to germinate all at about the same time and rise from the sediment and inoculate the upper water and bring about a cyanobacteria bloom that dominates the lake. In eutrophic lakes, akinetes can number several million per square meter. Medora's experience is that in lakes with a prior history of blooms of cyanobacteria that produce akinetes, about 30% of the time the lake can have a 1-2 week bloom, probably caused by akinetes, in the first or second season following the SolarBee deployment. After that one short bloom, the lake returns to good condition and remains so. More information is at spores.

Algae. Algae (the plural form of algal) are one-celled plants that do not have a central vascular system for respiration and nutrient flow. Usually algae are very small, microscopic size. However, some plants are much larger, such a sea lettuce, but are still algae because each cell can survive on its own and there is no central vascular system.

Various estimates indicate there are over 70,000 species of algae that inhabit fresh water. And most of these species have a “cousin”, with very similar characteristics, found in salt water marine systems such as oceans.

Most algae species in lakes can be found in both the water column and as periphytic (attached) algae growing on different substrates, including rocks, bottom sediments, and submersed aquatic plants. In the periphytic form, algae often grow in hair-like strands that can form dense mats.

Algae, like other plants, are autotrophs, meaning they use sunlight and "lifeless" dissolved chemicals to produce "life" through a process called photosynthesis. All other organisms, including bacteria, fish, birds, humans and everything in-between, are heterotrophs, and must eat plants, or else eat something that did eat plants, in order to have "life". Thus algae is at the base of the aquatic food web in lakes: lifeless nutrients >> living algae >> living zooplankton >> living fish.

During sunlight periods and photosynthesis, part of an algal cell takes in carbon dioxide and emits oxygen. But a different part of the algal cell respires like a human being, taking in oxygen and emitting carbon dioxide every minute of the day. On a sunny day, algae photosynthesis produces more oxygen than respiration uses up, so algae is a net producer of oxygen. But on a cloudy day with little photosynthesis, algae respiration can cause the lake to become so short on oxygen so that there are fish kills and even algae kills.

There are typically only about 20-30 species of algae present in a lake in a significant quantity at any one time, with 1-2 species being dominant depending on the length of daylight hours, water temperature, amount and kinds of nutrients, predators, and other factors.

Medora generally considers lake algae as falling into one of three categories as mentioned below.

1) “Good” green algae and diatoms. These algae are small-celled, usually under 100um, and are not visible to the naked eye. They just put a pleasing tint into the water, green from green algae in the summer and brown from diatoms in colder water in the spring and fall. These algae are planktonic, so they go where the water takes them. And instead of clumping together, they emit enzymes to hold themselves apart from each other.

   You can think of good green algae as having a soft cell wall like a pea, and diatoms as having a hard cell wall like a chicken egg.

   Because they are small, good algae and diatoms are readily eaten by filter-feeding daphnia and other zooplankton, as long as the water is over 10˚C so that the zooplankton are active. Because good algae and diatoms are constantly cropped down by zooplankton, they never form a standing "bloom" in natural summer conditions, and the lake retains high water clarity all summer, and stays aesthetically appealing for all uses.

Good algae and diatoms are at the bottom of a healthy food chain, where nutrients flow all the way up into big healthy fish: Lifeless nutrients > Algae > Zooplankton > Small fish > Piscivore fish

The primary competitive advantages of good green algae and diatoms, compared to cyanobacteria, are (a) they start earlier in the spring than cyanobacteria, and (b) due to their small size, they reproduce faster than cyanobacteria, and (c) if nothing happens to kill them off, they can use up all the nutrients so that cyanobacteria never gets traction in the lake. When good green algae and diatoms remain dominant all summer, they are constantly cropped down by zooplankton and the lake stays clear all summer. This is similar to a coral reef, where there are plenty of nutrients but they flowing up the good chain quickly so the water stays clear.

The primary disadvantage of good green algae and diatoms is that they are slightly heavier than water. The typical specific gravity is 1.03, so they are always sinking. If they sink down through the thermocline, they die due to lack of sunlight. In many lakes in the US, this happens to a significant portion of the good green algae and diatoms by mid-summer, giving cyanobacteria the opportunity to become dominant in the lake.

With SolarBees in the lake, the machines are set to pull in 3000 gallons per minute of water horizontally from just above the thermocline, in a 6-12 inch thick band that draws water from 35-40 acres in a 360° pattern around each machine. The good green algae and diatoms which were just about to sink through the thermocline are instead pulled into the SolarBee and lifted back up to the surface and spread out form there. Consequently they remain viable all summer, and use up the nutrients above the thermocline, and thus prevent cyanobacteria from ever getting traction. Wind mixing cannot re-suspend good green algae and diatoms the way SolarBees can; many of the successful SolarBee applications have been in lakes which have constant high winds, some 40 mph, but still had cyanobacteria problems anyway.

2) <u>"Bad" algae, cyanobacteria, often referred to as "blue green algae"</u>. Cyanobacteria, like other bacteria, has a slimy wall. And the chlorophyll in each cell is spread throughout the entire cell. This contrasts with a true algae cell which has a firmer wall, like a pea, and the chlorophyll is in sacks called chloroplasts.

   Medora's experience indicates that most of the harmful algae bloom (HAB) problems in US lakes are caused by only about 30 species of cyanobacteria.

   Cyanobacteria is found in many lakes and can destroy a lake's utility by producing potent toxins (cyanotoxins), taste, and odor in the lake water. The toxins can kill or harm humans that contact the lake water, and even harm humans that live several miles from the lake due to wind carrying the tips of waves into the region. Animals, especially cows and dogs, are killed each year by drinking water which contains cyanotoxins. There is also a concern that some toxins in lake water are getting through drinking water plants and slowly building up in humans that drink the water. The taste and odor are usually a musty or fishy smell due to "MIB" and "geosmin" produced by cyanobacteria, and can cause complaints by consumers to the water treatment plant, but the toxins present a more serious health problem.

When a lake has a cyanobacteria bloom, the toxins, taste and odor usually extend throughout the full depth of the water column, from the surface down to the sediment. This is probably because even though the cyanobacteria bloom "grew" in the upper water in order to receive sunlight, the dead cells are inedible by zooplankton and are constantly "raining down" from the upper water to the sediment. Consequently, if there are cyanobacteria blooms in the region of a water treatment plant intake there is often no benefit to a water treatment plant having multiple intake gates available at various elevations, because the water at all depths will likely contain the cyanobacteria contaminants. SolarBee machines usually have a fast payback in lakes with cyanobacteria blooms and water treatment plants due to reducing the amount of activated carbon that the plant needs.

If an algaecide is applied to a lake to stop a cyanobacteria bloom, the cyanobacteria cells may lyse (be destroyed and split apart) and release a flood of toxins, taste, and odor compounds into the water. Therefore algaecides should be used carefully and, preferably, before the bloom becomes large. See the topic "cyanobacteria management plan (CMP) " about a recent US EPA program to guide managers of public water systems on how to deal with cyanobacteria blooms.

Cyanobacteria tends to become dominant in a lake when there are high levels of nutrients, warm water, long daylight hours, and little effective mixing to re-suspend good green algae and diatoms to keep them from sinking out of the sunlight. In most lakes in the US, these conditions occur by or before early July. After cyanobacteria becomes dominant in the lake, it usually remains dominant until the fall turnover.

Various species of cyanobacteria can store nitrogen and phosphorus nutrients for later use, adjust their buoyancy downward to get nutrients off the lake bottom and then come up to the surface for sunlight, clump together for protection (forming harmful algae blooms, HABS) and to shade out and kill good algae, emit toxins and taste and odor to kill or ward off predators, form resting akinetes (spores) to lie on the lake bottom until the next year when by some signal they all come up to the surface to take over the lake, and, at a size of over 100um, they are too large for the average daphnia to eat them. They have other competitive advantages, too, as shown in the paper at the link at the end of this section.

Finally, cyanobacteria stops the flow of nutrients up the food chain into big healthy fish, and instead creates a problematic biochemical oxygen demand (BOD) load as they are slowly decomposed by bacteria at the bottom of the lake: Lifeless nutrients > Cyanobacteria > BOD load at the sediment of the lake. Often the cyanobacteria BOD load at the lake sediment causes the bottom anoxic zone of the lake to move faster and higher upward in stratified summer conditions, thus causing more problems with iron, manganese, phosphorus and sulfides. Therefore, the elimination of cyanobacteria blooms at the top of the lake will usually improve the bottom of the lake too.

3) Filamentous algae is usually “good” algae that was growing on the bottom and then pops up to the top, in May or June, due to trapped gas bubbles. Filamentous algae are generally good food for fish and ducks, and is harmless except for causing the lake to be rather unsightly for a week or two. The jar test (access at www.medoraco.com/jar-test) shows how to determine whether filamentous algae are “good” green algae or “bad” cyanobacteria.

Also see cyanobacteria, diatoms, filamentous algae, food chain, limiting nutrient, mechanisms, trophic state, and toxins. Also, search medoraco.com for "comparison" to see a more complete comparison of “good” green algae and diatoms versus “bad” cyanobacteria, and search for "jar" to see a quick and inexpensive jar test to determine which of these three types of algae your lake may has at any time.

Algaecides. A chemical used to kill algae. In some cases, the cyanobacteria (a.k.a blue-green algae) cells may lyse (be destroyed and split apart) and release a flood of toxins or taste and odor. See information at copper, herbicide, and peroxide.

Alkalinity. See carbonate alkalinity and pH.

Alternative stable states. There is a theory that says all lakes are either (a) algae dominated, or else (b) macrophyte (plant) dominated, and the lake can switch back and forth between the two, as simple as flipping a light switch, depending on changes caused by storms, nutrient loading, or other events. Medora's experience does not support this theory, because when SolarBees have been installed in lakes and the cyanobacteria blooms have cleared up, there have been the same or reduced macrophytes despite the improved water clarity. Also see macrophytes.

Alum, applied in lakes to reduce phosphorus. Alum is an aluminum-based liquid flocculent. It has been applied successfully for many years to meet wastewater phosphorus (P) discharge permit levels. Alum has also been applied to some lakes to flocculate and settle out dissolved phosphorus and phosphorus-containing organic material such as algae and bacteria. The theory is that the alum pulls the phosphorus out of the water and then, after the alum flocs settle onto the bottom sediment, they continue to bind onto the phosphorus to prevent it from getting into upper water where it could fuel cyanobacteria blooms.

During an alum application on a lake, the output of each individual spray nozzle must be constantly correlated to the boat speed and an accurate bathymetric map. Because when a nozzle is passing over 20 ft deep water at 3 mph it must apply far more alum than when it is passing over 5 ft of water at 2 mph. Also, a high dose of alum is lethal to fish. So, boat speed, water depth and fish health must all be accounted for at each nozzle during the alum application.

Alum was tested to reduce cyanobacteria blooms in over 100 lakes worldwide from 1970-2005, but generally failed to improve the lakes. However, since 2005 there has been a resurgence of using alum for lakes in the U.S. based on the possibility that in prior years there was just not enough alum applied. As more is learned about alum, though, it is still not considered a good solution for lake management, because:

1) Alum is effective to take phosphorus out of the water only on the day of application. It does nothing to remove future phosphorus that enters the top of the lake and fuels algae blooms from runoff, atmospheric deposition from wind and dust, septic tank infiltration, or other sources.

2) The temporarily-clear water following an alum application may allow macrophytes, water weeds, to become a worse nuisance than the prior cyanobacteria blooms.

3) Studies have indicated that the alum releases a significant portion of the phosphorus back into the water within months of the application, thus largely un-doing any attempt to stop “internal loading” of phosphorus.

4) When alum is applied only to the deep parts of the lake, it does not stop phosphorus release from shallow sediments caused by nightly lateral mixing, or shallow water phosphorus release caused by high pH from attached algae in the shallow photic zone, both of which can fuel cyanobacteria blooms.

5) Fish, such as carp and others, disturb the sediment and cause a phosphorus release. Even the wind can disturb the shallow sediment and cause more phosphorus release.

6) Alum is often sold as being a 5-10 year solution for cyanobacteria, aka blue-green algae, blooms, but many or most applications reduce blooms for only a few weeks to 1-2 years. So, a commitment to alum obligates the lake owner to spend $5,000 to $10,000 per acre for alum every few years into infinity, which is a staggering amount of money to have to come up with regularly.

7) Aluminum is toxic. There are very stringent limits for aluminum in drinking water. Most lake owners are uncomfortable with putting permanent toxins into their lake even one time, much less repeatedly into infinity, which will cause the bottom of the lake to become toxic to important benthic organisms. And if toxic sediment ever needs to be dredged and disposed of, the aluminum content will make the disposal a more costly problem.

Due to the problems of alum applications in lakes, some alum vendors “lower the bar” by defining "success” as “less phosphorus in the water column shortly after the alum application". But that approach basically ignores the reason alum was applied to the lake in the first place, which was to stop cyanobacteria blooms. A more correct measure of success would be the time it takes for cyanobacteria blooms to start re-occurring in the lake after the alum is applied. For most alum applications, the owner can expect "success" by this definition to last for only several weeks or months, or possibly a year or two. If the alum vendor is promising success for a longer period, five years for example, then the alum vendor should provide a performance bond where the lake owner gets a full refund if an algae bloom occurs before then.

More information is also at carp, flocculants, internal loading.

Alum, effect on reuse storage lakes when alum was used in the wastewater treatment plant. To reuse more wastewater for irrigation, some cities are pumping treated wastewater into lakes for storage. This practice can create ecology problems for the lake. A condensed description of the problem is that the typical 10 mg/l BOD load from the treated wastewater makes the hypolimnion even more anoxic than usual in the summer. Then the sulfate from the aluminum sulfate used at the wastewater plant forms sulfides, which become so prevalent that, after fall turnover, even algae cannot grow in the lake due to lack of dissolved oxygen (DO) for respiration at night. Consequently, the lake develops totally clear water because no algae will grow in it, and very strong odors, and it can remain that way for weeks or months. Medora has some experience in helping cities to avoid this type of problem.

Anearobic. Water in this condition has a high shortage of oxygen, it is "negative" in oxygen similar to the way a checking account at a bank can go negative when it is out of funds and then checks "bounce". The only biological activity in the water is bacterial anaerobic digestion by either (a) facultative bacteria that have switched from aerobic to anaerobic digestion, or (b) true anaerobes. More information is at aerobic, anoxic, dissolved oxygen, ORP, and oxygen.

