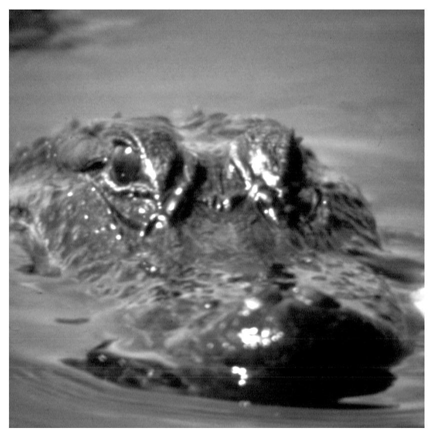
A Beginner's Guide to Water Management — Nutrients

Information Circular 102



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

August 2000

UNIVERSITY OF FLORIDA
IFAS

Florida LAKEWATCH

Florida LAKEWATCH
7922 NW 71st Street
Gainesville, FL 32653-3071
Phone: (352) 392-4817
Citizen message line: (800) 525-3928
Fax: (352) 392-3462
E-mail: lakewat@ufl.edu
Web address: http://lakewatch.ifas.ufl.edu/

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Lake Eloise in Polk County, Florida

Photo courtesy of Central Florida Visitors And Convention Bureau

Introduction

Nutrients are substances required by all organisms for growth, and they are found in all waterbodies. Algae and aquatic plants need nutrients in order to grow. To help you work more effectively with waterbody managers, this circular provides basic information about nutrients, their relationship to the growth of algae in waterbodies, and conceptual and mathematical tools you can use to achieve water management goals relative to algal abundance.

You'll notice that our main focus is on algae with little mention of rooted and/or floating leaved aquatic plants. While aquatic plants are a major factor influencing the limnology of Florida lakes, for the purposes of this circular, we've chosen to concentrate on algae and the various factors that can limit or enhance algal abundance in waterbodies. The dynamics of larger rooted and/or floating-leaved aquatic plants (called macrophytes) will be discussed in a separate publication.

While reading this circular we'd like for you to keep in mind that all water quality management efforts, whether focused on nutrients or some other waterbody characteristic, should be based on well-defined management goals. And contrary to what most of us might think, defining management goals often takes place in the public/political arena instead of a scientific one. However a more scientific approach, including the information provided in this circular, can be valuable in that it can provide a perspective for evaluating various management options and their feasibility.

When exploring the scientific water management arena, citizens as well as waterbody managers should keep in mind that generalities, particularly statistically derived ones, may not always apply to an individual waterbody. They should also be aware that the management of a specific waterbody can be as much an art as it is a science at this point in time.

It's also important to remember that water management, and each of its related disciplines (law, public policy, science, etc.), is constantly evolving. The only commonality is that concerned and well-intentioned people are involved throughout the process.

The following topics described in this circular represent water management concepts related to nutrients as Florida LAKEWATCH professionals have come to know them:

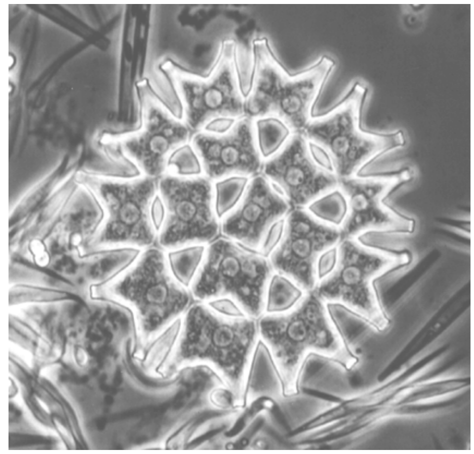
1 Background Information About Algae
- Types of Algae
- Measuring Algae
- The Role of Algae in Waterbodies
- When Are There Too Many Algae?

2 The Concept Of Limiting Nutrients
- About Phosphorus
- About Nitrogen
- Determining The Limiting Nutrient In A Waterbody

3 Using Models to Predict Algal Abundance

4 Limiting Environmental Factors Other Than Nutrients

Part 1 Background Information About Algae


Mary Cichra

Algae are a wide variety of tiny and often microscopic plants, or plant-like organisms, that live both in water and on land. If your management goals include the manipulation of algae in your waterbody, then the more you know about algae, the better.

Types of Algae

One common way to classify water-dwelling algae is to categorize them based on where they live. Using this system, three types of algae are commonly defined as follows:

- **phytoplankton** float freely in the water;
- **periphyton** are attached to aquatic vegetation or other structures; and
- **benthic algae** grow on the bottom or bottom sediments.

Algae may further be described as being **single-celled**; **colonial** (grouped together in colonies) or **filamentous** (appearing as hair-like strands). The most common forms of algae are also described by their colors: green, blue-green, red, and yellow. All these classifications may be used together. For example, to describe blue-green, hair-like algae that are attached to an underwater rock, you could refer to them as "blue-green filamentous periphyton."

Free-floating algae, called **phytoplankton**, are further classified into three categories: **green algae**, **diatoms**, and **blue-green algae**.

The word ***algae*** is plural (pronounced AL-jee), and ***alga*** is the singular form (pronounced AL-gah).

The amount of and types of algae found in lakes (called phytoplankton community structure) changes with increased nutrient concentrations.

In Florida, the phytoplankton of nutrient-poor lakes are often dominated by green algae; diatom abundance tends to be greatest in moderately nutrient-rich lakes; and blue-green algae (also called cyanobacteria) tend to be the predominate phytoplankton in nutrient-rich lakes.

Measuring Algae

In addition to describing types of algae, it's also useful to measure quantity. The amount of algae in a waterbody is called **algal biomass**. Scientists commonly make estimates of algal biomass based on two types of measurements — (1) chlorophyll concentrations and (2) counting and measuring individual algae. These are described as follows:

1 Chlorophyll Concentrations

Because almost all algae contain chlorophyll (the green pigment found in plants), the concentration of chlorophyll in a water sample is used to indicate the amount of algae or algal biomass present. Chlorophyll concentrations are expressed as units of **micrograms per liter** (abbreviated **µg/L**) or in **milligrams per cubic meter** (abbreviated **mg/m^3**). These are equivalent units of measure and either may be used to describe chlorophyll concentrations.

It should be remembered that collecting algae from water samples does not provide measurements for all types of algae, only the phytoplankton.

It's a common practice for scientists to use the phrases **chlorophyll concentration** or **chlorophyll *a* concentration** when they are referring to the amount of algae in a waterbody. **Chlorophyll *a*** is one of several types of chlorophyll, as are **chlorophyll *b*** and **chlorophyll *c***. The measurement of all three of these types of chlorophyll in one water sample is referred to as a **total chlorophyll** concentration.

NOTE: In this document, all estimates of the amount of algal biomass in a waterbody will be based on total chlorophyll measurements.

☛ *See Appendix B for more information on **chlorophyll**.*

2 Counting Individual Algae

In certain cases, scientists prefer to count individual algal organisms in a water sample. They typically identify the individual algae by genus and species, and then calculate cell volume by approximation to the nearest simple geometrical shape, such as a sphere or a cylinder. Using this information, the total biovolume of algae in any sample can be estimated.

The Role of Algae in Waterbodies

Regardless of what humans might think, algae are essential to aquatic systems. As a vital part of the food web, they provide the food and oxygen necessary to support most aquatic animal life. Certain algae, such as the larger benthic forms, also provide habitat for aquatic organisms. Occasionally, algae can become troublesome. For instance:

Algae can be categorized based on where they live.

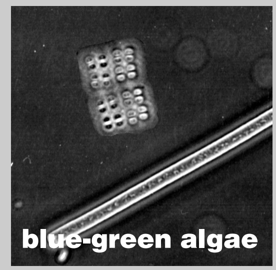
Phytoplankton

float freely in the water and can be classified into three main categories:

- diatoms
- green algae
- blue-green algae.

Christine Taylor

Mary Cichra



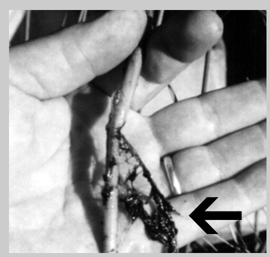
Mary Cichra

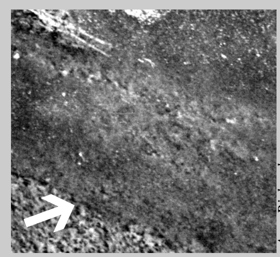
Periphyton

are attached to aquatic vegetation or other underwater structures.

