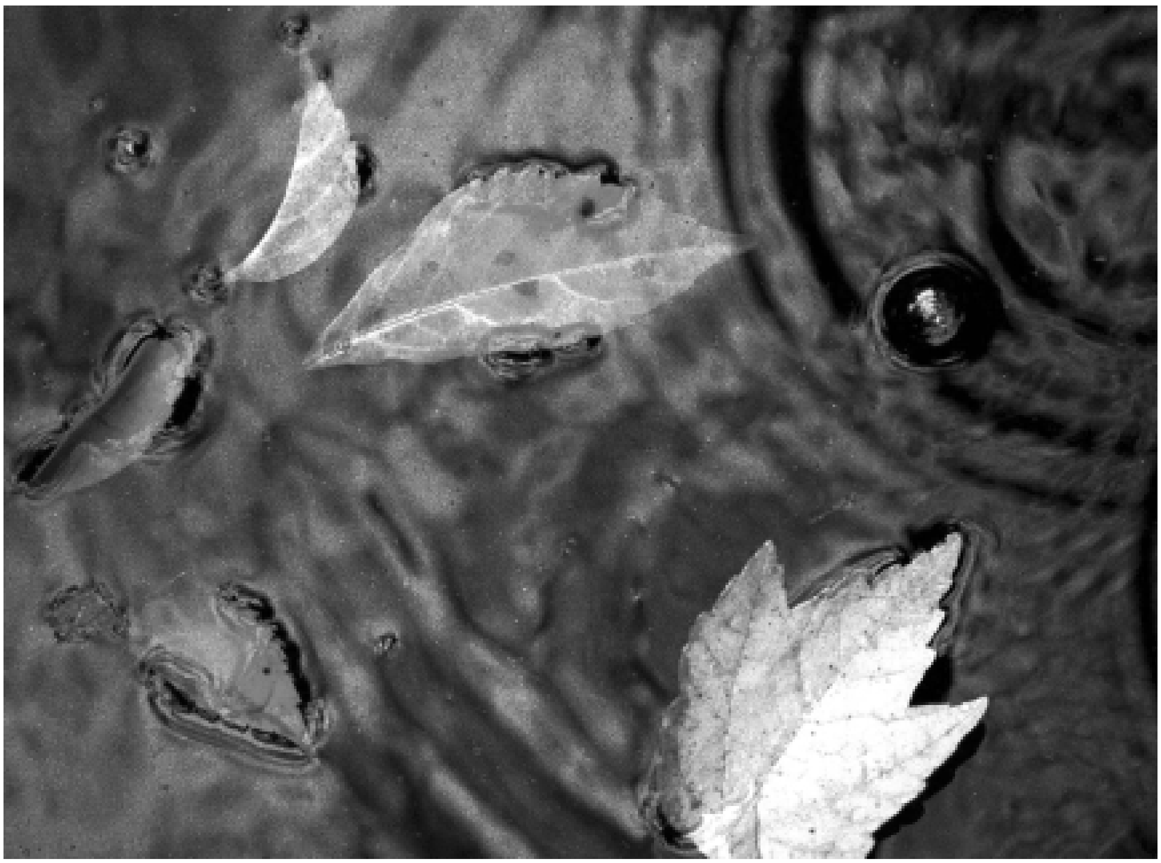
A Beginner's Guide to Water Management — Color

Information Circular 108



Joe Richard

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

January 2004
1st Edition

UNIVERSITY OF FLORIDA EXTENSION
Institute of Food and Agricultural Sciences

Florida LAKEWATCH

This publication was produced by:

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

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

As always, we welcome your questions and comments.

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A Listing of Florida LAKEWATCH Information Circulars

Note: For more information related to color in lakes, we recommend that you read Circulars 101, 102 and 103.

Beginner's Guide to Water Management – The ABCs (Circular 101)
This 44-page publication, in a user-friendly glossary format, provides a basic introduction to the terminology and concepts used in today's water management arena.

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 in lakes. Limiting nutrients are discussed, along with conceptual and mathematical tools that can be used to achieve a variety of water management goals. The booklet is 36 pages in length.

A Beginner's Guide to Water Management – Water Clarity (Circular 103)
Anyone interested in the subject of water clarity can benefit from reading this 36-page circular. Topics include the many factors that can affect water clarity in Florida lakes, techniques for measuring it, as well as discussion of the methods used for managing this important lake characteristic.

A Beginner's Guide to Water Management – Lake Morphometry (Circular 104)
Knowledge of the size and shape of a lake basin (i.e., lake morphometry) can tell us a great deal about how a lake system functions. It can also help us appreciate lakes for what they are and manage them with more realistic expectations. This 36-page booklet is recommended for anyone interested in learning more about the terminology and techniques currently being used to study lake morphometry in Florida.

A Beginner's Guide to Water Management – Symbols, Abbreviations and Conversion Factors (Circular 105)
This 44-page 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.

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

A Beginner's Guide to Water Management – Fish Kills (Circular 107)
In an effort to alleviate concerns voiced by the general public regarding fish kills, this 16-page booklet discusses five of the most common natural causes of fish kills: 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 of the circular provides steps one can take to help biologists determine the cause of the event including a listing of fish health diagnostic laboratories and instructions on how to collect fish and/or water samples for analysis.

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 at: ***http://lakewatch.ifas.ufl.edu/LWcirc.html*** *or from the UF/IFAS Electronic Document Information System (EDIS):* ***http://edis.ifas.ufl.edu.***

Sarah Hanson, a 5th grade student at the Narcoossee Community School in Osceola County, Florida holds up a water sample from Lake Tohopekaliga.

Introduction

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. Such events often take us by surprise as many of us carry a mental image of a lake or waterbody as we first saw it and generally don't expect changes to occur. In reality, however, many lakes and waterways in Florida can display a wide variety of hues over time, ranging from a clear blue to vivid green, to orange or almost black.

Water color can be influenced by any number of factors: some colors occur naturally; some may be human-induced or result from a combination of circumstances. For example, heavy rain events are known to wash organic substances into the water where they dissolve and act as a dye; seasonal algae blooms can result in such high concentrations of algae that the water becomes tinted with the coloration of the algal cells; or wind events may stir up fine particles off the bottom, re-suspending them into the water column. Color may also be the result of inorganic materials (e.g., clay particles, etc.) from storm-water runoff or shoreline erosion.

It's no wonder that many visitors and/or residents are often bewildered when they see the spectrum of colored lakes and waterbodies throughout Florida. Sometimes, these differences are misinterpreted as an indication of pollution. In rare instances, they may be correct, but most of the time lake color is a result of naturally occurring processes that have more to do with the geology of the soils *under* the lake bed or runoff from areas within the surrounding watershed.

Admittedly, accepting colored lakes as "normal" can be difficult, especially since colorless or "clear" water is traditionally considered the ultimate water quality standard in many states. While this may be true when it comes to drinking water, it doesn't always apply for many of Florida's unique aquatic systems.

So, how do we know if colored water is natural?

Collecting long-term color data is a good way to start — especially if it's combined with long-term water chemistry measurements for algae (total chlorophyll), nutrients (total nitrogen and total phosphorus) and water clarity. With such information, we can discern much about what is happening in a lake or waterbody. Thanks to Florida LAKEWATCH (FLW) volunteers and a dedicated staff, we now have access to data for hundreds of lakes throughout the state. In fact, much of the material provided in this circular was made possible by our volunteers and the samples they've collected. (In addition to the usual monthly sampling regimen, our water chemistry technicians have been able to use the same water samples to conduct color analysis on FLW lakes two to four times a year.)

These efforts have allowed us to compile and analyze data from thousands of samples and, as a result, identify some rather strong patterns between a lake's water color and its biological productivity (i.e., the amount of algae, aquatic plants, fish and other wildlife). We've also learned just how important color can be to lake management even though it is often overshadowed by concerns about nutrients, algae or aquatic plants. This is unfortunate as color may well be influencing many of these same lake characteristics.

We hope you find this publication useful in your quest to learn more about the aquatic environment and, as always, we welcome your questions and comments. Because this material is intended for a varied audience including citizens, students and scientists, we've tried to organize the information into agreeable portions for everyone. Think of this circular as an educational buffet; feel free to take what you want and leave the rest for those with larger appetites.

