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Seasonal Changes In Lakes

***Below is an overview** of what happens in lakes in the northern US during the four seasons. The lakes in warm southern regions don't have ice in the winter but the other three seasons spread out over more months to give these lakes a repeating cycle too.*

Please let Medora Corporation know if you would like to see improvements to this paper. Also, a more complete definition of various terms used below can be found in the paper entitled "Lakes A to Z Help Guide", which can be accessed on our website at www.medoraco.com/documents/lakes-a-to-z-help-guide/download

Winter.

Winter ice on a lake prevents all wind mixing. The temperature at the top of the ice is the same as the air temperature, and the temperature at the bottom of the ice, at the ice-water interface, is at the coldest possible liquid water temperature, 0˚C (32˚F) . When extremely cold air temperatures occur, for instance -20˚C (-4˚F), the low temperature moves down through the ice and the ice gets thicker as more water on the bottom side of the ice loses its "heat of fusion" and changes from a liquid to ice.

Convective mixing under the ice. Water is unique in that it is the most dense, the "heaviest", at 4°C (39˚F), and water which is either warmer or colder than 4˚C will be "lighter" and will "float" on top of 4˚C water. So during winter, the bottom of the lake always has the most-dense water, it is at 4˚C . But there is also a continuous flow of ground heat upward into the bottom water, causing the bottom water to warm up a little bit and become less dense, and then rise upward. But as the rising water gets closer to the ice at the surface it cools off again to 4˚C, the most dense point, and so it falls back down toward the bottom. So there is a constant gentle flow of water rising from the bottom of the lake due to ground heat, and water sinking down from the top of the lake to take its place.

Dissolved oxygen (DO). After ice forms and prevents wind mixing, the DO at the bottom of the lake starts to decline due to bacterial respiration at the sediment, even though the respiration is at a low rate due to the cold temperatures. The low DO condition at the sediment can spread throughout all of the water in the lake from the gentle convective mixing mentioned above, and cause fish kills under the ice if the DO falls to less than 2 mg/l. If the ice stays clear and allows sunlight to get through, the result is strong photosynthesis and algae growth just beneath the ice. The algae can push up the DO to higher than saturation right beneath the ice, in the 10-20 mg/l range which, through convective mixing, can help the entire lake. But if snowfall or turbidity prevents light from getting through the ice, the result is less photosynthesis under the ice and lower DO throughout the lake.

Spring.

When the ice thaws in the spring, usually about April 15 in the northern US, the water in the lake is at 0˚C at the top, the same as the ice before it melted, and at 4˚C at the bottom, where the most dense water is.

Daily mixing. As spring progresses, solar insolation (rays) warms up the top of the lake during the day, but as the surface water increases from 0˚C to 4˚C it becomes more dense and falls to the bottom of the lake, causing mixing of the lake, and causing the next highest layer of water to become the top layer. This process continues whenever the sun shines, until the entire lake is warmer than 4˚C. And even then, if the lake is warmer than 4˚C, for instance 7˚C, on a cold spring night the air can cool the surface layer down to 4˚C , which makes it sink to the bottom. So between continuous daytime mixing that starts as soon as the ice goes out, and some nighttime mixing, the entire lake stays well mixed as the water gradually warms to above 4˚C.

By the end of April or early May, the all-day mixing usually stops because all the water in the lake is warmer than 4˚C, and the nights are sufficiently warm so that the surface water stays above 4˚C and does not plummet to the bottom. After that, the daily sun penetration starts heating up several feet of water at the top of the lake, usually the top 4 - 10 feet. The upper warm water floats on top of the colder more dense water below.

Thermocline. The upper warm water is called the epilimnion, and the bottom colder water is called the hypolimnion. The separation point is called the thermocline, and it will persist until fall turnover. After the thermocline forms, usually wind mixing can mix only the water above the thermocline, the epilimnion, and the lake is considered to be "stratified". Most textbooks define the thermocline as a 1˚C temperature change in 1 meter of depth change, though Medora defines it differently as mentioned below.