Benthic

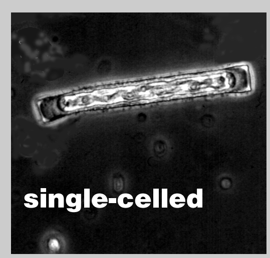
algae grow on bottom or bottom sediments.


Amy Richard

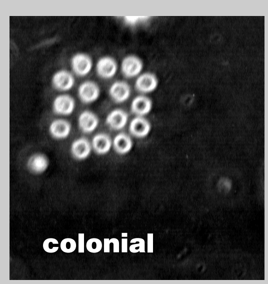

Amy Richard

Algae may further be described as:

- single-celled
- colonial
- filamentous



Mary Cichra



Mary Cichra

Amy Richard

♦ The concentration of phytoplankton (free-floating algae) in the water strongly influences water clarity.

Milt Putnam, UF/IFAS Communications

Water clarity is commonly measured by using a Secchi (pronounced SEH-key) disc. A Secchi disc is a flat 8-inch diameter disc that has a cord attached through the center. The disc is lowered into the water and the depth at which it vanishes from sight is measured, usually in feet or meters. This measurement of the transparency of the water is called the Secchi depth. In waters with low concentrations of phytoplankton (less than 10 µg/L), Secchi depths are generally greater than 10 feet. In waters with high concentrations of phytoplankton (greater than 40 µg/L), Secchi depths are typically less than 3 feet.

♦ Benthic algal blooms, filamentous algal blooms, and periphyton blooms can create accumulations along shorelines and have the potential to interfere with recreational activities such as boating and fishing, as well as block lake access and navigation.

♦ Algal blooms can block sunlight, shading submersed aquatic plants which may be deemed desirable.

♦ An algal bloom can trigger a chain of events that can result in a fish kill. This is most likely to occur after several days of hot weather with overcast skies and is related to oxygen depletion in the water. It is not related to the toxicity of the algae.

When Are There Too Many Algae?

Algal blooms may be caused by human activities, or they may be naturally occurring. Sometimes, what seems to be an algal bloom is merely the result of wind blowing the algae into a cove or onto a downwind shore, concentrating it in a relatively small area. (This is known as wind-rowing.) Looking at algae from the non-scientific point of view, some people consider algae to be unsightly, particularly when it is abundant. For instance, a phytoplankton bloom can make water appear so murky that it's described as "pea soup."

In Florida, when chlorophyll concentrations reach a level over 40 µg/L, some scientists will call it an algae bloom or algal bloom. The public, however, usually has a less scientific definition – often defining algal blooms as events in which more algae can be seen in the water than they are accustomed to seeing. In some cases, this may even be a relatively low amount.

Algae and Fish Kills

When algal biomass exceeds 100 µg/L (measured as chlorophyll concentrations), there is an increased probability of a fish kill. Fish kills, however, typically only occur after three or four cloudy days. During this time, algae consume oxygen rather than produce it because they don't have sunlight available to help them photosynthesize more oxygen. This can lead to oxygen depletion. Without oxygen, aquatic organisms, including fish, die. Chlorophyll concentrations below 100 µg/L generally do not adversely affect fish and wildlife, but dead fish and wildlife can occasionally be found.

Health Concerns

Newspapers and magazines often present articles describing toxic algae. However, most algae are not toxic and pose very little danger to humans. It should be remembered that toxic algae can be found in all aquatic environments. Known health problems associated with algal blooms in lakes and ponds have generally been associated with high concentrations of three species of blue-green algae: *Anabaena flos-aquae, Microcystis aeruginosa,* and *Aphanizomenon flos-aquae*. With few exceptions, only fish and invertebrates have died from the effects of these toxic algae.

In Florida, it is extremely rare for algae to cause human illness or death. People are more likely to suffer minor symptoms such as itching. However, several species of algae produce gases that have annoying or offensive odors, often a musty smell. These odiferous gases may cause health problems for some individuals with breathing difficulties.

To be prudent, people should inform their doctor if they are experiencing any health problems and live near a waterbody or use a waterbody often. This is critically important in recent years because there is an alga called *Pfiesteria* that is known to cause severe health problems. *Pfiesteria* tends to be found primarily in tidal waters. While prudence must be the watchword when using any waterbody, it must also be recognized that people will face a greater risk during their drive home from the grocery store than from *Pfiesteria* or any other algae.

Part 2 The Concept of Limiting Nutrients

Marilyn Bachmann

A limiting nutrient is a chemical necessary for plant growth — but is available in smaller quantities than needed for algae to increase their abundance. Once the limiting nutrient in a waterbody is exhausted, the population of algae stops expanding. If more of the limiting nutrient is added, larger algal populations will result until their growth is again limited by nutrients or by other limiting environmental factors.

It's helpful to know if there is a limiting nutrient (or some other limiting factor) in your lake, as an increase of the limiting nutrient could affect change in the lake.

There are many potentially limiting nutrients. For example, silica is sometimes known to limit the growth of diatoms. Although scientists may debate which nutrient is the limiting factor at any given time, phosphorus and nitrogen are most often the limiting nutrients in Florida waterbodies.

About Phosphorus

Phosphorus is an element that, in its different forms, stimulates the growth of algae in waterbodies. Phosphorus compounds are also found naturally in many types of rocks and soils. In fact, phosphorus is mined in Florida and other parts of the world for a variety of agricultural and industrial uses. In most freshwater lakes in Florida, the limiting nutrient is believed to be phosphorus rather than nitrogen.

The chemical symbol for the element **phosphorus** is **P**.

In waterbodies, phosphorus occurs in two forms: **dissolved** and **particulate**.

Dissolved phosphorus is defined based on its size, as that which is small enough to pass through a 0.45 micron filter. It includes phosphorus forms like soluble reactive phosphorus and soluble organic compounds that contain phosphorus.

Its counterpart **particulate phosphorus**, is too big to pass through a 0.45-micron filter. It is formed when phosphorus becomes incorporated into particles of soil, algae, and small animals that are suspended in the water. Both dissolved and particulate phosphorus can change from one form to another very quickly (called cycling) in a water body and there is ongoing scientific inquiry about when, where, and how often these specific forms of phosphorus are found in waterbodies. This is important because algal cells and plants can only use phosphorus in certain forms.

Understanding the relationship between algae and phosphorus is further complicated by the fact that an algal cell's ability to use specific forms of phosphorus is strongly influenced by several factors including pH, water hardness (caused by the presence of calcium and/or magnesium), the amount of dissolved oxygen in the water, and thermal stratification (layers of water having different temperatures).

This process of phosphorus cycling makes it difficult to measure dissolved or particulate phosphorus in a waterbody at a given time. However, **total phosphorus** concentrations (abbreviated TP), which include both dissolved and particulate forms, can be used to gain an estimate of the amount of phosphorus in a system. Florida LAKEWATCH measures total phosphorus because it provides a snapshot of the total phosphorus concentrations in a lake at a given time.

There are many ways in which phosphorus compounds find their way into waterbodies. Some of the more common pathways are described as follows:

♦ Some areas of Florida and other parts of the world have extensive phosphate deposits in the soils. In these areas, rivers and water seeping or flowing underground can become phosphorus enriched and may carry significant amounts of phosphorus into waterbodies.

♦ Sometimes phosphorus is added intentionally to waterbodies as a management strategy to increase fish production by fertilizing aquatic plant and algal growth.

♦ Phosphorus can enter waterbodies inadvertently as a result of human activities like landscape fertilization, crop fertilization, wastewater disposal, and stormwater run-off from residential developments, roads, and commercial areas.

Waterbodies in the Florida LAKEWATCH database analyzed prior to January 1998, had total phosphorus concentrations which ranged from less than 1 to over 1000 µg/L (0.001 to 1 mg/L)**. Analysis of total phosphorus concentrations in Florida shows the following relationships. These relationships should be of interest to anyone trying to manage phosphorus concentrations in a Florida lake—and are important to consider when attempting to evaluate the feasibility of goals you or others may set for phosphorus levels in a waterbody.[1]**

There seems to be a relationship between the location of a waterbody and its total phosphorus concentration.