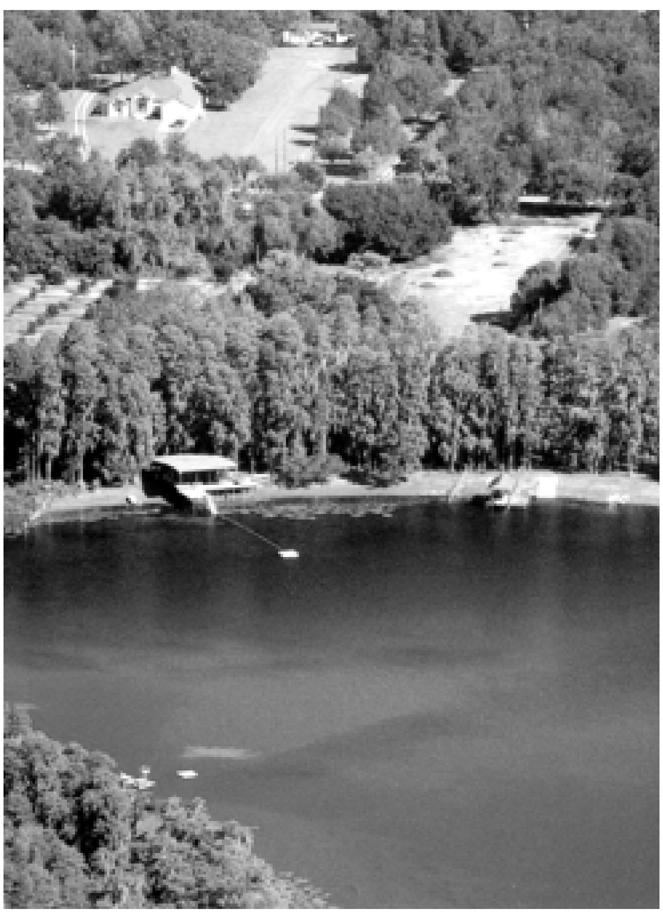
Bon appetite!

Included in this circular:

List of Figures

Joe Richard

Joe Richard



FCCDR/USF

Joe Richard

Part 1
Two Ways to Define Color in a Waterbody

There are two basic terms commonly used when referring to the color of the water in a lake or waterbody. One is known as **apparent color** and the other as **true color**. When communicating with lake residents, lake managers and others, it's helpful to know the difference between the two. In Part 1, we'll begin our discussion by defining these two types of lake color and in Part 2, we will go into greater detail about what influences both types. In Part 3, we'll delve even deeper to see how color can influence the biology of a lake (i.e., the amount of algae, aquatic plants and wildlife).

Apparent Color

Apparent color is the color of the water as seen by the human eye. For example, when a person looks into a lake, the water may appear to be colorless (i.e., clear), blue, green, yellow, red, brown, black or somewhere in between.

Most of the time, apparent colors are the result of substances that are either **suspended** or **dissolved** in the water column. However, there are other factors that can affect the apparent color of a lake including the color of the lake bottom (i.e., is it light or dark?); the depth of the lake; reflections from the sky, trees or structures surrounding the waterbody; and the presence or absence of aquatic plants. Some of these factors can be difficult to measure, which is why lake management professionals prefer to use true color measurements when assessing a lake.

See page 2 for information on true color.

Measuring Apparent Color

Some water management professionals assess the apparent color of lake water using the Forel-Ule color scale, a system developed by European lake scientists. The scale classifies lake color into 22 categories ranging from blue, greenish blue, bluish green, green, greenish yellow, yellow and brown. Using the scale, one can determine the apparent color of a lake by visually matching (i.e.,, with the naked eye) the color of the water with the Forel-Ule color spectrum.

In Europe, this system has been used as a way of defining the various levels of a lake's productivity: lakes with water that appears to be blue are considered to be less productive. Green, yellow and brown lakes are considered to be more productive. In the United States, the Forel-Ule system is seldom used for measuring the apparent color of water because it is cumbersome and difficult to use.

Suspended substances can include algal matter (i.e., floating in the water column or stirred up bottom sediments due to wind mixing or boating activity) or non-algal matter such as finely ground calcium carbonate particulates from limestone. Depending on the source, these substances may impart any number of colors to the water, including a blue-green tint, various shades of brown, gray, green or even orange.

Dissolved substances often include metallic ions of iron and manganese from natural sources (e.g., rocks and soils) as well as humic acids and tannins derived from organic matter (e.g., dead leaves and plants, etc.). These substances usually impart a reddish or brown stain to the water.

Illustrating the Difference Between Suspended and Dissolved Substances

The following activities provide a handy visual aid for understanding the difference between suspended and dissolved substances:

Suspended substances

Fill a clear glass jar with water. Next, find several pieces of chalk and break them up or grind them into a coarse powder. Add this mixture to the water. If you were to stir the mixture vigorously with a spoon, the chalk would become suspended into the water, changing the overall color. Depending on how much agitation is used, the chalk may stay in the water column, sink to the bottom or float to the top.

Dissolved Substances

Now fill a clear jar with water and place three to four tea bags into it and place it out in the sun for about 30 minutes. Tannins from the tea leaves will begin to stain or color the water. This is an example of dissolved substances. The same process can be found in lakes that are colored by tannins from decaying leaf material, plant stems or roots found within the waterbody and/or surrounding watershed.

Important Points to Remember About Apparent Color

• Most of the recognizable apparent color in a lake is the direct result of suspended substances in the water (i.e., both algal and non-algal matter).

• Apparent color can change significantly once suspended substances are filtered out of a water sample. That is why scientists rely less on apparent color when studying lakes and instead, usually insist on taking true color measurements before coming to any conclusions about lake color.

• Nutrients can influence the apparent color of water *indirectly* by increasing algal populations. (e.g., Once algal populations increase, the algae themselves are known to release organic substances that can tint the water various shades of green or even brown.)

• Criteria used to determine apparent color is considered to be somewhat subjective whereas true color is based on actual water analysis measurements.

True Color

True color is defined as the color of water resulting from dissolved substances only; all suspended substances have been removed and are therefore not allowed to "conceal" or influence the color of the water. In the United States, when lake management professionals talk about "color," they are generally referring to true color.

Measuring True Color

True color is determined by first filtering a water sample to remove all suspended substances. After the samples have been filtered, they are compared to a specific color scale. This comparison is generally done in a laboratory with a spectrophotometer.

In the United States, the most commonly used color scale is the **platinum-cobalt color scale**. This system is comprised of 1,000 color units or **platinum-cobalt units** (**PCU** or **Pt-Co units**). If one were to use the platinum-cobalt color scale to measure lake water that is especially clear (i.e., colorless), the color readings would probably be less than 10 PCU, whereas lakes that have a little color will have a true color measurement ranging from 20 to 50 PCU. On the far end of the spectrum, lake water that is extremely dark in color will have a color reading of 500 PCU or higher.

In Florida lakes, true color generally ranges from 5 PCU to 600 PCU. Of course, there are always exceptions: Lake Charles in Marion County has shown true color readings approaching 700 PCU! To the naked eye, such a lake appears to be almost black in color.

Important Points to Remember About True Color

• True color measurements are especially helpful to lake scientists because they provide a standardized way of assessing the color of a waterbody.

• True color is a component of apparent color.

• True color does not stay constant; it can increase dramatically, especially after prolonged rain events or it can decrease under severe drought conditions.

• Waterbodies with limited suspended particles will generally have true color measurements that coincide with the visual appearance of the water. However, in waterbodies with an abundance of suspended particles, true color measurements will not necessarily coincide with apparent color. For example, algae or clay particles can make the water appear to be a certain color, but once the particles are filtered out, its appearance may change significantly. That's one reason why lake management professionals prefer to use true color measurements instead of apparent color.

How Does Florida LAKEWATCH Measure True Color?

Florida LAKEWATCH measures the true color of lake water using the **platinum-cobalt color scale**. These measurements are processed two to four times a year from water samples that volunteers provide (i.e., the same samples that are being processed for total nitrogen and total phosphorus analysis each month). Usually, an equal amount of water is taken from each of the bottles collected for a lake, for a given month. The water is then combined to form an 'average' color sample for that lake. In some instances, water samples from individual stations are analyzed separately, particularly if there are obvious visible color differences between the sampling stations.