Anoxic. Anoxic water has little or no measurable DO, and it is the mid-point between aerobic and anaerobic. After the thermocline sets up in a lake in the spring, the hypolimnion, the higher-density water below the thermocline, will usually not receive any new dissolved oxygen from wind mixing or algae growth until fall turnover. So, if a lake is 20 ft deep and a thermocline sets up at 6 ft deep by May 1, then the water between 6 ft deep and 20 ft deep will typically not receive any new oxygen until September 1 at fall turnover (exact months vary depending on latitude). So, all summer long the oxygen level in the deep water declines from about 9 mg/l, saturation, in the spring, toward 0 mg/l. The water at the very bottom sediment becomes anoxic first, due to bacteria at the sediment using up the oxygen, and this anoxic condition slowly works its way upward from the sediment all summer until fall turnover when the whole lake becomes wind-mixed and oxic again.

In lakes without a significant biochemical oxygen demand (BOD) load at the bottom, the summertime anoxic zone is just a thin layer of water at the bottom of the lake. In lakes with a larger BOD load, the anoxia can extend all with way up to the thermocline. Usually the anoxic zone will not go higher than the thermocline, because water above the thermocline gets oxygen continuously from both algae growth and wind mixing.

In anoxic conditions, the bottom sediments will release dissolved phosphorus (P), ammonia nitrogen (N), ferrous iron, manganese, and hydrogen sulfide. Also, mercury in the water will become methylated, meaning it can bio-accumulate in the food chain to very high concentrations. And if there are dead cyanobacteria cells at the bottom of the lake, as bacteria degrade them they can release toxins plus odorous MIB and geosmin into the water. Many of these substances can make problems for a drinking water treatment plant that is taking water from beneath the thermocline. SolarBee machines set for hypolimnetic aeration can usually keep dissolved oxygen high enough in the water going to the treatment plant to prevent these problems from occurring.

In anoxic conditions, the oxygen in the water has been depleted but there is not a huge un-met need for more oxygen at that water temperature. But if the temperature is warm enough, and enough time passes, the water can become anaerobic, very septic and odorous, with only anaerobic bacterial digestion occurring.

More information is at aerobic, anaerobic, dissolved oxygen, hypolimnion, ORP, and oxygen.

Autotroph. An autotroph, sometimes called a "primary producer", is an organism capable of creating "life" by synthesizing its own food from inorganic substances using light or chemical energy. Algae and other plants are technically photoautotrophs in that they use solar energy for converting inorganic matter/nutrients (e.g., carbon dioxide, nitrogen, phosphorus, oxygen, etc.) into living organic matter. Some bacteria are called chemoautotrophs in that they get their energy from chemical transformations.

Bacteria (other than cyanobacteria which are described elsewhere) . Most bacteria in water are planktonic, and are 0.2um to 30um in size, too small to be visible to the naked eye. Most bacteria are heterotrophs since they cannot create "life" from minerals and sunlight like a plant can. Instead they must find organic carbon-based material to eat in order to have life. In lakes and in the oceans, bacteria can be 1000 times as numerous as algae cells and number 15,000,000 bacteria per tablespoon.

In most lakes, bacteria are thought to be organic carbon (C) limited, compared to algae which is usually nitrogen (N), phosphorus (P), or sunlight limited. Bacteria compete with algae for dissolved N and P in the water, but bacteria actually help algae in the recycling of C in lakes as mentioned below.

Bacteria cooperate with algae to re-cycle C in the lake. C starts out as carbonic acid in the water, H_2CO_3, which is essentially a carbon dioxide (CO_2) molecule loosely attached to a water (H_2O) molecule. Algae needs CO_2 for photosynthesis, so it takes CO_2 molecules from the carbonic acid to make organic C for cell growth and repair, and ultimately exudes about 50% of that organic C into the water. Bacteria uptake this organic C and respire CO_2, which combines with water again to form H_2CO_3, and then the cycle repeats. Bacteria are likely the main pathway in lakes for the recycling of carbon in lakes.

There is a theory that when a drum of liquid bacteria or enzymes are added to a lake to control cyanobacteria, aka blue-green algae, the main reason the liquid may appear effective is because the base liquid, methanol for instance, becomes an organic C source for the existing bacteria in the lake. This C source then allows those bacteria to outcompete the algae for N and P. So the base liquid may be the most important part of the inoculation.

Though there is still some uncertainty whether bacteria in lakes (if they have enough C) can out-compete algae for N and P, in the ocean bacteria are generally considered to be the stronger competitor.

Bathymetric map. A bathymetric map is a contour map of the lake basin. These maps are essential for accurate lake volume estimates, and are the basis for charts created for municipal raw water storage reservoirs that show elevation versus acres versus volume of the lake.

Beach problems. Beaches are unsafe for swimming if the fecal count is high, because swimmers can experience dysentery, gastrointestinal illness, and swimmer's itch. A common criteria to close a beach is when fecal coliforms exceed an average of 200 colony forming units (CFU) per 100 ml of water in five tests in a 30 day period, or if a single test is over 1000 CFU per 100ml.

Fecal matter usually comes from ducks, geese, other animals, or humans (such as small children or babies) while swimming or if living on boats in the water.

Practices to reduce droppings from ducks and geese include short barrier fences around the beaches, flashing light deterrents near the beach, eliminating "raking" of the beach so that birds do not go onto the beach to find bugs to eat, and others.

It is unclear whether circulation of water adjacent to a beach, with a SolarBee machine or Aeration Plus machine, will eliminate beach closings caused by high fecal coliforms.

Benthic. Benthic means the lake bottom. Benthic organisms include clams, worms, crustaceans, and other creatures that utilize detritus that has settled on the lake bottom. Benthic creatures are vital to the lake ecology.

Bio-accumulation. This terms usually refers to the accumulation of a large weight of toxic substance in an organism caused by eating hundreds of smaller organisms which have that same substance in them. Also see mercury.

Biochemical Oxygen Demand (BOD). This is a measure of the "strength" of the organic contaminants in water.

There are thousands of different kinds of organic contaminants in water, far too many to test for each one individually. So, instead, the contaminants are all "lumped together", and the BOD is an approximation of the amount of dissolved oxygen (DO), in mg/l or ppm, that aerobic bacteria would require to digest about 65% of the organic material in question in about 5 days, and convert it into just water, carbon dioxide, and trace minerals.

The BOD term is usually used for wastewater, but it applies to lake water as well, in particular to the bacterial digestion of organic material such as dead algae and other detritus at the bottom of stratified lakes in the summertime. For perspective, most raw sewage has 200-250 mg/l of BOD, treated sewage has 5-30 mg/l of BOD depending on the type of system, and after the treated sewage is discharged into rivers and lakes, most lake water is 0-3 mg/l of BOD.

Bloom. A "bloom" usually refers to excessive algal growth.

In the spring and late fall, an algae bloom of any species can occur when the water temperature is below 10˚C (50˚F), because then the zooplankton are not active to constantly crop down good green algae and diatoms.

In summer months, most blooms are presumed to be dominated by cyanobacteria, aka blue-green algae, because cyanobacteria are generally too large to be kept cropped down by zooplankton. Cyanobacteria blooms of 200,000 to 2,000,000 cells/ml are not unusual. Often these are referred to as "harmful algae blooms" (HABs).

It is presumed by environmental regulators that cyanobacteria blooms produce toxins which can injure humans and pets. Many jurisdictions have adopted a modified version of the World Health Organizations guidelines for determining safety goals or lake-posting programs when scum forming cyanobacteria blooms are present in the summer:
Allergenic people: problem level is 20,000 cells/ml, or 10 ug/l or mg/M3 of chlorophyll-*a*
Common public goals: problem level is 30,000 cells/ml, or 15 ug/l or mg/M3 of chlorophyll-*a*
General Public: problem level is 100,000 cells/ml, or 50 ug/l or mg/M3 of chlorophyll-*a* .

More information is at algae and cyanotoxins.

Blue-green algae. This is the term formerly used for cyanobacteria. More information is at algae, diatoms, cyanobacteria, food chain, jar test, and toxins.

Boating. In addition to all the standard safety practices, boaters should:

1) Avoid cyanobacteria toxins. Know how to identify cyanobacteria, and always avoid areas with cyanobacteria blooms. More information is at cyanobacteria, toxins, and jar test.

2) Avoid spreading invasive species, both plants and animals. Learn the proper ways to de-contaminate boats and trailers. More information is at invasive species.

Bonding. There are various molecular bonding mechanisms that have a significant effect on lake science. The main ones are ionic bonding, hydrogen bonding, and static bonding.

Ionic bonds are where the molecule can be thought of as "breaking apart" into completely different substance when it is dissolved in water. A common example is table salt, NaCl, which ionizes into Na+1 and Cl-1 in water. So chlorine, which is very toxic, can be manufactured from table salt. Also, water itself ionizes, to a degree, into H+ and OH- ions, which affects pH. More information is at ions and ionic bonding.

Covalent bonds are not involved much in lake science. These bonds are usually too strong to be broken by water, and the material is insoluble. Covalent bonds are present in the methane molecule, CH4, for example.

Hydrogen bonding is a relatively weak bond between similar molecules based on a (+) or (-) atomic charge at the end of each molecule. Water molecules are connected by hydrogen bonding, so water molecules in a vessel or reservoir are all connected to a degree, like a string of taffy. More information is at hydrogen bonding.

Static bonding is a bond formed between two materials which does not involve any change in chemistry of the two materials, yet it affects how the materials act. An example is the manner in which phosphate, P04, attaches to soil or clay particles during rain runoff events. These bonds can be fairly strong, but the materials, phosphate and the soil, still have their own identity and are not changed by being bonded together.

Bottom-up theory. The theory that cyanobacteria can be controlled by limiting the nutrient flow, usually nitrogen (N) and phosphorus (P), into the lake. In other words, manipulate the food chain from the bottom side up, starting with nutrients. Invariably, these efforts fail when nonpoint source nutrients are the main source of nitrogen and phosphorus. More information is at algae, circulation, cyanobacteria, food chain, nonpoint source, point source, top-down theory, and watershed protection.

Carbon. Carbon (C) is the number one nutrient needed for life, and the other two major nutrients are nitrogen (N) and phosphorus (P).

Bacteria compete with algae in a lake for N and P. But bacteria cooperate with algae to re-cycle C in the lake. C starts out as carbonic acid in the water, H2CO3, which is essentially a carbon dioxide (CO2) molecule loosely attached to a water (H2O) molecule. Algae needs CO2 for photosynthesis, so it takes CO2 molecules from the carbonic acid to make organic C for cell growth and repair, and ultimately exudes about 50% of that organic C into the water. Bacteria uptake this organic C and respire CO2, which combines with water again to form H2CO3, and then the cycle repeats. Bacteria are likely the main pathway in lakes for the recycling of C in lakes.

More information is at algae, bacteria, food chain, limiting nutrient, nutrients, and Redfield ratio.

Carbonate alkalinity. Carbonate alkalinity, sometimes shortened to just "alkalinity", is important because it indicates how resistant the water is to pH changes. Carbonate alkalinity is measured in mg/l (same as ppm) and consists of carbonate, bicarbonate, H+ ions and OH- ions in the water. The main source of carbonate alkalinity in natural waters is the dissolution of limestone/calcite ($CaCO_3$) and magnesite ($MgCO_3$). Alkalinity is also affected by the amount of carbon dioxide (CO2) in the water.

Carbonate alkalinity gives an indication of how much acid the water can neutralize before the acid causes the pH to drop, referred to as the "buffering" capacity of the water. Due to buffering, when acid is added to natural water, some water forms a base to neutralize the acid. And when a base is added to the water, some water forms an acid to neutralize the base. These chemical reactions happen quickly and automatically in natural water.

Natural lake water usually has 40-200 mg/l of carbonate alkalinity. At the lower end of this alkalinity spectrum there are apt to be daily fluctuations of pH in the water since even a small amount of algae will use up the carbon dioxide (CO_2) and buffering by mid-afternoon, resulting in less carbonic acid in the water and a higher pH. Then, at night, algal respiration puts CO_2 back into the water, causing more carbonic acid which lowers the pH.

At the higher end of the lake alkalinity spectrum, and in the ocean which has over 500 mg/l of carbonate alkalinity, even a very strong algae crop will not use up the buffering or cause high daily fluctuations in pH.

Carbonate alkalinity can help diagnose lake problems: For example, if carbonate alkalinity is low, such as 50 mg/l, then an afternoon pH of 9.2 indicates a small algae crop and therefore, at worst, a low toxin concentration in the water. But if carbonate alkalinity is high, such as 180 mg/l, then an afternoon pH of 9.2 may indicate a severe algae bloom with possibly high concentrations of toxins in the water, a condition which should be addressed.

Carp, various species of interest. Sterile Triploid Grass Carp, a version of White Amur, have been stocked in some US lakes and ponds to control various macrophytes (water plants). The stocking rate has varied from 3 to 100 carp per acre, depending on climate, nutrient levels in the water, and project goals regarding how much vegetation to leave standing. The average life span of the carp is 15 years, so in some programs 1/3 of the carp are replaced every 5 years.

Silver Carp, which eat algae and cyanobacteria, are used in some countries to control algae blooms. They can grow to 100 lbs., and can eat their body weight in algae each day. Basically they short circuit the steps in the food chain where zooplankton eat algae and then many fish species eat the zooplankton, so eventually a lake with Silver Carp will probably have no other fish species.

Several invasive species of Silver Carp and Bighead Carp are now making their way up the Mississippi river system. These carp can become frightened by boats, and jump out of the water and hit a boater with the same force as a bowling ball, so they can be very dangerous. Efforts are being made to keep these carp from getting into the Great Lakes.

All carp, because they stir up sediment to find food, tend to re-suspend phosphorus and thwart the effects of applying flocculants such as alum to settle phosphorus.

Chain of lakes. A group of lakes close to each other, where the water flows from one to the other, for instance, from Lake A to Lake B to Lake C and so on. In those circumstances, methods to control cyanobacteria in a downstream lake will constantly by thwarted by the inflow of cyanobacteria from an upstream lake. So it is more effective to start lake restoration projects in the upstream lake.

Chlorophyll-*a* . Chlorophyll-*a* is a pigment that reflects green light, giving algae and higher plants a characteristic green color. It is the primary pigment found in all plants, including both green algae and cyanobacteria. So though it can give a good indication of total algal biomass, it cannot indicate whether the algae are good green algae versus harmful cyanobacteria. See phycocyanin for information on pigments found only in cyanobacteria, and "bloom" for typical limits set for chlorophyll-*a*.