For example, lakes in the New Hope Ridge/Greenhead Slope Lake Region✪ of northwestern Florida (in Washington, Bay, Calhoun, and Jackson counties) tend to have extremely low total phosphorus values (below 5 µg/L). While lakes in the Lakeland/Bone Valley Upland Lake Region of central Florida (in Polk and Hillsborough counties) tend to have very high values (above 120 µg/L).[2]

✪ *Lake Regions are geographical areas in which lakes have similar geology, soils, chemistry, hydrology, and biological features. In 1997, using Florida LAKEWATCH data and other information, the United States Environmental Protection Agency designated 47 lake regions in Florida using these similarities as their criteria. For more information, see Lake Regions in the Appendix A.*

Using the Florida LAKEWATCH database, it can be shown that there is a seasonal pattern for total phosphorus concentrations in Florida lakes.

Monthly total phosphorus concentrations tend to be lower during December and January, but higher and more variable during the rest of the year. Typically, the maximum measured total phosphorus concentration occurs most frequently in August and October or from February through May in some lakes. Minimum measured total phosphorus concentrations occur most frequently from November through February.

1 *For more information on a specific LAKEWATCH waterbody, you can call the Florida LAKEWATCH office (1-800-LAKEWATCH) and request a data packet for that waterbody. It's also recommended that you refer to the following LAKEWATCH handouts—* ***Florida Lake Regions: A Classification System****;* ***Trophic State: A Waterbody's Ability to Support Plants, Fish, and Wildlife****; and* ***Florida LAKEWATCH Data — What Does It All Mean?***

2 *Total phosphorus concentrations in an individual waterbody may not be at these levels all the time; they can be quite variable over time.*

A Bum Rap

Because waterbodies with low concentrations of total phosphorus (TP) will have relatively clear water, the public may think their water quality is better than waterbodies with higher TP. It's a misconception however, that clearer water is intrinsically better than water that is less clear.

Unfortunately, the association of clear water with low phosphorus levels has given the public the mistaken notion that phosphorus is a pollutant.

Amy Richard

Total Phosphorus and Biological Productivity

One major task that lake experts are faced with in water quality management is assessing the **biological productivity** of a waterbody — and determining whether it's changing over time. However, overall biological productivity is difficult to measure in a waterbody because it involves measuring many different parameters over a period of time. Such an approach would be prohibitively expensive and time consuming. Because of this, many aquatic scientists use **total phosphorus** measurements, often alone, as an indirect way of assessing the biological productivity of a waterbody.

Why?

Because phosphorus is one of the main nutrients that can limit the biological productivity of a waterbody. However, this is not always the most accurate way to assess the biological productivity of a waterbody. Other factors may also limit biological productivity, such as availability of light.

☛ *See **Color** and **Humic acids** in Appendix B.*

Biological Productivity is the amount of algae, aquatic plants, fish, and wildlife that a waterbody can produce and sustain.

☛ *For more information, see **Part 4 Limiting Environmental Factors Other Than Nutrients** on page 23.*

Trophic State

While discussing a lake's biological productivity with aquatic scientists, you may hear the term **trophic state**. Trophic state is just another way of saying biological productivity. The **Trophic State Classification System** is one method scientists use to quickly and easily describe the biological productivity of a waterbody. It's one of the more commonly used systems worldwide and is used by Florida LAKEWATCH.

The Trophic State Classification System classifies lakes and/or waterbodies into one of four trophic states:

♦ waterbodies with low productivity are called **oligotrophic** (oh-lig-oh-TROH-fic);

♦ those with moderate productivity are called **mesotrophic** (mes-oh-TROH-fic);

♦ moderate-to-highly productive waters are called **eutrophic** (you-TROH-fic);

♦ and highly productive waters are called **hypereutrophic** (HI-per-you-TROH-fic).

☛ *For more information, see **Trophic state** and **Trophic State Index** in Appendix B.*

Phosphorus As A Limiting Nutrient

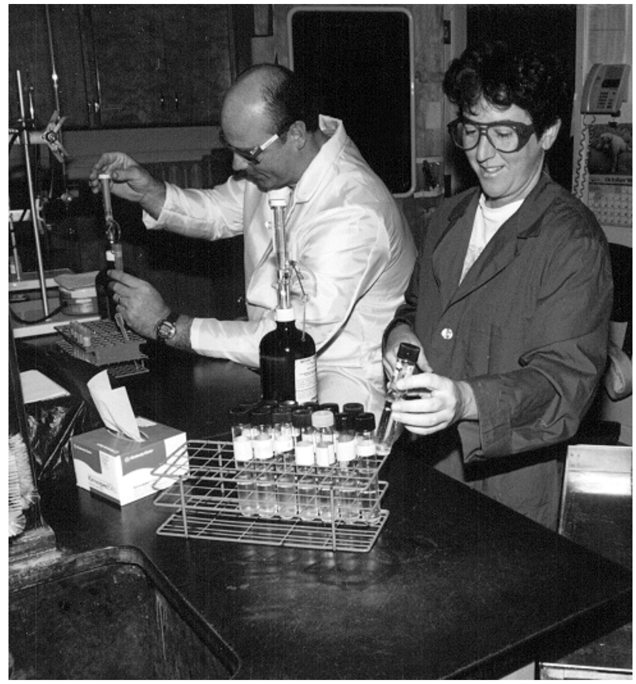
Because phosphorus is frequently the limiting nutrient in the growth of free-floating algae in lakes, it is strongly believed in the scientific community that waterbodies with *higher* phosphorus levels will have *higher* levels of algae and waterbodies with *low* phosphorus concentrations will have *lower* levels of algae. This belief is based in part on surveys of lakes, both in Florida and throughout the world, and on results of whole-lake experiments.

A picture of this relationship emerges when average yearly chlorophyll concentrations, from a group of LAKEWATCH lakes, are plotted on a graph versus the total phosphorus concentrations. (See Figure 1 on page 8.) The graph shows that increasing phosphorus values are generally accompanied by increasing chlorophyll levels.[3]

Consequently, aquatic scientists almost always recommend the manipulation of phosphorus, called phosphorus control, as a primary management strategy for controlling algal biomass.

The high priority placed on phosphorus control by regulatory and professional management agencies in Florida is evidenced by its use in the multi-million dollar lake management programs at Lake Apopka and Lake Okeechobee.

However, phosphorus is not always the limiting nutrient and phosphorus removal may not be the best management approach to controlling algal biomass.



Joe Richard

☛ *See **Determining the Limiting Nutrient In A Waterbody** (page 11); **Part 3 Using Models to Predict Algal Abundance** (page 17); and **Limiting Environmental Factors Other Than Nutrients** (page 23).*

3 *This relationship is indicated by the observation that the points in the graph that are further to the right are also generally higher up. The correlation is true in spite of the fact that chlorophyll concentrations can be highly variable for any specific total phosphorus concentrations.*

4 *This distribution of trophic state is based solely on total phosphorus values without utilizing information on nitrogen concentrations, chlorophyll concentrations, Secchi depth, or aquatic plant abundance.*

Total Phosphorus and Trophic State

Using ONLY average concentrations of total phosphorus (TP) from the Florida LAKEWATCH database, Florida lakes were found to be distributed into the four trophic states as described below.[4]

♦ Approximately 42% of the lakes (those with TP values less than 15 µg/L) would be classified as **oligotrophic**. *Oligotrophic lakes have very low levels of biological productivity.*

♦ About 20% of the lakes (those with TP values between 15 and 25 µg/L) would be classified as **mesotrophic**. *Mesotrophic lakes have moderate levels of biological productivity.*

♦ 30% of the lakes (those with TP values between 25 and 100 µg/L) would be classified as **eutrophic**. *Eutrophic lakes have moderately high levels of biological productivity.*

♦ Nearly 8% of the lakes (those with TP values greater than 100 µg/L) would be classified as **hypereutrophic**. *Hypereutrophic lakes have very high levels of biological productivity.*

