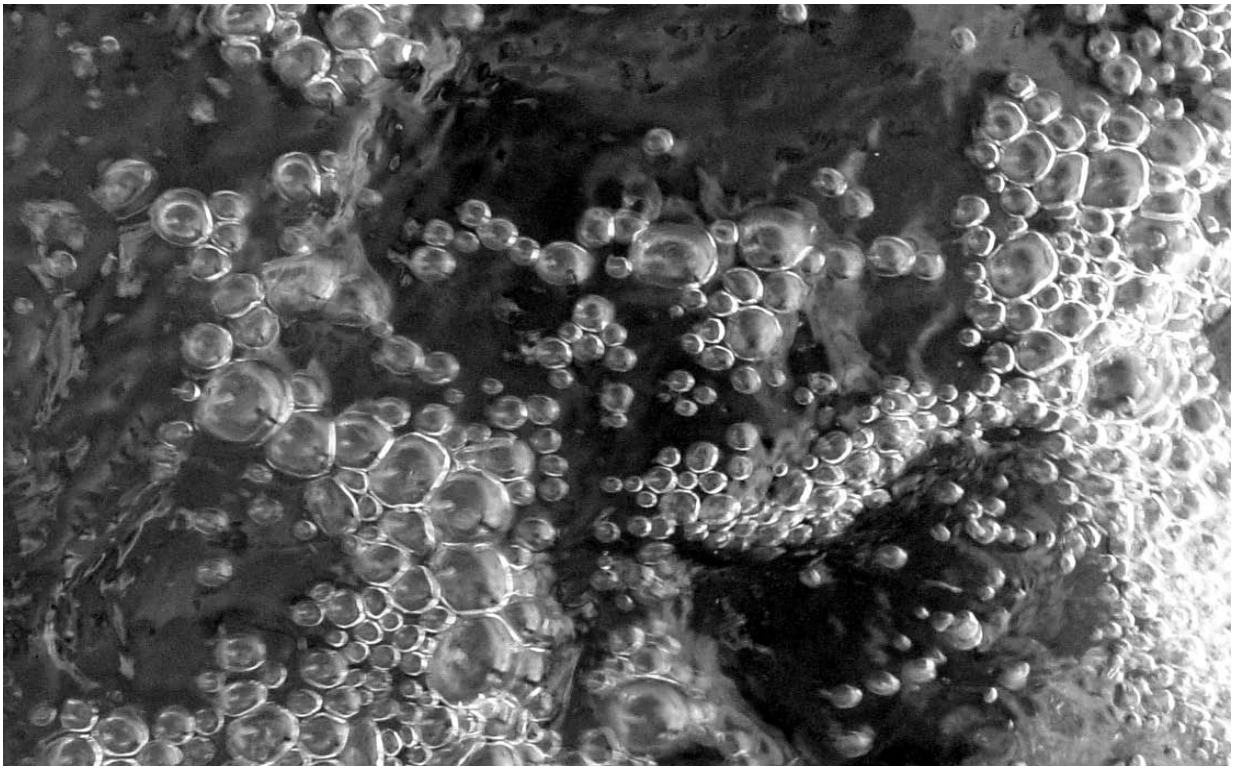
A Beginner's Guide to Water Management — Oxygen and Temperature

Information Circular 109



Florida LAKEWATCH
Department of Fisheries and Aquatic Sciences
Institute of Food and Agricultural Sciences
University of Florida
Gainesville, Florida

June 2004
1st Edition

UNIVERSITY OF FLORIDA
IFAS

Florida LAKEWATCH

Florida LAKEWATCH would like to extend a special thanks to the Lake County Water Authority for their financial assistance.

This publication was produced by:

Florida LAKEWATCH © 2004
University of Florida / Institute of Food and Agricultural Sciences
Department of Fisheries and Aquatic Sciences
7922 NW 71st Street
Gainesville, FL 32653-3071
Phone: (352) 392-4817
Toll-Free Citizen Hotline: 1-800-LAKEWATch (1-800-525-3928)

E-mail: lakewat@ufl.edu
Web Address: http://lakewatch.ifas.ufl.edu/

Copies of this document and other information circulars are available for download from the Florida LAKEWATCH Web site:

http://lakewatch.ifas.ufl.edu/LWcirc.html

As always, we welcome your questions and comments.

A Beginner's Guide to Water Management — Oxygen and Temperature

Information Circular 109

Florida LAKEWATCH
Department of Fisheries and Aquatic Sciences
Institute of Food and Agricultural Sciences
University of Florida
Gainesville, Florida

June 2004
1st Edition

UNIVERSITY OF FLORIDA
IFAS

Florida LAKEWATCH

Florida LAKEWATCH would like to extend a special thanks to the Lake County Water Authority for their financial assistance.

This publication was produced by:

Florida LAKEWATCH © 2004
University of Florida / Institute of Food and Agricultural Sciences
Department of Fisheries and Aquatic Sciences
7922 NW 71st Street
Gainesville, FL 32653-3071
Phone: (352) 392-4817
Toll-Free Citizen Hotline: 1-800-LAKEWATch (1-800-525-3928)

E-mail: lakewat@ufl.edu
Web Address: http://lakewatch.ifas.ufl.edu/

Copies of this document and other information circulars are available for download from the Florida LAKEWATCH Web site:

http://lakewatch.ifas.ufl.edu/LWcirc.html

As always, we welcome your questions and comments.

A Listing of Florida LAKEWATCH Information Circulars

Beginner's Guide to Water Management – The ABCs (Circular 101)
An introduction to the terminology/concepts used in today's water management arena, in a glossary format. 44 pp.

A Beginner's Guide to Water Management – Nutrients (Circular 102)
A basic introduction to the presence of phosphorus and nitrogen in lakes — two nutrients commonly associated with algal growth and other forms of biological productivity. Limiting nutrients are discussed, along with conceptual and mathematical tools that can be used to achieve a variety of water management goals. 36 pp.

A Beginner's Guide to Water Management – Water Clarity (Circular 103)
Anyone interested in the subject of water clarity can benefit from reading this circular. Topics include factors that can affect water clarity in Florida lakes; techniques for measuring water clarity; and methods used for managing water clarity. 36 pp.

A Beginner's Guide to Water Management – Lake Morphometry (Circular 104)
The size and shape of a lake basin (i.e., lake morphometry) can tell us a great deal about how a lake system functions. In some instances, it can help explain why one lake has more algae or aquatic plants than another. It can also be helpful in anticipating changes that may occur due to management practices or prevailing weather patterns. This booklet covers many of these concepts as well as techniques used to evaluate lakes. 36 pp.

A Beginner's Guide to Water Management – Symbols, Abbreviations and Conversion Factors (Circular 105)
This booklet provides the symbols, abbreviations and conversion factors necessary to communicate with water management professionals in the U.S. and internationally. Explanations for expressing, interpreting and/or translating chemical compounds and various units of measure are included. 44 pp.

A Beginner's Guide to Water Management – Bacteria (Circular 106)
This circular begins with a brief tutorial on the presence of naturally occurring bacteria in Florida lakes followed by a discussion of bacterial contamination and how one might test for it. Also included: wastewater treatment plants versus septic tank systems; indicators used for detecting bacteria; and laboratory methods commonly used for analysis. Lastly, an easy 4-step process is provided for tracking down bacterial contamination in a waterbody. 38 pp.

A Beginner's Guide to Water Management – Fish Kills (Circular 107)
A discussion of the five most common natural causes of fish kills including low dissolved oxygen; spawning fatalities; mortality due to cold temperatures; diseases and parasites; and toxic algae blooms. Human-induced events are also covered, along with a section on fish stress — a component of virtually every fish kill situation. The last section provides instructions on how to collect fish and/or water samples for analysis. 16 pp.

A Beginner's Guide to Water Management – Color (Circular 108)
Aside from water clarity, the color of water in a lake is one of the main attributes that captures people's attention — particularly if the color begins to change. While most of these changes are the result of natural processes, it's important to know that changes in color can affect the biological productivity of a waterbody, including the abundance of aquatic plants and/or algae. Topics include apparent color, true color, suspended substances, dissolved substances, and a brief discussion about light refraction. The last section provides two empirical models that can be used to determine if color is the result of algae or suspended solids (i.e., in a specific lake). 32 pp.

Copies of these publications can be obtained by contacting the Florida LAKEWATCH office at ***1-800-LAKEWATch*** *(1-800-525-3928). They can also be downloaded for free from the Florida LAKEWATCH Web site:*
http://lakewatch.ifas.ufl.edu/LWcirc.html
or from the
UF/IFAS Electronic Data Information Source (EDIS): ***http://edis.ifas.ufl.edu***

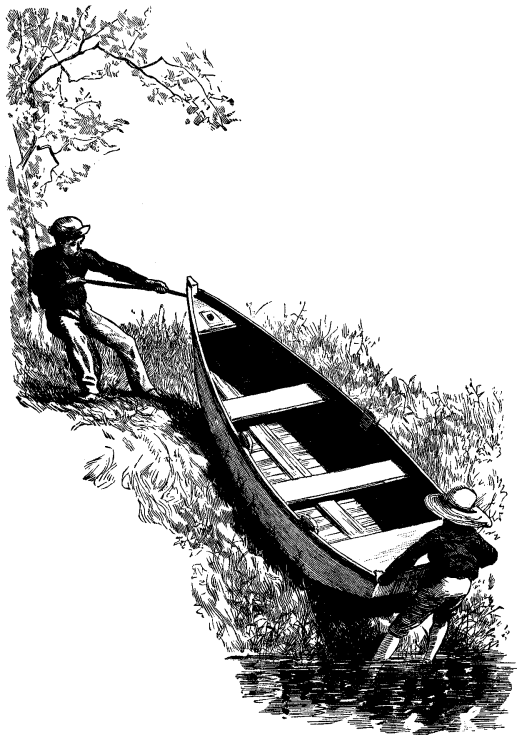
David Watson

West Crystal Lake in Seminole County.

Introduction

In 1957, G. Evelyn Hutchinson, a world famous limnologist (lake scientist), had this to say about the importance of oxygen in aquatic systems:

"A skillful limnologist can probably learn more about the nature of a lake from a series of oxygen determinations than from any other kind of chemical data. If these oxygen determinations are accompanied by observations on Secchi disk transparency, lake color, and some morphometric[1] data, a great deal is known about the lake."



Many would agree that this statement is as valid today as it was in 1957. However, he did forget to mention one thing: in addition to oxygen, the temperature of water is an equally important component of lake ecosystems. In fact, oxygen and temperature are so closely linked that it's nearly impossible to discuss one without the other. Sometimes it's difficult to know which should be considered first.

For the purposes of this circular, we'll start with oxygen as it is key to the survival of all aquatic organisms — not to mention us landlubbers!

Part 1 begins with a brief tutorial about oxygen in water, including how it enters and exits a waterbody and how it is measured. In Part 2, we will delve into the physical properties of water (e.g., forms of water, density of water, etc.) and the influences that temperature has on each of these characteristics. In Part 3, we will tie it all together with information on how these dynamics affect the ability of plants and animals to live in water (a.k.a. biological productivity). Part 4 includes more technical information on the methods used to obtain oxygen and temperature measurements.