Circulation. Circulation usually refers to Medora's SolarBee (large lakes, to 35 acre spacing) and Aeration Plus (small lakes, to 5 acre spacing) equipment that circulates just the upper water of the lake, the epilimnion, to defeat cyanobacteria, aka blue-green algae. There are four main mechanisms by which epilimnetic circulation reduces or eliminates the cyanobacteria:

1) Circulation helps the "little creatures" in the epilimnion, the algae and bacteria. It eliminates the problem of bacteria being limited by organic carbon, so that all three beneficial organisms, good green algae, diatoms, and bacteria can compete to use up the dissolved nitrogen (N) and phosphorus (P) in the epilimnion all season. Since good green algae and diatoms start early in the spring, circulation causes the epilimnion to stay "short" of N and P all summer so that cyanobacteria can never get enough N and P to gain traction. At the same time, the good green algae and diatoms are constantly kept cropped down by zooplankton, so there is never a "bloom" of these algae, and the lake stays clear all year.

2) Circulation takes away the buoyancy-adjusting advantage of cyanobacteria. It pulls in good green algae and diatoms that were about to fall through the thermocline and elevates them back into the sunlight at the top of the lake, and it also pops buoyant cyanobacteria up to the surface of the lake where most species are destroyed by sunlight.

3) Circulation aids the zooplankton. By helping the green algae and diatoms, the zooplankton numbers stay high, including the larger daphnia. Then, when other food is gone, the large daphnia will crop down cyanobacteria to some degree.

4) Circulation helps spread cyanophages, viruses of cyanobacteria, which kill 30% of cyanobacteria naturally even without circulation.

Wind mixing does not accomplish any of these 4 mechanisms, because with wind mixing all streamlines are parallel and very shallow, perhaps a foot or two deep, and the only effect is to pile water higher on the leeward side of the lake which then creates a "backflow" across the thermocline. Some of SolarBee's best successes have been in lakes that have rather-constant high winds of 40-60 mph.

In old lake improvement systems "circulation" sometimes referred to an attempt to control cyanobacteria by circulating water with a pump from the outlet end of a water body back to the inlet end. This method never worked to control cyanobacteria.

More information is at algae, bacteria, cyanobacteria, cyanophage, diatoms, epilimnion, and limiting nutrient.

Chlorinated lakes and ponds. Occasionally treated drinking water is chlorinated and then stored in outdoor lakes . And reuse wastewater is sometimes chlorinated and stored in lakes or ponds as well. If a chlorinated lake or pond develops an algae bloom, usually a SolarBee's circulation will not eliminate the bloom because there is no food chain to direct the nutrients into because there are no zooplankton or fish in the water. In these lakes, the only solution to an algae problem is to add more chlorine or else hydrogen peroxide, both of which will kill all algae. In that event, a SolarBee can be used to circulate the algae-killer more effectively. More information is at algae, food chain and nutrients.

Clean Water Act. In 1972 the US Congress passed the Clean Water Act in response to pollution in the nation's waterways. The goal was to restore and maintain the chemical, physical, and biological integrity of all US waters. The US EPA created rules to regulate point source pollution, but not nonpoint source pollution. More information is at point source and nonpoint source.

Clear period. The period in the spring, usually one to two weeks in May in most of the U.S., when the lake clarity is good as the lake transitions from cold water diatoms to warm water green algae.

Colonies. An aggregation of algal cells growing together as descendants of a single cell. Some colonial algal species are held together within a gelatinous matrix, while others can form chains. For example, microcystis (a cyanobacteria) are very tiny cells that look like green paint on the lake surface. Several types of diatoms, green algae, and blue-green algae can form colonies and chains.

Competition between organisms. Competition for nutrients or light is an important factor in lake ecology. More information is at limiting nutrient.

Concentration in water, English and Metric. Concentrations of a substance in water is usually given as ppm in the English system or mg/l in the Metric system. Below is conversion information to go from the English to the Metric system:

1 part per thousand = 1 ppt is the same as 1 gram per liter = 1 g/l
1 part per million = 1 ppm is the same as 1 milligram per liter = 1 mg/l
1 part per billion = 1 ppb is the same as 1 microgram per liter = 1 ug/l
1 part per trillion = 1 ppt is the same as 1 nanogram per liter = 1 ng/l

The above are weight ratios, not molar ratios. For example, 1 ppm means 1 lb. of solute per 1,000,000 lbs. of water.

Conductivity. A simple way to determine the salinity, or total dissolved solids (TDS), in water is to measure the electrical conductivity of the water using an electric meter compensated for water temperature. This works because water conductivity is affected by the amount of salts dissolved in water, it does not matter what kind of salts they are. To convert conductivity in microSiemens/cm, µS/cm, to total dissolved solids (TDS) in mg/l, multiply by 0.666.
Example 1: 600 microSiemens/cm, µS/cm, of conductivity x .666 = 400 mg/l of TDS.
Example 2 with larger electrical units: 3.2 milliSiemens/cm, mS/cm, of conductivity x (1000 µS/cm per milliSiemens/cm) x 0.666 = 2131 mg/l of TDS
More information is at total dissolved solids and salinity.

Convective mixing. Oten called free convective mixing or nightly convective mixing. See nightly convective mixing.

Copper. Copper is necessary for life, but too much copper is toxic to most organisms. Because copper is inexpensive and an effective toxin, various forms for copper-based herbicides have been used for many years to kill cyanobacteria, aka blue-green algae.

Unfortunately, copper also kills "good" algae and bacteria along with the cyanobacteria. Shortly after copper is applied, the water becomes full of nutrients from the decaying organic material, and usually another cyanobacteria bloom re-appears in several weeks to take advantage of the high nutrients.

A copper ion has a (+) charge that attaches directly to an algal cell, which has a (-) charge, which kills the algal cell or prevents it from reproducing. The (+) charge can also cause a copper ion to attach to a (-) carbonate ion in natural water, rendering that copper ion ineffective for killing algae. Therefore, herbicides have been developed that have "chelated", or coated copper ions, with the chelating material designed to prevent the ion from attaching to a carbonate, thus allowing it to kill an algae cell instead.

Many species of cyanobacteria adapt to copper, causing increasing amounts of copper to be needed for cyanobacteria control. At some point, the high dosage of copper may kill the fish in a lake, too, or may cause the bottom of the lake to become toxic, either of which can result in a ban on any further copper usage for that lake.

If copper is applied to control a cyanobacteria, aka blue-green algae, bloom, it may cause the cells to lyse (be destroyed and split apart), and release a flood of toxins or else taste and odor. So an early application when the bloom is small may be advantageous over a later application when the bloom is large.
See also algaecide, herbicides, and peroxide.

Cranberry bogs. Cranberries are grown in bogs or ponds which can be dry for part of the growing season but have sufficient water depth for harvesting in the fall. Cranberry bogs can develop insect problems which lead to repeated application of insecticides. If a cranberry bog area is converted into a recreational lake later, the lake may not have a complete food chain due to the insecticide residuals in the sediment which can kill zooplankton.

Cyanobacteria. Cyanobacteria are photosynthetic bacteria that, in the past, were commonly referred to as blue-green algae. See "algae" above for more information, specifically "bad" algae, and how cyanobacteria differ from "good" green algae and diatoms. Of perhaps 70,000 species of algae, less than 100 of them appear to be cyanobacteria which create numerous lake problems of toxicity, taste, and odor.

Cyanobacteria are among the oldest organisms on the planet, first appearing around 3.5 billion years ago, and most likely created, by photosynthesis, the 21% oxygen now found in our atmosphere. These organisms contain gas vesicles that enable them to regulate their buoyancy in water. They tend to rise near the surface early in the day to access sunlight, and can descend into deeper, more nutrient-rich waters at night. Some species contain toxins, called cyanotoxins, capable of causing skin irritations, liver damage, neural damage, and even death. Cyanobacteria blooms are most common in warm summer months. The three most common genera are Anabaena, Aphanizomenon and Microcystis (aka Anny, Fanny, and Mike). These algae also cause taste and odor problems in drinking water reservoirs.

Large daphnia can eat some cyanobacteria but it is not their preferred food. Consequently cyanobacteria are generally considered inedible, and are normally degraded through microbial decomposition at the bottom of the lake rather than enhancing the food chain. Upon death they release very noxious, putrid eye-watering odors.

More information is at algae, blue-green algae, cyanophage, cyanotoxins and daphnia. Also, search medoraco.com for "comparison" to see a more complete comparison of “good” green algae and diatoms versus “bad” cyanobacteria, and also search for "jar" to see a quick and inexpensive jar test to determine which of these three type of algae your lake may have at any one time.

Cyanobacteria Management Plan (CMP). In 2015, the US EPA produced a 59-page paper to help public water system managers deal with cyanobacteria and cyanotoxins. The paper recommends a Cyanobacteria Management Plan (CMP) be developed by cities that use surface water for drinking water plants, and gives guidance on when and how to issue a cyanotoxin Health Advisory. This paper can be found at medoraco.com, search for EPA.

Cyanophage. A virus is a piece of DNA attached to a protein, and is neither dead or alive until it finds a host and becomes activated. A phage is a virus that attacks bacteria. Putting this all together, a cyanophage is a virus that attacks a certain species of cyanobacteria.

Cyanophages and pathogenic bacteria are the only real natural enemies of cyanobacteria, other than the few instances where a daphnia is large enough to eat cyanobacteria.

Cyanophages do not attack cyanobacteria for food, as viruses are not technically alive, and can only infect when they meet during chance encounters. Instead cyanophages invade cyanobacteria for replication, using them as a source for materials to make new cyanophages. A cyanophage may attach to a cyanobacteria cell for a period of time before suddenly lysing (destroying and splitting apart) the cell, which results in the cyanophage being replicated. It is uncertain what causes a cyanophage to go into the mode of lysing the cyanobacteria cell.

An estimated 30% of all cyanobacteria in lakes are killed by cyanophages. Cyanophages are generally found in discrete isolated areas throughout the lake, so it is possible that one of the mechanisms which make SolarBees effective for controlling cyanobacteria is that the SolarBee mixing spreads the cyanophages better throughout the entire lake epilimnion.

More information is at cyanobacteria and circulation.

Cyanotoxins. Cyanotoxins are toxins produced by cyanobacteria. They are very potent; a small laboratory the size of a typical office could hold enough toxins to kill the entire US population. Cyanotoxins are similar to those found in molds and used to produce penicillin and various antibiotics.

Cyanotoxins can build up in a human liver, and cause skin problems and many auto-immune type diseases. Recently they have been linked, by several different research groups, to causing Alzheimer's disease. Diseases from cyanotoxins can occur after years of weak exposure, or immediately after one strong exposure.

It is estimated that there are over 100 different cyanotoxins. The main groups of cyanotoxins are hepatotoxins (affecting the liver), neurotoxins (affecting nervous system), and dermatoxins (affecting skin), and cylindrospermopsin. The US EPA is considering setting a Maximum Contaminant Level (MCL) for various cyanotoxins. More information is available at epa.gov.

It is unknown what causes cyanobacteria to turn on or off the production of toxins, and it cannot be accomplished in a lab either. But it is now thought that most cyanobacteria blooms do produce toxins at some point. And if the lake water is being used for drinking water, some toxins may get through the water treatment plant and accumulate in the bodies of consumers of the water.

Pathways to becoming ill from cyanotoxins include drinking or otherwise ingesting water which contains them, swimming in water which contains them, and, more recently, even living within several miles of a lake which contains cyanobacteria blooms; because in windy weather, the tips of waves are blown off and can carry cyanotoxins throughout the region.

Dams. Most rivers in the US have multiple dams that back up water into reservoirs. There are now over 80,000 dams in the US, and they supply an estimated 70% of Americans with drinking water. Key information affecting efforts to improve water quality in these reservoirs are:
- Uses of the reservoir.
- Typical surface elevation of the reservoir, and how much the surface elevation fluctuates.
- A bathymetric map of the reservoir.
- Whether the dam has a bottom outlet, and how much water goes out through the bottom of the dam versus over the top, as well as how much is pulled out for water treatment plants or other uses.
- The storage capacity at various elevations, both surface acres and acre-feet.
- The water treatment plant intake tower design, including the size and elevation of the various intake gates, and which gates are used.
- The location, acres and depth of the typical "deep hole" in front of the dam which was formed by the original river channel and/or from excavation of dirt to construct the dam.
- Whether the deep hole in front of the dam cuts through water layers or aquifers which contain dissolved iron or manganese in the water.
- The history, prior studies, water plant intake data, and any other information available about the historical water quality.

Often the bottom outlet of a dam, if there is one, is not usable due to being covered with sediment. But, if there is a usable bottom outlet, one technique to try to control algae blooms is a summertime release of anoxic bottom water which has phosphorus in it. The theory is that this phosphorous would have mixed throughout the lake water at fall turnover, and thus been available for algae blooms in the following season. But bottom releases to control future algae blooms have generally not been effective at preventing cyanobacteria blooms though, plus in many cases it results in the permanent loss of valuable water in the lake.

Daphnia. Daphnia are tiny fresh water nearly-transparent crustaceans shaped like a seahorse. They are a cladocera, which is one of the three main groups of zooplankton, and are very common in lakes and wastewater ponds. Daphnia are perhaps the most important zooplankton and are an essential link in the food chain as they eat algae and in turn are eaten by fish. They are generally active when the water is over 50˚F (10˚C). Each day, a single daphnia can filter and clean up water of about the same volume as a small office. Daphnia have nearly constant "diarrhea" and the fecal material is an important source of organic carbon for bacteria in the water. Most daphnia can open their mouth far enough to eat green algae and diatoms, but not far enough to eat cyanobacteria. Consequently their role in controlling cyanobacteria is not well understood, though it is likely that large daphnia can and will eat cyanobacteria when they run out of good green algae and diatoms to eat.

Density of water. Water density is a function of temperature, dissolved salts, and pressure. And when two volumes of water have different densities and are placed into the same container, such as a cup of salt water and a cup of fresh water, or else a cup of warm water and a cup of cold water, instead of mixing they form thin horizontal layers in the reservoir, with the most dense layers at the bottom and progressively less dense layers above. Virtually every reservoir, from a cup size to a large lake, has these thin stratified horizontal water layers caused by density differences.