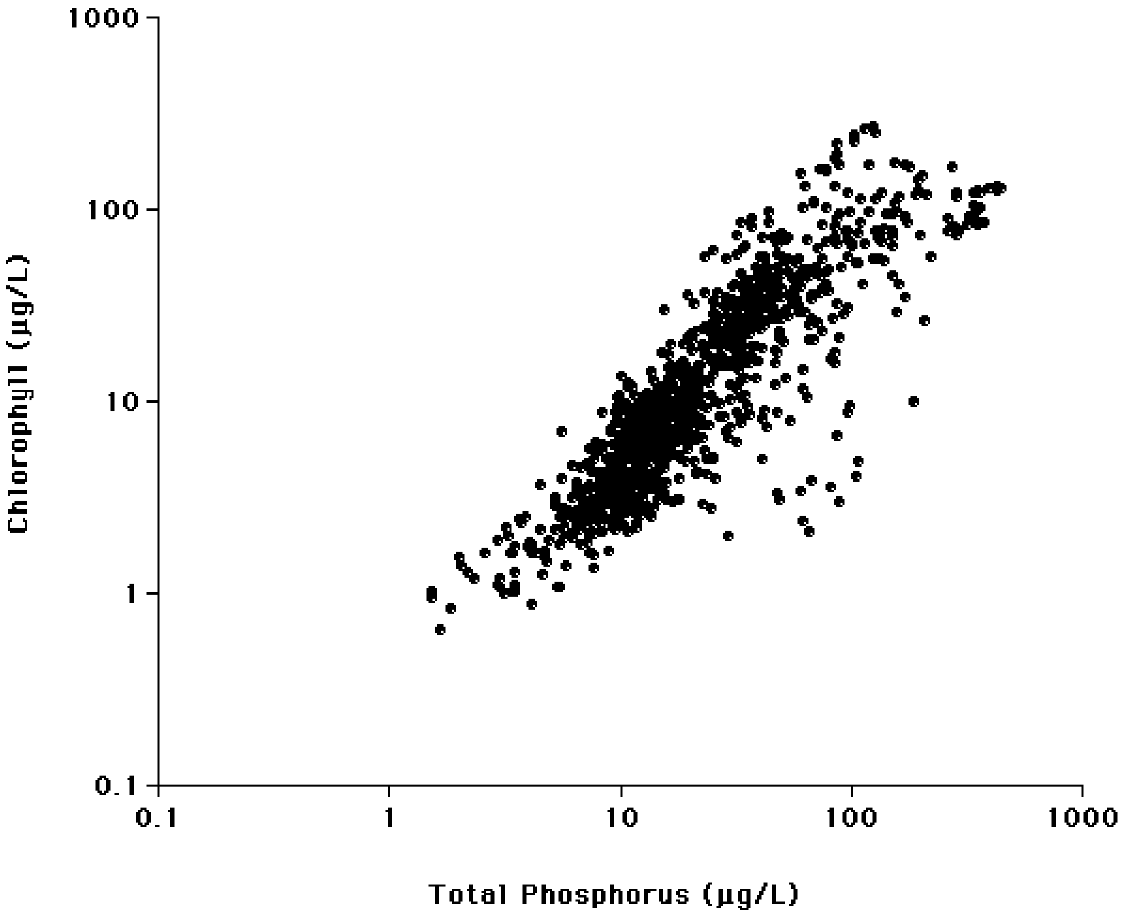


Figure 1.
The relationship between total phosphorus concentrations and total chlorophyll concentrations for Florida lakes.

The graph shown here in Figure 1 is a scatter plot graph. Scatter plot graphs are good for plotting more than one type of measurement on the same graph. Notice how this scatter plot graph represents both total chlorophyll and total phosphorus concentrations at the same time. You'll see more of these types of graphs in this circular as well as water management publications, meetings, and seminars.

While studying this graph, you may also notice that the numbers on each axis are represented in multiples of 10. It's arranged this way because this particular scatter plot graph is formatted using a common logarithmic scale.[5] Rather than plotting the phosphorus and chlorophyll concentrations directly, we plotted logarithms of the concentrations. By using this type of logarithmic scale, we were able to stretch out the scale at the lower end of the graph so that more of the individual points could be seen.

☛ For more on **logarithmic scales** see Appendix A.

5 *Remember that common logarithms are the exponents of the number 10. For example in the equation $10^2 = 100$, we can see that the logarithm of 100 is 2. And using the equation $10^3=1000$, we can see that the logarithm of 1000 is 3. Similarly, the equation $10^1=10$ tells us that the logarithm of 10 is 1.*

About Nitrogen

The chemical symbol for the element **nitrogen** is **N.**

Nitrogen is also a necessary nutrient for the growth of algae and aquatic plants. Various forms of nitrogen can be found in water including organic and inorganic forms.

Organic forms of nitrogen are derived from living organisms and include amino acids and proteins.

Inorganic forms are composed of materials other then plants or animals (i.e., mineral based) and include nitrate ($N0_3^-$), nitrite ($N0_2^-$), unionized ammonia (NH_4), ionized ammonia (NH_3^+), and nitrogen gas (N_2).

Total nitrogen (abbreviated **TN**) is a measure of all the various forms of nitrogen found in a water sample, except nitrogen gas. Not all forms of nitrogen can be readily used by algae — especially nitrogen bound with particulate organic matter. In general, algae and aquatic plants directly utilize inorganic forms of nitrogen such as nitrates, nitrites, and ammonia.

Nitrogen finds its way into aquatic environments from both natural and man-made sources including:

♦ **the air** — some algae can "fix" nitrogen, or pull nitrogen out of the air in its gaseous form and convert it to a form they can use;
♦ **stormwater run-off** — nitrogen can even come from "natural" run-off from areas where there is no human impact because it is a naturally-occurring nutrient found in soils and organic matter;
♦ **fertilizers**; and
♦ **animal and human wastes** (sewage, dairies, feedlots, etc.).

Waterbodies in the Florida LAKEWATCH database analyzed prior to January 1998, had total nitrogen concentrations which ranged from 50 to over 6000 µg/L (0.05 to 6 mg/L)**. Analysis of total nitrogen concentrations in Florida shows the following relationships that should be of interest to anyone trying to examine nitrogen concentrations in their lakes. As with phosphorus, these relationships provide a useful background against which a waterbody manager can evaluate the feasibility of specific management goals.**

♦ **The location of a waterbody has an important effect on its total nitrogen concentration.**

For example, lakes in the New Hope Ridge/Greenhead Slope Lake Region✪ in northwestern Florida (Washington, Bay, Calhoun, and Jackson counties) tend to have very low total nitrogen values (below 220 µg/L). While lakes in the Lakeland/Bone Valley Upland Lake Region in central Florida (Polk and Hillsborough counties) tend to have high values (above 1700 µg/L).

✪ *Lake Regions are geographical areas in which lakes have similar geology, soils, chemistry, hydrology, and biological features. In 1997, using Florida LAKEWATCH data and other information, the United States Environmental Protection Agency designated 47 lake regions in Florida using these similarities as their criteria.*

☛ *For more information, see **Lake Regions** in Appendix B.*

♦ **Total nitrogen concentrations, like phosphorus concentrations, can vary seasonally in individual lakes.**

The variability in monthly total nitrogen concentrations is relatively low however, when compared to the amount of variation observed in algal levels and in total phosphorus concentrations in Florida lakes throughout a year. If there is a period when total nitrogen concentrations can be expected to be low, it generally occurs during the months of January and February. Maximum total nitrogen concentrations generally occur most frequently during the months of April, May, and October.

Nitrogen As A Limiting Nutrient

Like phosphorus, nitrogen is an essential nutrient for all aquatic plants. In some cases, an inadequate supply of TN in waterbodies has been found to limit the growth of free-floating algae (i.e., phytoplankton). This is called **nitrogen limitation**, and occurs most commonly when the ratio of total nitrogen to total phosphorus is less than 10. In other words, the TN concentration divided by the TP concentration is less than 10 (TN/TP < 10).

☛ *For more information see **Determining the Limiting Nutrient In A Waterbody** on pages 11-16 and **Part 4 Limiting Environmental Factors Other Than Nutrients** on page 23.*

Photo courtesy of Central Florida Visitors and Convention Bureau

Sunset fishing for bass on Lake Elbert in Winter Haven.

