WaterColumn

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Oxygen –The Most Important Water Quality Parameter?

~ *Bill Jones*

I'm often asked, "If you could sample only one thing on a lake, what would it be?" For me, the answer would be dissolved oxygen. Dissolved oxygen (DO), the measure of gaseous oxygen in water, is necessary for good water quality. It is essential for gilled fish and insects, and influences many different biological and chemical processes in lakes and streams.

Oxygen Properties and Dynamics

The concentration of dissolved oxygen in unpolluted fresh water can vary greatly and is influenced by temperature, atmospheric pressure, and salinity. For example, cold water can contain more oxygen than can warmer water (Table 1).

Table 1. Oxygen saturation in fresh water.

Temperature (°C)	*Temperature (°F)*	*Solubility (mg/L)*
0	32	14.62
10	50	11.29
20	68	9.09
30	86	7.56

Oxygen (O_2) enters lakes from the atmosphere through diffusion and mixing by waves. Although diffusion from the atmosphere is a relatively slow process, it is responsible for most of the dissolved oxygen in our lakes. Oxygen is also produced by algae and aquatic plants as a by-product of photosynthesis as the following process shows:

Carbon dioxide + Water + Nutrients + Light ⟶ Glucose + Oxygen

Photosynthesis converts the light energy of the sun to chemical energy that living organisms can use for life. It is said that life on Earth as we know it would not have been possible were it not for all the excess oxygen produced by algae in the "primordial soup" that existed on early Earth millions of years ago.

Oxygen in lakes is consumed by:

- Respiration of fish and aquatic organisms (much like we consume oxygen when we breathe)
- Respiration of aerobic bacteria and microbes as they decompose dead organic materials (leaves, twigs, algae, fish, etc.) both in the water and on the lake bottom.
- Chemical reactions, for example, the reduction of nitrate (NO_3) to ammonia (NH_4) in the hypolimnion.

In respiration, the reverse process occurs where organisms use the chemical energy formed by photosynthesis to power their bodies:

Glucose + Oxygen ⟶ Carbon dioxide + Water + ENERGY

When the concentration of DO in water is in equilibrium with oxygen in the atmosphere, it is called *100 percent saturated* and occurs at the concentrations shown in Table 1. DO in biologically productive (eutrophic) lakes can become *supersaturated* when oxygen is produced by algae or rooted aquatic plants more quickly than it can escape into the atmosphere. In some cases, the DO concentration can build up to greater than 200 percent saturation (Figure 1). When DO concentrations exceed 110 percent saturation, harm may come to certain fish. Excess dissolved oxygen can lead, in rare cases, to "gas bubble disease" in fish where the oxygen bubbles or emboli can block the flow of blood through blood vessels.

On the other hand, in biologically productive, thermally stratified lakes with an abundance of decaying organic material, the oxygen consumption by aerobic bacteria can use up much of the available oxygen in the hypolimnion, leading to *under-saturated* conditions. If bacterial respiration is great enough, *anoxic* conditions may result. Limnologists consider DO concentrations of less than 1.0 mg/L to be anoxic.

The limnologist, Arthur Hasler, referred to strongly eutrophic lakes as being *physiologically senile*. Such lakes produce more plant and animal material than they can use or decompose. As a result, the excess biological material accumulates on the lake bottom as muck and may even reduce lake depth.

It is quite common within dense aquatic plant beds that daytime dissolved oxygen is supersaturated but night time DO is under saturated due to aquatic plant respiration. Such large daily swings in DO can be devastating for aquatic animal life in dense aquatic plant beds.

Figure 2 summarizes many of the processes that affect the distribution of oxygen within lakes.