Because this publication is intended for a varied audience, we've tried to present the material in reader-friendly portions and placed the technical information into sidebars. Be sure to take a minute to review the outline on the following page to familiarize yourself with the chapter headings and content.

Lastly, we'd like to explain why LAKEWATCH doesn't include oxygen monitoring in its normal sampling routine. Even though it is obviously important, this type of sampling is not logistically feasible on a regular basis. As described in Part 4, the equipment is expensive and the process can be difficult to do. However, arrangements can be made if you suspect that oxygen problems are occurring your lake. For more information, please call us at 1-800-LAKEWATCH (525-3928).

Editor's Note: While many of the concepts described in this circular are similar in the saltwater environment, we will be limiting our discussion to freshwater systems.

---

[1] *The term* ***morphometric*** *refers to the size and shape of an object.*

List of Figures

Figure 1
The Three Forms of Water and the Energy Required to Move From One Form to Another 9

Figure 2
Water Density and Temperature in Water 10

Figure 3
Lake Stratification and Temperature Profiles 11

Figure 4
Diel (Daily)l Oxygen Curve 18

Figure 5
Dissolved Oxygen Percent Saturation 25

Table 1
Correction Factors for Lake Altitude 26

Joe Richard

Table of Contents

Introduction i

List of Figures ii

Table of Contents iii

Part 1 Oxygen and Water
Oxygen, Temperature and Altitude 1
Dissolved Oxygen 1
Measuring Dissolved Oxygen (DO) in Water 3
Oxygen Saturation 3
Sidebar: The Difference Between Dissolved Oxygen and Oxygen Saturation 3
Part 1 Section Summary 5

Part 2 Temperature and Water
Factors Influencing Water Temperature 7
Sidebar: The Relationship Between Air Temperature and Water Temperature is Two-Sided 7
Forms of Water 8
Water Density 8
Sidebar: Lake Stratification and Temperature Profiles 11
Sidebar: Technically Speaking: Definitions for the Physical Properties of Water 10
Thermal Stratification in Lakes 11
Sidebar: Plants and Their Effect on Stratification 12
Lake Turnovers 13
Sidebar: Saltwater Stratification 14
Sidebar: Turnover Terminology 15
Part 2 Section Summary 15

Part 3 Biological Productivity, Oxygen and Temperature
Oxygen and Biological Productivity 17
Algae, Aquatic Plants and Oxygen 18
Other Factors That Can Decrease Oxygen in Water 19
Temperature and Its Affect on Fish Populations in Florida Lakes 19
Sidebar: Analyzing Fish Kills 20
Sidebar: Cold-water Vs. Warm-water Fish 21
Part 3 Section Summary 21

Part 4 Methods Used for Measuring Dissolved Oxygen in Water
Electronic Measuring Methods 23
Chemical Analysis 24
Sidebar: Technically Speaking: The Mechanics of a DO Meter 24
Sidebar: What Does LAKEWATCH Do? 26
Part 4 Section Summary 26

Selected Scientific References 27

Florida LAKEWATCH (General Information) 28

Joe Richard

Part I
Oxygen and Water

Water's ability to hold and release oxygen is perhaps its most valuable attribute, as oxygen is critical to the survival of all aquatic life. Because of this unique trait, many organisms including algae, bacteria, aquatic plants, amphibians, insects, and fish are able to breathe or "respire" underwater. The downside of this arrangement is that oxygen concentrations tend to fluctuate considerably within the aquatic environment. Sometimes there can be a surplus and, at other times, oxygen levels can drop so low that fish and other animals can become stressed or even die. When this happens, people become alarmed and frequently, the first assumption is that the fish kill resulted from pollution. However, what many people don't realize is that the vast majority of these events are the result of naturally occurring processes.

To have a better understanding of these processes — and the effects they can have on the biological community of a lake or waterbody — we will begin with a look at the relationship between oxygen and water.

Oxygen, Temperature and Altitude

The first thing you need to know about oxygen and water is that there are two main factors that set the limits on how much oxygen can be "held" by a freshwater lake: **temperature** and **altitude**.

In the southeastern portion of the United States, water temperature plays the largest role in influencing the amount of oxygen in a waterbody. The rule of thumb: warm water holds less oxygen than cool water.[2]

Because most lakes in Florida are situated at sea level or just above sea level, lake altitude is not really a factor. However, in areas of higher elevation, even in neighboring Georgia, altitude can play a role in the amount of oxygen available in water. The rule here: as altitude increases, the amount of oxygen in a lake decreases. This can be explained by simple physics. At higher altitudes, there is less pressure being exerted on the surface of a waterbody and, as a result, there is less oxygen being "pushed" into the water from the atmosphere.

Dissolved Oxygen

Water — H_2O — is a simple molecule made up of two atoms of hydrogen (H_2) and one atom of oxygen (O). However, the oxygen that fish and other organisms use underwater does not come from the actual water molecules themselves. That's because the single atoms of oxygen found in water molecules are bound to the two hydrogen atoms and are not available. Instead, all aquatic organisms use dissolved oxygen gas (O_2) that is constantly entering water from two main sources: the **atmosphere** and from **photosynthesis**.[3]

Oxygen from the atmosphere continuously enters the surface of a waterbody through a process known as **diffusion**. Molecule by molecule, oxygen gas (0_2) is pushed into the water by pressure from the air above. Wind and wave action can accelerate the diffusion process because waves create more surface area for oxygen to enter the water. Artificial wave action, via aerators, can also increase oxygen concentrations in water.

---

2 *There are times when cooler water may not necessarily hold more dissolved oxygen than warm water. See Lake Turnover section described on page 13.*

3 *The term "dissolved oxygen" is a bit of a misnomer as the oxygen gas (0_2) that enters water doesn't dissolve, but instead, moves around through the water column amongst the water molecules (H_20).*

Joe Richard

Photosynthesis is perhaps the most critical source of oxygen, especially in waterbodies where algae or aquatic plants are abundant. As we learned in grade school, photosynthesis is a process whereby plants and algae use carbon dioxide, water, and sunlight to make their own food. Oxygen is a by-product of this activity. As long as photosynthesis is taking place, oxygen is continuously being released into the water. In the early morning hours, or in the evening, or during low light conditions, photosynthetic activity is reduced. At night, it stops all together.

The amount of oxygen in a lake or waterbody is constantly changing.

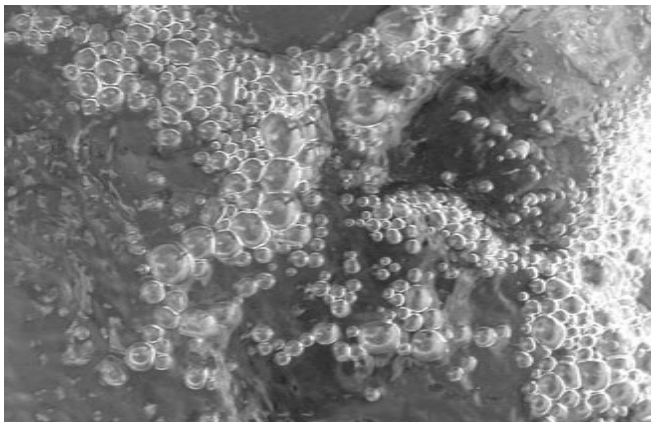
The amount of oxygen in a lake or waterbody is constantly changing. This is due to the fact that, even as oxygen is entering the aquatic environment, it is also being removed by biological activity within the water. Biological activity includes the regular day-to-day functions of virtually all the inhabitants of a waterbody, including algae, bacteria, fish, insects, plants, etc. As these organisms carry on about their normal activities, they are constantly removing oxygen from the water and releasing carbon dioxide as a by-product. This process is known as **respiration**.

Respiration is essentially the opposite of photosynthesis. Much of the time, the respiration that occurs within a waterbody is offset by photosynthesis so there is a surplus of oxygen available in the water. But not always. As mentioned earlier, photosynthetic activity is reduced under low light conditions (e.g., cloudy weather). This means that once the sun goes down, algae and aquatic plants are no longer *producing* oxygen but they are continuing to *consume* oxygen. As a result, the lake's oxygen supply takes a double "hit." If a lake experiences several days of low oxygen production due to cloudy weather or other low light conditions, it could encounter low oxygen concentrations that can be detrimental to fish and other organisms in the water.

For more on the subject, see LAKEWATCH Information Circular 107 A Beginner's Guide to Water Management – Fish Kills (Understanding Fish Kills in Florida Freshwater Systems).

Additionally, in lakes where a large amount of aquatic vegetation or algae have died all at once, increased activity within the bacterial community alone can pull oxygen from the water faster than it can be replaced (i.e., as the bacteria work to decompose the plant or algal material). If there is enough dead plant or algal material involved, oxygen problems can occur even during daylight hours.

See Part 3 for more about the effects that low oxygen can have on the biological productivity of a waterbody.



Measuring Dissolved Oxygen (DO) In Water

Dissolved oxygen concentrations can be determined by conducting a series of complex chemical reactions or they can be measured electronically with an oxygen meter. The disadvantage to chemical analysis is that it involves substances that are potentially dangerous and it is time consuming. Today, most scientists rely on electronic meters even though there are complications related to their use, as well. For one thing, they must be calibrated properly for accurate readings. Otherwise, the measurements are meaningless, or worse, inaccurate readings can lead to the wrong conclusions when monitoring a lake. Secondly, a good meter costs about $1,000; for many individuals or monitoring programs, this can be prohibitive.

See Part 4 on page 23 for detailed information on how to measure DO using chemicals and/or with a DO meter.

What is the "normal" dissolved oxygen concentration in freshwater systems?

In most freshwater environments, DO measurements usually range somewhere between six and ten milligrams per liter (mg/L). When measurements drop down to three or four milligrams per liter, fish and other aquatic life will begin to experience stress, especially if the drop in oxygen occurs suddenly. Few organisms are able to survive in water when dissolved oxygen levels are below 2 milligrams per liter.

Note: In water management circles you may also see measurements that are represented as parts per million (ppm). This is the same as "milligrams per liter."

See Part 3 on page 17 for more about the effects of low oxygen on aquatic life.

Oxygen Saturation

Many people will be surprised to learn that there are times when a waterbody can actually become supersaturated with oxygen. In other words, the water is holding so much oxygen that it isn't able to hold anymore. Under these conditions, water can be described as having a dissolved oxygen saturation of greater than 100 percent. At times, this percentage can be as high as 140, 150 or even 300 percent!

When water is supersaturated, oxygen molecules will begin to move around within the water column, looking for a little elbowroom. If there is none available, the oxygen gas will return to the atmosphere or attach itself, in the form of bubbles, to submersed plants or along the bottom. In the summer, when daylight hours are at a maximum, this happens with some regularity.