HEALTH CONCERNS

Like many people throughout the world, Floridians are concerned about water quality. Water quality is sometimes defined in terms of human health effects and toxicity to aquatic organisms. With regard to nitrogen, total nitrogen in surface waters does not reach high enough levels to pose a direct threat to human health. The maximum allowable level of nitrate, a component of the total nitrogen measurement, is 10 mg/L in drinking water. Generally, concentrations of nitrates in surface waterbodies do not reach this level because nitrates are readily taken up by plants and used as nutrients. Most forms of nitrogen are harmless to fish and aquatic organisms except unionized ammonia and nitrite, which can be toxic.

However, nitrites are usually not a problem in waterbodies; if there is enough oxygen available in the water, nitrites oxidize and are readily converted to nitrates.

Total Nitrogen and Trophic State

When ONLY the average concentrations of total nitrogen (TN) from the Florida LAKEWATCH database are used, Florida lakes were found to be distributed into the four trophic states as described below.[6]

♦ Approximately 14% of the lakes (those with TN values less than 400 µg/L) would be classified as **oligotrophic**. *Oligotrophic lakes have very low levels of biological productivity.*
♦ About 25% of the lakes (those with TN values between 401 and 600 µg/L) would be classified as **mesotrophic**. *Mesotrophic lakes have moderate levels of biological productivity.*
♦ 50% of the lakes (those with TN values between 601 and 1500 µg/L) would be classified as **eutrophic**. *Eutrophic lakes have moderately high levels of biological productivity.*
♦ Nearly 11% of the lakes (those with TN values greater than 1500 µg/L) would be classified as **hypereutrophic**. *Hypereutrophic lakes have very high levels of biological productivity.*

6 *This distribution of trophic state is based solely on total nitrogen values without utilizing information on total phosphorus concentrations, chlorophyll concentrations, Secchi depth, or aquatic plant abundance.*

Determining The Limiting Nutrient In A Waterbody

Aquatic scientists routinely recommend nutrient (phosphorus and nitrogen) control to manipulate algae populations in a waterbody. Controlling nutrients, as a way of manipulating algae, is one strategy for managing fisheries, water clarity, and wildlife populations. This strategy, however, only works if phosphorus and/or nitrogen are the environmental factors limiting algal abundance.

If nutrients are the environmental factors limiting algal abundance, you may be able to achieve overall management goals through nutrient control.[7] However, there are many methods for managing the growth of algae in waterbodies and the appropriate method of nutrient control is often debated at length. This debate can often be sidetracked by discussions over which nutrient, phosphorus or nitrogen, is limiting.

If nutrients, rather than some other environmental factor, are limiting the growth of algae in a waterbody, there are a few possibilities that deserve consideration.

If nutrients, rather than some other environmental factor, are limiting the growth of algae in a waterbody, there are a few possibilities that deserve consideration:

♦ Phosphorus and/or Nitrogen Is The Limiting Nutrient

There are two approaches that can be used to help you and/or a water manager decide whether:

♦ *phosphorus* is the limiting nutrient,
♦ *nitrogen* is the limiting nutrient, or
♦ *both* phosphorus and nitrogen are limiting nutrients in a waterbody.

One involves the use of a **TN/TP Ratio** (total nitrogen/total phosphorus ratio) and the other involves the use of **Phosphorus Threshold Value**.

☛ *See pages 13-16 for more on how* ***TN/TP ratios*** *and* ***Phosphorus Threshold Values*** *can be used to determine limiting nutrients in waterbody.*

♦ Some Nutrient Other Than Phosphorus Or Nitrogen Is the Limiting Nutrient

As mentioned earlier in this circular, nutrients like silica can be limiting in some Florida waterbodies. In addition, micronutrients[8] that are also necessary for the growth of plants and algae (such as molybdenum and zinc), may be in limited supply in some circumstances. Tests to evaluate these substances as potential limiting nutrients are sometimes recommended. The tests are relatively expensive, so they should only be considered if phosphorus and nitrogen are eliminated as possibilities.

In addition, nutrients are not always the limiting factor. Other environmental factors such as highly colored water can also influence the abundance of algae in a waterbody.

☛ *For more on limiting environmental factors see* ***Part 4 Limiting Environmental Factors Other Than Nutrients*** *on pages 23 and 24.*

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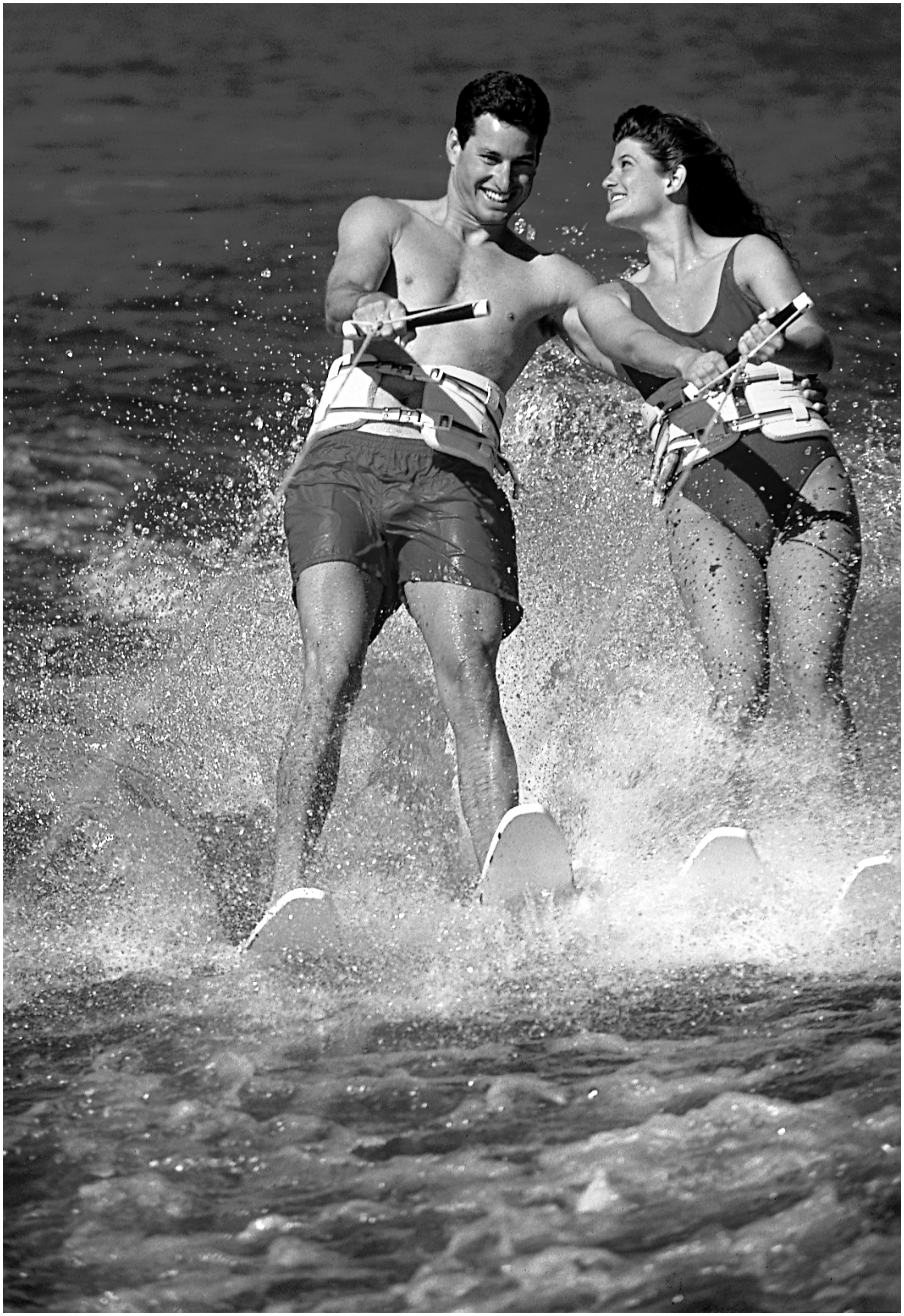
7 *If you have not developed a management plan yet, you may want to read the booklet* ***How To Create a Lake Management Plan*** *by Jess VanDyke, Northwest Florida Regional Biologist, Department of Environmental Protection/Bureau of Aquatic and Invasive Plant Management. Free copies are available from Florida LAKEWATCH.*

8 *The term* ***micronutrient*** *indicates that plants and algae need only tiny amounts of this nutrient. Contrary to its name, a micronutrient is of no smaller importance than a nutrient.*



Cypress Gardens, Florida

Photo courtesy of Central Florida Visitors and Convention Bureau

Using A TN/TP Ratio To Determine Whether Phosphorus and / or Nitrogen Is The Limiting Nutrient

Calculating a relatively simple ratio can sometimes provide a useful clue as to the relative importance of nitrogen or phosphorus toward the abundance of algae in a waterbody. Studies of Florida lakes have shown that the ratio of total nitrogen to total phosphorus (TN/TP) may indicate which nutrient plays the most significant limiting role.