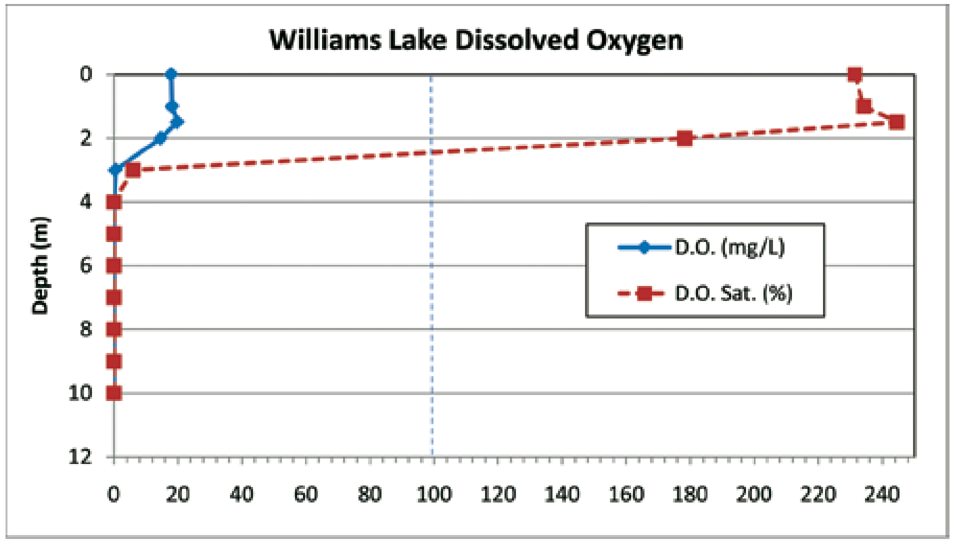

Figure 1. Depth profiles of dissolved oxygen (DO) and oxygen saturation in Williams Lake, Noble Co., Indiana from 8/2/2004. Excessive algal photosynthesis created supersaturated oxygen conditions in the surface waters (20 mg/L; 240 percent saturation) while respiration of bacteria decomposing dead organic matter consumed all the dissolved oxygen in the hypolimnion (0 mg/L; 0 percent saturation). The dashed vertical line represents 100 percent saturation.

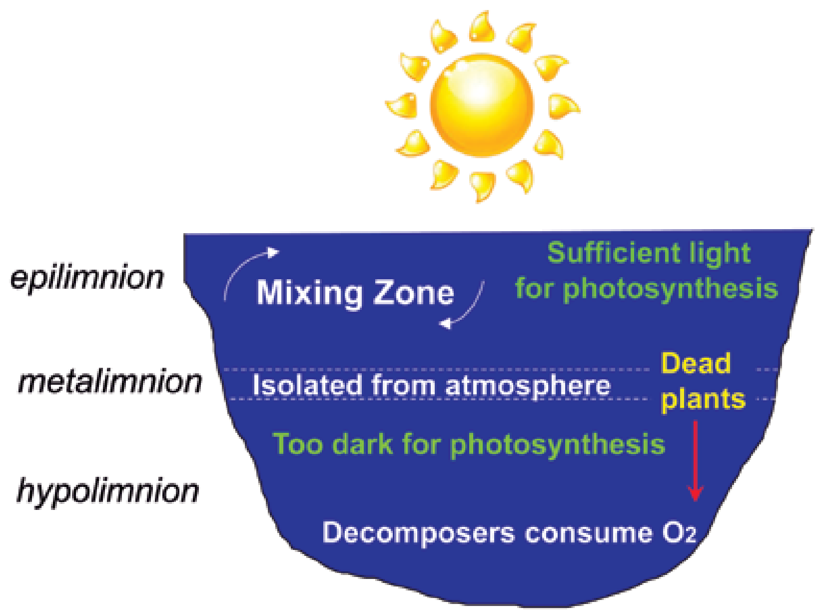

Figure 2. Where light is sufficient for photosynthesis to occur, oxygen is produced by photosynthetic algae and plants. Mixing of atmospheric oxygen into lakes occurs within the epilimnion of thermally stratified lakes but the metalimnion prevents mixing throughout the lake. The hypolimnion is often too dark for photosynthesis. The lack of oxygen input and the consumption of oxygen during bacterial respiration often lead to an oxygen deficit in the hypolimnion. A steady rain of dead plants, algae and other detritus provide continual organic matter inputs to the lake sediments.

Dissolved oxygen in rivers and streams is often 100 percent saturated due to the mixing of atmospheric oxygen into the flowing, turbulent waters. DO concentrations in rivers and streams may vary significantly over time; however, this is largely due to changing water temperature affecting the saturation of oxygen in water (Figure 3).