Water is filtered to remove any particulate material. Afterwards, the sample is spun in a **centrifuge**,* measured on a **spectrophotometer**,** and compared to a series of **platinum-cobalt standards** (i.e., standards that simulate the color of lake water).

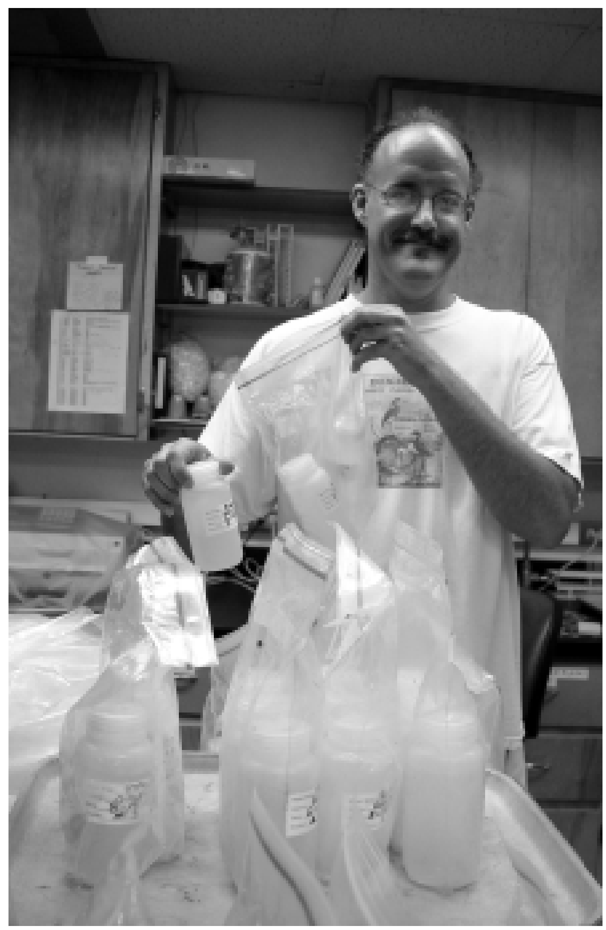
At the end of the year, color measurements are averaged for each lake and that number is included as part of the annual periodic water chemistry data.

Color data from Florida LAKEWATCH lakes can be obtained by:

• accessing the annual data report on the FLW website: http://lakewatch.ifas.ufl.edu/

• calling 1-800-LAKEWATch (1-800-525-3928) to obtain a copy of the printed page from the annual report;

• requesting a printout of the annual data packet, which now includes color data in the form of tables and graphs.



Note: Florida LAKEWATCH evaluated frozen water samples among a wide range of true color values and they did not change significantly over time.

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* A **centrifuge** is a machine that uses centrifugal force (i.e., intense spinning) for separating substances of different densities.

** A **spectrophotometer** is an instrument that is used for measuring the relative intensities of light found in different parts of a light spectrum.


David Watson

Grasshopper Lake in Lake County.

An Anecdote About True Color

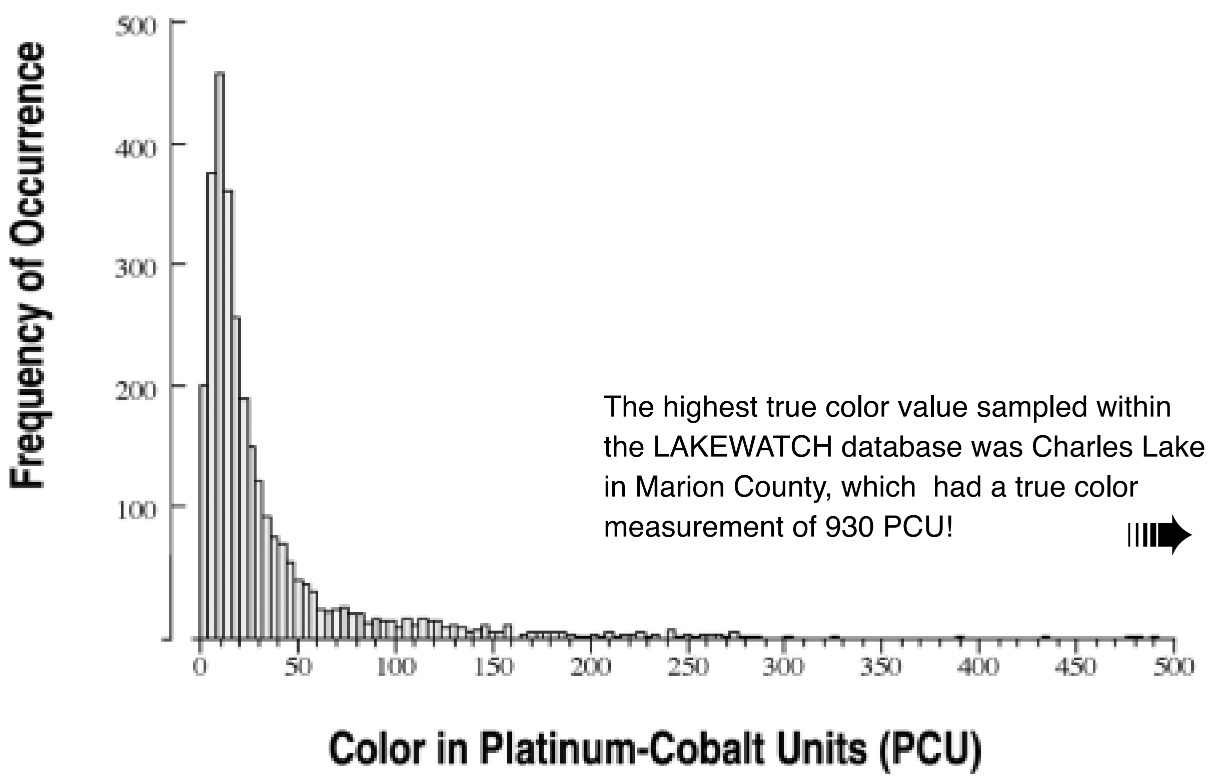
True color has been found to be strongly linked to the amount of seasonal rainfall a watershed receives and the amount of runoff that seeps into a waterbody. This phenomenon has been documented with LAKEWATCH data numerous times. For example, in 1993 -1994, Grasshopper Lake, in Lake County, had Secchi depth values greater than 12 feet. This happened to be during a time of extremely dry weather. Following heavy rains in 1995 - 1996, the same lake had Secchi depth measurements of less than three feet. The difference in water clarity was associated with a change in true color from 0 PCU in the dry years to more than 50 PCU after the heavy rains.