Text books also refer to a metalimnion, a middle zone between the warm epilimnion and the cold hypolimnion, but few of the thousands of lakes that Medora has studied have a measurable or significant metalimnion, and for Medora's purposes this term can be ignored.

The thermocline in most US lakes is usually found between 4-10 feet deep from the surface, though occasionally it is deeper such as 14-20 feet in some large clear lakes. On a few very large lakes, the "fetch" of the lake may set the thermocline depth; that is, the distance that the wind can line up and blow across and mix the upper water deeper into the lake. But in most lakes in the US the thermocline depth is determined by how far down the sunlight can penetrate through the algae and other turbidity in the water. For instance, in a wastewater lagoon the thermocline is usually at 1.5 - 2 feet deep, and in a 10 ft deep lake the thermocline is usually 3-5 ft deep, and in a 25 ft deep lake the thermocline is usually 5-10 ft deep.

SolarBee machines deployed for control of cyanobacteria, aka blue-green algae, have the intake plate set at the thermocline. For Medora's purposes, the thermocline is defined as the "first depth of significant stratification", where there is change in temperature, pH, and DO all occurring at the same depth. Frequently there is also an increase in conductivity, a measure of total dissolved solids (TDS) at the thermocline, since the cold more-dense water forms a "shelf" where detritus from the upper water falls down onto and does not go any further down.

Usually the thermocline depth can be detected within 2 weeks of ice-out. And though the changes in the four parameters mentioned above will become more pronounced as the thermocline "hardens" as summer approaches, typically the thermocline will remain at exactly the April-indicated-depth all the way through

August 15 when fall turnover is getting close, though in August the thermocline may become a little bit deeper, perhaps a foot or so.

Diatoms first. Diatoms, which are photosynthetic like algae and usually considered to be in the algae family, typically dominate the lake after ice-out, giving the water a brownish color. Diatoms have silicate exoskeletons, like an eggshell, so their essential nutrients include not only carbon (C), nitrogen (N), and phosphorus (P), but also silica. Diatoms are huge phosphorus (P) scavengers, and can uptake nearly all the P nutrients in the lake. But once the thermocline forms, and only the upper water is being mixed by wind, diatoms beneath the thermocline die from lack of sunlight, and diatoms above the thermocline quickly run out of P in the upper water. About that same time the zooplankton "wake up", too, as the water warms up to 10˚C (50˚F). Consequently, with a lack of P plus predation by zooplankton, the diatom population in the upper water crashes shortly after the thermocline sets up, and the lake usually enters a two week "clear period".

Clear period. In most US lakes, the clear period lasts from about May 1 to May 15. During this period, there are usually 20-30 species of green algae, often called "good" algae since it is edible and kept cropped down by zooplankton, that are trying to get traction and dominate the lake. Each species has it's own "sweet spot" where it may gain control of the lake, depending on temperature, sunlight, nutrients, wind mixing, zooplankton predation, and other factors.

Green algae dominance. Following the clear period, various green algae species will dominate the lake for the rest of the spring and summer unless/until a cyanobacteria bloom occurs. With green algae there are no "bloom" problems because zooplankton keep these algae cropped down. Consequently, when green algae are predominate the water stays relatively clear, usually 5-20 ft of clarity, and has a nice green tint to it since individual green algae cells cannot be seen with the naked eye.

Filamentous algae. Filamentous algae, often called attached algae, is basically "good" green algae that forms stringy material or mats that are attached to the shallow bottom of a water body in spring or early summer. In flowing waters, attached algae can grow on rocks, branches, and other hard surfaces, and they get their nutrients from the waters flowing by. But in ponds and lakes where water is more stagnant, attached algae grow on sediments where organic material has been deposited, and get their nutrients from nutrient-rich interstitial water (i.e., water within the sediments). When attached algae cover an area, DO gas produced through daytime photosynthesis, and CO_2 gas produced from continuous respiration, can get trapped in the algal mats, causing them to float to the surface as small chunks or mats. These floaters are considered unsightly, but they are not harmful. Filamentous algae are consumed by some fish, birds and other aquatic animals. The floating mats will eventually sink following a good rain storm that allows the trapped gases to escape. In short, filamentous algae can be unsightly, but is usually "good" edible algae, and usually lasts for only a few weeks in the spring. For more on determining if floating clumps of algae are filamentous algae versus cyanobacteria, see the Kansas Jar test, available at medoraco.com, search for "jar".