By calculating TN/TP ratios for 534 Florida lakes...

and plotting them on a scatter plot graph, a useful relationship emerges.

The scatter plot graph shown here (see Figure 2), illustrates that based on the relationship between total chlorophyll, total phosphorus values, and TN/TP ratios, Florida waterbodies can be loosely divided into three groups:

Lakes with a TN/TP ratio less than 10 (represented by a △ in the graph)
Lakes with a TN/TP ratio between 10 and 17 (represented with a ❍ in the graph)
Lakes with a TN/TP ratio greater than 17 (represented with a ● in the graph)

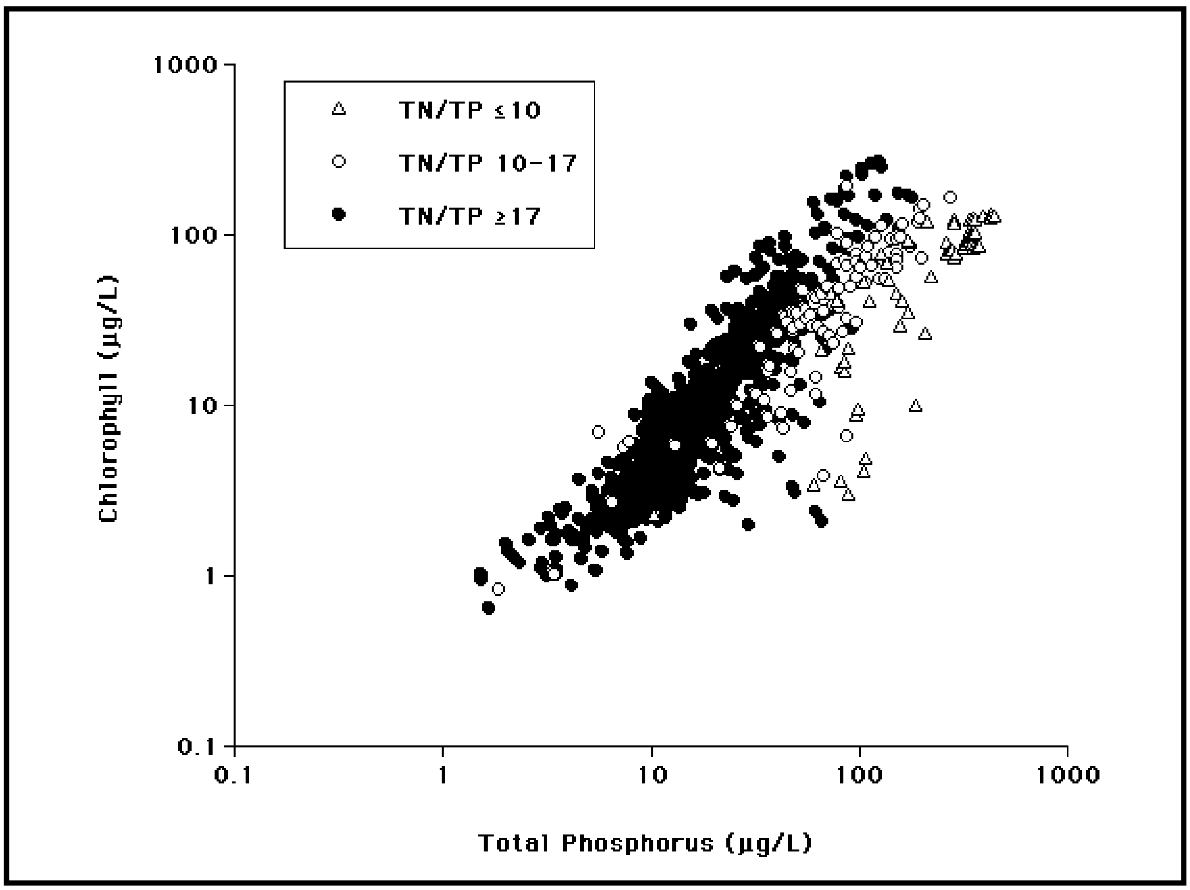


Figure 2. The relationship between total phosphorus concentrations and chlorophyll concentrations for Florida lakes.

Lakes with a TN/TP ratio less than 10 (represented with a △ in the graph)

Notice that lakes in this group tend to be grouped in the upper right-hand corner of the graph, beyond where the 50 µg/L mark would be on the total phosphorus axis. Also notice that none of these lakes appear on the graph anywhere below the 50 µg/L mark on the total phosphorus axis. This can be interpreted to mean that phosphorus may not be the only factor affecting the growth of algae in these lakes.

Lakes with a TN/TP ratio between 10 and 17 (represented with a ❍ in the graph)

Notice that, similar to the lowest TN/TP ratio group, this group of lakes also tends to be grouped in the upper right-hand corner of the scatter plot graph — with a few lakes scattered down toward the bottom left hand corner. Also, notice how many of lakes with higher TN/TP ratios (greater than 17 and represented by ●), have higher chlorophyll levels than lakes with the same amount of phosphorus (lakes represented by the △ and the ❍).

This can be interpreted to mean that a specific amount of phosphorus in the △ or ❍ lakes will not produce as much algae as that same amount of phosphorus in lakes with a TN/TP ratio greater than 17 (● lakes). Something is limiting the growth of algae (chlorophyll) in these lakes. However, it's unclear as to whether it's nitrogen or phosphorus.

Lakes with a TN/TP ratio greater than 17 (represented with a ● in the graph)

The broad range of the black dots on graph can be interpreted to mean that lakes with the highest TN/TP ratio (greater than 17) generally have more chlorophyll per unit of phosphorus than lakes with lower TN/TP ratios. In other words, there seems to be a stronger correlation between phosphorus and chlorophyll in these lakes.

In light of these observations, some scientists think that something other than phosphorus must be limiting the algal growth in the lower two TN/TP ratio groups (the △ and ❍ lakes) **— possibly nitrogen. Therefore, these scientists hypothesize:**

- when the TN/TP ratio is less than 10, a lake is nitrogen-limited;
- when the TN/TP ratio is between 10 and 17, there appears to be a gray area (nitrogen ***or*** phosphorus could be limiting);
- when the TN/TP ratio is greater than 17, a lake is phosphorus-limited.

Aquatic scientists have differing opinions as to whether 10 and 17 are the exact boundary values and whether this relationship applies to all waterbodies. Perhaps the TN/TP ratio can be useful in helping you decide whether nitrogen or phosphorus is the limiting nutrient in your waterbody.

To calculate a TN/TP ratio...

Take the TN (total nitrogen) value and divide it by the TP (total phosphorus) value.

For example: If your lake's TN value is 300 and the TP value is 30, you'll need to divide 300 by 30 ... giving you a TN/TP ratio of 10.

$$300 \div 30 = 10$$

NOTE: *The TN and TP values you use to calculate this ratio can be from one day's water sample, or they can be attained by averaging a year's worth of monthly sample concentrations — called an annual mean.*

Using a phosphorus threshold to determine whether phosphorus OR nitrogen is the limiting nutrient

There appears to be two phosphorus thresholds in Florida lakes.

1 In lakes with TP concentrations above 100 µg/L, there is the potential for nitrogen to be the limiting nutrient, rather than phosphorus. Why?