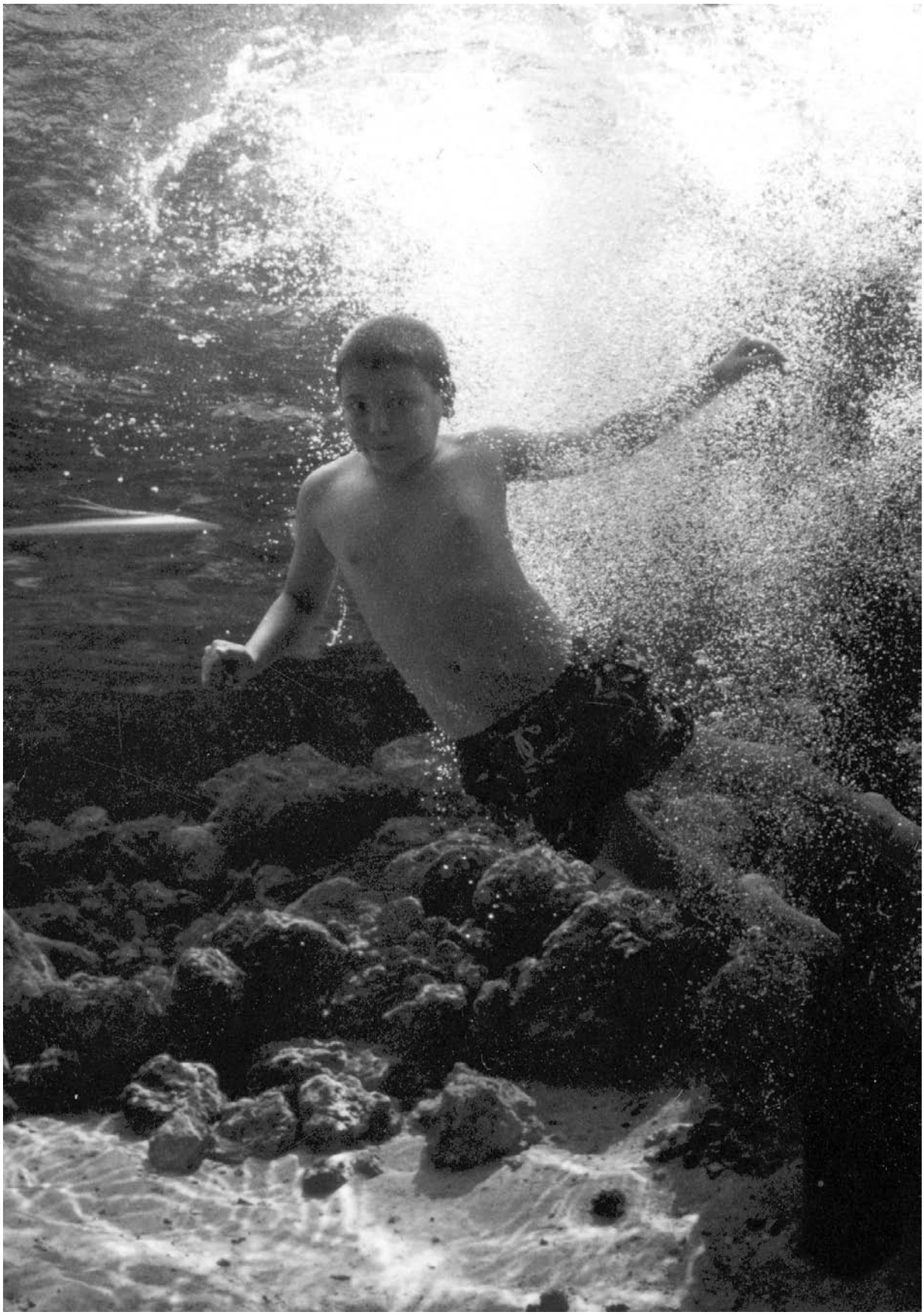
The Difference Between Dissolved Oxygen and Oxygen Saturation

It is important to note that oxygen saturation is NOT the same as dissolved oxygen:

• ***Dissolved oxygen*** is the amount of oxygen measured in water, in milligrams per liter (mg/L).

• ***Oxygen saturation*** is the potential that a waterbody has for holding oxygen, based primarily on water temperature and altitude.

• ***Percent oxygen saturation*** is the ratio between actual dissolved oxygen measurements and the water's potential for holding oxygen. Knowing the percent oxygen saturation of a waterbody can help determine whether there is an oxygen surplus or a deficit. If there is a deficit, it means that the amount of respiration occurring in the water, from aquatic life, is exceeding photosynthesis and/or diffusion. Under such circumstances, the potential for a fish kill or other oxygen related problems is high (i.e., illness, fish stress, etc.).



Joe Richard

Fanning Springs, Florida

Measuring percent oxygen saturation

Scientists have developed a technique for calculating the percent oxygen saturation of a waterbody. Using a nomogram,[4] one can use both the temperature of the water and dissolved oxygen measurements to determine what the percent oxygen saturation should be at any given time.

See page 25 for a detailed explanation on how to use a nomogram.

Part 1 Section Summary

Oxygen, Temperature and Altitude — Temperature and altitude are the two main factors that set the limits on just how much oxygen can be "held" by water. In the southeastern portion of the United States, the temperature of the water plays the largest role. The rule of thumb is that warm water holds less oxygen than cool water.[5] In areas of higher elevation (i.e., outside of Florida), lake altitude can play a role; as altitude increases, the amount of oxygen in a lake decreases.

Dissolved Oxygen — In the aquatic environment, virtually all aquatic organisms use dissolved oxygen gas (O_2) for respiration. This gas is constantly entering water from two main sources: the atmosphere and from photosynthesis.

The atmosphere continuously provides oxygen gas through a process known as diffusion (i.e., tiny oxygen molecules are pushed into the water by pressure from the atmosphere above).

Photosynthesis is thought to be the predominant source of oxygen in many lakes, especially in waterbodies where algae or aquatic plants are abundant. (Algae and plants use sunlight and carbon dioxide for growth and release oxygen into the water as a by-product.)

Furthermore, the amount of oxygen in a waterbody is constantly changing due to biological activity within the water. Aquatic organisms remove oxygen from the water in a process known as respiration, which is essentially the opposite of photosynthesis. Much of the time, respiration that occurs within a waterbody is offset by photosynthesis, so there is a surplus of oxygen in the water; but not always. Depending on the water temperature, the amount of sunlight, and activities within the aquatic environment, respiration can sometimes create an oxygen deficit, causing problems for a lake's inhabitants.

Measuring Dissolved Oxygen (DO) In Water — Dissolved oxygen concentrations can be determined by conducting a series of complex chemical reactions or measured electronically with an oxygen meter (a.k.a. a DO meter).

Chemical analysis involves substances that are potentially dangerous and the process is time consuming. Today most scientists use electronic meters. When using a DO meter, one should always be sure it is calibrated properly.

See page 24 for instructions on how to use a DO meter.

In most freshwater environments, DO measurements typically range between six and ten milligrams per liter (mg/L). At three or four milligrams per liter, fish and other aquatic life will begin to experience stress.

Oxygen Saturation — Oxygen saturation is NOT the same as dissolved oxygen. Dissolved oxygen is the amount of oxygen measured in water, in milligrams per liter (mg/L). Oxygen saturation is the potential that a waterbody has for holding oxygen, based primarily on water temperature and altitude. Percent oxygen saturation is the ratio between actual dissolved oxygen measurements and the waterbody's potential for holding oxygen. Knowing the percent oxygen saturation of a waterbody can help determine whether there is an oxygen surplus or a deficit.

If there is a deficit, it means that the amount of respiration occurring in the water (i.e., from aquatic life) is exceeding photosynthesis and/or diffusion. Under such circumstances, the potential for a fish kill or other oxygen related problems is high (i.e., illness, fish stress, etc.).

---

4 *A nomogram is a graphic representation that consists of several lines marked off to scale and arranged in such a way that a straight-edge can be used to connect known values on two separate parallel lines (a line above and a line below), where an unknown value can be read at the point of intersection along a middle line. See Figure 5 on page 25.*

5 *There are times when cooler water may not necessarily hold more dissolved oxygen. See* ***Lake Turnover*** *section described on page 5.*

Joe Richard

Lake Alice on the University of Florida campus in Gainesville, Florida.

Part 2
Temperature and Water

Now that we have a better understanding of the relationship between oxygen and water, we can begin to look at the role that temperature plays in all of this. We will start off with a quick review of how lake water cools and/or heats and then continue with more detailed information on the influence that temperature has on the physical properties of water, including the forms of water and their related densities. After that, we will discuss thermal stratification and lake turnovers — two phenomena that are closely linked with water temperature.

Factors Influencing Water Temperature

Energy from the sun and **air temperature** are the two main factors that influence water temperature. But there are other influences, as well. Inflows and outflows (creeks, streams, wastewater discharge, groundwater seepage, etc.); the shape and depth of the lake basin (i.e., lake morphometry); wind and waves; even the color of the water can influence temperature.

The size of a waterbody and the volume of water generally determines just how much influence air temperature will have on a lake. For instance, in the summer months, water in a small shallow lake will heat up faster than a large deep lake. The same is true during the winter in northern climates; a small shallow lake may freeze while large deep lakes may only experience ice formations along the shoreline, or not at all.

Thanks to the ever-present energy from the sun, water temperatures are slower to change than air temperature. Of course, in the wintertime, the sun has a more difficult time doing its job.

Because water temperatures are slow to change, the aquatic environment is a fairly stable place to live for many organisms.

The relationship between air temperature and water temperature is two-sided.

While it's true that air temperature is a major influence on water temperature, the reverse is also true. Lakes, ponds, and coastal areas (bays, marshes, etc.) act as thermal reservoirs for the surrounding countryside. In other words, a large lake or waterbody can help keep the surrounding landmass cooler in the summer and warmer in the winter. This phenomenon is known as the **thermal inertia of the hydrosphere**.

At times, a nearby lake or waterbody can even offer protection from freezes during periods of cold weather by transferring heat from water back into the air. Thus, lakes serve as natural climate modifiers in agricultural areas, protecting crops from frost and freeze damage by warming the air. In Florida, many orange groves, nurseries and farms are located near lakes to take advantage of this protection.

Such an arrangement may seem ideal but it can also result in contention between lake management and the agricultural community. For example, some years ago a group of lake managers proposed lowering the water levels in Lake Apopka, to solidify the lake bottom and improve the lake's fishery. Ultimately, this strategy was not selected — partly because the loss of water would have greatly reduced the freeze protection for orange groves near the lake. Community leaders judged the risk of freeze damage to the region's agriculture to be unacceptable.

Professionals who manage freshwater systems should remember that there are often many factors that have to be considered when developing a lake management plan.

Joe Richard

Forms of Water

Depending on its temperature, water exists in three distinct forms — a solid, a liquid, and a gas:

Solid – At or below zero degrees Celsius (i.e., 32 degrees Fahrenheit), water becomes solid in the form of ice.

Liquid – At zero to 100 degrees Celsius (33 - 212 F) water exists as a liquid.

Gas – At 100 degrees Celsius (212 F), water changes from a liquid to a gas, through boiling. However, it can also change from a liquid to a gas, at any temperature above freezing, through evaporation.