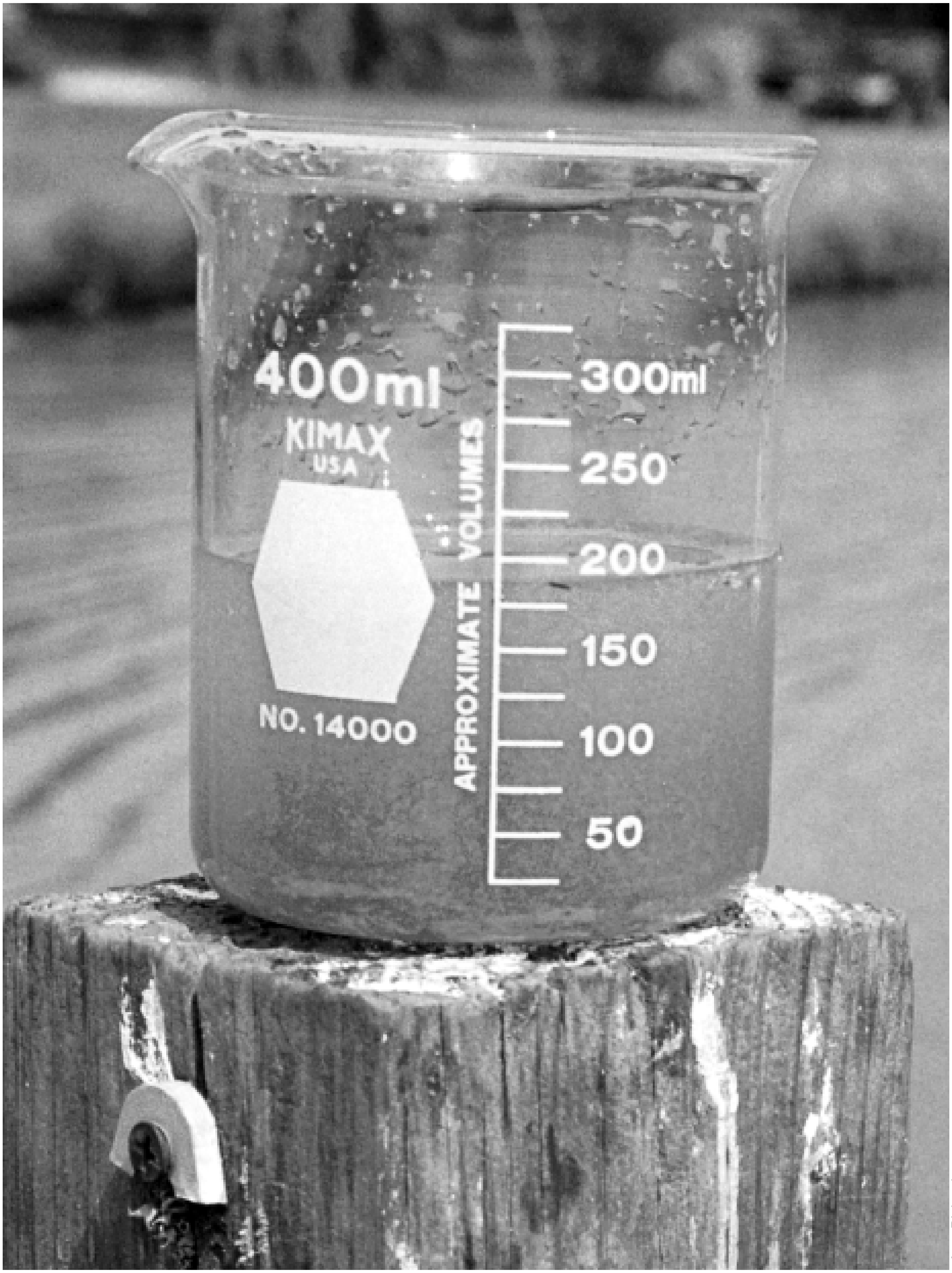

David Watson

Bladderwort *(Utricularia spp.)*, a submersed plant, grows abundantly in Grasshopper Lake when water clarity is sufficient.

Figure 1 Color Frequency in Florida Lakes

The graph below is an illustration of the frequency of occurrence that color values occurred in lakes throughout Florida. To be more specific, 3,223 true color measurements have been collected and plotted from 670 waterbodies, located within 48 Florida counties. Color measurements ranged from 0 PCU to 930 PCU, with a median of 18 PCU. Because there are very few lakes that had color measurements exceeding 500, the y-axis in this graph (i.e., Frequency of Occurrence) stops at 500. Notice the left portion of the graph clearly shows that the lion's share of lakes in this data set (i.e., about 79 percent) had color measurements that were less than 50 PCU.





Amy Richard

Suspended algal matter can easily be seen in this glass beaker. The sample was pulled from the adjacent pond at the UF/IFAS Department of Fisheries and Aquatic Sciences in Gainesville.

Part 2
More About Suspended and Dissolved Substances

Now that we've learned about the two basic ways that lake scientists define color, we will discuss suspended substances and dissolved substances in greater detail, as they are particularly important to understanding the color of a waterbody.

Suspended Substances

There are any number of naturally occurring suspended substances that can be found in Florida lakes or waterbodies. In lake management circles, they are also referred to as **suspended matter** or **particulates** and they are usually classified into two basic groups: **algal matter**, which consist of algae cells suspended in the water column and **non-algal matter** which includes fine soil particles or non-living plant material. Both are described in greater detail below.

Algal Matter

In many cases, apparent color in Florida lakes is due to large concentrations of algae suspended in the water. In other words, if there are enough algae in the water column, lake water will appear to be the same color of the actual algal cells. Sometimes, this results in a short-term event — an algae bloom for example — or sometimes lakes maintain a particular color for many months or years, due to the presence of a dominant algal species. Depending on the species and the amount of algal cells in the water, such blooms can impart a variety of colors to the water:

• Blue-green algae are dominant in the more eutrophic lakes and impart a dull-green appearance to the water. When large amounts of blue-green algae float to the surface, it may look like someone dumped a bucket of blue-green paint into the water.

A Mystery Color?

During the months of March, April or May, many Florida lakes have been known to take on a bright yellow hue. As a result, FLW has heard from many people who are under the impression that an algal bloom is occurring in their lake when, in fact, what they are seeing is pine and oak pollen floating on the surface or suspended in the water column. A clue for determining whether or not it's algae: If a yellow powdery substance has collected on cars, windows and other outdoor objects in the area, there's a good chance it's pollen.

• Yellowish-brown colors are frequently noticed in waterbodies where diatoms dominate the algal population.

• *Botryococcus* (pronounced Ba - TREE - o - cockus) is a type of algae that gives many Florida lakes a rusty or orange-brown color. It is often most visible during afternoon hours when it tends to float to the surface. At times, *Botryococcus* produces an oily sheen on the water, fooling people into thinking there's been a gasoline or oil spill.

• Many turbid lakes display a green hue due to green chlorophyll pigments within the algae. However, at times, some waterbodies have been known to develop a blood-red color. The cause of this red coloration is the alga *Euglena*, which produces a red pigment during intense periods of sunlight to protect its green chlorophyll pigment.

Non-algal Matter

Suspended particulate matter that is not of algal origin can also influence the apparent color of water. This includes both organic matter (e.g., tiny particulates from dead aquatic and terrestrial plants) or inorganic particles (e.g., clay, sand, soils). These materials are usually introduced to a lake from storm-water runoff or erosion of the shoreline. In Florida, these lakes, which are often described as "muddy," are in the minority. However, they do exist. In the northern part of the state, some lakes receive large amounts of red clay resulting in a distinctive reddish "Georgia clay" appearance. Lake Talquin and Lake Seminole are good examples. Other lakes receive inputs of grayish-white colored clay, giving them a milky white appearance.

In flatter parts of the state, erosion or runoff-related color is rare. However, the central and southern portion of Florida does have its share of lakes that are influenced by non-algal suspended sediments from *within* the lake itself. Lake Okeechobee and Lake Apopka are prime examples. In Okeechobee, water depth at numerous mid-lake locations is typically 2.7 meters (8.8 feet) and in Lake Apopka, the average mid-lake depth is 1.7 meters (5.6 feet). Because of the shallow depth and large amount of fetch in both lakes, wind is able to constantly re-suspend sediments from the bottom and mix them throughout the water column causing changes in apparent color.[1] This is known as **turbidity-related color**. Needless to say, water clarity at these same mid-lake locations is quite low (i.e., as measured by a Secchi disk), typically less than 0.33 meters (one foot).

There are also instances in which colloidal substances (i.e., particles tiny enough to pass through a filter) remain in a sample and affect water color. This is particularly true in limerock pits where inorganic materials such as calcium and magnesium carbonates will give water a green or emerald hue.

Can nutrients, such as nitrogen and phosphorus, add color to water in a lake?

Phosphorus and nitrogen are nutrients found in virtually every lake or waterbody. They are also naturally occurring in plants and soils. In fact, Florida's phosphorus-rich soils are what motivated many farmers to move to Florida in the early 1900s. Phosphate mines are also prevalent in various regions of the state, for the same reason.

As far as color is concerned, when nitrogen and phosphorus are dissolved in water, the inorganic compounds are generally colorless so they don't really add to the apparent and/or true color of a waterbody **directly**. However nutrients can affect color **indirectly** by influencing the growth of algae.

Example 1: In lakes where algae are abundant, the apparent color of the lake is affected because you are seeing the color of algal cells in high densities.

Example 2: Should algae concentrations begin to increase in lakes that previously had low algal abundance, one of the first things people notice is a shift in from a bluish color to various shades of green. This change is largely due to the release of organic matter from within the algal cells, which will be evident in a true color measurement.

For more on nutrients and algae, see **A Beginner's Guide to Water Management — Nutrients** (Circular 102).

Dissolved Substances

Dissolved substances can affect both true and apparent color. These substances enter lakes via a variety of pathways including surface water runoff from the surrounding watershed, following rain events, and the leaching of organic compounds from decomposing plant material within the lake itself.