Water is the most dense at 39˚F (4˚C), so both warmer and colder water are less dense than water at that temperature. Consequently 39˚F water, being the most dense, is at the bottom of a lake in the winter. This "warm water" at the bottom is essential to fish health, so in designing lake restoration systems in cold climates it is important not to disturb the very bottom water.

Dissolved salts also increase water density. In anoxic bottom waters, calcium, iron, manganese, and magnesium precipitates go back into solution, so bottom waters can have higher dissolved solid concentrations making them denser than oxygenated waters above. Medora's testing indicates that 10 mg/l difference in salinity can cause a measurable new water layer to form.

Pressure also affects density. Water that is 8 ft deep is about 0.1% denser than water 1 ft deep. That's why a SolarBee, when set at the thermocline at 8 ft deep for instance, can pull water from a 35-40 acre circle even though all of the epilimnion is at nearly the same temperature. In short, in epilimnetic deployments, the density difference caused by pressure is a large factor in how the SolarBee machines pull water in from so far away. More information is at circulation.

Dermatoxins. Toxins that affect the skin. More information is at cyanotoxins.

Detention Pond. A pond that temporarily slows down water from going into a receiving body. Shortly after the rain ends, the detention pond will be empty. A slightly different version is the "wet detention pond", which holds the water a little longer before allowing it into the receiving stream, sometimes for several days after the rain event. See stormwater for more detailed information.

Detritus. Detritus is particulate and dissolved non-living organic matter. The main source of detritus in a lake is through the decomposition of algae and aquatic macrophytes (weeds). Detritus is colonized by living algae, bacteria, fungi, and small animals such as rotifers, and is a vital part of the aquatic food web.

Diatoms. Diatoms are a beneficial microscopic cold water algae with a hard exoskeleton. These algae are typically brown, and impart a brown tint to lake water in the spring and fall. You can think of diatoms as having a wall like an eggshell, high in silica and calcium, compared to green algae as having a soft outer wall like a pea, and cyanobacteria as having a slimy outer wall like other bacteria.

Diatoms are huge phosphorus scavengers, and do best in full lake mixing in the fall and after ice-out in the spring, where they can go from top to bottom and get all the phosphorus they need. In the spring, after the thermocline forms, the deeper diatoms die from lack of sunlight, and those above the thermocline quickly use up all phosphorus in the epilimnion. And about that time the daphnia are waking up too, with water over 50˚F (10˚C), and the daphnia crop the remaining diatoms down. This results in the spring "clear period", where the lake clears up for a week or two as it transitions from cold water with diatoms to warmer water with green algae.

Diatom blooms can temporarily plug filters in drinking water plants during the spring. SolarBees cannot do much about this, the city has to just wait at bit for the water to warm up enough for daphnia to crop the diatoms down or until the thermocline forms and drives the daphnia to a phosphorus limitation.

SolarBee circulation has been shown, in a peer-reviewed paper written with Palmdale CA, to keep diatoms viable all season long instead of just in cold fall and spring weather.

Dead skeletons of prehistoric diatoms are mined in a few places in the US, and sold as "diatomaceous earth". Diatomaceous earth is often purchased in bags and smeared onto inline lake screens to form a filter cake which the water must pass through, creating a very effective one-step filtration system to turn lake water into clean water for drinking and showering at campgrounds, etc.

More information is at algae. Also, search medoraco.com for "comparison" to see a more complete comparison of “good” green algae and diatoms versus “bad” cyanobacteria.

Dinoflagellates. Dinoflagellates are a group of photosynthetic motile algae characterized by two flagella, like legs, that enable them to move in stagnant waters. The "dino" means they have an armor-like exoskeleton. Some dinoflagellates produce very strong toxins that can kill fish, particularly in estuarine and marine waters. For example, dinoflagellates are responsible for lethal “red tides”. Similar to cyanobacteria, dinoflagellate blooms are considered HABs (harmful algal blooms). Also, as with cyanobacteria, water turbulence and circulation by SolarBees can significantly inhibit their growth.

Dissolved oxygen (DO). The amount of oxygen dissolved in water, and available for biological use and chemical reactions.

Saturation refers to the maximum amount of DO water can hold. Both lower temperature and higher pressure result in higher DO saturation concentrations in water. Examples of the approximate saturation of DO in water at standard atmospheric conditions are: 50˚F (10˚C) >> 11 mg/l of DO, 68˚F (20˚C) >> 9.5 mg/l of DO, 86˚F (30˚C) >> 8 mg/l of DO.

If an attempt is made to raise the DO above saturation, with aeration for instance, the excess oxygen above saturation will just bubble out of the water. One exception, though, is that algae can produce and put DO into water at rates far higher than saturation. Medora's crews have seen DO in warm water approach 20 mg/l in water bodies with high algae growth.

There are many brands of instruments and meters that measure DO. However they only go down to "0", they do not go into negative numbers. If a DO meter reads "2 mg/l" of DO, all of the oxygen needed for biological use and chemical reactions in the water have been met, and there are still 2 mg/l of "excess" DO left. However, if a DO meter reads "0 mg/l", showing all of the DO has been depleted, there is no way of knowing just how "short" the DO was from meeting all of the biological and chemical needs of the water. In that case, an ORP meter can be used to determine how "short" the water is in DO from meeting all of the biological and chemical needs.

More information is at aerobic, anoxic, anaerobic, oxidation-reduction potential (ORP) meters, and oxygen.

Dredging. Dredging refers to removing excess sediment and muck from a lake. To dredge a lake, usually adjacent land must be purchased to deposit the muck onto, and a several-foot-tall dike is built all around the perimeter of the purchased land. Then a floating dredging machine works on the lake to pull up the muck and pump it to shore and over the dike onto the purchased land. The muck settles on the purchased land, and the water which carried the muck over is decanted back into the lake through a return pipe that goes through the dike. After the dredging is completed, the purchased land is then dried out so the muck and dike can be removed, and the land can be re-sold.

It can take many years to dredge a lake, and the cost can easily be tens of thousands of dollars per acre. Consequently, dredging is usually not feasible except for very small water bodies or very-high-value water channels.

Duck problems. Fecal material from ducks can make beaches unsafe. More information is at beach problems.

Duckweed. Duckweed is a small floating plant about the size of a grain of rice. It can cover a small pond, or a bay in a larger lake, and make the water surface look like a green carpet or lawn. Duckweed shades out and kills algae, and can cause a high biochemical oxygen demand (BOD) at the sediment when it dies off in the fall. At medoraco.com, search for "duckweed" to see a white paper about the problems it causes and ways to attempt to eradicate it.

Dye and tracer tests. SolarBee flow patterns in lakes and other reservoirs have been verified by various dye tests and other tracers. Rhodamine FWT Red 200 Liquid Dye is one that has been used, along with a GFL-1 fluorometer to measure the concentration of dye.

English to Metric, concentration conversions. See concentration.

Epilimnion. "Epi" means "upper", so the epilimnion is the upper portion of the lake above the thermocline. In most US lakes and other fresh water bodies the epilimnion extends from the surface to 4-8 feet deep, but in some large lakes it can extend much deeper.

Usually the epilimnion is mixed well enough by wind so that the water temperature, dissolved oxygen (DO), pH, and conductivity, from the surface down to the thermocline, are nearly the same at every test point in the lake. However, as mentioned above in "circulation", wind mixing does not have the characteristics needed to prevent cyanobacteria, aka blue-green algae, blooms.

Also, possibly due to less wind mixing in some areas, in some lakes there is a "stairstep" effect where these four parameters vary a little bit every foot or so from the surface down to the thermocline. But even in these lakes, the thermocline can usually be identified fairly easily by the large change in two or more of these parameters.

The epilimnion is usually the only part of the lake with enough sunlight for significant algae growth. In a healthy lake there is a repeating cycle in the epilimnion where the lake gets a little greener due to good green algae growth, then the daphnia crop the algae down and the lake becomes a little clearer, then the daphnia die off from lack of food, and then the algae comes back, and the cycle repeats every several days.

During these cycles, DO and pH vary like a gentle sine wave; DO may vary from just below saturation to just over saturation, for instance 8 to 10 mg/l. And pH swings, caused by algae uptake and respiration of carbon dioxide may rise just a bit from the background pH of the water as found in the hypolimnion. For instance, if the pH of deep water is 8.5, in a healthy epilimnion the pH may swing between 8.6 and 8.9 during the cycles caused by algae and daphnia.

However if the epilimnion becomes dominated by cyanobacteria, then these sine wave cycles stop. The DO may go to 11 mg/l or higher, and stay there until full turnover, and the pH may go to 9.3, for instance, and stay there until fall turnover.

After fall turnover there is no thermocline and the wind mixes the entire lake from top to bottom. So at every depth and every test location, the water is homogeneous regarding temperature, dissolved oxygen (DO), pH, and conductivity. However, on some fall days, heat from the sun can temporarily cause the lake to re-stratify with an epilimnion, but usually only during the day, and then at night the lake returns to full-depth mixing.

Eutrophication. Eutrophication refers to nutrient enrichment (eu = rich, trophic = food) of water bodies, primarily with nitrogen (N), phosphorus (P) and organic matter. Usually cyanobacteria blooms dominate eutrophic lakes by middle or late summer if steps are not taken to defeat cyanobacteria. Also see trophic status.

External loading. External loading usually refers to nutrients, primarily nitrogen (N) and phosphorus (P), that enter a lake through runoff, and become food for algae and cyanobacteria. If "good" algae get the nutrients, the nutrients flow up the food chain into larger fish, and cause no problems. If "bad" cyanobacteria get the nutrients, there will usually be a toxic harmful algae bloom (HAB) on the lake for the rest of the summer. Watershed protection measures are usually an attempt to minimize external non-point source loading, and are virtually never successful in controlling algae blooms. More information is at internal loading, nonpoint source, point source, and watershed protection.

Fecals. Fecal bacteria can make beaches unsafe. More information is at beach problems.

Fetch. Fetch refers to the distance on a body of water over which a given direction of wind can mix surface waters and build waves. Fetch on the ocean can be thousands of miles, while fetch on a small, forested lake may be less than a mile. Generally, the greater the fetch the deeper the depth of the summer thermocline. However, in most lakes and ponds the thermocline depth is not a function of fetch, instead it is a function of how far the sunlight can penetrate through the algae and other turbidity in the lake.

Filamentous algae. A long slender cell or series of attached cells. Filaments can be microscopic for some algae, but the term filamentous algae generally refers to macroscopic (large) mats of algae that can cause aesthetic and recreational impairment. These algae typically grow attached to the bottom organic substrate (i.e., muck), or on rocks in flowing waters. When gases, such a dissolved oxygen (DO) produced through photosynthesis, get trapped in the filaments, the buoyancy of the gas causes the algal mat to rise to the surface. This is common in shallow ponds and along near-shore areas in larger lakes.

Filamentous algae floating on the surface can look bad, but is not harmful and does provide good fish food. Usually the filamentous season only lasts a few weeks on each lake, in May or June.

More information is at algae, and also search medoraco.com for "jar" to see a quick and inexpensive jar test to determine whether filamentous algae is helpful green algae versus harmful cyanobacteria.

Fish Kills. A fish kill is when an abnormally high number of fish die within a few days.
Fish kills can occur in lakes in summer when there are cyanobacteria blooms, and the cyanobacteria respiration at night causes the dissolved oxygen (DO) to fall to less than 2-4 mg/l before morning. Also, a large algae die-off, from either an herbicide or a cloudy day, can cause bacterial decomposition where the bacteria drive the DO low enough to create a fish kill. A summer storm event can also cause a lake to mix unexpectedly, and if the volume of anoxic bottom water is relatively large compared to the oxic surface water volume, a fish kill can occur.

Fish kills can also occur at fall turnover in a eutrophic lake when the anoxic hypolimnion mixes throughout, and may drive the DO to less than 2-4 mg/l.

Fish kills occur in winter, too, usually in eutrophic ice-covered shallow lakes, due to low DO, or after ice-out if there is are spring turnovers due to wind or convective mixing before the thermocline sets up.

Fish farm ponds, and mosquito fish ponds. Fish farm ponds are stocked with thousands of fish that are growing each day, resulting in a biochemical oxygen demand (BOD) that changes daily. Therefore an aeration system must be sized for the highest demand that may possibly be needed but, for energy savings, operated as infrequently as possible while still maintaining the target DO in the water at all times. There is not a natural food chain is these ponds because the fish eat the zooplankton, so there are no zooplankton to eat good green algae. Therefore circulators, such as SolarBee machines, which help create good green algae which is then eaten by zooplankton, cannot eliminate algae blooms in these ponds.

In much of the world, mosquito fish are put into ponds as a common way to fight the spread of malaria. Mosquito fish, which are usually only 2-3 inches long, multiply very quickly and can soon number in the millions, even in very small ponds. Consequently, at some point the entire pond biology can crash when there is a massive die-off of mosquito fish caused by a lack of food in the pond.

Floating islands. Various man-made floating islands and other devices have been designed, with plants on them, and the plant roots extending down into the water. The goal is to have the plants absorb the nitrogen (N) and phosphorus (P) from the water in order to prevent cyanobacteria, aka blue-green algae, blooms. The area of the islands needed can range from 5-10% of the lake size.

If the floating islands have the plants removed and replaced once per year or more, the plant mass may remove enough nutrients from the water to result in less algae blooms. And SolarBee circulation has been used to vastly increase the nutrient uptake of the plants. But the initial expense of the floating islands, plus the expense of regularly removing the plants, usually make floating islands cost prohibitive.

If the plants are not removed regularly, most likely the islands will have just a one-time uptake of nutrients. Some islands have become so heavy with bacteria growth on the plant roots and islands that they have sunk to the bottom of the lake.

Floating plants. Usually this term applies to plants that are rooted to the lake bottom with leaves that float on the water surface. Examples are water lilies and water shield. More information is at free-floating plants and macrophytes.

Flocculants. Flocculants are chemicals or natural substances that promote the clumping together of smaller particles into larger particles. Often they are applied to lakes to drag phosphorus out of the water and to the bottom of the lake. Common flocculants for lakes are alum, chitosan, various bentonite and other clays, and one clay that contains lanthanum. More information is at alum and lanthanum flocculants.

Free Convective Mixing. See nightly convective mixing.

Free-Floating Plants. - These are plants that float on the water and are not attached to any substrate. Examples include the tiny duckweed and water meal, as well as much larger plants such as water hyacinth.