Biotic Needs

Sufficient dissolved oxygen in the water makes life possible for fish, aquatic insects, gilled snails,

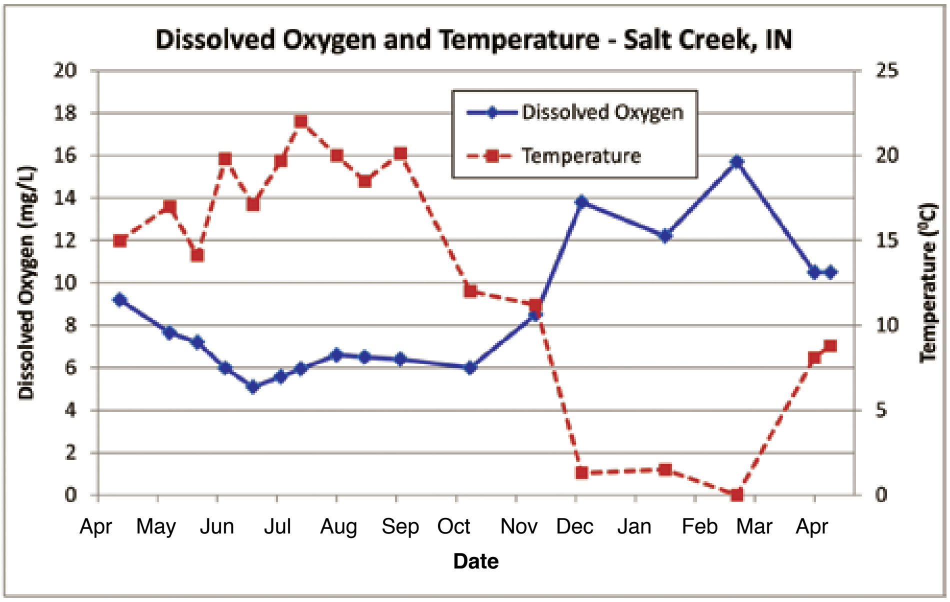

Figure 3. Annual DO variation in a stream is clearly influenced by water temperature. As waters cool DO concentration increases; as they warm DO decreases.

mussels, crayfish, frog tadpoles, and many other aquatic organisms. Different organisms have different preferred DO concentrations but, in general, the following guidelines apply:

- 0-2 mg/L: not enough oxygen to support life
- 2-4 mg/L: only a few kinds of fish and insects can survive
- 4-7 mg/L: acceptable for warm water fish
- 7-11 mg/L: very good for most stream fish including cold water fish

Chemical Changes

The presence of oxygen allows many important chemical reactions to occur in water. For example, in well-oxygenated lakes dissolved phosphorus (phosphate) and iron combine to form an iron-phosphate precipitate that settles to the lake bottom. This is a very important chemical process that removes phosphorus from the water column, but it only occurs when oxygen is present.

However, if lake water becomes anoxic, often seen in the hypolimnion, the iron-phosphate bond breaks and phosphorus is released back into the water from the lake sediments. This process is called *internal phosphorus loading* and can be a significant *internal* source of phosphorus loading to lakes. Internal phosphorus loading can significantly delay the recovery of eutrophic lakes even after external, or watershed sources, of phosphorus are controlled.

These chemical changes due to the presence or absence of oxygen are called *oxidation-reduction reactions*. While we won't describe the details here, oxidation-reduction reactions affect the forms of many aquatic chemicals in addition to phosphorus. For example, nitrate and ammonia are both inorganic, dissolved forms of nitrogen. Nitrate occurs readily in oxidizing conditions when oxygen is plentiful but ammonia occurs primarily in reducing conditions in the absence of oxygen, often within the hypolimnion. Ammonia is oxidized (converted) to nitrate when sufficient oxygen is present. Because of this, we can predict the forms of some chemicals in lakes based on the oxygen concentrations (Figure 4). We would expect more nitrate than ammonia in well-oxygenated water and the reverse in poorly oxygenated or anoxic water as shown in Figure 4.