See Figure 1 on page 9 for a diagram of the three forms of water and the energy required to move from one form to another.

While Floridians are less familiar with water's solid form (i.e., ice, snow, and sleet), we are quite familiar with the liquid version as it is abundant throughout the state in thousands of lakes and ponds, dozens of rivers, springs, and along 1,200 miles of coastline.

The third form of water — the gas or "vapor" phase — is not as visible as the other two, but its presence is definitely felt in the form of humidity, especially on a hot summer day. Or it can also take the form of fog on a cold morning. Needless to say, the liquid form is the most popular, as residents and tourists spend billions of dollars on water-related activities every year.

Water Density

Water density changes with water temperature. Anyone who is interested in studying the aquatic sciences will need to be familiar with the following temperature-related dynamics, as they can have a major influence on the biology and chemistry of lakes.

See Figure 2 on page 10.

As water cools from 35 degrees Celsius (95 F), it becomes more dense until it reaches its maximum density at 4 degrees Celsius (39.2 F). After that, an interesting phenomenon occurs: as water becomes colder than 4 degrees Celsius, the density begins to decrease. Finally at zero degrees Celsius, water becomes ice and is less dense (i.e., lighter) than its liquid counterpart. At this point, ice floats to the surface even though it is a solid.

This is a good thing. Otherwise, ice would form on the bottom of the lake, increasing in volume and eventually displacing all the liquid water.

If this were to happen, there would be no habitat left for fish and other organisms. Moreover, floating layers of ice on the surface of a lake also act as a thermal barrier, helping to prevent further loss of heat from the waterbody.

There is another interesting aspect to the relationship between water density and water temperature that causes significant changes in lakes:

The difference in water density, for every one degree of change (Celsius), increases dramatically at higher water temperatures, whereas the smallest density difference for one degree of change occurs at 4 degrees Celsius (39.2 F).

In other words: the difference in water density between 29 and 30 degrees Celsius (84.2 - 86 F) is significantly greater than the difference in water density between 4 and 5 degrees Celsius (39.2 - 41 F) — about 40 times greater!

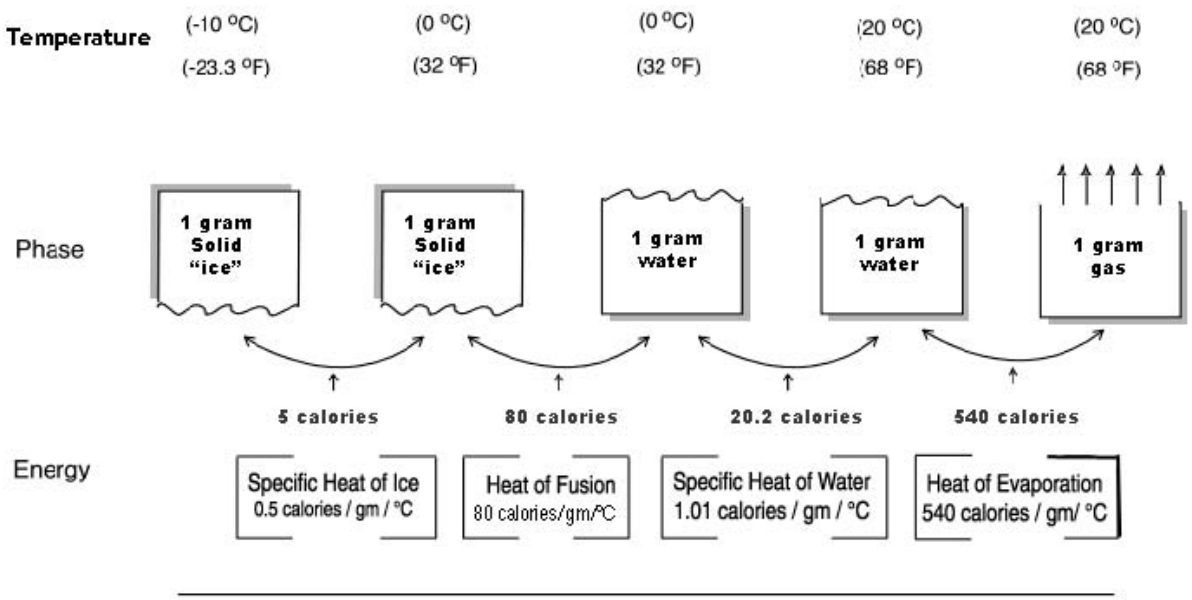
See Figure 2 on page 10 for an illustration of the relationship between water density and temperature in water.

Accordingly, as the difference in density increases, so does the amount of energy required to mix the two layers of water. For example, during the summer in Florida, it is common to have water temperatures of 30 degrees Celsius at the top of a lake and 29 C at the bottom. So, although the lake may only have a one degree difference in water temperature between the top and bottom, the density difference between the two layers may be great enough to prevent the water from physically mixing (i.e., from wind/wave action).

If these conditions were to last long enough, it could result in a loss of oxygen within the bottom layer and ultimately have a detrimental affect on aquatic organisms, including mussels and other invertebrates.

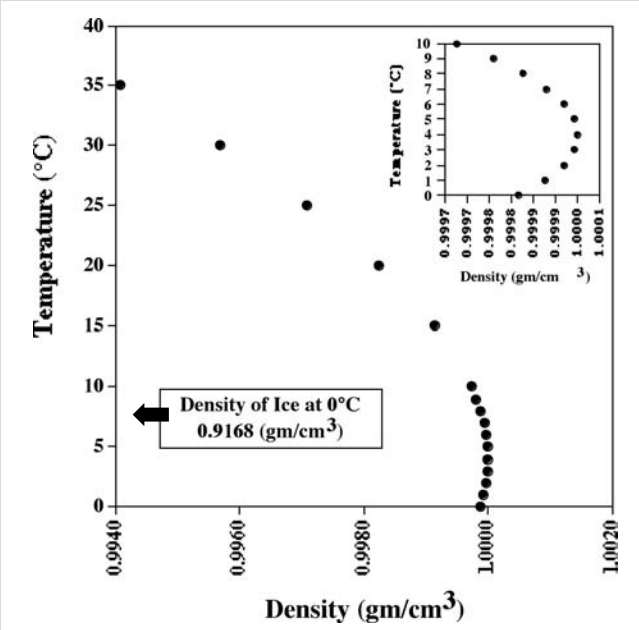
See the next section of this chapter for more about thermal stratification.

Figure 1
The Three Forms of Water and the Energy Required to Move From One Form to Another



The figure above describes the three different forms of water and the amount of energy required for a "phase change" to occur from one to another. Notice that it takes a lot more energy for water to change from a liquid to a gas (i.e., about 540 calories per gram [gm] of water) compared to the energy it takes to change from a solid to a liquid, which is about 80 calories.

Figure 2 Water Density and Temperature in Water



David Watson

Figure 2 illustrates the relationship between water density and temperature in water. The smaller graph shows the expanded relationship between zero and 10 degrees Celsius, indicating that the maximum density is at 4 C.

Technically Speaking: **Definitions for the Physical Properties of Water**

Professionals describe the physical properties of water using a somewhat specialized vocabulary. Anyone wanting to learn about oxygen and temperature in water should be familiar with the following terms and definitions:

Calorie – A calorie is a measure of energy. The scientific community defines a calorie as the amount of energy required to raise the temperature of 1 gram of water by one degree Celsius.
*Note: This is not the same as a food calorie (a.k.a. **kilo calorie** or **big calorie**) which equals 1,000 "energy" calories. In other words: a 165-calorie bagel should really be referred to as a 165-**kilo calorie** bagel.*

Heat – refers to the motion of the particles of matter.

Heat of fusion – is the heat that is required to convert one gram of a material from its solid form to a liquid state at the melting temperature (i.e., measured in calories). The mathematical equation for the heat of fusion is **L = Q/m**, where **Q** is the total heat absorbed and **m** is the mass of the substance.

Heat of evaporation – is the heat of water at the point of evaporation (i.e., boiling water). Additionally, there is a relationship between the amount of evaporated water and the heat energy used to make it evaporate. This quantity can be measured in units of calories. The heat of evaporation is also determined based on the temperature dependence of the vapor pressure and air pressure.

Phase change – refers to the process by which water changes from one form to another (e.g., from a liquid to a solid). During a phase change, the physical properties of water may change, but its chemical properties remain the same.

Specific heat – is the amount of energy (i.e., measured in calories) required to raise the temperature of one gram of water, by one degree Celsius.

Temperature – A measure of the average kinetic energy of molecules.

Thermal Stratification in Lakes

If you swim in a lake during the summer, you may notice that the water near your feet (i.e., the deeper water) is cooler than the water at the surface. This is because the surface water has been warmed by the sun and, as a result, has become less dense or "lighter" than the cooler water below it. This warm/cool layering effect is known as **thermal stratification**.

Most of the time, such density differences are caused by differences in water temperature. Even a difference as slight as one degree can result in stratification. Furthermore, as the difference in temperature increases (i.e., between the surface water and the bottom of the lake), so will the stability of the stratified layers; the "stronger" the stratification, the more difficult it is for the water to mix.

A textbook example of thermal stratification can be found in many of the deeper lakes up north. In fact, much of the terminology used to describe this concept was originally developed from research conducted on northern lakes. In a "typical" northern lake, it has been found that differences in water density will cause the water column to split into three distinct temperate regions. These regions are defined as follows:

• The uppermost, well-mixed layer of warmer water is called the **epilimnion**.

• The deeper, relatively undisturbed layer of cooler water is the **hypolimnion**.

• The layer of water between these zones is the **metalimnion**, the zone where water temperature changes most rapidly in a vertical direction.

Within the metalimnion, there is an area scientists refer to as a **thermocline**. Technically speaking, a thermocline is defined as a layer of water where the temperature decline exceeds one degree Celsius (1 C) per meter. In other words: the area acts as a barrier, or a transitional zone, separating the upper warmer layer from the deeper cooler layer. The upper warmer part of the metalimnion mixes with the epilimnion, while the bottom cooler part of the metalimnion mixes with the hypolimnion.

Lake Stratification and Temperature Profiles

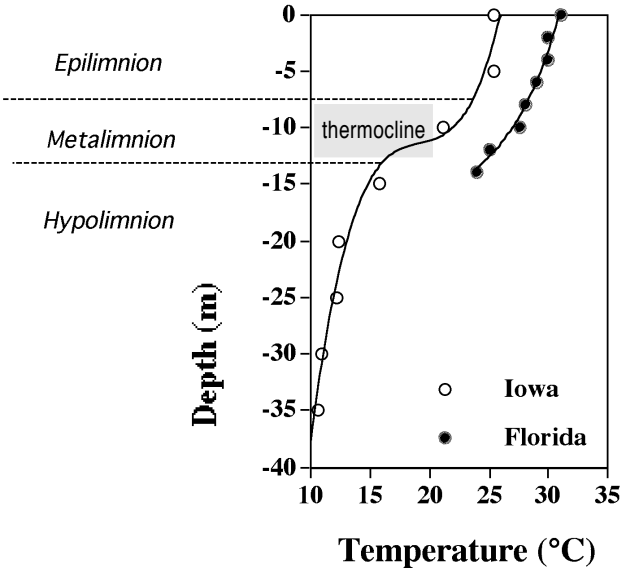
Figure 3 (below) compares the relationship between lake depth and temperature for a lake in Iowa and Florida. Both temperature profiles shown in the graph were taken in August.