Summer.

Thermocline persists and splits the lake into two kinds of water. The thermocline that exists at the start of summer causes, in effect, two separate water bodies to take form and develop in entirely different manners: (a) the epilimnion, which is the warmer upper water, and receives enough sunlight to grow algae, and which is wind mixed, and (b) the hypolimnion, which does not have enough sunlight for algae or other plants, and which is the colder deeper water and receives almost no mixing. Each has their own chemistry and biology.

A strong summer wind or storm can sometimes temporarily mix a lake deeper than the thermocline, but after the wind subsides the sun will quickly re-set the thermocline to the former depth in a few days.

Also, in a very large lake, a strong wind can blow water to a higher level at the leeward end. For instance a strong west wind can "pile up" water on the east end of the lake temporarily. When this happens, a "seiche" can form, which is essentially a "rocking thermocline" where the higher water level on the east end causes the thermocline to temporarily be depressed and then rock up and down throughout the entire lake. Usually the higher water level on the leeward end, the east end in our example, sets up a "return flow" across the top of the thermocline, flowing in a westerly direction to even out the hydraulic pressure in the lake.

No general diffusion occurs between water layers to "even out" the chemistry. Dissolved substances in a lake cannot move from the hypolimnion to the epilimnion, or vise versa, or between any two water layers in the lake, unless actual physical mixing of the water occurs. This is due to hydrogen bonding of water molecules and also the way water naturally forms thin horizontal layers in all reservoirs based on density differences between the layers. So if the hypolimnion has a concentration of 1 mg/l of phosphorus (P) at 18 feet deep, for instance, that P cannot diffuse very far upward or downward without actual physical mixing of the water, which would occur only with some sort or energy input or energy transfer that destroys the density difference between the layers of water. The main point is that molecular chemicals in the lake do not "spread out" evenly, like a gas would in a jar of air. Instead they are usually trapped in the water they are in, and that water is trapped in its own thin horizontal layer in the lake due to its density, and the chemicals cannot move around unless there is physical mixing of the water itself. Consequently, only the nitrogen (N) and phosphorus (P) nutrients in the epilimnion, can fuel algae growth. And the nutrients in the hypolimnion cannot get into the upper water since they are trapped in unmixed dense water at the bottom of the lake.

Finding the thermocline. The thermocline depth, for Medora's purposes of deploying SolarBee machines as mentioned above, is the depth of the "first significant stratification". This is the depth where it appears the wind is not mixing below it, as indicated by testing for temperature, DO, pH, and conductivity. When there are "Stair Step" changes in all four of these parameters, Medora also considers "Secchi depth" to determine the "thermocline depth" for purposes of deploying SolarBee machines. A Secchi disc is a flat piece of plastic about 8 inches diameter, with alternating quarters of the disc painted white and black, and as it is lowered into the water it disappears at some depth, giving a standard measurement for water clarity. Usually the thermocline is 2X the "Secchi" depth clarity. So if the Secchi depth is 3.0 feet, normally the sun penetration depth and thermocline is about 3.0 ft X 2 = 6 ft deep.

The epilimnion in the summer, where the food chain starts. The sun penetrates the epilimnion to support photosynthesis from the surface to the thermocline. In the littoral (near-shore shallow zone), the entire depth is considered to be part of the epilimnion, so macrophytes (water plants) also get enough light to grow there.

Cyanobacteria can take over the epilimnion in summer. Of the 70,000 algae species, only a few are cyanobacteria, aka blue-green algae, perhaps less than 100. But they now cause harmful algae bloom (HAB) problems in over 70% of US lakes. In some warmer areas, or regions beside oceans, such as California, Oregon, Washington, Texas, Florida and other states, cyanobacteria can be a year-around problem, not just in summer.