Measuring dissolved oxygen

Measuring dissolved oxygen within lakes is an important component of water quality monitoring and assessment studies. A modern dissolved oxygen meter with a submersible probe is a simple and reliable tool to measure DO (Figure 5).The probes are calibrated in an internal chamber containing moist, saturated air to the theoretical saturation value based on ambient temperature and atmospheric pressure.

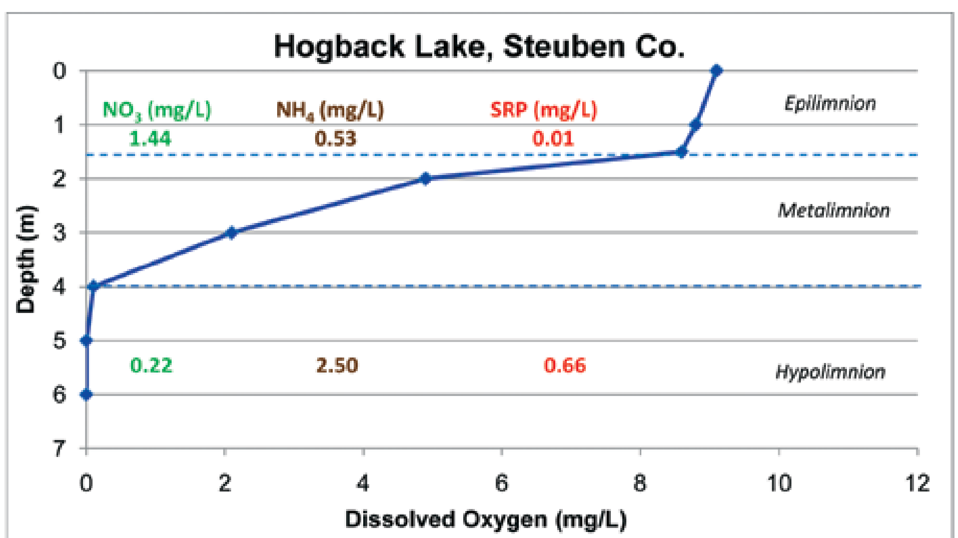

Figure 4. High oxygen concentrations within the epilimnion (0-1.5 m) and low concentrations within the hypolimnion (4-6 m) affect the quantity and form of nitrate, ammonia, and soluble phosphorus (SRP) within Hogback Lake on 6/29/2010.

Figure 5. Portable dissolved oxygen and temperature meter with submersible probe as used in the Indiana Clean Lakes Program.

With a modern temperature and dissolved oxygen meter, one can measure both the concentration of DO in the water (as mg/L) and the percent saturation of oxygen. As discussed earlier, percent saturation allows us to evaluate the relative magnitude and importance of photosynthesis and respiration within the lake.

A depth profile of oxygen concentrations and saturation within a lake is made by lowering the submersible probe down through the water and recording data at different depths. Limnologists typically measure DO and saturation at every meter of depth from the surface to just above the lake bottom. A depth profile thus made can reveal a variety of conditions of importance in assessing lake condition.

Figure 6 illustrates DO depth profiles of two deep, high-quality Indiana lakes, Clear Lake in Steuben County and Crooked Lake in Whitley County. Both lakes are mesotrophic (medium level of biological productivity) and contain ample DO well down into the hypolimnion. The DO concentration in Clear Lake never goes below 5 mg/L and Crooked Lake doesn't go anoxic until right near the bottom. These results suggest that Clear Lake has little excess organic matter in the sediments and Crooked Lake has some, but not enough to render the entire hypolimnion anoxic, like Williams Lake (Figure 1) or Hogback Lake (Figure 4). The large lake volumes of these lakes dilute watershed inputs. Low internal biological productivity in Clear and Crooked lakes prevents the excessive bacterial respiration that consumes DO because there is less organic matter waste present for bacteria to decompose.

The Crooked Lake DO depth profile also shows a phenomenon somewhat common in some clear lakes – a *metalimnetic oxygen maximum* at 6 meters. This supersaturated oxygen layer is evidence of a dense layer of photosynthetic algae at that depth in the cooler, denser metalimnion. The cooler water slows the algal sinking rate because cool water is denser than warm water and some algal species actually prefer cooler water with less intense light. They happily photosynthesize under these conditions and the oxygen they create gives them away.