It seems reasonable to assume that when the phosphorus concentration is high (e.g., above some threshold level), the probability that phosphorus will be the limiting nutrient decreases simply because of its abundance. Several observations support the idea that a phosphorus threshold of 100 µg/L separates Florida lakes that are phosphorus limited from those that are not. For example:

- Many lakes with total phosphorus concentrations exceeding 100 µg/L have TN/TP ratios that suggest they are not phosphorus limited (their TN/TP is generally less than 17, as shown in Figure 3 on page 16).
- Evidence from surveys of lakes suggests that concentrations of total phosphorus above a threshold value of 100 µg/L do not correspond to higher concentrations of chlorophyll.

2 A second threshold of 50 µg/L is evident from Figure 3 on page 16.

Lakes with a TN/TP ratio less than 10 (which suggests a nitrogen limitation) generally do not occur✪ when total phosphorus concentrations are less than 50 µg/L. This observation suggests that waterbodies with TP less than 50 µg/L are indeed most likely to be phosphorus limited.

✪ *There is one documented exception.*

Check your Florida LAKEWATCH data to see if your waterbody falls into one of these categories. If so, phosphorus may NOT be a limiting nutrient.

Phosphorus control pitfall...

In nitrogen limited waterbodies, it may well be that both phosphorus and nitrogen need to be controlled simultaneously in order to manipulate chlorophyll concentrations. The TN/TP ratio offers a clue to understanding why. There is a positive relationship between phosphorus and chlorophyll in lakes with a TN/TP ratio less than 10, as shown in the upper graph in Figure 3 (page 16). This relationship suggests that by lowering the phosphorus concentration in one of these lakes, the chlorophyll concentration can be made to decrease.

This may be true — if the lake maintains a TN/TP less than 10. However, as TP is lowered, the TN/TP ratio will increase because its denominator is becoming smaller. If the TN/TP ratio becomes greater than 10, the chlorophyll concentration could actually stay the same, even though phosphorus has been reduced. Additional research is needed before phosphorus control techniques alone can be relied upon to reduce chlorophyll concentrations in lakes with high phosphorus concentrations (TP greater than 50 µg/L).

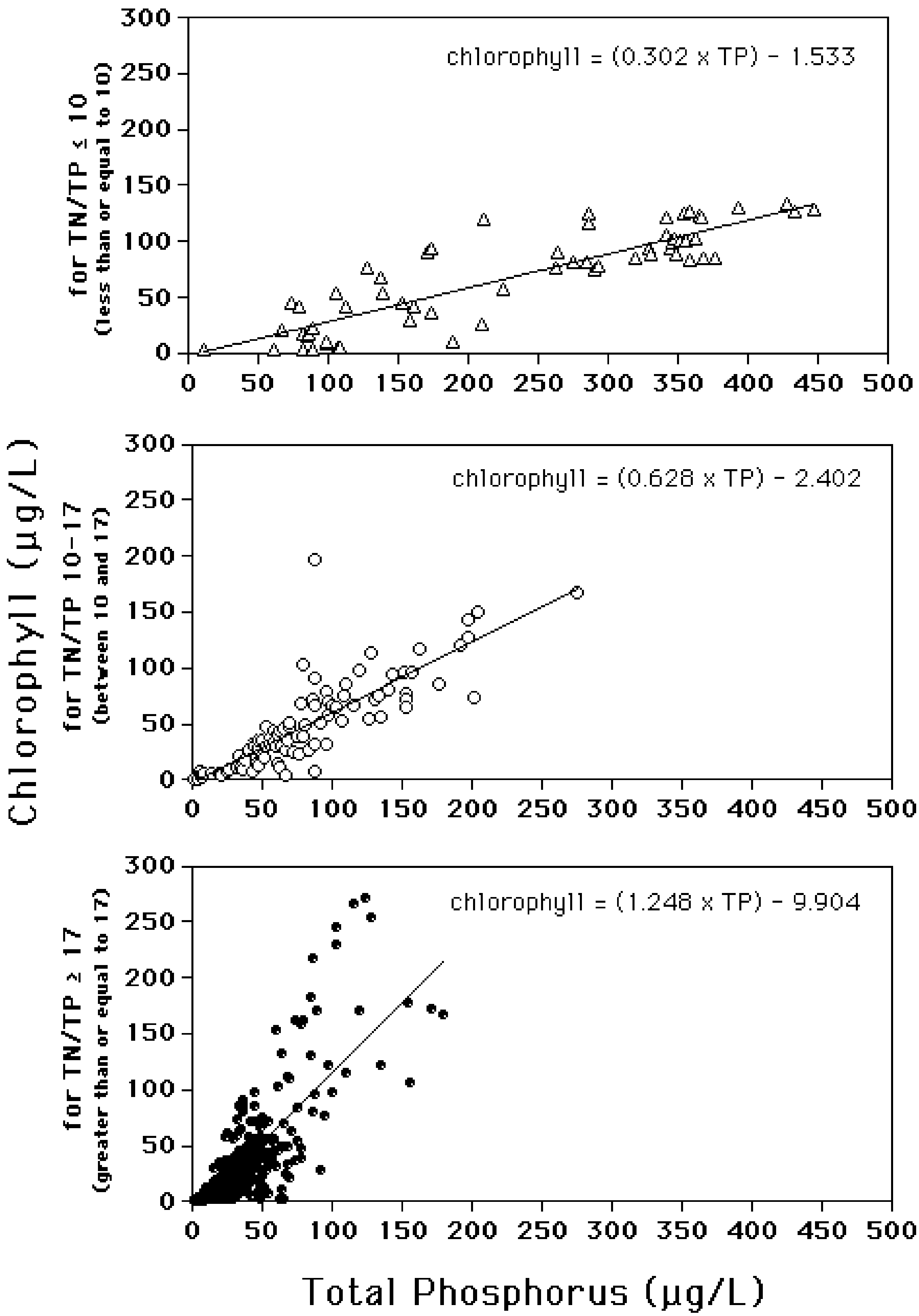
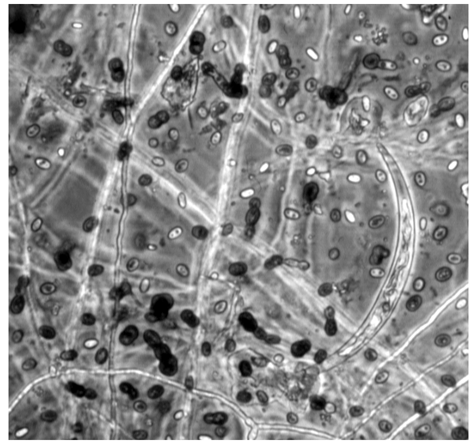


Figure 3. The relationship between total phosphorus concentrations and chlorophyll concentrations for Florida lakes with different total nitrogen to total phosphorus ratios.

Part 3

Using Models to Predict Algal Abundance



Mary Cichra

It is possible to estimate how much algae can be expected in your lake based on hypothetical changes in the amount of nutrients entering the waterbody. These hypothetical situations can be graphed as nutrient-chlorophyll relationships similar to Figure 1 on page 8, or converted into mathematical formulas referred to as **empirical models.**

Unlike *experimental* models, where phosphorus would actually be added to a waterbody and then observed for changes, an *empirical* model is a mathematical equation that is derived purely from statistical data analysis of available data from a chosen group of lakes.

In this circular, we've provided three empirical models that were developed using data from 534 waterbodies within the Florida LAKEWATCH database (see pages 19-20). Using these models, or formulas, you can predict what algae levels (chlorophyll concentrations) could be expected in your lake based on a hypothetical nutrient concentration (e.g., total phosphorus, total nitrogen, or both).

In other words, if you're concerned about how a possible increase in phosphorus might affect your lake, you can plug a hypothetical total phosphorus concentration (perhaps a higher TP concentration than your lake is currently experiencing) into the formula at the top of page 19. The answer you get from calculating the equation will represent an estimated or predicted chlorophyll (algae) concentration for your lake.

Once you have a chlorophyll prediction, you can decide whether a specific management strategy is realistic. You can then evaluate whether it is worth the cost of implementing that strategy. For example, is it worth a large expenditure of dollars to decrease algal levels so that water clarity increases from 0.5 foot of visibility to 1.0 foot? If not, you may wish to focus on other management problems such as aquatic weed control.