As illustrated in the figure, the uppermost layer of warmer water is called the **epilimnion**. The deeper, relatively undisturbed layer of cooler water is the **hypolimnion** and the layer of water between these zones is the **metalimnion**. This is the zone where water temperature changes most rapidly in a vertical direction (a.k.a. the **thermocline**).

Notice that in the Florida lake, there is a much smaller temperature difference between the surface and bottom; temperatures range from about 30 degrees Celsius (C) down to 24 C, a difference of only 6 degrees. In the Iowa lake, the temperature span is considerably larger, ranging from 25 C down to about 10 C (i.e., a 15-degree difference). This tells us that the stratification in the Florida lake is not as strong or stable as the stratification in the Iowa lake.

Note: While "strong" stratification happens less frequently in Florida's shallow lakes, it does occur in the deeper spring-fed or sink hole lakes found throughout the state.

Figure 3



As a general rule, warmer water above the thermocline does not mix significantly with the cooler water below the thermocline. Consequently, the location of the thermocline in northern lakes is relatively stable over a period of weeks. However, during spring and summer months, it is constantly being pushed deeper into the water column as the upper layer of water warms up along with the air temperature.

Amy Richard

Plants and Their Effect on Stratification

Although plants generally increase oxygen levels in lakes, via photosynthesis, an abundance of aquatic plants can also increase a lake's stratification and, as a result, restrict the potential for oxygen in the water. Too many plants can block out sunlight, creating substantial temperature differences between water on the surface and the bottom. Additionally, dense aquatic plants can reduce wind and wave action, limiting the ability of lake water to mix and become further oxygenated.

In the fall, when the water begins to cool, the thermocline will migrate upward until density differences are so weak that mixing occurs once again, between the surface and the bottom. This mixing is commonly referred to as a **lake turnover**.

See page 13 for more about lake turnovers.

In Florida, the stratification dynamic is a little different. Because most lakes in the state are relatively shallow, there is usually only a small difference between water temperature measured at the surface and at the bottom. As you can see from Figure 3, even in August, there is a much smaller temperature difference between the surface and bottom of the Florida lake versus the Iowa lake: the surface/bottom temperatures shown for the Florida lake range from about 30 degrees Celsius down to 24 C — a difference of only six degrees. In the Iowa lake, the temperature span is considerably larger, ranging from 25 C down to about 10 C (i.e., a 15-degree difference). This tells us that stratification in the Florida lake is not as "strong" or stable as stratification in the Iowa lake. Of course, there are always exceptions. Florida's deeper sinkhole lakes sometimes experience substantial stratification, particularly during calm sunny days when there is plenty of solar energy available to warm undisturbed surface waters. This temporary condition can last a few hours or days, depending on weather conditions.

There are many reasons to study thermal stratification in a lake:

Temperature differences within a stratified waterbody can help us predict the amount of oxygen that should be available to fish and other organisms. For example, lakes that experience greater differences in water temperature from top to bottom generally tend to have less oxygen near the bottom, even though the water is cooler. (Note: While cooler water has the potential to hold more oxygen, there are times when dissolved oxygen concentrations are lower in cool water, especially at greater depths where there is no access to atmospheric oxygen and photosynthetic activity is limited due to lack of sunlight.)

See Part 3 for more about the effects that stratification can have on the biological activity within a lake.

Lake Turnovers

When a lake is stratified, water within the various layers does not mix unless something forces it to such as boat traffic, wind or storm events, etc. This is because water of differing densities is naturally resistant to mixing.

In some strongly stratified lakes, water may completely mix only once or twice a year, which is the only time when water temperatures are uniform throughout the water column from the surface to bottom. This phenomenon usually only occurs in the spring and fall and is referred to as a lake turnover because the lake's water completely mixes or "turns over."

In the fall, turnovers take place when air temperatures begin to drop and the surface waters of a lake begin to cool. As surface waters cool, they become more dense and begin to sink to the bottom, breaking through the stratified layers. As a result of this process, the water within the lake is allowed to mix. This scenario is common in deepwater lakes up north.

In contrast, shallow waterbodies, like many of the lakes here in Florida, turn over on a regular basis. Because they are shallow, even the slightest wind and wave action can mix the water column, from top to bottom throughout the year.

If a Florida lake does happen to maintain stratification, a lake turnover will generally occur in the fall, but it can also occur during the summer given the correct environmental conditions. For example, heavy winds and/or cold rain can break the stratification by physically mixing surface and bottom waters. This mixes higher oxygen concentrations within the surface water with the relatively low oxygen concentrations in the bottom layer of water.

If the volume of low oxygen water at the bottom of the lake is much greater than the volume of oxygen-rich water near the surface, the mixing action can result in lowering DO levels throughout the entire water column. As we learned earlier, if oxygen concentrations should fall below 2 or 3 mg/L, there is a distinct chance that fish and other aquatic organisms will begin to have trouble.

David Watson

Heavy winds and/or cold rain can break up the stratification by physically mixing surface and bottom waters.

Saltwater Stratification

In addition to thermal stratification, lake water can stratify due to differences in salinity. This is because salt water is more dense than freshwater.* In many coastal Florida lakes, surface waters are relatively fresh and float on top of the denser salt water underneath. At times, this can result in a lake supporting both freshwater and saltwater fish! This peculiarity occurs in several lakes in northwestern Florida (i.e., the Panhandle), and other coastal areas throughout the state.

** Typical lake water, with no salinity, has a density of 1.00000 (gm/cm^3) whereas the density of seawater (at approximately 35 parts per thousand) is 1.02822 (gm/cm3).*

Choctawhatchee Basin Alliance

Western Lake in Walton County, Florida.

Part 2 Section Summary

Factors Influencing Water Temperature – Energy from the sun and the temperature of the air surrounding a lake or waterbody are the main influencing factors on water temperature. Other influences include inflows and outflows, lake morphometry, wind, waves and lake color. The size of a water-body and the volume of water generally determine the influence that air temperature will have on a lake. Also, due to the sun's energy, water temperature is slower to change than air temperature.

Forms of water – Depending on its temperature, water exists in three forms: solid, liquid and gas.

Water Density – In its liquid form, water density changes with temperature. The difference in density, for every single degree of change (Celsius), increases dramatically at higher water temperatures, whereas the smallest density difference for one degree of change occurs at 4 degrees Celsius (39.2 F). Accordingly, as the difference in density increases, so does the amount of energy required to mix the two layers of water.

Thermal Stratification – Because deeper water is cooler and denser than surface water, a layering effect often develops in lakes; cooler water stays deep and warmer water (i.e., which is less dense) is found near the surface. This condition is called thermal stratification; the differences in water densities are the result of differing temperatures.

Thermal stratification is often considered the most important aspect of temperature's influence on lakes. Shallow Florida lakes are not as well stratified as the deep-water lakes in northern states, but there are differences in temperature between the surface layer and water near the bottom, often times by several degrees. Stratification makes it more difficult for mixing to occur between the layers. This lack of "mixing" can keep oxygen from reaching the deeper, stratified water and, under certain conditions, and can result in low oxygen problems within a waterbody.

Lake Turnovers – Layers of water can "turn over" when wind and wave action effectively mixes the water, despite density differences. Although mixing adds oxygen, extreme situations and rapid mixing can have negative effects. Storms with strong winds and large amounts of cold rain during extremely hot weather can rapidly mix a lake. During these warm weather conditions, there is more oxygen in the surface water and less in the bottom water. Rapid mixing can lower the oxygen concentrations throughout the water column enough to stress or kill fish.

Deep lakes found up north and even some of Florida's deeper lakes naturally experience lake turnovers each fall as surface waters cool and begin to sink to the bottom.

Turnover Terminology

In lake science circles, there are several terms that are used to describe the frequency of lake turnovers:

Lakes that mix only once a year are often referred to as **monomictic**. Accordingly, lakes that mix once a year, during the coldest part of the year, are referred to as **cold monomictic** lakes. Some deeper Florida lakes are considered to be cold monomictic waterbodies because they mix in the wintertime (i.e., once the water cools down enough to "de-stratify").

Warm monomictic lakes tend to mix only once, during the warmest part of the year. Many Canadian lakes fit this category as they mix during the summer, just after the spring thaw and before freezing again in the fall.

Most northern lakes in the U.S. are considered to be **dimictic** because they mix twice a year (i.e., in the fall and the spring).

Shallow lakes, like many of the waterbodies found in Florida, are considered to be **polymictic** because they can turn over many times each year.

Jennifer Donze

Amy Richard

Geoff Brown studies a sampling of aquatic plants during a water quality workshop on Hall Lake in Leon County, Florida.

Part 3
Biological Productivity, Oxygen and Temperature

After reviewing the relationship between oxygen, temperature, and water, we can now discuss how these factors affect the biological productivity of a lake (i.e., the ability of plants and animals to survive in the aquatic environment). We'll start by introducing a few key terms that scientists commonly use to describe biological productivity. Using these definitions, which are part of the **Trophic State Classification System**, lakes are grouped into one of four categories called **trophic states**:[6]

Oligotrophic (oh-lig-oh-TROH-fic) lakes have the lowest level of biological productivity. A typical oligotrophic waterbody will have clear water, few aquatic plants, few fish, not much wildlife, and a sandy or rock/gravel bottom.

Mesotrophic (mees-oh-TROH-fic) lakes have a moderate level of biological productivity. A typical mesotrophic waterbody will have moderately clear water and a moderate amount of aquatic plants, fish and wildlife.

Eutrophic (you-TROH-fic) lakes have a high level of biological productivity. A typical eutrophic waterbody will either have lots of aquatic plants and clear water or it will have few aquatic plants and less clear water (i.e., dominated by algae). In either case, it has the potential to support lots of fish and wildlife.

Hypereutrophic (hi-per-you-TROH-fic) lakes have the highest level of biological productivity. A typical hypereutrophic waterbody will have very limited water clarity (i.e., due to an abundance of algae) and the potential for lots of fish and wildlife. It may also have an abundance of aquatic plants.

Oxygen and Biological Productivity

Over the years, there has been extensive research conducted to document the relationship between the biological productivity of a lake and the amount of oxygen in the water. As a result of this work, there are a few generalizations that can be made. For example, oligotrophic lakes seem to experience relatively small changes in oxygen concentrations over a 24-hour period. This can be attributed to the fact that lakes with low productivity experience less photosynthetic activity and also less respiration (i.e., due to the smaller number of aquatic organisms within the waterbody).