Food chain. The flow of nutrients upward into ever-larger organisms. Good algae are at the bottom of the food chain in a healthy lake. When good green algae and diatoms dominate in a lake, nutrients flow all the way up into big healthy fish: Lifeless nutrients, including the main ones carbon dioxide (CO2) and nitrogen (N) and phosphorus (P) >> Good Green Algae and Diatoms >> Zooplankton >> Small fish >> Piscivore fish

Cyanobacteria stops the flow of nutrients flow all the way up into big healthy fish, because zooplankton usually cannot keep cyanobacteria cropped down. So the food chain is shortened to: Lifeless nutrients >> Bad algae, aka cyanobacteria, aka blue-green algae. Often the cyanobacteria also produce toxins, taste, and odors in the water. Since nothing eats cyanobacteria, it dies and falls to the bottom of the lake. It is digested by bacteria there, which increases the biochemical oxygen demand (BOD) load at the bottom.

More information is at algae and cyanobacteria.

Gas vesicles. - Bladder-like buoyancy-conferring cavities found in cyanobacteria cells. Gas vesicles allow a cyanobacteria cell to better adjust its buoyancy and position in the water column. Generally, cells move upward towards the lake surface early in the day to better access sunlight and atmospheric carbon dioxide & nitrogen while blocking light to other algae below, and then move down into more nutrient-rich waters at night. In addition to using gas vesicles, some cyanobacteria add or throw off carbon ballast weight to adjust their buoyancy.

More information is at algae and cyanobacteria. Also, search medoraco.com for "comparison" to see a more complete comparison of “good” green algae and diatoms versus “bad” cyanobacteria.

Gas vacuoles. A stack of gas vesicles in a cyanobacteria cell.

Geese problems. Fecal material from geese can make beaches unsafe. More information is at beach problems.

Geosmin. A compound produced by cyanobacteria that gives water an “earthy” taste and odor. This is the same odor released from terrestrial garden soils when tilled. More information is at cyanobacteria and MIB.

HAB. A harmful algal bloom. Blooms of cyanobacteria , aka blue-green algae, are the usual cause of a HAB in freshwater systems. And toxic dinoflagellate blooms that cause lethal “red tides” are the usually cause of a HAB in marine coastal waters. HABs are stimulated by nutrient enrichment and characterize eutrophic waters. More information is at algae and cyanobacteria.

Headwaters. The upper tributaries of a river. Headwaters begin at the outer reaches of a watershed.

Herbicide. A chemical used to kill plants in the lake, usually algae or macrophytes (water weeds). It can be a contact herbicide, which needs to actually touch the plant to kill it, or else a systemic herbicide, which just needs to be in the water to kill the plant. More information is at algaecide, copper, and peroxide. Also, a duckweed white paper can be found at medoraco.com, search for "duckweed".

Hepatotoxins. Toxins that affect the liver. More information is at cyanotoxins.

Heterocysts. Specialized cells in some cyanobacteria where the fixation or incorporation of nitrogen gas (N2) into the algal cell takes place. The atmosphere on Earth is 79% N2 gas. And even though N2 gas is generally insoluble in water, the top few feet of a lake will contain some N2 gas due to wind mixing, and heterocysts can turn this N2 gas into the nitrogen nutrient required for cell growth.

Heterotroph. A heterotroph, sometime called a "secondary producer", is not capable of synthesizing its own food from non-living matter. These organisms must eat organic matter, either plants or something which ate plants, and which are either living or "freshly dead", in order to have life. All animals, including humans and most bacteria, are heterotrophs. Generally any organism that is not an autotroph is a heterotroph. More information is at autotroph.

Humic matter. Dark, organic material produced by the decomposition of terrestrial plant material such as wood, leaves, or other material. Dissolved humic substances can impart a yellow-brown color to the water, the same as putting a tea bag into a glass of water. Humic matter is part of natural organic matter (NOM) which contributes to formation of trihalomethanes (THMs), an undesirable disinfection byproduct (DBP) when lake water is chlorinated.

Hydrogen bonding. In a water molecule, H2O, the two hydrogen atoms are at one end, each with a (+1) atomic charge, (+2) total, and the oxygen is at the other end with a (-2) atomic charge. The result is that in any water body, the (+2) ends of the one water molecule, call it "A" are attracted to the (-2) end of several nearby water molecules, call them "B", "C", and "D". This attraction is called hydrogen bonding between water molecules, and causes water molecules to form clusters, and those clusters to be attracted to yet other clusters.

The effect is that adjacent water molecules are not totally "free", instead they are more like very soft taffy, all connected together. When you fill a glass of water at a kitchen sink, there is direct connection between the water in your glass and the water in the tank several miles away. Hydrogen bonding affects virtually all chemical properties of water.

Also, for evaporation to occur the hydrogen bonds needed to be broken, and for condensation to occur hydrogen bonds need to be formed. More information is at bonding.

Hydrogen peroxide. See peroxide.

Hydrogen sulfide. In anaerobic digestion at the bottom of a lake or pond, the sulfur ions from decomposition of organic material react with hydrogen ions in water: (S-2) + (H+1) > HS-1, a liquid with no smell. Then, (HS-1) + (H+1) > H2S, hydrogen sulfide, an odorous gas that smells like rotten eggs and which the nose can detect even at low levels to 25 ppb. The lower the pH, the more H+1 ions there are in the water and the easier this happens.

Also, if rising H2S gas bubbles pass through a layer of water that contains dissolved oxygen (DO), then the H2S is converted into sulfate, SO4, which has no odor, or else H2SO4, weak sulfuric acid. SolarBees have been used to create an oxygenated "odor cap" on smelly lakes or ponds, and stormwater ponds, by being set to circulate just the top 3 feet of the pond to keep DO in that layer, through both algae growth in the day and surface re-aeration at night, so that no sulfide odors can escape.

Most people refer to all sulfur-based smells as hydrogen sulfide, though many smells are actually other sulfur-based gases called mercaptans. Sulfur chemistry is extremely complex, and involved many kinds of mercaptans.

If a lake or pond has a high overload of organic material, the hydrogen sulfide at the bottom and rising upwards as a gas can absorb so much of the DO in the pond that algae will not have enough DO for respiration at night. Since algae cannot survive the nights, the pond will remain totally clear for days but have a strong odor.

More information is at alum's effect on re-use storage lakes, and at re-use storage lakes and ponds.

Hypolimnetic Aeration. Applying air to the hypolimnion, usually to raise the dissolved oxygen (DO) at the bottom of the lake in order to prevent phosphorus (P) from being released at the sediment. One problem is that air is 79% insoluble nitrogen N2 gas, so the nitrogen bubbles will rise to the surface, and may drag bottom chemicals, such as P, to the surface and actually cause algae blooms instead of prevent them. More information is at aeration, hypolimnetic oxygenation, and hypolimnion.

Hypolimnetic Oxygenation. Applying pure oxygen to the hypolimnion, usually to raise the dissolved oxygen (DO) at the bottom of the lake. This avoids the problem of using air only, where 79% is insoluble nitrogen N2 gas, creating bubbles that rise and may drag phosphorus (P) up to the surface. Pure oxygen is expensive, whether it is delivered and stored in large thick-wall vessels, like propane tanks, or whether it is generated on-site with an oxygen generator. Pure oxygen is also explosive. There have also been problems of distributing the oxygen so as to cover the entire bottom of the lake. Since most lakes are not level on the bottom, some parts get too much oxygen and other parts not enough. More information is at aeration, anoxic, hypolimnetic aeration, and hypolimnion.

Hypolimnion. The hypolimnion is the lower portion of the lake, from the thermocline to the lake bottom. In theory there is a metalimnion too, a middle zone between the epilimnion at the top and the hypolimnion at the bottom, but in the US the vast majority of lakes virtually never have a metalimnion, instead there is a thin thermocline between the epilimnion and the hypolimnion.

After the thermocline sets up in the spring, whole-lake wind mixing stops and, barring a major summer storm, the hypolimnion remains cool, dark, and stagnant until the fall turnover. Bacterial decay of organic matter on the sediments causes water at the sediment interface to become anoxic and have increased concentrations of phosphorus (P), ammonia nitrogen (N), ferrous iron, manganese, and hydrogen sulfide. The anoxic water at the bottom also methylates mercury, so that it bio-accumulates. By slow diffusion the anoxia can move up the water column and reach the thermocline in highly eutrophic lakes.
More information is at anoxic, epilimnion, and mercury.

Ice, and ice effects. Depending on latitude, winter ice on lakes in North America can become 0.5 inch to 60 inches thick. As air temperature plummets, the ice becomes thicker as the cold temperatures moves downward through the ice. Algae survive under the ice and produce dissolved oxygen (DO) under the ice, but sunlight is usually stopped early in the winter by snow, so then the algae dies.
The ice on some lakes melts slowly in the spring, with the first open water appearing near the shore. But on some large lakes in the Great Plains, due to accumulations of wind-blown dirt, the ice gets "heavy" and sinks to the bottom of the lake one day in the spring, and finishes melting there.

A significant problem in lake restoration is that in the spring the wind may blow a many-acre chunk of ice across the lake, dragging with it any lake-restoration machine which is trapped in the ice. Medora's SolarBees are made to handle these events with no damage to the machine or the anchoring system. When the ice finally melts, later in the spring, the machine and anchor can be towed back to their original position.

Internal Loading. Internal loading refers to nutrients, primarily phosphorous (P) and nitrogen (N), that are released from the sediment and "re-cycled" in the lake to become food for algae. If "good" algae get these nutrients, they flow up the food chain into larger fish, and cause no problems. If "bad" cyanobacteria get these nutrients, there will usually be a toxic harmful algae bloom (HAB) on the lake for the rest of the summer. When flocculants are applied to a lake, it is usually an attempt to minimize internal loading.

The two main nutrients of concern for cyanobacteria, aka blue-green algae, blooms are phosphorous (P) and nitrogen (N). Nitrogen can go through nitrification and denitrification, and eventually leave the lake as insoluble N2 nitrogen gas. More information is at nitrogen. But phosphorous may never leave the lake, and instead be used again and again in a repeating cycle that creates algae blooms.

If the lake has good green algae and diatoms all year, then the P cycle is: Phosphate PO4 dissolved in water >> uptake by algae >> zooplankton >> small fish >> piscivore fish . So a large portion of P is permanently tied up in larger fish, some of which are caught by fishermen and removed from the lake, and the large fish which die in the lake have P tied up with calcium in fish bones which take many years to decay and re-release the P. But a portion of the P, from detritus, still returns to the sediment. If it is not attached to, or covered up by, silt there, it can be re-released for later use by algae and bacteria.

If the lake has cyanobacteria blooms, after the bloom develops the P cycle is: Phosphate PO4 dissolved in water >> uptake by cyanobacteria >> nothing eats it so dead cells are decomposed by bacteria at the bottom of the lake >> large amounts of P are recycled within the lake.

More information is at external loading, flocculants, nitrogen and phosphorus.

Interstitial water. Water within the sediments at the bottom of the lake. It is usually high in nutrients from the decay of organic material that has fallen to the sediment.

Ion, ionic bonding. Ions are particles which, when they are dissolved in water, can be thought of as "breaking apart". For instance, table salt, sodium chloride, NaCl, can be thought of as breaking apart into Na+1 and Cl-1 when dissolved in water. That leaves the NA+1 or the CH-1 ions free to react with other chemical ions in the water. In actuality, if there was one cup of water and all the water was later evaporated out of the cup, every one of the NA+ 1 ions will have found a CL-1 ion and formed un-ionized dry table salt, which would seem impossible. This example shows that "breaking apart" is just a convention, a way to think about ions, it likely does not actually happen. More information is at bonding.

Iron. Iron makes up 15% of the Earth's crust, and iron in water is usually either ferrous (un-oxidized) or ferric (oxidized).

Ferrous (ends in "s", think of the word "sugar", and how is dissolves in water) iron is found in anoxic water, such as at the bottom of a stratified lake and in water wells. It is dissolved, clear, and cannot be strained out of the water with a paper filter (like a coffee filter) or sand filter. Ferrous iron at 0.3 mg/l or higher concentration will leave red stains when it finally contacts oxygen and oxidizes.

Ferric iron is oxidized iron and can be thought of as small red pebbles that can leave a red stain. Ferric iron can be filtered with a paper or sand filter. Most water treatment plants remove iron by oxidizing it from ferrous iron to ferric iron, and then filtering it out of the water. Also, ferric iron is sometimes found in the epilimnion of a lake attached to suspended clay particles.

All living organisms contain iron, so dead algae and cyanobacteria cells digested by bacteria at the bottom of the lake release iron. If the lake is in summer stratified conditions, which will have anoxic conditions at the sediment, the iron in the bottom water is ferrous iron, and it can cause problems if drawn into a water treatment plant. But if the lake has no thermocline and is in full-depth wind mixing mode, there will be oxygen from top to bottom, and all iron in the water will be ferric iron.

In lakes where there are both iron and manganese problems for a water treatment plant that is pulling in deep water, if oxygen in introduced in the deep water, through either nightly convective mixing or else hypolimnetic aeration or oxygenation, the iron will "grab" the oxygen first, so that all iron must be oxidized before any of the manganese will be oxidized.

More information is at anoxic, hypolimnetic aeration , hypolimnetic oxygenation, hypolimnion, manganese, and nightly convective mixing.

Invasive species. Species of plants or animals that are not native to a lake. Invasive species can be transported into the lake by flooding or runoff from other water bodies, or by boats, birds, humans, ship ballast water, and other ways. Common examples of invasive plants (macrophytes) are Eurasian watermilfoil, hydrilla, curly-leaf pondweed, and coontail. Common examples of invasive animals are zebra mussels, quagga mussels, and Silver Carp.

Medora has extensive protocols to prevent the spread of invasive species by its lake machines. Strategies include pressure washing, using 409 spray, and desiccation.

More information is at macrophytes and carp.

Jar test. There is a simple test to determine if algae in a lake is "good" green algae and diatoms versus "bad" cyanobacteria, aka blue-green algae (download this testing method at www.medoraco.com/jar-test). Basically, if a sample of water is put on your desk, the next day the good algae will be at the bottom of the jar and the cyanobacteria will be floating.

Lake and lake size. The term "lake" refers to a large body of water, either naturally-formed or manmade. There are no numerical limits, such as depth or area, that distinguish a lake from a pond.