Organic

The dominant dissolved substances found in water are typically organic compounds including humic acids and tannins that originate from many types of terrestrial and aquatic plants. There are literally hundreds of lakes in Florida that are colored due to the presence of these substances. (See Figure 1 on page 5.) As mentioned in Part 1, Lake Charles, in the Ocala National Forest, is a good example of this type of lake; the clear brown tea-colored water is the result of humic acids entering the waterbody from the surrounding watershed. Lakes with small amounts of these substances will generally appear green in color. (In this instance, the color is not related to algae.) As the waterbody receives more dissolved organic matter, the color will begin to shift from green to yellow-green, to a yellow-brown and then a "clear" brown.

In addition to the compounds described above, algae can be another source of dissolved organic matter in water. The substances are released

1 *Fetch is the distance that wind can travel over water before intersecting a land mass.*

directly into the water from the algal cells. This type of organic matter can change the true color of a lake by affecting light absorption. (See Part 3 for more on this.) However, when algae are very abundant, they can also affect apparent color as described on page 7. (See section on Algal Matter.)

Inorganic

Dissolved inorganic substances can also influence color in lakes. For example, in waterbodies that receive inputs that are high in dissolved iron compounds, apparent color might be described as rusty or orange-brown.

Long-term Color Changes

Joe Richard

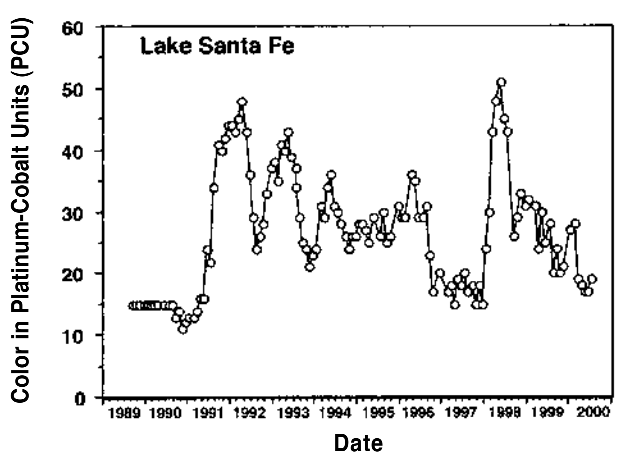
Those who have been fortunate enough to live on or near a Florida lake for a long period of time will tell you that the color of their lake seems to change seasonally, due to one or more of the influences described in this publication. However, it may also change over a period of years, based on regional climate patterns. For example, in 1991 and again in 1998, residents from Lake Santa Fe in Alachua and Bradford Counties, were alarmed to see the color of the water change from a clear green, with a color measurement of 15 PCU, to a dark reddish brown, with color values exceeding 40 PCU. (See Figure 2.)

It turns out that rainfall patterns were largely the culprit. While looking at Figure 2, notice that for several years prior to each event, color concentrations were low. Due to a marked lack of rainfall, there was less of an opportunity for tannins and other dissolved substances to wash or seep into the lake. As a result, Lake Santa Fe became fairly clear and stayed that way from about 1989 to 1991 and again from 1996 through mid-1998.

However, once the drought events were over and north Central Florida was back to its normal pattern of heavy afternoon thunder showers, rain water quickly began to flood the dying vegetation around the lake and surrounding swamp. This resulted in the release of dissolved substances into the lake.

Within a few months, the lake was tea-colored once again. As mentioned in Part 1, the same scenario occurred in Grasshopper Lake, in Lake County, with an even greater effect on Secchi depth (i.e., after heavy rains, Secchi depth measurements went from 12 feet to less than three). Of course, not everything is this easy to explain, but in Florida, if a lake should happen to change from a green to a brown color, there's a good chance it is related to rainfall patterns.

Figure 2 **Color Measurements Over Time (1989 - 2000) from Lake Santa Fe in Alachua/Bradford County.**



Joe Richard

To the naked eye, Florida's freshwater springs often appear blue in color, both above and below the surface. The remarkable water clarity is due to a lack of dissolved organics and suspended matter; with millions of gallons of water bubbling out of the ground every day at these locations, there is no opportunity for suspended or dissolved materials to accumulate in the water column. However, aquatic plants may be abundant. Pictured above: Two youngsters hover just beyond the main vent at Fanning Springs, which descends to a depth of about 15 feet.

Part 3
Light and Color in Water

Now that we know a little more about the various substances that can cause lake water to change and/or retain color, we will begin to explore the effects that it may have on a lake's biological productivity (i.e., the amount of plant and animal life supported by the lake). But before we do, we need to take a short detour into the physical sciences to learn about visible light. Granted, it may seem a bit odd to go off on this tangent, but rest assured, it is quite relevant; without visible light, we would not be able to see any of the colors discussed in this circular — or much else, for that matter. Ultimately, our little detour will lead us back to one of the main interests that lake scientists have regarding lakes: the growth of algae and aquatic plants.

Visible Light

Whether emanating from a firefly, a lightbulb or the sun, visible light is a form of electromagnetic (EM) radiation. Like other types of EM radiation (e.g., radiowaves, microwaves, infrared light, X-rays, etc.), visible light is a form of energy that travels outward from its source and widens as it goes. See Figure 3 for an illustration of how the various forms of EM radiation are categorized within the earth's electromagnetic spectrum. Notice that the low energy forms of radiation, such as radio waves have the longest wavelengths (i.e., around 3,000 nm) and high energy radiation, such as x-rays and gamma rays have shortest wavelengths (100 nm).

As its name suggests, visible light is the only type of EM radiation that is visible to the human eye. That's because, when we see light, we are seeing a combination of electromagnetic waves that are just the right size and intensity for our eyes to detect (i.e., between 400 and 700 nanometers on the EM spectrum).[2] Most of the time, this light appears to be white in color. However, if one were to pass a beam of light through a prism, the primary colors of the rainbow would emerge: red orange, yellow, green, blue, indigo and violet. This occurs because the prism separates the wavelengths, allowing us to see them individually.

When light shines down into a lake, it behaves in much the same way. While passing through water, light becomes refracted and is absorbed at different rates and depths. Colors such as red orange and yellow are the first to be absorbed as they have a lower radiant energy than blue wavelengths.[3] Once red and yellow wavelengths are absorbed by water, the higher energy blue wavelengths (indigo, blue and violet) are the only ones still visible to the eye. This explains why deep lakes, with clear water, often appear to be blue in color.

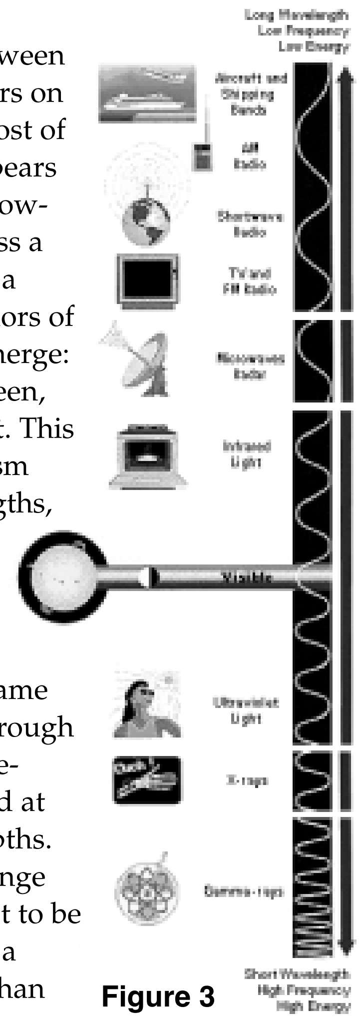


Figure 3

http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html

2 *Within the EM system, radiation wavelengths range from 100 to 3,000 metric units known as nanometers (nm).*

3 *Red has the lowest radiant energy of the visible light spectrum with an electron voltage of 1.8 and violet has the highest radiant energy with an electron voltage of 3.1*

Of course, light behaves differently in lakes with suspended or dissolved matter, as these substances can alter the way light refracts and is absorbed as it passes through the water column. This is crucial to the biology of a lake.

So, Why Do We Need To Know About Light Absorption In Lakes?