On the other end of the spectrum, more productive waterbodies, such as eutrophic and hypereutrophic lakes, have been found to experience large fluctuations in oxygen concentrations over a 24-hour period. This is attributed to the fact that lakes with lots of aquatic plants and animals tend to experience high levels of photosynthetic activity and respiration; there's simply a lot more going on within the system. These waterbodies also happen to have the greatest potential for oxygen-related problems.

See Figure 4 on page 18 for an example of the fluctuations that occur in dissolved oxygen concentrations within a lake or waterbody, during a 24-hour period.

---

6 *The Trophic State Classification System was developed in 1980 by two Swedish scientists, Forsberg and Ryding. It is based on four main criteria: total chlorophyll, total phosphorus, total nitrogen and water clarity (Secchi depth). There are times when LAKEWATCH includes aquatic plants as an additional criteria for assessing productivity.*

Algae, Aquatic Plants, and Oxygen

In Florida, it has been documented that hypereutrophic lakes, with chlorophyll concentrations of 100 milligrams per liter (mg/L) or greater, have an increased risk for catastrophic oxygen loss — especially during extended periods of cloudy weather or after a die-off of a dense algal bloom. Some of the most problematic situations exist when there are several consecutive days of hot cloudy weather, with little or no wind. Such conditions represent a double jeopardy for aquatic life. It works like this:

As the layer of warm surface water increases in volume (i.e., from solar heating), there is less potential for water to hold oxygen in the top portion of the lake. If there is no wind, there is even less oxygen diffusing into the water from the atmosphere. Likewise, cloudy weather reduces the amount of photosynthetic activity within the aquatic community. Under such hot conditions, algae and aquatic organisms continue to respire, using oxygen faster than it is being produced or diffused into the lake. If the oxygen deficit becomes large enough, it can have a detrimental effect.

Even more dramatic reductions can occur following a massive algal bloom. As algae begin to die, oxygen levels can drop due to bacteria working overtime to decompose the dead algal material and consuming more oxygen as a result.

A similar dynamic can occur with larger aquatic plants (aquatic macrophytes), including **emergent plants**, **submersed plants**, **floating plants or floating-leaved plants**.[7] During daylight hours, all of these plants add oxygen to the water (and air) via photosynthesis. But they also *use* oxygen 24-hours a day. Accordingly, an overabundance of plants can have a variety of negative effects on oxygen concentrations in lakes:

• When there are too many aquatic plants dying (e.g., from natural causes or weed control) oxygen levels can drop dramatically due to activity within the bacterial community as it works to decompose the dead plants. When this happens, bacteria consume even more oxygen.

• When floating and floating-leaved plants are too thick, they can prevent oxygen from diffusing into the water. They can also reduce mixing within the water column by preventing wave action.

• Shade created by an abundance of floating plants and floating-leaved plants can prevent light from reaching submersed plants and algae, limiting their ability to produce oxygen.

---

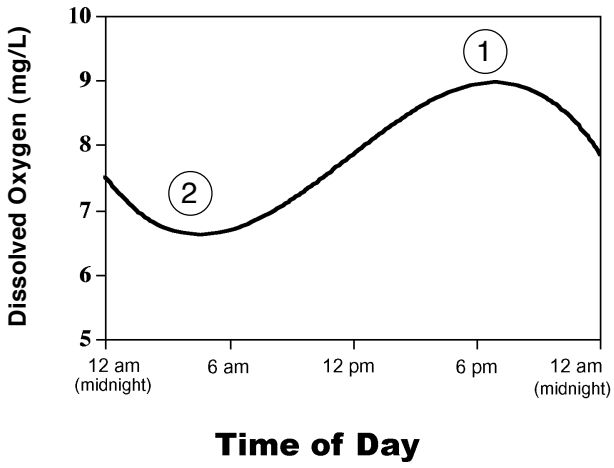
7 ***Emergent plants*** *— aquatic plants that emerge or protrude out of the water.*

Submersed plants *— aquatic plants that grow below the surface.*

Floating plants *— aquatic plants that float on the surface; roots are not attached to the bottom (e.g., water hyacinth).*

Floating-leaved plants *— aquatic plants that are primarily rooted to bottom sediments but also have leaves that float on the water's surface (e.g., water lilies.)*

Figure 4 Diel (Daily) **Oxygen Curve**



1 At "normal" summer temperatures (i.e., in a waterbody), dissolved oxygen concentrations will generally be high if algae and aquatic plant populations are actively photosynthesizing and producing more oxygen than is being consumed. This usually occurs in the mid to late afternoon.

2 Conversely, DO concentrations will fall below saturation if there is not enough wind to mix the water or if plant and animal populations are consuming more oxygen than is being produced. That's why the lowest DO levels often occur during pre-dawn hours. Also, on cloudy days, when there is less photosynthetic activity, DO concentrations can potentially drop to lethally low levels.

Other Factors That Can Decrease Oxygen In Water

For the most part, we have been focusing on the effects that aquatic plants and algae have on oxygen concentrations in a waterbody. However, it's important to note that other substances, from outside the lake, can also play a role in the oxygen "equation." For example, if a lake is receiving heavy inputs of natural organic matter (i.e., dissolved substances from leaves, twigs, grasses, etc.), oxygen concentrations in the water can dip to levels that are below saturation.

This situation generally occurs in Florida's highly colored lakes due to inputs from the watershed (i.e., during periods of heavy rain) and the dynamic is similar to that of a large algal bloom die-off. Once the material is introduced to the waterbody, organisms within the bacterial community will begin to work harder to decompose the material and, as a result, may deplete oxygen faster than it is being produced.

Temperature and Its Effect On Fish Populations in Florida Lakes

As described in the thermal stratification section (Part 2), water temperature is rarely uniform throughout an entire lake. In fact, it can vary by one or two degrees, even within a range of a few feet. Because of this, the distribution of many fish species also varies throughout a waterbody. Different species thrive at different temperatures and as a result, they tend to stay in a particular area within a lake, where the temperature is best for them.

But that's not all. Ambient water temperature "drives" several important life processes for fish including their metabolic rate, growth rate and reproduction.

Metabolic rate – Because fish are cold-blooded animals, their rate of activity is based on the temperature of the water. For example, if we were to compare a fish living in a northern lake with a similar species in a southern lake, we would find that the northern fish has a slower metabolism than its southern counterpart; the cooler water in the northern lake basically lowers a fish's energy requirements and as a result, they need less food.

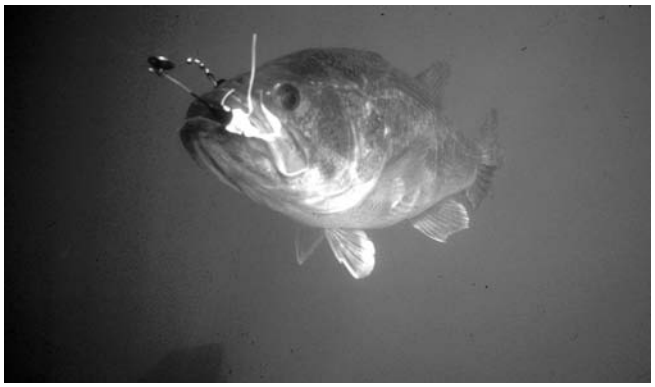
Growth rate – Following that same line of thought, it also means that northern fish grow more slowly than a similar species in warmer southern waters. In essence, cooler water translates into a shorter growing season for fish. This has been documented over and over again. For example, largemouth bass in a northern lake may take up to 15 years to reach a weight of ten pounds while the southern warm-water variety may reach the same weight in only five years.

Reproduction – Water temperature is also extremely important to fish reproduction. Changes in temperature are one of the main triggers for fish spawning activity. Rapid changes in temperature in a lake can cause fatalities for most fish species during their reproductive period; eggs or newly hatched fry can die from a dramatic temperature drop. Sometimes dramatic temperature variables cause adults to abandon the nest.

Of course, each of these processes are affected in a slightly different way, depending on the individual species. (Details are beyond the scope of this publication. For more information, refer to the sources provided in the back of this booklet.) Since there are several variables that can affect the ideal temperature for individual species, only general statements can be made.

In the book, *Principles of Fisheries Science* (W. Harry Everhart, Alfred W. Eipper and William D. Young, 1975), the authors state that 21 degrees Celsius represents a general division between cold-water and warm-water fish populations. This means that cold-water species, including trout, do not live at temperatures above 21 C (69 F), whereas warm-water species, such as channel catfish, do best when water temperatures are well above 21 degrees. In fact, a channel "cat" can even survive for a while when water temperatures climb into the 30-degree range (90 F)!

Fish populations in Florida are considered to be "warm-water" species because they can tolerate warm water temperatures year-round. More than 100 native warm-water species thrive in the various freshwater habitats around the state, though most people only come into contact with about a third of them. Out of all of these fish, it is safe to say that the largemouth bass is the single most popular species.



Joe Richard

Largemouth bass *(Micropterus salmoides salmoides)*

However, many people do not know that there are two different subspecies of largemouth bass in our midst; both the Florida largemouth bass *(Micropterus salmoides floridanus)* and northern largemouth bass *(Micropterus salmoides salmoides)* are stocked in lakes throughout the south, providing excellent fishing. They also provide a perfect example of the various temperature tolerances that exist in fish, even within a single species. A case in point: it is thought that severe freezes in the late 1970s helped deplete fish populations in a number of southern states when water temperatures dropped low enough to kill many stocked Florida largemouth bass. However, Northern largemouth bass survived just fine because of its tolerance for lower water temperatures.

While there was no immediate mass die-off of the Florida subspecies (i.e., in Florida), water temperatures did get low enough to stress the fish in many lakes within the northern portion of the state. It was later theorized that the stress, from the low temperatures, may have made many of the Florida subspecies susceptible to disease, as sick fish appeared in north Florida lakes for months following the freeze and many probably ultimately died.

For more information on fish stress, refer to UF/IFAS LAKEWATCH Information Circular 107, Understanding Fish Kills in Florida Freshwater Systems.

Florida lakes are also home to many exotic subtropical and tropical fish species. Several consecutive years of mild winters have allowed populations of these fish to colonize in lakes further north in the state and produce large numbers of offspring. One example is the blue tilapia *(Oreochromis aurea)* from Africa's Nile River.

This fish was inadvertently introduced into Florida waterbodies in 1961 and is now successfully reproducing in 24 counties. However, those who worry about the further spread of such fish, can take some comfort in knowing that their distribution is often naturally limited by their sensitivity to low temperatures.

This very scenario was demonstrated recently in Lake Alice, a small waterbody on the University of Florida campus in Gainesville, located in north central Florida. For several years, the lake supported a population of blue tilapia that was estimated to be around 12,000 fish. However, in December 2000, Gainesville temperatures were considerably colder than the fish's native African habitat and it stayed that way for several weeks. By January, dead tilapia began to float to the surface of the lake. By the middle of the month, all but a few of the tilapia had died, while native species survived the cold temperatures with few problems.

Analyzing Fish Kills

While cold-water stress often contributes to fish die-offs, it may not be the only factor. For example, if the dead fish happen to be tropical or subtropical (exotic) species only, temperature is likely the main reason for the die-off. But if there are many different species of fish that have died, it is less likely that low temperature was the cause.