Taking DO measurements at different times helps explain how your lake changes through the seasons and through the years. You could track how oxygen increases or decreases due to biological activities and how your lake changes over time. For example, if the amount or depth of anoxia increases from year to year, the lake is on a course for serious problems, even if the surface waters don't exhibit any symptoms of eutrophication.

Summary

In this article, we've learned why dissolved oxygen measurements are among the most useful and important to make in lakes. This simple measurement truly grants us a window into many biological and chemical processes that should be of interest to lake residents and users alike. In summary, with dissolved oxygen data, we can discover:

- If there is adequate oxygen for fish and other aquatic life.
- How oxygen concentrations vary with depth or in different areas of the lake or during the day.
- If we would expect internal phosphorus loading in the lake.
- Where photosynthesis and respiration dominate within the lake and whether this could have impacts on biota or chemistry
- Whether lake conditions are improving or degrading over time.

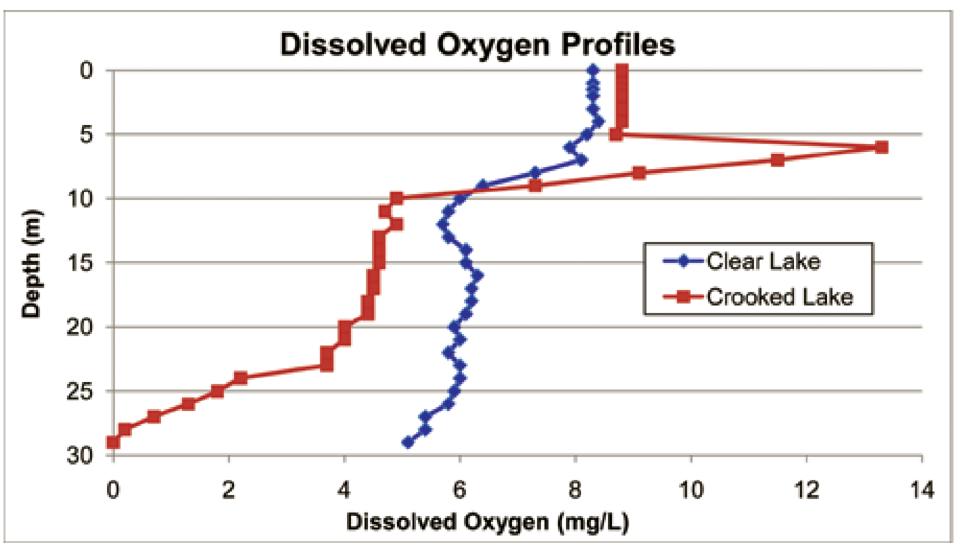

Figure 6. DO depth profiles for two deep Indiana lakes – Crooked Lake in Whitley Co. (2008) and Clear Lake in Steuben Co. (2010). Despite their deep depth and strong thermal stratification, both lakes remain oxygenated in the summer hypolimnion.

The 23rd Annual Indiana Lakes Management Conference

Figure 7. An enthusiastic group attending the 23rd Annual Indiana Lake Management Conference filled the Lake James meeting room at the Potowatomi Inn.

The Indiana Lakes Management Conference occurred on March 24-26, 2011 at the Potawatomi Inn in Pokagon State Park. More than 150 lake residents and enthusiasts joined the Indiana Lakes Management Society for the 23rd annual conference. Many thanks to our sponsors including Aquatic Control, Aquatic Weed Control, Clarke Aquatic Services, Aquatic Enhancement and Survey, Indiana Watershed Leadership Academy, Cygnet Enterprises, and Davey Resource Group.

This year's conference highlighted opportunities to make waves within your community. ILMS welcomed Eric Eckl of Water Words That Work who hosted a full-day session focused on communication. Concurrently, individuals from around the state highlighted on-going efforts to manage Indiana's lakes. Sessions focused on fisheries management, state rules and laws affecting Indiana's lakes, partnerships between lake associations and professional managers, and the latest happenings of the Lakes Management Work Group (Figure 7). Two Saturday workshops detailed management of lakes for plants and algae concerns and stressed the importance and opportunities for partner development.