Cyanobacteria were commonly called "blue-green algae" until about 2012, mostly due to their pigmentation. But cyanobacteria is a better name because these algae have a slimy wall and other characteristics of bacteria even though they are photosynthetic like green algae. Medora has a paper about differences between good green algae and cyanobacteria, see medoraco.com and use the search tool to search for "comparison", but here is a brief list of some of cyanobacteria's advantages: They are too big for most zooplankton to eat, they can adjust buoyancy (with gas vesicles, like air bags, or by adding or getting rid of carbon weight) to go to the lake bottom for nutrients and then to the top to get sunlight (some species can travel up to 40 ft per hour), they can emit toxins and taste and odor to ward off competitors and predators, they can band together with filaments to form particles visible to the human eye that can shade out and kill good algae and diatoms plus protect themselves from predators, they can fix N from the atmosphere, they can store P in advance of when they need it, and they can create millions of resting daughter cells per square meter, call akinetes, that can rise up from the sediment the next season to take the lake over in a single day when the opportunity is right.

Cyanobacteria prefer warm water, long daylight hours, and high levels of nutrients such as in eutrophic or hyper-eutrophic lakes. They often get their "opening" to take over a lake in a still period that has little or no wind and as the green algae and diatoms, since they are heavier than water, are slowly falling down through the thermocline into the darkness below. Oftentimes the cyanobacteria in the water somehow (nobody knows exactly how) signal the resting spores in the sediment (akinetes) to all come up the next day and take over the lake. Cyanobacteria take over many northern US lakes by June 15 to July 15, and once it happens they usually dominate in the lake until fall turnover.

The hypolimnion in the summer. After the thermocline forms in the spring, the water beneath it, called the hypolimnion, will usually receive no mixing until fall turnover. The water temperature remains cool, though it does warm up a few degrees from when the thermocline formed in the spring. The pH usually remains the same as when the thermocline was formed, and can be considered the "background pH of the lake" to judge the severity of algae blooms in the epilimnion, since algae blooms will usually raise the pH. The dissolved oxygen (DO) usually starts at saturation, about 8 mg/l, the same as 8 ppm, when the thermocline forms, and gradually declines all summer. The DO declines fastest at the sediment, due to bacterial respiration, and usually goes to 0 mg/l there. This "anoxic zone" gradually works it way upward all summer due to bacterial respiration, and sometimes reaches the thermocline. A number of substances become dissolved in the water at the sediment in anoxic conditions, including ammonia nitrogen, phosphorus, iron, manganese, and sulfides. And the anoxic condition also methylates mercury which was already in the water, causing it to bio-accumulate. See medoraco.com, search for "Lakes A-Z" for more detailed information about the hypolimnion, anoxic zone, mercury, and other terms.

Fall.

Fall turnover. Most northern US lakes have the fall turnover by the end of August or in early September, which destroys the thermocline. In warm southern states like California, these months are different; usually the spring thermocline is set up by February, and the fall turnover does not occur until late October or else in November.

You can think of fall turnover in a lake as similar to trying to stand a pencil up on its point; a pencil is "top heavy", and keeps falling over when you let go of it. A fall lake turnover is similar; as fall approaches there are shorter days, and there is not enough sunlight to make up the heat loss at the surface from evaporation. Plus the night air is cooler, causing further cooling of the surface of the lake. So eventually the top several feet of the lake are cooler and more dense than the bottom water, and the lake becomes "top heavy". Then the entire water column flips over, causing whole-lake mixing from top to bottom.

Full-depth mixing. Within a day or two after turnover, all water in the lake is at the same temperature, saturation DO, pH, and conductivity. Iron and manganese that had been dissolved in deep water become oxidized into particles that settle onto the sediment. Just like at ice-out in the spring, the slightest wind can mix the entire lake again from top to bottom.

On warm summer days a temporary thermocline may be set up, with stronger algae growth in the upper water, but each night the thermocline get destroyed as the nightly convective mixing from evaporative cooling causes full depth mixing.

The full depth mixing after turnover destroys any particular algae dominance in the lake, so cyanobacteria HABs are destroyed. And as winter approaches and the water turn even colder, cold water diatoms still thrive, resulting in the water having a brown color.

These fall conditions continue until winter arrives and ice forms on the lake, repeating the cycle that started with Winter above.