When fisheries biologists examine fish kills, they also research weather conditions prior to the event. If a cold front came through a week before the dead fish appeared, it is possible that the fish died right away and sank, resurfacing after a few days or even weeks.

Seeing large numbers of floating dead fish on the surface of your lake can be very disconcerting and concern is highly justified. That is why, when LAKEWATCH volunteers note weather conditions accurately, the information gives researchers a better overall picture of the lake's ecology and can help explain the reasons contributing to a fish kill, should one occur.

For more on fish kills, see LAKEWATCH Information Circular 107 Understanding Fish Kills in Florida Freshwater Systems.

Part 3 Section Summary

Oxygen and Biological Productivity

Years of research have shown that there is a relationship between the amount of oxygen found in the water and the biological productivity of a lake (i.e., the amount of algae, aquatic plants, fish and wildlife). Lakes with low productivity tend to experience small changes in oxygen concentrations, over a 24-hour period, and highly productive lakes experience much larger fluctuations.

Algae, Aquatic Plants and Oxygen

Both algae and aquatic plants play a major role in the oxygen cycle as suppliers (via photosynthesis) and consumers (via respiration). If algae and/or plants are extremely abundant in a waterbody, there are a number of negative (oxygen-related) effects that can occur — especially when combined with changes in weather or increases in water temperature.

Other Factors That Can Decrease Oxygen In Water

Large inputs of dissolved and particulate organic matter can reduce oxygen concentrations in lakes.

Temperature and Its Effect On Fish Populations in Florida Lakes

Water temperature "drives" several important life processes for fish including their metabolic rate, growth rate, and reproduction. Because fish are cold-blooded animals, their rate of activity is based on the temperature of the water. This means that northern fish grow more slowly than a similar species in warmer southern waters. Also, because their energy requirements are less than warm-water fishes, cold water fishes tend to need less food. During reproductive cycles, rapid changes in water temperature can cause fatalities for most fish eggs and larvae.

Fish found in Florida lakes are considered to be "warm-water." There are also many exotic tropical and subtropical fish species found in lakes throughout the state which are even less cold tolerant than our native warm-water species. Fortunately, further distribution of these exotic fish is "naturally" controlled by occasional cold temperatures.

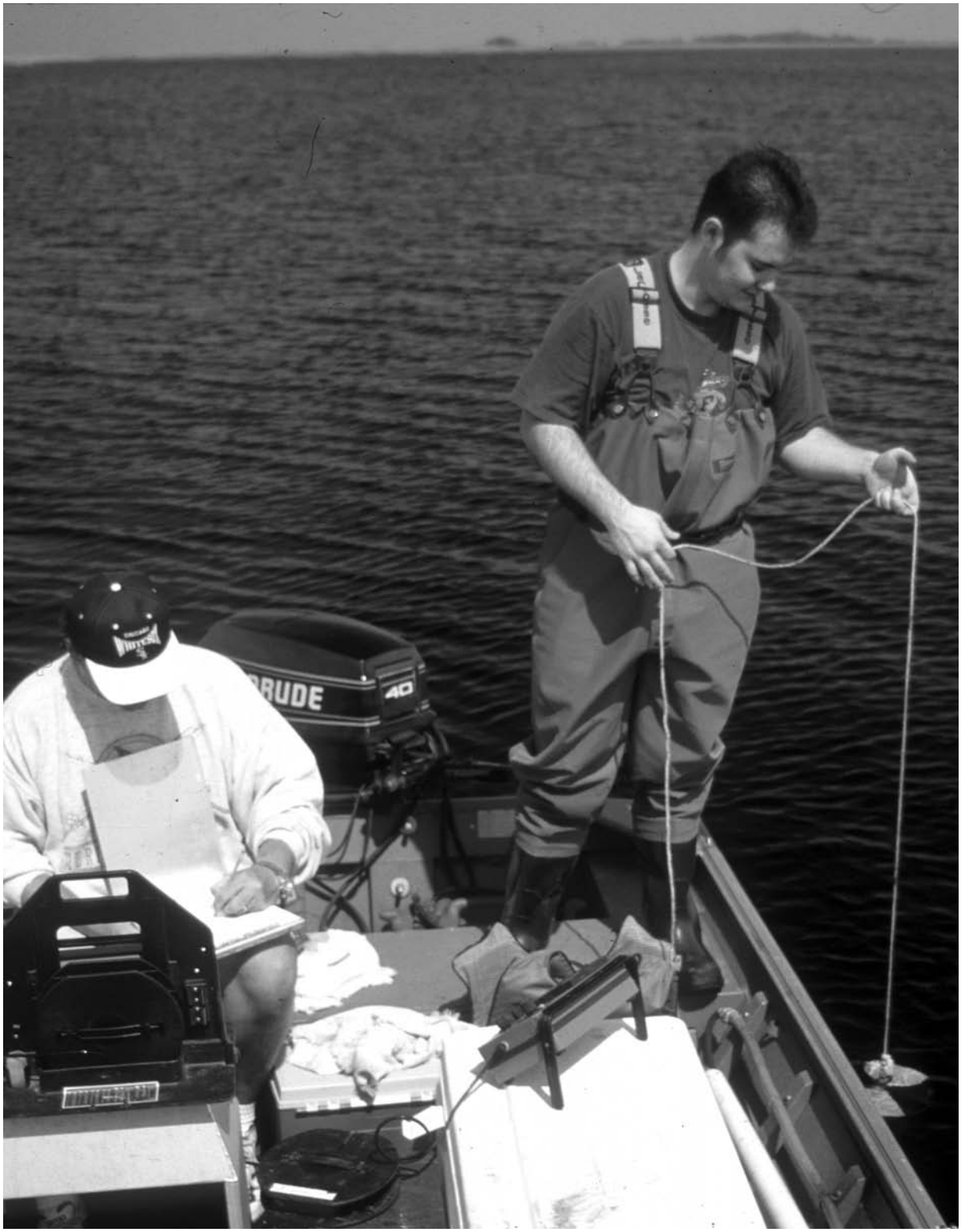
Cold-water Vs. Warm-water Fish

Discussions about cold-water versus warm-water fish can be confusing as some warm-water species do live in northern lakes. For example, some people may be surprised to learn that the largemouth bass subspecies *Micropterus salmoides salmoides* can found in lakes as far north as Maine and Minnesota. While it is difficult to visually distinguish it from the Florida largemouth bass *(Micropterus salmoides floridanus)*, these fish are genetically distinct.

For a fisheries manager, this is important information as cold water temperatures can affect one subspecies much more dramatically than another. An example: in the 1980s, when large numbers of bass began dying in lakes in upstate New York (i.e., the result of low pH, caused by acid rain), biologists considered restocking the lakes with Florida largemouth bass. They theorized that since the Florida version seemed to do well in lakes with naturally low alkalinity (pH), they would also do well in the northern lakes. However, their "good idea" would not have worked because the Florida subspecies cannot tolerate cold-water temperatures, and would have died that first winter.

For more information on temperature related fish kills, refer to LAKEWATCH Information Circular 107, Understanding Fish Kills in Florida Freshwater Systems.

LAKEWATCH director Mark Hoyer with a Florida largemouth bass *(Micropterus salmoides floridanus)*.



Chuck Cichra

Electronic dissolved oxygen (DO) meters, like the one shown here in the foreground (on the left), cost about $1,000. For many individuals and/or monitoring groups, this cost is prohibitive. Also, the underwater probe that is used along with the meter is expensive (i.e., around $200) and once they break, the entire probe has to be replaced. This is one reason why Florida LAKEWATCH is not able to offer oxygen monitoring on a regular basis. Pictured above: One student is about to lower a Secchi disk into the Suwannee River to measure water clarity while another prepares to record the measurement.

Part 4

Methods Used for Measuring Dissolved Oxygen in Water

Scientists measure dissolved oxygen concentrations using electronic instrumentation and/or chemical analyses:

Electronic Measuring Methods

Today, scientists mostly rely on electronic dissolved oxygen (DO) meters as a convenient way to measure dissolved oxygen in the field. These instruments eliminate the need for transporting potentially dangerous chemicals and the process is less time consuming than laboratory chemical analyses.

A DO meter requires no reagents and most of the substances that would normally interfere with chemical determinations have little effect on sensor determinations. The most reliable readings are obtained from waters with DO concentrations that are one milligram per liter (mg/L), or higher. Readings for samples with lower concentrations are only approximate.

A reliable, oxygen meter can be purchased for about $1,000. It is essential that the meter be calibrated correctly for accurate readings. Otherwise, the measurements are meaningless. Worse yet, inaccurate readings can lead to the wrong conclusions when monitoring a lake.

A Test for Determining if a DO Meter is Measuring Accurately

There are a few easy procedures that can be done to test whether a DO meter is calibrated properly (also known as "setting a standard"):

1 Collect three containers, with lids, and partially fill them each with water (i.e., about 2/3 full).

2 Now take two of the containers and add varying amounts of ice to each. Leave one of the water containers at room temperature. This will provide you with three containers of water, with temperatures ranging from about 10, 15 and 20 degrees Celsius. (Room temperature is about 20 C.)

3 Aerate the water within each of the containers by shaking them and occasionally lifting the lids, allowing air in. This technique generally provides water samples with an oxgen saturation approaching 100%.

4 Now, measure and record both water temperature and dissolved oxygen concentrations from each of the containers, using a electronic DO meter. (Most models measure DO and temperature.)

5 Find the nomogram chart (on page 25), and place it in front of you, along with a ruler or straight-edge of some kind.

6 On the top axis of the nomogram (i.e., the upper-most horizontal line) plot the three water temperature values you just collected. Then plot their corresponding dissolved oxgyen values on the bottom horizontal axis.

7 Using the ruler or straightedge, draw a line from each of the temperature values down to their corrsponding dissolved oxygen values on the bottom axis. The lines you draw should intersect the middle line in the chart (a.k.a. the diagonal Percent Saturation Line).

8 Check to see where the lines are crossing along the Percent Saturation Line. They should be hitting at or near the 100 percent mark (i.e., within at least 0.5 points). If they are close, you'll know that the DO meter is calibrated and working properly. If they are not close, you'll know that adjustments need to be made to the DO meter.

Chemical Analysis

Chemical analysis of the oxygen content in a water sample involves a complex series of chemical reactions that occur upon adding various chemical reagents at timely intervals. The standard Winkler procedure is used to test for dissolved oxygen in relatively pure waters. If oxidizing or reducing substances are present (e.g., nitrites or ferrous iron), they often cause interference leading to erroneous results.

Modified Winkler methods include the addition of reagents that eliminate interferences (i.e., like those mentioned above) and are suitable for determining dissolved oxygen in most natural waters. Before the electronic age, the azide modification of the Winkler method was the standard method for dissolved oxygen determinations. The analysis involved the following series of field and laboratory procedures. As one can imagine, such tedious procedures can make it difficult to analyze samples, especially if a large number of samples need to be processed.

Field Procedures

• A sample of water, collected in special glass bottle (BOD bottle) with a glass stopper lid, is treated with manganous sulfate and azide.