Lake restoration projects. Most lake restoration projects take years to plan, get funding for, and carry out. Most have the goal to make the lake more safe, usable and attractive by reducing blooms of cyanobacteria, aka blue-green algae. Unfortunately, most lake restoration projects fail, and the lake owners will be addressing the same problems every few years into infinity. Consequently, lake owners would be well-advised to check at least 5 references of any consultants they use for their projects, and also get a performance warranty where the cost of the consultant and the entire project is refunded if it is unsuccessful in improving the lake for the quoted number of years. Finally, if machinery is involved the lake owner should consider renting the machines before purchasing them, with an option of apply some of the rent to the purchase price.

Lateral mixing. In a stratified lake in the summer, each day as the sun starts going down the shallow water around the edge of the lake, the littoral zone, cools off faster than the deep water, the pelagic zone. The cooling is caused by evaporation occurring at the surface, resulting in a heat loss which is not made up by sunlight. Every few minutes, for many hours from late afternoon through the night, the cool surface water plummets downward into the shallow sediment where it picks up dissolved phosphorus from interstitial water (water between dirt particles) and then continues flowing down the sloped sides of the lake toward the deep water. When this cool phosphorus-laden water reaches the point where the thermocline meets the sloped sidewalls, it spreads out across the lake at the top of the thermocline. This carries phosphorus throughout the lake which, by wind mixing, will become mixed throughout the epilimnion and can fuel cyanobacteria, aka blue-green algae, growth. An estimated 20% or more of the phosphorus loading in the lake epilimnion may be due to lateral mixing.

Lanthanum-based flocculants. Lanthanum-based flocculants are being applied to some lakes instead of alum. Medora has not had experience on whether it works better than alum, but has noticed that approvals in some jurisdictions have taken a number of years due to health concerns about lanthanum. Lake owners are advised to conduct research into lanthanum before going this route. More information is at flocculants and alum.

Legal matters, maritime law. Maritime law, which governs matters of the sea, also governs matters involving US navigable waters. If an "aid to ecology", such as a SolarBee machine, is placed in navigable water with permission of the governing authority for that region and water body, then the same protections are given as for an "aid to navigation", such as "No Wake" buoys and other safety and navigation buoys. And in maritime law, the buoy is never "at fault" if there is a collision with a boat.

SolarBees for lakes come equipped with buoy marker lights and other safety features. Hundreds of SolarBee machines have been placed in lakes, including lakes with heavy boat traffic, water skiing, fishing, swimming, and even air craft takeoffs and landings. Medora knows of only one accident on the water, a very minor one caused by a boater's negligence, and the boat owner covered the cost of the repairs for the city.

Limiting nutrient. With this concept, to control cyanobacteria, aka blue-green algae, in a lake you first determine which nutrient is in the shortest supply, and then you reduce that nutrient even more.

Algae needs sunlight to survive, and also the three main nutrients; carbon (C), nitrogen (N) and phosphorous (P), in an atomic ratio (Redfield ratio) of generally about 106 to 16 to 1, respectively. C, carbon dioxide for algae, is considered virtually unlimited in natural water. And many cyanobacteria have heterorcysts to "fix" atmospheric N found in the top few feet of water. So for cyanobacteria, P is often the limiting nutrient.

The Redfield ratio is an atomic ratio, but most water tests show mg/l, a weight ratio. The Redfield ratio based on mg/l for pure N and pure P becomes about 7 to 1. And the Redfield ratio based on mg/l for dissolved nitrate, NO3, and phosphate, PO4, the forms most often found dissolved in lake water, becomes about 10.4 to 1.

In the US, P is usually considered the limiting nutrient between the Appalachian Mountains and the Rocky Mountains, and N is usually considered the limiting nutrients on the East Coast, West Coast and in the oceans. In some lakes, though, it appears algae can be P limited one day, and N limiting the next, so general rules don't always apply.

Bioassays are often used to test for the limiting nutrient. Three bottles of lake water are obtained, and C is added to one bottle, N is added to one bottle, and P is added to one bottle. Then, the bottle which had the limiting nutrient added to it will become the greenest due to stronger algae growth.

Another way to determine the limiting nutrient for algae is to test the lake water during a bloom. The nutrient which is at or near 0 mg/l dissolved in the water is probably the "limiting" nutrient.

Limnology. Limnology is the study of biology, chemistry and physics of fresh water (not salt water) reservoirs, lakes and ponds.

Littoral Zone. The littoral zone is the shallow water around the edge of a lake that is above the thermocline, and where the sun penetrates all the way to the sediment. The littoral zone is strongly influenced by waves and wind mixing, and typically represents the most biologically productive area of a lake. Macrophytes, submerged water plants, often thrive in the littoral zone due to the abundance of nutrients and sunlight. More information is at pelagic zone and thermocline.

Lyse. To destroy an organic cell by lysis, which is the rupturing of the cell's outer membrane. When a cyanobacteria cell is lysed, whether from an algaecide or a cyanophage, the cell breaks into multiple pieces and can release toxins and taste or odor chemicals if they were in the cell.

Macrophytes. Macrophytes are aquatic plants that are large enough to see with the naked eye and, unlike algae, contain a vascular system for transporting nutrients and water throughout the plant. Aquatic macrophytes are grouped into three general categories:

1) Emergent aquatic plants, cattails for example, are rooted in the bottom sediments and protrude up above the water's surface.

2) Submersed aquatic plants, Eurasian watermilfoil for example, are rooted to the bottom and grow below the water's surface.

3) Floating-leaved aquatic plants have leaves that float on the water's surface and can be either rooted to the bottom, water lilies for example, or completely free floating, duckweed for example.

Native macrophytes are usually more-deeply rooted. Invasive macrophytes are typically lightly-rooted, and can spread rapidly through fragmentation, and in some cases will replace native macrophytes. Examples of aggressive invasive species include Eurasian watermilfoil, curly-leaf pondweed, and coontail.

Manganese. If water has iron in it, it often has manganese too. Like iron, manganese in anoxic water, such as at the bottom of a stratified lake and in water wells, is usually dissolved, clear, and cannot be strained out of the water with a paper or sand filter. Manganese at 0.01 mg/l or higher will leave black stains when it contacts oxygen and oxidizes.

Oxidized manganese can be thought of as small pebbles that can leave a black stain, and which can be filtered with a paper or sand filter. Most water treatment plants remove manganese by oxidizing it and then filtering it out of the water. But if there is too much manganese, the removal system may not be able to handle it.

Manganese seems to get into lakes and dams mostly from shallow groundwater. Especially if the dam has a deep hole in front of it where earth was excavated to build the dam.

In a lake which has no thermocline and is in full-depth wind mixing mode, there will be dissolved oxygen from top to bottom, and all manganese in the water will eventually be oxidized.

Manganese chemistry is perhaps the most difficult chemistry in the field of lakes and drinking water. For unknown reasons, it seems to take at least two hours for manganese to oxidize when the oxidizer is just dissolved oxygen (DO) in the water. So if manganese is getting into a water treatment plant from an aquifer directly in front of a dam, hypolimnetic aeration will usually not be enough to keep the un-oxidized manganese out of the water treatment plant. And if the water treatment plant inadvertently over-oxidizes the manganese, such as with ozone, later in the distribution system the manganese may go through a reduction which causes the distribution water pipe to develop a black coating.

In lakes where there are both manganese and iron problems for a water treatment plant that is pulling in deep water, if oxygen in introduced in the deep water, through either nightly convective mixing or else hypolimnetic aeration or oxygenation, the iron will "grab" the oxygen first, so that all iron must be oxidized before any of the manganese will be oxidized.

More information is at anoxic, hypolimnetic aeration , hypolimnetic oxygenation, hypolimnion, iron, and nightly convective mixing.

Maritime law. See legal matters.

Mechanisms. See circulation for mechanisms on how SolarBee circulators control cyanobacteria.

Mercury. Mercury is a potentially-toxic element found in most US lakes. It usually got into the lake through mining and other human activities.

In many regions the primary cause is atmospheric deposition onto the land by coal-burning power plants from the US and worldwide. Mercury is often found in nature with coal veins. So coal that is mined and burned in power plants has caused mercury to cover much of the US, more so prior to stringent power plant pollution rules than today. When it rains, stormwater runoff brings the mercury into rivers and lakes.

Mercury can be non-harmful in dissolved oxic forms, and tremendously toxic in anoxic methylated forms. Mercury is spread evenly throughout the water in the reservoir and normally, since most lake water is oxic, it passes through organisms without bio-accumulating. But when mercury is in anoxic water at the bottom of a stratified lake in the summer, it "methylates", and bio-accumulates in organisms as it goes up the food chain. So a fish can have 10,000 times more mercury per volume of tissue than the water has. Therefore in virtually every reservoir in the US, there are now recommended limits on how many fish should be eaten. The US Army Corp of Engineers believes mercury is one of the biggest health problems in US water.

Mercury methylation and mercury bioaccumulation occur at ORP of -200mv and lower. So if ORP is higher than -200mv at the bottom of a reservoir, the mercury will stay un-methylated in water and pass through organisms without accumulating in tissue. In short, a hypolimnetic aeration system that achieves ORP higher than -200mv is enough to prevent mercury problems, the ORP does not need to get all the way to +80 mv where it shows free dissolved oxygen (DO).

More information is at oxidation-reduction Potential (ORP), anoxic, and anaerobic.

Metalimnion. A deep thermally-stratified lake can be divided into three parts: a warmer mixed layer on top (epilimnion), a cold stagnant layer below (hypolimnion), and a transitional layer in the middle (metalimnion, see also thermocline). In the US, the vast majority of lakes don't have a metalimnion, instead they have a rather sharp thermocline between the epilimnion and the hypolimnion.

Metric to English, concentration conversions. See concentration.

MIB. MIB refers to methylisoboneol. MIB is a compound released by cyanobacteria and actinomycetes, the bacteria which digest cyanobacteria and fibrous wood products, that gives water a musty or fishy taste and odor. More information is at cyanobacteria and geosmin.

Midge fly. Midge flies are a non-biting nuisance insect that grows in aquatic environments. Sometimes called "blind mosquitos", they have been known to exit a lake in huge swarms, often covering large areas of nearby homes. Eggs are laid on the surface of the lake, but the eggs sink and the larvae grow at the anoxic sediment until they are ready to emerge from the water. Midges exist in much of the US, and on both the east and west coasts. SolarBees have had some successes in controlling midge flies, and more tests are pending.

Morphology. The shape and contours of a lake basin. Naturally-forming lakes have more rounded boundaries with the deepest waters often near the middle. In contrast, reservoirs formed by dam have an arm associated with each point of inflow, and the deepest part of the reservoir is in the original river channel at the dam.

Motile. Moving, or capable of moving. Most algae are not motile. But cyanobacteria, aka blue-green algae, can regulate their position in a stagnant water column through buoyancy changes using gas vesicles or else by adding or subtracting carbon ballast weight. And dinoflagellates use flagella, like arms, for a swimming-type movement .

Natural Organic Matter (NOM). NOM refers usually to the natural humic acid and fulvic acids in lake water which form trihalomethanes (THM) when chlorine is added to the water. THMs have been linked to cancer, and are regulated in most of the world. Using SolarBees in lakes to reduce cyanobacteria blooms has not consistently led to fewer THMs being formed in chlorinated water. Consequently Medora manufactures THM removal aeration systems for chlorinated water. NOM is part of the Total Organic Content, TOC, of the water. Also see humic matter.

Navigable Waters. Waters which the US government maintains control of for business or transportation. Most rivers and lakes in the US are considered to be navigable waters. Also see legal matters.

Neurotoxins. Toxins affecting the nerves or nervous system. The two main neurotoxins produced by some species of cyanobacteria are anatoxins and saxitoxins. More information is at cyanotoxins.

Nightly Convective Mixing, aka Free Convective Mixing. This is mixing, or more accurately water transport, caused by cooling of a thin surface layer of water at the top of a pond, lake, or ocean. The cooling can be from evaporation at the surface, or from a cold weather front moving through. The cool dense layer of surface water plummets downward to, and often past, the point of neutral buoyancy, and then spreads out there. It is not known how thick the layer of water is that plummets downward, but it is likely thinner than 0.1 inches. After the first layer plummets downward, the next layer cools off and it too plummets downward, and the process continues every several minutes all night long, in the case of nightly convective mixing, or until sunlight heats up the surface of the water.

Based on continuous data monitors in lakes in the US, it appears that in the summer a surface water layer plummets downward every 15 minutes, starting at about 4:00 p.m., when sunlight is too weak to make up the heat loss from evaporation, and this process continues all night until about 8:00 a.m. the next morning.

The surface layers that plummet downward are usually high in dissolved oxygen (DO), and have a higher pH than deep water. In lakes, the usual effect is that the plummeting surface water goes all the way to the bottom of the lake, and satisfies some of the sediment oxygen demand. In lakes with iron and manganese dissolved in anoxic bottom water in the summer, usually the nightly convective mixing will start reversing the problem and oxidizing these metals by the end of July, in the northern US, several weeks before full-lake turnover occurs.

Nightly convective mixing is how oxygen gets 400 ft deep into the ocean, and also why the water in Lake Baikal, the world's deepest lake at 5300 ft deep, has relatively all "new" water at the bottom, 20 year-old water, instead of having 600 year-old water at the bottom.

Nitrogen, and Nitrogen Cycle. Nitrogen, N, is needed by all life forms and is a component of protein found in every living cell.

When an organic cell dies, the protein is rapidly converted to ammonia N by ammonification bacteria. At a pH under 8.5, most of the N is in the form of dissolved NH_4 liquid ammonium ions, which cannot be stripped out of the water with mixing or aeration. At a pH over 9.3, most of the N is turned into insoluble NH_3 ammonia gas that is easily stripped out of water with mixing. At a pH in between 8.5 and 9.3, some of both species of N are present.

N which is dissolved NH_4 liquid ammonium ions, which is usually most of the N, can only be removed from the water by going through nitrification followed by de-nitrification.

This is a brief description of the nitrification process, also sometimes referred to as the "oxidation of ammonia": Aerobic nitrosomas bacteria, using dissolved oxygen (DO) for respiration and ammonia for food, oxidize ammonium ions to form nitrite (NO_2), which is then further oxidized by other bacteria to form nitrate (NO_3). This occurs if the temperature is favorable (8-20°C, 46-68°F), and if the pH is favorable (7.5 to 8.5 is best, ceases at 6.0), and if the DO level is favorable (0.5 - 2.5 ppm minimum concentration, about 4.6 lbs. of

DO is needed per lb. of nitrogen) and if the carbonate alkalinity is sufficiently high (nitrification uses up bicarbonates at 7:1 ratio, so it decreases alkalinity) and if there are no toxic chemical inhibitors present.