Humans aren't the only ones who make use of light and its radiant energy. It is also critical to the survival of nearly all animals and plants, both terrestrial and aquatic. When radiant energy falls on a lake it is reflected off the surface; utilized by plants; or converted to heat, contributing to the thermal stratification of the water. This in turn affects the rates of various biological and chemical processes within the lake — even the behavior of aquatic organisms.[4]

Photosynthesis is one of the most important of these processes as it enables plants and algae to utilize sunlight for creating food, and then releases oxygen into the water as a by-product. In fact, during this process, plants use the same portion of the visible light spectrum that we do (i.e., wavelengths between 400 and 700 nm). In the lake science arena, this portion of the spectrum is known as **Photosynthetic Active Radiation** or **PAR**. Scientists who study light in waterbodies are particularly interested in PAR, as it is a measure of the amount of light that is available at various depths and therefore can help us predict the abundance and type of plants (including algae) that might be expected to grow under those conditions.

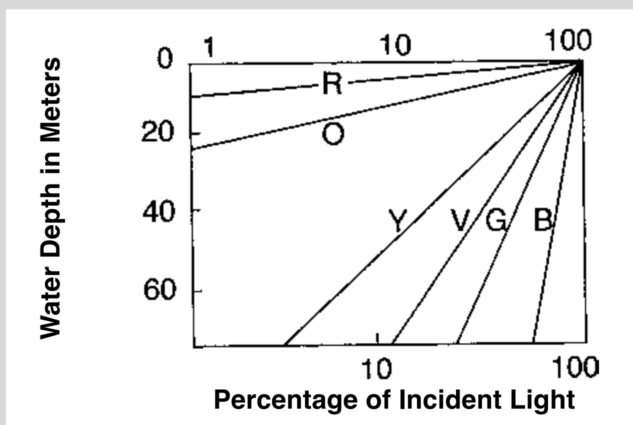
Measuring Light in a Lake

Generally, a light meter is used to measure the intensity of light just below the surface and at different depths. Information from the meter can then be used to calculate light attenuation (i.e., the depth at which light is no longer able to penetrate into the water column). For more on how this is done, see the mathematical formula provided on page 13. For the average citizen, the only drawback to this process is that light meters are expensive and require special training to operate.

Fortunately, there is another way to assess the depth of light penetration in water: A simple and inexpensive device known as a Secchi disk can be used. This device generally consists of a 20-cm (8-inch) disk that is white in color or has black and white quadrants painted on it. A string or rope is attached through the center. The rope is

4 *Further discussion of chemical processes and/or the behavior of aquatic animals, as it relates to light, is outside the scope of this publication. For more on the subject, see G.E. Hutchinson (1957) and R.G. Wetzel (1975).*

Joe Richard



Wetzel, 1975

Figure 4
An illustration of the transmission of light by distilled water at six wavelengths (i.e., the percentage of incident light that would remain visible after passing through various water depths). This diagram is based on the common (base 10) logarithmic scale, as indicated by the x-axis along the bottom.

Red (R) = 720 nm Orange (O) = 620 nm Yellow (Y) = 560 nm Green (G) = 510 nm Blue (B) = 460 nm Violet (V) = 390 nm

What is a Secchi Disk?

A simple and inexpensive device known as a Secchi disk can be used to measure light attenuation in water. This device generally consists of a 20-cm (8-inch) disk that is white in color or has black and white quadrants painted on it. (LAKEWATCH uses white disks.)

A string or rope is attached through the center. The rope is marked off in increments of meters or feet and a small weight is attached underneath the disk itself so that it will sink quickly when lowered into the water. As the disk is being lowered, the individual holding the device can use the markings on the rope to determine the depth at which the disk disappears. This measurement is commonly referred to as a **Secchi depth** or **water clarity measurement**.

The Secchi disk was invented around 1860 by an Italian named Pietro Angelo Secchi.

Amy Richard

marked off in increments of meters or feet and a small weight is attached underneath the disk itself so that it will sink quickly when lowered into the water. As the disk is being lowered, the person holding the device can use the markings on the rope to determine the depth at which the disk disappears. This measurement is commonly referred to as a **Secchi depth** or **water clarity measurement**. Once it is obtained, the measurement can be used to estimate light attenuation. A general rule of thumb is to multiply the Secchi depth by two. For example, if the average depth of a lake is eight feet and the Secchi reading is five feet, then we can multiply the Secchi depth by two to get our estimate:

2 x 5-foot Secchi depth = 10 feet of light penetration.

In this particular example, our calculation tells us that light is reaching the bottom of the lake. However, in the same lake, if the Secchi reading is only three feet, then it would tell us that light does not penetrate to the bottom:

2 x 3-foot Secchi depth = 6 feet of light penetration.

If this were the case, submersed aquatic plants would not be able to grow on the bottom, due to the lack of sufficient sunlight.

Mathematical Formula Used to Calculate Light Attenuation

The intensity of light diminishes with water depth in an exponential way. Professionals measure the intensity of light just below the surface and at different depths using light meters. They mathematically describe the decrease in light, with depth, by the following equation:

$$I_z = I_0 e^{-kz}$$

Where:

I_z is the intensity of light at depth **Z**.

I_0 is the intensity of light immediately below the surface of the water.

e is the natural logarithm

k is the vertical attenuation (reduction) coefficient for the downward penetration of light (also known as "irradiance").

Joe Richard

Part 4
Color and Its Influence on Algae and Aquatic Plants

Because light is so critical to the growth of aquatic plants and algae, lake scientists have spent a great deal of time observing and documenting just how much light is required for optimal growth. From their research, they have developed special terminology that helps describe their observations. For example, the terms **euphotic zone** and **euphotic depth** are frequently used to describe just how far light is able to penetrate into the water column:

- Euphotic zone is the portion of the water column where light is still present (i.e., greater than one percent of the surface light level).
- Euphotic depth is considered to be the depth at which light levels fall below one percent of PAR.

Both the euphotic zone and euphotic depth of a lake are directly influenced by the amount of color in the water (i.e., the amount of suspended and/or dissolved substances). As the amount of color increases in a lake, light penetration decreases and results in a limited amount of algal and/or submersed aquatic plant growth. To be more specific, algae have a difficult time growing when light levels fall below one percent surface PAR (1 PAR) and aquatic plants are affected when light falls below 10 percent of the surface PAR (10 PAR). Of course, there is some variation to this rule as different species of algae and aquatic plants require differing amounts of light.

Algae, Color and Light

Thanks to Florida LAKEWATCH data and an analysis made by Brown et. al. (2000), we know that a high true color value (i.e., 50-100 PCU) can have a negative effect on a lake's algal biomass.[5] In other words, it can limit the amount of algae growing in the water column. However, it must also be said that, most of the time, phosphorus and nitrogen have a much greater effect on algal abundance.

For more on the relationship between algae, color, nutrients and water clarity, see Part 5.

Aquatic Plants, Color and Light

As mentioned earlier, when light levels fall below 10 PAR, there is insufficient light for most submersed aquatic plants to grow or remain established in a lake.

How do we know this?

LAKEWATCH data and analysis by Bachmann et al. (2002) shows that Florida lakes with low true color measurements (i.e., values less than 50 PCU) can have as much as 100 percent of the lake bottom covered in plants.[6] (In scientific circles, this is expressed as **100 Percent Area Covered** or **100 PAC**.) However, once the true color exceeds 50 PCU, the percentage of the bottom that is covered seldom exceeds 40 PAC.

In addition, researchers have used the same data to calculate how light affects submersed aquatic plants that grow up through the water column. This measurement is known as the **percent volume inhabited** or **PVI**. The results are

5 *Claude D. Brown, Mark V. Hoyer, Roger W. Bachmann and Daniel E. Canfield, Jr. 2000. Nutrient-chlorophyll relationships: an evaluation of empirical nutrient-chlorophyll models using Florida and north-temperate lake data. Canadian Journal of Fisheries and Aquatic Sciences. 57(8): 1574-1583.*

6 *Roger W. Bachmann, Christine A. Horsburgh, Mark V. Hoyer, Laura K. Mataraza and Daniel E. Canfield, Jr. 2002. Relations between trophic state indicators and plant biomass in Florida lakes. Hydrobiologia. 470: 219-234.*

similar.[7] Lakes with color measurements that fall below 50 PCU have supported plant growth that takes up as much as 80 percent of the lake's volume (80 PVI). However, once true color values exceed 50 PCU, things change dramatically as these lakes generally have plant growth totaling 10 PVI or less. (See Figure 5 below.)

So what does this mean to the average lake user or lakefront resident?