As part of the conference, ILMS completed their annual meeting. As part of this effort, ILMS members elected new board members Kyle Turner of Beaver Dam/Loon Lake Conservation Club, Brigitte Schoner of Whippoorwill Lake, and Steve Lee of Aquatic Control and re-elected Heather Buck of Christopher B. Burke Engineering, Ltd. Additionally, Sara Peel of the Wabash River Enhancement Corporation and Ed Sprague of Skinner Lake were elected president and vice-president of the society, respectively. ILMS would like to thank out-going board members Jed Pearson of Indiana DNR, Nate Long of Aquatic Control, and Ed Spanopoulos of Cygnet Enterprises for all of their efforts during their time on the board.

At their annual banquet, ILMS recognized the ILMS Student Scholarship recipients, Lake/Watershed Group of the Year, the Volunteer of the Year, and the Legislative Award winner. Scholarship recipients included Abigail Grieve, Indiana University School of Public and Environmental Affairs; Caitlin Grady of Purdue University; and Matt Linn of Manchester College. Students received a $500 scholarship and free conference attendance.

ILMS was pleased to recognize the Clear Lake Township Land Conservancy (CLTLC) for its commitment to improving conditions in and around Clear Lake. Over the last few years, CLTLC members educated themselves and watershed residents about water quality influences on Clear Lake, Clear Lake's water quality issues, and the best management practices that can address those issues. More importantly, they've learned about watershed collaboration seeking assistance from local and regional governmental agencies and non-profit organizations. CLTLC's partnership with the Steuben County Drainage Board resulted in improved stream stabilization to a tile outlet and through their efforts to restore a wetland within their watershed; they've enlisted the assistance of the US Fish and Wildlife Service. Their efforts have expanded outside of their immediate landowners to include watershed landowners in their efforts as well. While CLTLC is just getting started, their efforts serve as an inspiration to other lake associations and watershed groups showing just what can be accomplished from a small but dedicated group of volunteers.

ILMS also recognized Joe Costello of the Sylvan Lake Improvement Association for his volunteer efforts and service to Sylvan Lake. For 33 of the past 40 years, Joe has unswervingly served the lake. Accomplishments during his tenure include: installation of a lake-wide sewer in 1974 (the second of its kind nationwide); conversion

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of the lake from a carp-dominated fishery to one of the best fisheries in the state through a whole-lake fish eradication and restocking in 1984; salvation of Boy Scout Island through the $1.25 million purchase of the island and future transfer of said island to the Gene Stratton Porter State Memorial. Joe's efforts to work to improve Sylvan Lake through his leadership and fund-raising were key in bringing this lake to its current high quality.

Additionally, ILMS was pleased to recognize our first outstanding implementation project recognizing the Town of Cedar Lake. Since the late 1980s, the Cedar Lake Enhancement Association has been working to protect and enhance Cedar Lake and its watershed. The latest effort by the Cedar Lake Public Works Department to reduce stormwater impacts to Cedar Lake represents opportunities to innovate with low-cost solutions to standard problems. Clearing an existing right-of-way of overgrown trees and invasive honeysuckle and removing eroded material throughout the project area paved the way for the installation of rock check dams and native plants. This effort was completely funded by the Town of Cedar Lake and implemented by their employees, serving as a learning experience with techniques that will be reproduced at additional sites around the lake. For their innovation and perseverance, ILMS was pleased to recognize the Town of Cedar Lake.

The Indiana Clean Lakes Program convened a special breakfast for volunteers participating in the Volunteer Lake Monitoring Program on Saturday morning. The breakfast offered the opportunity for volunteers to meet with each other and with CLP staff to talk about the program. Later Saturday morning, three citizens were trained to become expanded volunteer monitors (Figure 8).

Figure 8. Abby Grieve (left) and Sarah Powers (center) train (l-r) Brigitte Schoner (Whippoorwill Lake), John Williamson (West Otter Lake), and Mike Marturello (Snow Lake) along the shores of Lake James.