The de-nitrification process can be summarized as follows: Various anoxic (DO must be near 0) de-nitrifying bacteria, through respiration that occurs by pulling oxygen off of NO3 nitrate molecules, convert nitrate into strippable N2 nitrogen gas. These bacteria need a carbon based food, it can be biochemical oxygen demand (BOD) material in the pond or else an added carbon source such as methanol or other substances. The pH should be in the 7.5 to 8.5 range. The process prefers a temperature of 30° C or higher, and almost slows to a stop at 5°C. De-nitrification produces bicarbonates so it increases alkalinity, giving back to the water about 50% of the alkalinity which was used up during nitrification.

In lakes, most of the N in the water is in the form of nitrate, NO3, though some N is continually gassed off due to denitrification creating N2 or else higher pH creating more NH3.

This points out a big difference between nitrogen, N, and phosphorus, P in lakes, the two usual limiting nutrients for algse. P never turns into a gas that leaves the water, so P generally keeps increasing each year as more P comes into the lake. More information is at external loading, internal loading, and phosphorus.

Nonpoint source. A source of lake pollutants and algae nutrients that flows into the lake, but where there is no specific pipe which can be pointed to or regulated. Nonpoint sources include runoff from farm fields, pastures and forests, inflow from groundwater, and atmospheric deposition from blowing dust.
Most watershed protection projects are aimed at reducing nonpoint source nutrients to prevent cyanobacteria blooms in lakes, but virtually no watershed project has ever accomplished this goal. More information is at Clean Water Act, point source and watershed protection.

Nutrients. The major "building block" nutrients needed for building organic organisms are carbon (C), nitrogen (N), and phosphorus (P). Others nutrients needed in a significant quantity are sodium, iron, calcium, silica, magnesium, and many others. After that some trace minerals are also needed, such as zinc, selenium, silver, and many others.

For algae, observation of ocean plankton from about 1930-1960 lead to the "Redfield atomic ratio" for C:N:P to be generally about 106:16:1. For animals, Medora's experience indicates the C:N:P ratio is generally 60:10:1. For both plants and animals, these ratios can vary widely by species. But it is not surprising that plankton reflects the content of the ocean it lives in, or that animals, as heterotrophs that need to eat organic material, reflect the content of plants, which are autotrophs and at the bottom of the food chain.

More information is at limiting nutrient and Redfield ratio.

Oxidation-Reduction Potential (ORP) Meters. ORP meters are electronic devices with two electrodes that can measure how "short" the water is from having a positive dissolved oxygen (DO). They are needed because DO meters can only go to "0", they cannot produce a negative number. ORP measurements are made in millivolts (mv), and below is a rough interpretation.

+80 mv to +300 mv: There is free dissolved oxygen (DO) in the water. All oxic and aerobic activities can occur. Nitrification can occur if ORP is greater than +100 mv.

-80 mv to +80 mv: Nitrate, NO3, can serve as an electron acceptor or oxygen source for anoxic and anaerobic digestion. De-nitrification can occur. When sodium nitrate or calcium nitrate are added into a wastewater lagoon to stop odors, the goal is to raise the ORP to this level so the anaerobic bacteria get oxygen from the nitrate instead of the ORP being lower where the anaerobic bacteria get oxygen from sulfate, which cause sufide odors.

-400mv to -90mv: Sulfate, SO4, can serve as an electron acceptor or oxygen, for fermentative anaerobic digestion. Note that sulfate will form sulfides and strong odor at ORP -50mv and lower. Methane formation needs ORP of -200 mv to -350 mv.

ORP meters require extensive and frequent calibration, so they are not used as often as expected in most industries. Also, ORP is very important in evaluating mercury problems; mercury methylation and bioaccumulation occur at ORP of -200mv and lower.

More information is at dissolved oxygen, aerobic, anaerobic, and anoxic.

Oxic. Oxic describes water that contains dissolved oxygen (DO). More information is at aerobic and dissolved oxygen.

Oxygen. Oxygen is needed by most organisms for respiration. The Earth's atmosphere is comprised of about 21% oxygen and 79% nitrogen. Oxygen dissolved in lake water is called dissolved oxygen (DO), and lake water is usually considered saturated when DO is 7-12 mg/l (same as ppm) depending on water temperature and pressure. DO gets into the water from production by algae, during photosynthesis, or else by surface re-aeration from the atmosphere when the DO in the water is less than saturation. DO is used up in the water by respiration of bacteria, algae, zooplankton, fish, and other organisms in the water. More information is at aerobic and dissolved oxygen.

Pelagic zone. The deeper areas of the lake. Generally, where the water is deeper than the thermocline depth, which is usually 4-8 ft deep in most US lakes.

Partial lake treatment. When just part of the lake is treated, usually a high-value area instead of the entire lake. High-value areas are often areas in front of water treatment plants or homes, or else beaches and marinas.

SolarBee machines can be deployed for partial lake treatment of cyanobacteria blooms in front of a drinking water plant on a large lake, regardless of whether the water treatment plant intake is taking in shallow or deep water. Usually these machines have a fast payback due to carbon savings in the plant due to not having taste and odor issues in the water from cyanobacteria, aka blue-green algae, producing MIB and geosmin.

But SolarBee machines cannot be deployed to treat just part of the lake when the problem at a treatment plant is dissolved iron or manganese in the hypolimnion; in that application the entire lake hypolimnion must be treated.

Percolation ponds. Ponds that connect to underground aquifers. The aquifer can then be used to transport water from the percolation pond to a withdrawal point miles away from the pond. There are some large water systems in California where percolation ponds and aquifers are just as effective at transporting large volumes of water as tanks and pipelines would be.

Peroxide. Peroxide can be purchased as hydrogen peroxide, a liquid, H_2O_2, or as sodium percarbonate, powder or granules, $2Na_2CO_3 \cdot 3H_2O_2$. Both are strong oxidizers, and contain no metals, and can be used as algaecides.

Hydrogen peroxide is used in much of the world to kill algae on an emergency basis, because of its low-cost and short-term effectiveness. But in the US, hydrogen peroxide cannot be advertised or used as an algaecide because it is not registered under US EPA pesticide rules. And, so far, no company has been willing to pay the annual US EPA pesticide registration fee for a product which is no longer patentable.

Sodium percarbonate, though, is registered as a pesticide with the US EPA and is marketed under several different trade names in the US. Generally is it marketed as a product that is applied to the upper few feet of the lake to kill cyanobacteria, aka blue-green algae, and with the implication that it does not hurt "good" green algae and diatoms because they have thicker cell walls.

Medora's experience is that use of sodium percarbonate is not a good method to solve a cyanobacteria problem. It causes a flood of nutrients to be released due to killing all of the bacteria in the treated zone at the top of the lake, and may not kill the cyanobacteria near the bottom of the epilimnion, which will likely be mixed back into the upper water later. Usually a cyanobacteria bloom comes back soon after the application, causing continual and expensive re-applications to be needed. Nevertheless, in some lakes the future use of copper may have been banned by a higher authority, and at least sodium percarbonate can be applied without violating the copper ban.

Also see algaecide, copper, herbicide, and pesticide.

Pesticide. Generally, any chemical applied to kill plants or animals. In the US, pesticides are required to be registered with the US EPA. And when a pesticide is sold, the product has to include a label on how to apply it. More information is at copper, herbicide, and peroxide.

Periphyton. Algae that grow attached to substrates such as rocks, sediments, and macrophytes (water plants). Almost any algae in the water column can also become periphyton and attach to submerged surfaces.

Phage. A virus that attacks bacteria. More information is at cyanophage and virus.

pH. The pH of water is a measurement of how numerous the H^+ ions are compared to the OH^- ions. Water is usually thought of as being made up of just H_2O molecules, but in actuality H_2O molecules ionize somewhat into H^+ ions and OH^- ions. A pH of 0 to 6.9 indicates there are more H^+ ions than OH^- ions, and the water is acidic. A pH of 7 is neutral. A pH of 7.1 to 14 indicates there are more OH^- ions than H^+ ions, and the water is alkaline.

The scientific definition of pH is the negative logarithm of the hydrogen ion (H^+) concentration (or activity). Each one of the 14 increments on the pH scale represents a ten-fold change in hydrogen ion concentration. For example, lake water with a pH of 5.0 is ten times more acidic than lake water with a pH of 6.0.

When there is low carbonate alkalinity or "buffering" in a lake, carbon dioxide taken up by algae and aquatic plants during daytime photosynthesis, results in less carbonic acid, H2CO3, in the lake, so the pH goes up, and at night the algal respiration reverses the process and the pH goes down. More information is at carbonate alkalinity.

Photic Zone. – The photic zone in a lake extends from the surface downward to the depth where only 1% of surface light reaches, so 99% of surface light is absorbed down through this depth. This is the zone where algal and macrophyte photosynthesis can take place. The photic zone can be estimated at twice the Secchi depth, a measurement of clarity, and except in very clear, deep lakes, the photic zone usually ends at or slightly above the thermocline. More information is at Secchi depth and thermocline.

Phosphorus. Phosphorus (P) is one of the big three nutrients needed for all life. It is an essential component of adenosine triphosphate (ATP) which is found in all living cells and necessary to access energy stored in the cell. So it is also a component of most crops and lawn fertilizers, and is also found in all plants since they are at the bottom of the food chain. In lakes, P is often the limiting nutrient that determines the amount of algae or cyanobacteria, aka blue-green algae, growth. Lake water with a P concentration of more than 0.20 mg/l (0.20 ppm, 20 ug/l, 20 ppb) has enough P to fuel "bad" cyanobacteria blooms.

Dissolved P in lake water is usually in the form of orthophosphate, PO4, which can be tested for. Organic P, that which has already been assimilated into bacteria, algae, or other organic material, can be measured by testing for total P. If there is plenty of total P for blooms, but very little dissolved P, then P is likely the limiting nutrient in the lake.

P is constantly re-cycled within a lake, often referred to as "internal loading". The only way that P can leave a lake is by being in water that leaves the lake, for example by spring flooding over a dam, or by water going out through a dam outlet, or water used for irrigation or for a water treatment plant. So with the 80,000 dams in the US, and continued inflow from nonpoint runoff, often called "external loading", most US reservoirs have an abundance of P, and an estimated 50% of US lakes now have problems of excess cyanobacteria, aka blue-green algae, blooms.

Because P is essential for all life and there is no substitute, there has been a concern in recent years that there may be a shortage of P in 50-100 years for fertilizer for food crops. But hopefully methods will be developed in time so that P can be captured and reused from wastewater, lakes, and oceans.

More information is at alum, internal loading, external loading, nutrients and nitrogen.

Photo-oxidation. The break-down or oxidation of organic material by sunlight.

Photosynthesis. A biochemical process in algae, and other plants, that utilizes solar energy to convert "dead" carbon dioxide and other nutrients into "living" organic material for new cells and cell maintenance. It is remarkable that even with all of today's technologies, no laboratory can convert "dead" chemicals into "living" organic material the way plants can.

Photosynthetic organisms are called "primary producers", or autotrophs, because they produce organic matter from sunlight. In contrast are “secondary producers”, heterotrophs, which, to have life, must consume material produced by autotrophs. More information is at autotrophs and heterotrophs.

Phycocyanin. A blue-colored pigment found only in cyanobacteria, aka blue-green algae. It is used for collecting solar energy for photosynthesis. Since chlorophyll-*a* is a pigment found in both green algae and cyanobacteria, often the only way to determine whether cyanobacteria is present is to measure phycocyanin. More information is at chlorophyll-*a* and bloom.

Phytoplankton. Microscopic algae that live free floating in the water column.

Planktonic. Refers to free-floating organisms not capable of directed movement. Organisms such as green algae and diatoms, bacteria and viruses are not motile and move only where the water they are in carries them. Most planktonic organisms are heavier than water but have evolved shapes and other characteristics to reduce their sinking rates.

Point source. A source of lake pollutants and algae nutrients that flows into a river or lake from a specific pipe which can be pointed to and regulated, such as a municipal wastewater treatment facility effluent pipe. Point sources in the US are regulated by permits obtained at the state level in accordance with the USEPA National Pollution Discharge Elimination System (NPDES).

Point sources have been regulated to such a high degree that in most US watersheds it is the un-regulated nonpoint sources which contribute the vast majority of nutrients which cause cyanobactiera, aka blue-green algae, blooms in lakes. More information is at Clean Water Act and nonpoint source.

Red Tide. Red Tide usually refers to a harmful algae bloom in the ocean near a shore. Also see dinoflagellates.

Redfield ratio. The ratio of the main nutrients, carbon (C), nitrogen (N), and phosphorus (P) for algae. Observation of ocean plankton from about 1930-1960 lead to the "Redfield atomic ratio" for C:N:P to be generally about 106:16:1. The Redfield ratio is an atomic ratio, but most water tests show the concentration in mg/l, a weight ratio. The Redfield ratio based on mg/l for pure N and pure P becomes about 7 to 1. And the Redfield ratio based on mg/l for dissolved nitrate, NO3, and phosphate, PO4, the forms most often found dissolved in lake water, becomes about 10.4 to 1.

More information is at limiting nutrient and nutrients.

Reservoir. A term that usually applies to man-made bodies of water, such as those created by a dam or for storm water.

Retention Pond. A pond that keeps runoff water on the property and prevents it from traveling into a receiving body of water. The level may go up and down, but usually there is water in the pond. A slightly different version is the "dry retention pond", which does dry out several days after a rain event due to water leaving by ground infiltration or some other method. See stormwater for more detailed information.

Re-use, or reuse. Treated wastewater is being used throughout the country for irrigation, decorative ponds, greenhouses, and even drinking water in areas where it easier to clean up the wastewater than, for instance, desalinate nearby ocean water. Some estimates indicate about 15% of wastewater in the US was being reused by 2015, but that figure will probably double soon as process improvements are developed.

Medora has experience at controlling cyanobacteria, aka blue-green algae, blooms and odors in reuse ponds, golf course ponds, and storage tanks for reuse "purple pipe" systems.