It means that if a lake has significant color in the water, there is the potential for the lake to maintain less plant growth. This may be good news for individuals who aren't fond of aquatic plants in their lake (e.g., swimmers, waterskiers, etc.). However, others who like to bird watch or fish near aquatic plants might be less happy.

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7 *PVI is also used as an acronym for "Percent Volume Infested."*

Joe Richard

What About Emergent or Floating-leaved Plants?

While color can have a negative influence on submersed plants, things are a bit different when it comes to emergent or floating-leaved plants. In some instances, highly colored lakes (i.e., lakes with values higher than 50 PCU) have been known to support an abundance of emergent plants such as maidencane or various floating-leaved plants such as water hyacinth, water lettuce or spatterdock (a.k.a. cow lilies). While some of these plants may be submersed under water, growth is still possible as long as some of the leaves are above water or able to receive light.

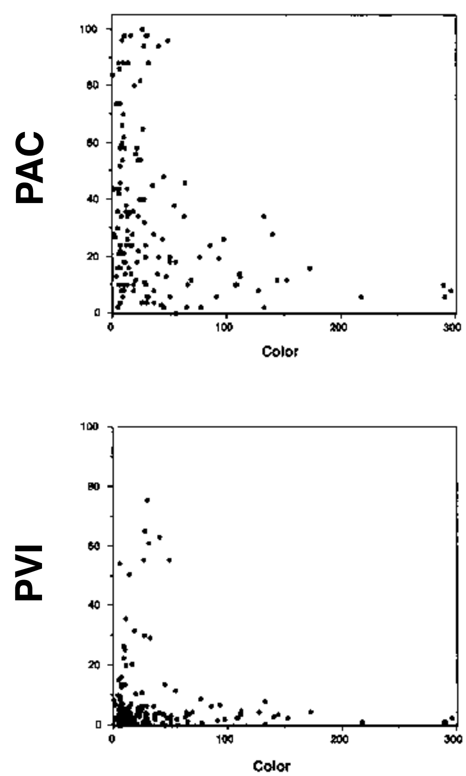
Figure 5 Color and Its Influence on PAC and PVI in Florida Lakes

The two graphs pictured here reflect some interesting patterns regarding aquatic plant abundance and color in Florida lakes:

The top graph illustrates the relationship between color and the **area** of a lake that is covered by plants (i.e., Percent Area Covered or PAC).

The bottom graph illustrates the relationship between color and the **volume** of a lake that is inhabited by plants (i.e., Percent Volume Inhabited or PVI).

Notice that when lake waters are highly colored, we do not find high percentages of the lake *area* inhabited by plants, nor do we find high percentages of the lake *volume* inhabited by plants. In fact, the highest percentages of plant abundance are found only in lakes with low color values (i.e., below 100 PCU). For lakes with color measurements below about 75 PCU, there is a good spread of PAC values (0 to 100%). However, notice that in the PVI graph, the majority of these lakes have PVI values below 10%. Only a few of them have higher values (i.e., ranging up to about 77%).



Aquatic Plants and Color

The **Tsala-Apopka Chain-of-Lakes**, located in Citrus County, in the west central portion of Florida, provides an excellent example of the influence that lake color can have on aquatic plant growth.

Dozens of lakes belong to this aquatic system — a fascinating network of islands, marshes, canals and lakes that seem to be loosely grouped into three pools: the Floral City, Inverness and Hernando Pools. The lakes within each pool are linked to each other by natural and artificial means, but many of the interconnecting waterways are intermittent, depending on rainfall and resulting water levels.

The lake shown in the distance is part of the Floral City Pool, within the greater Tsala-Apopka Chain-of-Lakes. The low water level is the result of severe drought conditions that affected this particular lake system for several years (2000 - 2003).

Figure 6a, shown below, depicts the amount of color measured in the Chain-of-Lakes in the late 1990s. Figure 6b provides an indication of the abundance of aquatic plants found in the Chain-of-Lakes within the same time frame. Compare Figure 6a with 6b. Notice that as color decreases (Figure 6a), the amount of submersed plants increases considerably (6b).

Note: The horizontal lines below each bar graph indicate which lakes are located in the three pools. Also, the lakes are listed in geographical order — as they exist within the prevailing water flow, which runs from south (S) to north (N) in this system.

Figure 6a
Color Measurements for the Tsala Apopka Chain-of-Lakes

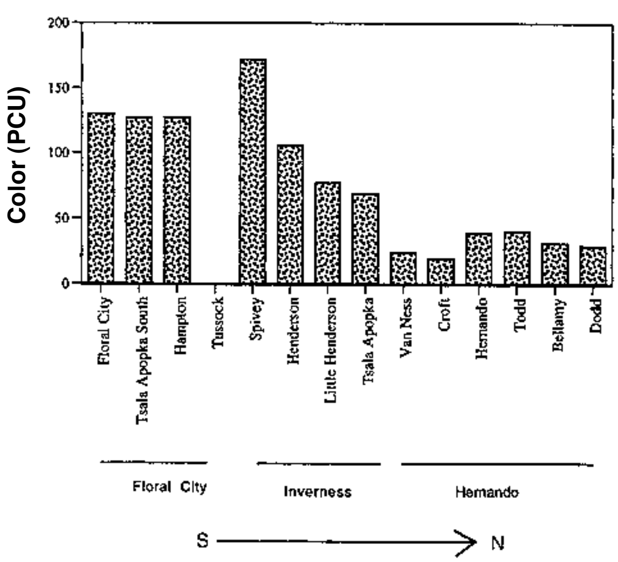
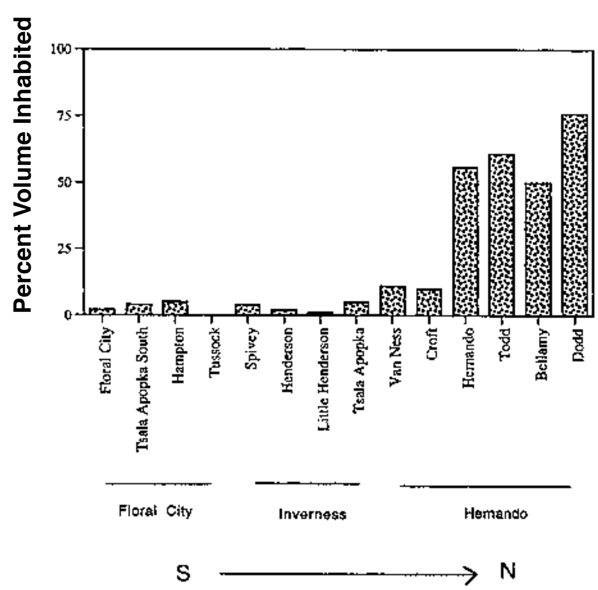


Figure 6b
Plant Abundance in the Tsala Apopka Chain-of-Lakes



Lake Wauberg in Gainesville, Florida.

Part 5
Color, Water Clarity and Algae

Without a doubt, water clarity is a major concern for most citizens who live on or use lakes. In Florida, water clarity is affected by three main factors:

- the amount of algae in the water;
- the amount of true color in the water;
- the amount of non-algal solids in the water (e.g., inorganic sediments such as sand and clay; and organic solids such as dead plant material).

For the most part, algae and true color are the major players.[8] We know this thanks to many scientific studies and long-term water chemistry data that have been collected by FLW volunteers around the state since 1986. However, it's not always easy to tell which of the two is having the greatest influence on water clarity. That's why scientists rely on mathematical equations, also known as **empirical models**, to try and predict such things and as a way of checking each factor against the other. The models are derived from statistical analysis of a specific set of data. In this case, they are derived from many years' worth of monthly water chemistry data, courtesy of Florida LAKEWATCH.

Using these equations, one can plug in known information from a data set (e.g., chlorophyll concentrations, Secchi depth or color measurements) and then do the necessary calculations. If the numbers don't match up, it may be an indication that some other factor is limiting water clarity, such as non-algal suspended solids.