• The glass stopper lid is immediately inserted so the bottle becomes air-tight, eliminating the possible introduction of additional oxygen.

• The bottle is inverted several times to mix the sample and reagents, at which time Manganous ions will react with dissolved oxygen present in the alkaline sample, forming a manganese (IV) oxide hydroxide flocculent. The azide suppresses interference from any nitrites that may be present.

Laboratory Procedures

• The solution is then acidified using sulfuric acid.

• The manganese (IV) flocculate is reduced by the addition of iodide to produce free iodine in proportion to the oxygen concentration.

• The liberated iodine is titrated to the starch-iodide end-point, using sodium thiosulfate or phenylarsine.

• A starch indicator is added to enhance end point determination by producing a color change from dark blue to colorless.

• The dissolved oxygen of the sample is calculated from the quantity of titrant used.

Technically Speaking: **The Mechanics of a DO Meter**

Jennifer Donze

A digital DO meter used by LAKEWATCH.

Dissolved oxygen meters use an electrode equipped with a temperature compensating thermistor. The electrode consists of a gold cathode and a silver anode surrounded by a potassium chloride electrolyte solution.

The sensor is isolated from the environment by a thin Teflon membrane that allows gases to enter. As oxygen passes through the membrane, it is consumed at the cathode and an oxygen pressure gradient is formed across the membrane.

The membrane offers a resistance to the diffusion of oxygen to the inside, with the amount passing through the membrane proportional to the oxygen pressure outside. The application of a polarizing potential between the cathode and anode produces an electrical current that is proportional to the amount of oxygen being reduced at the cathode. The meter instrumentation converts the flow of current to a reading that indicates the DO concentration in milligrams per liter (mg/L).

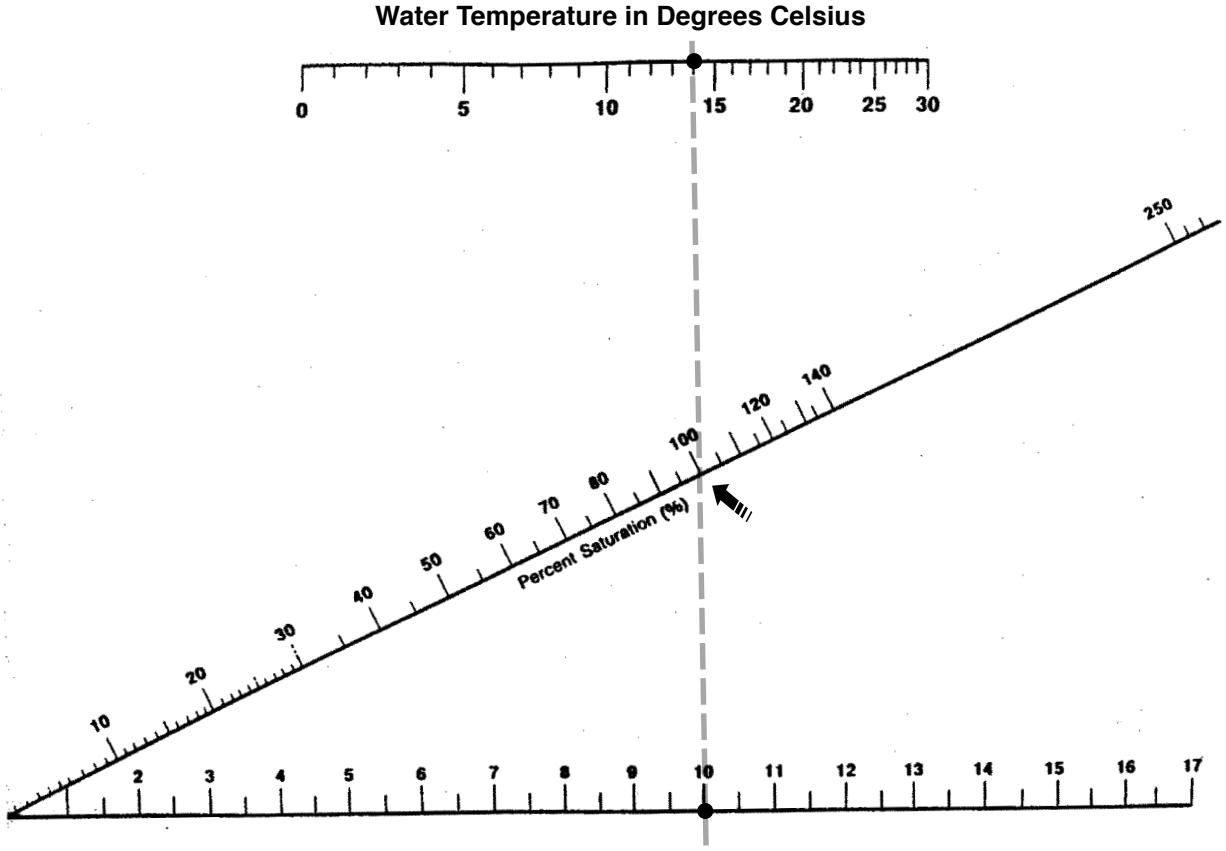
Note: Before using the DO meter, it is important that the sensor be fitted with a clean membrane and the meter is calibrated for local atmospheric pressure.

Figure 5 Dissolved Oxygen Percent Saturation

As described in Part 1, the **Percent Saturation of Dissolved Oxygen** depends on the temperature of the water and the elevation of the water testing site (i.e., ignoring biological activity). Because most of Florida is at sea level, lake elevation is not usually included in the formula. However, in the far northern part of the state or even in neighboring Georgia, some lakes are located at higher elevations so it is necessary to first use the table on page 26 to find the correction factor for altitude. Once you have this number, you can multiply it by the dissolved oxygen measurement (i.e., collected from the lake or waterbody in question). The resulting value is known as the **corrected dissolved oxygen concentration.**

Once you have the **corrected dissolved oxygen concentration** you can use the **nomogram** chart below to determine the **percent saturation** for the waterbody:

- Mark the corrected dissolved oxygen value on the bottom horizontal line of the chart.
- Now mark the corresponding water temperature on the upper horizontal line of the chart.
- Using a straight-edged instrument, connect the two marks and draw a straight line.
- Notice where the line crosses the percent saturation axis (i.e., the diagonal line).The numeric value that you see at this point of contact is known as the **percent dissolved oxygen saturation value**.



(Measured with a dissolved oxygen test kit or meter)

Example: If the water temperature for "My Lake" is 14 degrees Celsius (**14 C**) and if the dissolved oxygen concentration measurement is **10 mg/L**, it can be said that the **percent dissolved oxygen saturation** of the water in My Lake is **100%**.

Part 4 Section Summary

Methods Used for Measuring Dissolved Oxygen in Water — Dissolved oxygen concentrations can be determined by conducting a series of complex chemical reactions or measured electronically with an oxygen meter. Today most scientists use electronic meters because chemical analysis involves substances that are potentially dangerous and it is time consuming. However, there are complications related to the meters, as well. For one thing, it is essential that they be calibrated correctly for accurate readings. Otherwise the measurements are meaningless, or worse, inaccurate readings can lead to the wrong conclusions when monitoring a lake. Secondly, the cost of a good DO meter (i.e., about $1,000) can be prohibitive for many individuals or monitoring programs.

How Does LAKEWATCH Measure Oxygen and Temperature?

Florida LAKEWATCH does not regularly measure dissolved oxygen in lakes as it is too expensive and time consuming. However, DO measurements are taken electronically by our regional biologists when special circumstances warrant it. Temperature is not regularly monitored for the same reasons. However, it is possible to calculate an accurate correlation between air temperature and water temperature by obtaining air temperature data from regional weather stations. For more information, contact the Florida LAKEWATCH at s1-800-525-3928.

Table 1

Correction Factors for Lake Altitude

Using the known atmospheric pressure or altitude (i.e., elevation) for a specific lake location, use the table below to determine the correction factor. Once you have determined the correction factor, you can multiply that number by the dissolved oxygen measurement (i.e., collected from the lake or waterbody in question). The resulting value is known as the **corrected dissolved oxygen concentration**.

Atmospheric Pressure (mmHg*)	**Equivalent Altitude** (ft)	**Correction factor**
760	0	1.00
730	1094	0.96
699	2274	0.92
669	3466	0.88
654	4082	0.86
623	5403	0.82
593	6744	0.73
578	7440	0.76
562	8204	0.74
532	9694	0.70
517	10,472	0.68

* **mmHg** is the abbreviation for a unit of measure known as **millimeters of mercury,** which is used to measure the partial pressure of a gas.

Selected Scientific References

Boyd, C. E. 1990. Water quality in ponds for Aquaculture. Auburn University. Auburn, Alabama, USA.

Everhart, W. H., A. W. Eipper, and W. D. Young. 1975. Principles of fishery science. Comstock Publishing Associates, a Division of Cornell University Press. Ithaca, New York. USA.

Hutchinson, G. E. 1957. A Treatise on Limnology. Volume I. Geography, Physics, and Chemistry. John Wiley & Sons, Inc.. New York, New York. USA.

Wetzel, R. G. 1975. Limnology. W. B. Saunders Company. Philadelphia, Pennsylvania. USA.

Florida LAKEWATCH

Florida LAKEWATCH (FLW) is one of the largest citizen-based volunteer monitoring endeavors in the country with over 1,500 individuals monitoring more than 700 lakes and waterbodies, in more than 50 counties. Staff from the University of Florida's Department of Fisheries and Aquatic Sciences train volunteers throughout the state to conduct monthly long-term monitoring of both fresh and saline waterbodies. LAKEWATCH uses the long-term data to provide citizens, agencies and researchers with scientifically-sound water management information and educational outreach.

To become part of the FLW team, volunteers are required to have access to a boat and complete a two-hour training session. During the session, they will learn to collect water samples, take water clarity measurements, and prepare algae samples for laboratory analysis. Once a volunteer is certified by a regional coordinator and sampling sites are established, he or she will sample the designated stations once a month. Samples are frozen immediately upon being collection and are later delivered to a collection center, where they are stored until they can be picked up by FLW staff and delivered to the UF/IFAS water chemistry laboratory at the Department of Fisheries and Aquatic Sciences.

In return for participation, volunteers receive:

- Personalized training in water monitoring techniques;
- Use of lake sampling materials and water chemistry analysis;
- Periodic data reports, including an annual data packet regarding their waterbody;
- Invitations to meetings where FLW staff provide an interpretation of the findings as well as general information about aquatic habitats and water management;
- Access to freshwater and coastal marine experts;
- Free newsletter subscription and educational materials regarding lake ecology and water management.

For more information, contact:

Florida LAKEWATCH

UF/IFAS
Department of Fisheries & Aquatic Sciences
7922 NW 71st Street
PO Box 110600
Gainesville, FL 32653-3071
Phone: (352) 392-4817
Toll-free: 1-800-LAKEWATch (1-800-525-3928)
E-mail: lakewat@ufl.edu
Web-site: http://lakewatch.ifas.ufl.edu/