Re-use storage lakes. To reuse more wastewater for irrigation, some cities are pumping treated wastewater into lakes for storage. This practice can create ecology problems for the lake. A condensed description of the problem is that the typical 10 mg/l BOD load from the treated wastewater makes the lake hypolimnion even more anoxic than usual in the summer. Then, if aluminum sulfate was used at the wastewater plant to remove phosphorus (P) from the wastewater, the sulfate can form sulfides in the lake which become so prevalent that, after fall turnover, even algae cannot grow in the lake due to lack of dissolved oxygen (DO) for respiration at night. Consequently the lake develops totally clear water because no algae will grow in it, and very strong odors, and it can remain that way for weeks or months. Medora has some experience in helping cities to avoid this type of problem. More information is at alum used in reuse lakes, and at hydrogen sulfide.

Rotenone. Rotenone is a poison that is applied to lakes to kill all the fish. It is used when some species, usually trash fish or an invasive species, becomes too numerous and upsets the natural flow of nutrients up the food chain. Rotenone can be used as a "top down" method of controlling cyanobacteria, aka blue-green algae, by using it to eliminate an overpopulation of small fish which tend to eat the zooplankton which would otherwise have eaten algae and some cyanobacteria. More information is at top-down theory.

Salinity. A measure of the amount of salts in a solution. Salinity is usually measured by electric conductivity of the water in microSiemens per centimeter, µS/cm, with temperature compensation. But in very salty water the measurement is made in milliSiemens per centimeter, mS/cm, a unit which is 1000 times larger. For a close estimate in converting conductivity to Total Dissolved Solids in mg/l, TDS, multiply the µS/cm x 0.666.

> Example 1. Conductivity is measured at 600 µS/cm. Then 600 µS/cm x 0.666 = 400 mg/l of total dissolved solids (TDS). Also, 400 mg/l = 400 ppm, so there are 400 lbs. of various salts in every 1,000,000 lbs. of water.
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> Example 2. Conductivity is measured at 20 mS/cm. The "m" means milli, and a milliSiemens is 1000 times larger than a microSiemens. So 20 mS/cm x 1000 = 20,000 µS/cm . Then 20,000 µS/cm x 0.666 = 13,300 mg/l of total dissolve solids (TDS). Also, 13,300 mg/l = 13,300 ppm, so there are 13,300 lbs. of salt in every 1,000,000 lbs. of water.

The conductivity of ocean seawater in most places is about 51,000 µS/cm, or 51 mS/cm. So the total dissolved solids, TDS, is about 34,000 mg/l, 34,000 ppm, and 34 ppt.

More information can be found at conductivity.

Scum. The froth or other organic matter floating on a pond or lake surface. This can consist of filamentous algae, cyanobacteria, or organic compounds such as lipids (fats and oils) or protein (often from BOD reducing bacteria).

Seiche. A "rocking" thermocline. When sustained winds push waters to one end of a stratified lake, the result can be a tilting of the thermocline due to more water piled up on that end. When the winds stop, the water levels out, causing a "rocking" thermocline known as a seiche. The rocking motion causes small waves, so sometimes a seiche is also referred to as an internal wave.

Secchi Depth. Secchi depth is a measurement of water clarity derived at by using a Secchi disc.

The Secchi disc was invented by Pietro Angelo Secchi (science advisor to the Pope in the late 1800s). It is usually an 8-inch (20 cm) flat round plate, with alternating black and white quadrants, and a rope at the center to lower it into the water, usually from the shady side of a boat. The Secchi depth is the water depth at which the disc is no longer visible.

The Secchi disc is the oldest and arguably the most useful limnological tool, because water clarity gives a good indication of whether algae growth, pH, and dissolved oxygen (DO) are all in the normal range.

Sunlight penetration is about 15% at the Secchi depth, and 1% at 2X the Secchi depth. Usually the thermocline is at 2X the Secchi depth, and there is too little sunlight for algae growth beneath that depth. So if Secchi depth is 4 ft deep, then usually the thermocline is at 8 ft deep and all algae growth is occurring at 0-8 ft deep.

Sound, Sonic, and Ultrasonic Machines. Sound, sonic and ultrasonic machines have been devised to control cyanobacteria, aka blue-green algae, blooms over large areas. In the early 2000's, Medora tested several of these machines in ponds and tanks to kill cyanobacteria, but none of the tests showed any impact. Sound wave machines may have been improved since then, but Medora hears very few success stories involving sound waves. Medora's advice to prospective purchasers would be to check references first and, if references are OK, then rent these machines to try them out before buying them.

Spores. Some troublesome bacteria, cyanobacteria included, can be in a vegetative state which is active and can be killed, or it can be in a resting spore state, where the cell is inactive and resistant to most attempts to kill it. Spores of cyanobacteria are called akinetes, and rest at the bottom of the lake until they become vegetative and active. More information is at akinetes.

Stormwater ponds. These are ponds constructed to minimize the negative effects of storm water runoff by lessening the nitrogen (N), phosphorus (P), sediment, oil, heavy metals, and other debris that runs into the receiving stream, lake or ocean.

Usually stormwater ponds are designed to slow down the flow of water enough to allow the suspended sediment, and the N and P attached to it, to settle out in the pond instead of flowing through the pond and into the receiving stream. Most stormwater ponds are designed to hold 20 years worth of sedimentation before they need dredging.

A "detention pond" usually refers to a pond that slows down the runoff and delays the entry of the water into the receiving body. Shortly after the rain ends, the detention pond will be empty. A slightly different version is the "wet detention pond", which holds the water a little longer before allowing it into the receiving stream, sometimes for several days after the rain event.

A "retention pond" usually refers to a pond that holds water all the time, and is designed to prevent runoff from ever leaving the premises. The level may go up and down, but usually there is water in the pond. A slightly different version is the "dry retention pond", which does dry out several days after a rain event due to water leaving by ground infiltration or some other method.

Stratification. The presence of thin horizontal homogenous-density water layers in all water bodies, whether it is a bucket of water or a large lake. The most-dense thin layers are at the bottom of the water body, with progressively less-dense layers stacked above, all the way to the surface of the water body. The density difference between any two layers can be due to either water temperature, salinity, or water pressure caused by water layers above the layer in question. Due to hydrogen bonding between water molecules, it requires less energy in nature to "stack the water layers horizontally" based on density differences than to mix the water to become all the same density. Stratification always inhibits wind and other types of mixing.

Thermal stratification, as referred to in the lake industry, usually refers to summer-time conditions when water near the surface is warmed up by the sun, and the wind can only mix the "less-dense" epilimnetic water that extends from the surface of the lake down to the thermocline.

More information is at density of water.

Thermocline. The traditional definition of a thermocline is the depth, in stratified summer conditions, where the water has a 1°C decline in temperature within a 1 meter change of depth.

Thermoclines can be persistent or temporary. A persistent thermocline is one that sets up during the spring, establishes a stable epilimnion, and lasts until fall turnover. Usually the thermocline depth does not change from the first day it is detected, for instance May 15 in the northern US, all the way through summer and up through fall turnover. During hot windless days of summer, however, temporary weaker thermoclines lasting a day to several weeks can set up at depths above the persistent thermocline, creating a temporary stair-step thermal profile in the epilimnion. Also, after fall turnover, which usually occurs from Aug 20 to Nov 20 in the US, there can be temporary thermoclines set up during the day, on warm days, which then disappear with nightly convective mixing.

For cyanobacteria, aka blue-green algae, control, SolarBee machines are set to circulate horizontally just the epilimnion (upper) water of the lake, from the surface down to the thermocline, because that's the only water which receives enough sunlight for photosynthesis.

For Medora's purposes in deploying SolarBee machines, the "thermocline" is the depth of the "first significant stratification", where it appears the wind is not mixing below this depth based on testing the water temperature, dissolved oxygen (DO), pH, and conductivity.

More information is at circulation, epilimnion, and hypolimnion.

Top-down theory. The theory that cyanobacteria, aka blue-green algae, can be controlled by controlling organisms that are higher up the food chain than cyanobacteria. For instance, if cyanobacteria blooms are considered as being caused by a lack of zooplankton because there are too many fish in the lake eating the zooplankton, then a top-down approach might be to use rotenone to kill all of the fish in the lake.

Total Dissolved Solids (TDS). The concentration of dissolved minerals or salts in the water. TDS includes inorganic minerals such as calcium, manganese, sodium and potassium, and others, and well as dissolved organic matter. Conceptually, TDS is the residue left inside a container of water after complete evaporation, and is usually measured in mg/l, the same as ppm, which is a weight ratio of the minerals to the water.

TDS is usually measured by conductivity of the water, see conductivity for a conversion factor from conductivity to TDS. Also see salinity.

The TDS of mountain snowmelt lakes is often low, 50-100 mg/l, because fewer mineral are dissolved out of mountain rocks. The TDS of plains-area lakes is usually higher, often 200-400 mg/l. The TDS of water wells, because the water has been dissolving the aquifer rocks for thousands of years, usually ranges from 300 mg/l to 3000 mg/l.

Total Maximum Daily Load (TMDL) studies. A US regulatory term in the Clean Water Act. A TMDL study must eventually be completed for each impaired lake on the 303(d) list for each US state. The TMDL study should identify the maximum amount of pollution that the watershed should be limited to in order for the lake impairments to be reversed. TMDL studies consider both point source pollution, which can lead to tighter discharge permit requirements for cities, and nonpoint source pollution, which is nonregulated and beyond the scope of the Clean Water Act. In practice, most lake impairments are caused by nonpoint pollution, such as general runoff from land, and TMDL studies are ineffective at reversing lake impairments.

More information is at 303(d) list of impaired lakes, Clean Water Act, nonpoint source pollution, and point source pollution.

Toxins, toxicity testing. Toxicity testing in lakes usually refers to the measurement of cyanotoxins in the water. More information is at cyanotoxins.

Another form of toxicity testing determines the tolerance of organisms to specific toxins. The latter tests are called toxic bioassays. Results are given as the lethal dose or lethal concentration that kills 50% of the organisms over a given period of time, and expressed as LD_{50} and LC_{50}, respectively.

Toxicity testing in lakes is different than toxicity testing in wastewater, where minnows are used to check the levels of unionized ammonia, NH3 gas, in the wastewater effluent.

More information is at cyanotoxins.

Trophic Status. The trophic status usually refers to the level of algal nutrients, primarily nitrogen (N) and phosphorus (P), and organic production in an aquatic system. Lake water quality can be described by its trophic status:

> **Oligotrophic** (low food availability) lakes are more often found in mountain areas or lakes with very little nutrient inputs. These lakes are clear and blue with low algal productivity, and with Secchi depth visibility > 8 m (25 ft). Since there is little algae, there is not much of a food chain and so fish need to be stocked in these lakes.
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> **Mesotrophic** (moderate food availability) lakes have sufficient algal productivity to support lake fisheries, and have Secchi depths 2-4 m (6-12 ft)
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> **Eutrophic** (high food availability) lakes have large external nutrient inputs, and are characterized by excessive algae (primarily cyanobacteria) and aquatic weed growth. Fisheries are not as good, as cyanobacteria are not edible and their decomposition can deplete bottom waters of dissolved oxygen. Secchi depths in eutrophic lakes range 1-2 m (3-6 ft) and less than 1 m (3 ft) in hypereutrophic lakes. These lakes often have noxious odors associated with the presence and decomposition of cyanobacteria blooms.

Turbidity. Cloudiness in water caused by particulate matter suspended in the water that decreases water clarity and can affect beneficial uses. Turbidity is either inorganic, such as clay particles, or organic, such as algae cells.

Turbidity is measured in nephelometric turbidity units (NTU). EPA standards for drinking water state that at no time can turbidity (cloudiness of water) go above 5 NTU. And drinking water systems that filter must ensure that the turbidity goes no higher than 1 NTU (0.5 NTU for conventional or direct filtration) in at least 95% of the daily samples for any two consecutive months

Turnover. An event that causes a lake to mix from top to bottom. Lakes are thermally stratified during hot summer months, with warm water on top, then a thermocline, and then colder water below. Turnover in US lakes usually happens between August 15 and November 15, depending on latitude. As seasonal sunlight declines and nighttime air get cooler, evaporative and radiant heat losses from the lake are not replaced by the sun. Consequently the surface water becomes cooler and denser than the deeper water, making the water column "top heavy", similar to trying to stand a pencil up on its point, and so the lake "flips over" and mixes from top to bottom. There is no thermocline following turnover, and the wind mixes the entire water column so that most parameters such as dissolved oxygen (DO), pH, Fe, Mn, conductivity, and others become equal at every location and depth in the lake.

In lakes that do not freeze, the turnover conditions of wind-driven whole-lake mixing continues through the fall and winter until thermal stratification sets up again in late spring. For lakes that do freeze, ice stops the continuous turnover and wind mixing, and each lake develops its own under-ice conditions depending on ice clarity. More information is at ice.

Vesicles. - Bladder-like buoyancy-conferring cavities found in cyanobacteria cells. More information is at gas vesicles.

Virus. A virus is the same as a phage, a bit of DNA plus protein. Viruses are neither alive or dead, and they attack bacteria for replication purposes. Lake water typically contains more viruses than bacteria. More information is at cyanophage.

Water resuse. See reuse.

Watershed, and watershed protection. A watershed is the drainage area that flows into a water body. Drawing a line that connects the highest points around a water-body is one way to delineate a watershed's boundary. A more accurate delineation would also include areas that are drained into a water-body through underground pathways.

A watershed protection plan often consists of stormwater ponds, barrier berms, and changes in farming or other practices to prevent nitrogen (N) and phosphorus (P) from entering a lake via "external loading".

Watershed protection plans are a good thing, everybody should try to reduce pollution and be a better steward of the land. But watershed protection plans will not reverse a cyanobacteria, aka blue-green algae, problem in a lake. In one region in the US, after several counties spent millions of dollars on watershed protection over many years, the cyanobacteria problem in the lake because worse than ever. It appears now that the cyanobacteria had been sunlight limited, not phosphorus (P) limited, so the increased clarity of the water made the problem worse than ever. This is just one example of hundreds, or thousands, where watershed protection plans did not restore a lake to good water quality.

Zooplankton. Tiny animals that have some motility, but are also carried passively in a body of water. Three main groups of zooplankton are:

1) the relatively large cladocera, such as daphnia and water fleas, that are primarily filter feeders that eat algae and other phytoplankton, and

2) the relatively smaller copepods, that are frequently predaceous on other organisms, and

3) the rotifers, that are also predaceous but found more attached to sediments, aquatic plants, and detritus.

More information can be found at Daphnia.