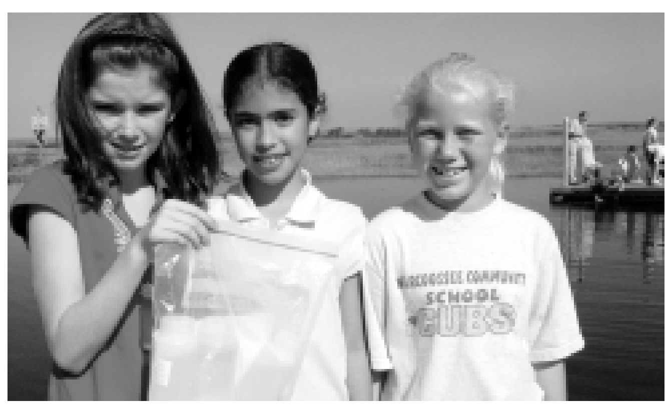
For lakes that are considered to be "algae dominated," an empirical Secchi-chlorophyll model is generally used to predict water clarity. Usually these equations only include Secchi depth and chlorophyll measurements as variables. However in Florida, color can also affect water clarity so it must be factored into the equation. The following Secchi-chlorophyll model was developed using FLW data from hundreds of lakes throughout the state:

$$\text{Log (Secchi)} = 0.86 - 0.36 \text{ Log (CHL)} - 0.27 \text{ Log (color)}$$

Where:
Log is the common (base 10) logarithm.
Secchi is the mean Secchi depth in meters.
CHL is the mean chlorophyll concentration in micrograms per liter (µg/L).
Color is the mean true color concentration in Platinum Cobalt Units (PCU).

Note: The model above is slightly different from the Secchi-chlorophyll model introduced in A Beginner's Guide to Water Management — Water Clarity (Circular 103). When it was published, LAKEWATCH did not have the data needed to include color in the equation. Now that we do, we can offer a new version for those who are interested in exploring the effects that color might be having on a specific lake.

See Appendix 1, on page 21, for more on how to use an empirical model.



Amy Richard

Students from the Narcoossee Community School in Osceola County, Florida hold up water samples collected as part of a LAKEWATCH training session.

8 *For more about water clarity and empirical models, see* ***A Beginner's Guide to Water Management — Water Clarity*** *(Circular 103).*

If a lake should have high true color measurements, an equation known as a **multiple nutrient-color regression model** can be used to determine whether *nutrients* or *color* are having a greater influence on chlorophyll concentrations (i.e., algae) in a lake. The equation looks like this:

$$Log\,(CHL) = -1.92 + 0.70\,Log\,(TP) + 0.75\,Log(TN) - 0.15\,Log(Color)$$

Where:

Log is the common (base 10) logarithm.

CHL is the average chlorophyll concentration in micrograms per liter (μg/L).

TP is the average total phosphorus concentration in μg/L.

TN is the average total nitrogen concentration in μg/L.

Color is the mean true color concentration in Platinum Cobalt Units (PCU).

This equation was developed in much the same way as the Secchi-chlorophyll model described on page 19. Both are the result of hours of mathematical analysis, using data from hundreds of Florida lakes.

Using this model, FLW researchers have been able to demonstrate that true color *does* have an influence on algal abundance, but phosphorus and nitrogen have the strongest influence.

But that's not all.

The model also helps us predict what chlorophyll concentrations *should* be for a specific lake. For example, if we were to work through the equation by plugging in actual TP, TN and color measurements from a lake, we could compare our answer with chlorophyll measurements (aka CHL) from the same lake. If the chlorophyll value is similar to our calculated answer (i.e., from the equation), we can conclude that nutrients and color are most likely having the greatest influence on algal abundance in the lake.

However, if the actual chlorophyll value from the lake is less than the value we've calculated, we can conclude that some other factor is influencing algal abundance — and generally it's the presence of suspended solids.

This exercise is important because it gives us a way of determining whether a lake's algal abundance is being affected by nutrients, true color or some other factor. It also tells us that further examination will be necessary to pinpoint exactly which factor is having the most influence.

See Appendix 1 on page 21, for a step-by-step example of how to use an empirical model.

Appendix 1

How to Use an Empirical Model

To illustrate how to use an empirical model, we will work with data from a hypothetical lake named **My Lake**. Let's say this waterbody has average chlorophyll concentrations of **10 micrograms per liter** (**10 μg/L**) and a true color measurement of **50 Platinum Cobalt Units** (**50 PCU**). Using the empirical model below, we can plug in these numbers and solve the equation for Secchi depth. Once we have an answer, we can compare it with the actual Secchi depth of the lake to see if they are similar. If the actual Secchi depth of **My Lake** is different from our calculated answer, there may be something else affecting the water clarity (i.e., other than true color), such as suspended sediments.

$$Log\ (Secchi) = 0.86 - 0.36\ Log\ (CHL) - 0.27\ Log\ (Color)$$

Where:
Log is the common (base 10) logarithm.
Secchi is the mean Secchi depth in meters.
CHL is the mean chlorophyll concentration in micrograms per liter (μg/L).
Color is the mean true color concentration in Platinum Cobalt Units (PCU).

You will need a calculator with a logarithm (LOG) button and an antilogarithm (anti-LOG) button to make the following calculations:

Step 1 Start by finding the LOG of the chlorophyll concentration for My Lake.

To find the LOG of a number on your calculator, type in the number on the keypad (in this instance, type in the number 10) and then push the button marked LOG. For this exercise, you should get an answer of **1**. Now that we know the LOG of our chlorophyll concentration, plug that into the equation. In other words, replace the letters **Log (CHL)** with the number **1**.

Example:

$$Log\ (Secchi) = 0.86 - \mathbf{0.36\ Log\ (CHL)} - 0.27\ Log\ (Color)$$

$$\Downarrow$$

$$Log\ (Secchi) = 0.86 - \mathbf{0.36\ (1)} - 0.27\ Log\ (Color)$$

Step 2 Multiply the chlorophyll LOG of 1 by 0.36 as provided in the equation.

Example:

$$Log\ (Secchi) = 0.86 - \mathbf{0.36\ (1)} - 0.27\ Log\ (Color)$$

$$\Downarrow$$

$$Log\ (Secchi) = 0.86 - \mathbf{0.36} - 0.27\ Log\ (Color)$$

Step 3 Find the LOG of the color measurement for My Lake.

To find the LOG of a number on your calculator, type in the number on the keypad (in this instance, type in the number 50) and then push the button marked LOG. For this exercise, you should get an answer of **1.699**. Now that we know the LOG of the color measurement for **My Lake**, plug that into the equation (i.e., replace the words **"Log (Color)"** with the number 1.669) and calculate as shown below:

$$Log\ (Secchi) = 0.86 - 0.36 - \mathbf{0.27\ Log\ (Color)}$$

$$\Downarrow$$

$$Log\ (Secchi) = 0.86 - 0.36 - \mathbf{0.27\ (1.699)}$$

$$\Downarrow$$

$$Log\ (Secchi) = 0.86 - 0.36 - \mathbf{0.45873}$$

Step 4 Now do the remaining calculations (subtractions).

$$Log\ (Secchi) = \mathbf{0.86 - 0.36 - 0.45873}$$

$$\Downarrow$$

$$Log\ (Secchi) = \mathbf{0.04127}$$

Step 5 Now find the antilogarithm of your result.

To do this, enter the logarithm into your calculator (i.e., the number from the right side of the equation). You should type in the number **0.04127**. While that number is on your calculator screen, push the antilogarithm key on the keypad, which is usually represented by the symbol $\mathbf{10^x}$.

> *Note: If your calculator doesn't have an antilog key, check the instruction booklet. Also, some calculators rely on another method of finding the antilog of a number. To do this, one would need to use the y^x button on the calculator where y = 10 and x = 0.04127 (from the equation above).*

Step 6 Check your answer.

You should get an answer of **1.0998**, which can be rounded to a hypothetical Secchi depth of approximately **1.1** meters, based on chlorophyll concentrations and true color values for **My Lake**. If the actual Secchi depth for **My Lake** happens to be 1 meter, we could say that the two numbers "agree" and the lake's water clarity (Secchi depth) is most likely affected mostly by chlorophyll (algae) and/or true color. However, If the actual Secchi depth of **My Lake** was substantially *less* than 1.1 meters (by ~ 0.5 meters or more), then the model would suggest that non-algal suspended solids may be impacting water clarity.

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Web Resources

For information about the earth's electromagnetic spectrum:
http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html

For information about plant management in Florida waters:
http://plants.ifas.ufl.edu/guide/

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 nearly 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 collected and are later delivered to a collection center, where they are stored until they can be picked up by one of our 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:

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