Probably the most important lesson learned when using empirical models is that small changes in nutrient concentrations will not always produce noticeable changes in algal levels and water clarity, except perhaps in oligotrophic waterbodies. In other words, if you want to decrease chlorophyll concentrations (meaning algal levels) to the point where people actually see a change in water clarity, you may have to decrease nutrient concentrations dramatically.

For step-by-step instructions on how to do empirical modeling calculations see **How to Use Empirical Models** on page 18.

☛ See page 19 for an ***An Empirical Model That Predicts Algae Levels from Phosphorus***.

☛ See page 19 for ***An Empirical Model That Predicts Algae Levels from Nitrogen.***

☛ See page 20 for ***An Empirical Model That Predicts Algae Levels from Both Phosphorus and Nitrogen.***

How To Use An Empirical Model

Consider that a hypothetical lake called **My Lake** has an average total phosphorus (TP) concentration of **10 µg/L**. Let's suppose that, for whatever reason, you suspect that the total phosphorus concentration in **My Lake** may increase to as much as **20 µg/L**. Using the following **phosphorus-chlorophyll** empirical equation, you can predict what the chlorophyll value in the lake might be if total phosphorus (TP) value reaches **20 µg/L**.

$$\text{Log (Chlorophyll)} = -0.369 + 1.053 \text{ Log (TP)}$$

To make this calculation...

use a calculator with a LOG button and follow these step-by-step instructions.

Step 1 **Start by plugging in the hypothetical TP concentration of 20 µg/L into the equation.** (Replace "TP" with the number 20.)
Now find the Log of 20 on your calculator.
*To find the Log of a number on your calculator, type in the number on the keypad (in this instance, type in the number 20) and then push the button marked "Log." For this exercise, you should get an answer of **1.3010**. See example below.*

Example: Log (chlorophyll) = – 0.369 + 1.053 x **Log (20)**

Log (chlorophyll) = – 0.369 + 1.053 x **1.3010**

Step 2 **Multiply that number** (1.3010) **by 1.053** (from the equation).

Log (chlorophyll) = – 0.369 + **1.053 x 1.3010**

Log (chlorophyll) = – 0.369 + **1.3700**

Step 3 **Now add – 0.369** (from the equation).

Example: Log (chlorophyll) = **– 0.369 + 1.3700**

Log (chlorophyll) = **1.0010**

Step 4 **Find the antilog of your result.**
*To find the antilog, leave the log answer (predicted chlorophyll value) on the calculator. You should see the number **1.0010**. While that number is on your screen, push the antilog key which is usually represented by the symbol* y^x. *(If your calculator doesn't have this button, check the calculator instruction booklet.)*

You should get an answer of 10.0231 — which can be rounded down to 10 to give you a predicted average chlorophyll concentration of 10 µg/L.

Log is an abbreviation for the mathematical term **logarithm**. A logarithm is the "exponent that indicates the power to which a number is raised to produce a given number." [i.e., for the number 100, the logarithm of 10^2 is 2].

Antilog is an abbreviation for the mathematical term **antilogarithm**. An antilogarithm is "the number corresponding to a given logarithm." [For the equation $10^2 = 100$, the antilog of 2 is 100].

An Empirical Model That Predicts Algae Levels from <u>Phosphorus</u>

For Florida lakes, the following empirical **phosphorus-chlorophyll** model was developed using data from 534 waterbodies within the Florida LAKEWATCH database. Using this model, you can predict algae levels (chlorophyll) by plugging in a hypothetical total phosphorus concentration for a lake. *[See the sidebar **How To Use Empirical Models** for step-by-step instructions on how to do the calculations.]*

$$\mathbf{Log\ (Chlorophyll) = -0.369 + 1.053\ Log\ (TP)}$$

Where: **Log** is the common logarithm,
Chlorophyll is the annual mean chlorophyll concentration in µg/L, and
TP is the annual mean total phosphorus concentration in µg/L.

*Data analysis shows this model has a 95% confidence limit that ranges from 30% to 325%. For more on confidence limits, see **How Much Confidence Can You Have In An Empirical Model?** on page 21.*

An Empirical Model That Predicts Algae Levels From <u>Nitrogen</u>

Empirical **nitrogen-chlorophyll** models can be derived in a manner similar to that described for the phosphorus-chlorophyll model above. Some aquatic scientists believe that both the nitrogen-chlorophyll models and the phosphorus-chlorophyll models should be used simultaneously to provide a more realistic prediction of how chlorophyll levels will be affected by specific changes in nutrient levels.

For Florida lakes, the following empirical nitrogen-chlorophyll model was developed using data from 534 waterbodies within the Florida LAKEWATCH database. Using this model, you can predict chlorophyll levels (algae levels) by plugging in a hypothetical total nitrogen concentration for a lake. Using a hypothetical total nitrogen concentration for your lake, see if you can predict what your chlorophyll levels would be using the equation below. *[See the sidebar example entitled **How to Use an Empirical Model** for step-by-step instructions. Apply the same steps to the equation below.]*

$$\mathbf{Log\ (Chlorophyll) = -2.42 + 1.206\ Log\ (TN)}$$

Where: **Log** is the common logarithm,
Chlorophyll is the annual mean chlorophyll concentration in µg/L, and
TN is the annual mean total nitrogen concentration in µg/L.

*Data analysis shows this model has a 95% confidence limit ranging from 23% to 491% for predicted chlorophyll concentrations (compared to 30% to 325% for the previous phosphorus-chlorophyll model). For more on confidence limits, see **How Much Confidence Can You Have In An Empirical Model?** on page 21.*

An Empirical Model That Predicts Algae Levels From Both Phosphorus and Nitrogen

The most reliable model (with the smallest confidence interval) is an empirical **nutrient-chlorophyll** model that factors in *both* nitrogen and phosphorus concentrations to predict chlorophyll levels. Using this model, you can predict algae levels (CHL concentrations) by plugging in hypothetical total phosphorus and total nitrogen concentrations for a lake.

For Florida lakes, the following empirical nutrient-chlorophyll model was developed using data from 534 waterbodies within the Florida LAKEWATCH database. *[See the sidebar example entitled **How to Use an Empirical Model** for step-by-step instructions. Apply the same steps to the equation below.]*

$$\textbf{Log (Chlorophyll)} = -1.10 + 0.91 \textbf{ Log (TP)} + 0.321 \textbf{ Log (TN)}$$

Where: **Log** is the common logarithm,
Chlorophyll is the annual mean chlorophyll concentration in µg/L,
TP is the annual mean total phosphorus concentration in µg/L, and
TN is the annual mean total nitrogen concentration in µg/L.

*Data analysis shows that this model is the best available model for Florida lakes. It has a 95% confidence limit ranging from 33% to 312% for predicted chlorophyll concentrations. This is the smallest confidence range for any published empirical nutrient-chlorophyll model that has been tested for Florida lakes. The confidence limit is also smaller than those established for the simple empirical phosphorus-chlorophyll (30% to 325%) or nitrogen-chlorophyll (23% to 491%) models. For more on confidence limits, see **How Much Confidence Can You Have In An Empirical Model?** on page 21.*

Keep practicing

Using the phosphorus–chlorophyll empirical model again (see top of page 21), plug in the following hypothetical total phosphorus concentration to see if you can predict an average chlorophyll concentration. *Be sure to check your answer.*

With a total phosphorus concentration of **178 µg/L** the formula should yield an average chlorophyll concentration of <u>?</u>. *See answer below.*

[Answer: 100 µg/L]

Sandy Fisher

How Much Confidence Can You Have In An Empirical Model?

Scientists often choose to answer this question by calculating confidence limits for their predictions. By doing a mathematical analysis from the very same database used to create the empirical models, scientists can calculate these confidence limits.

A 95% confidence limit gives the range that an empirical model prediction can be expected to fall into 95% of the time. Confidence limits can be calculated for 90% confidence ranges, 85% confidence ranges, etc. (Water managers usually prefer to use higher confidence limits.)

Let's use the hypothetical lake ***My Lake*** again as an example:

After analyzing the same 534 waterbodies from the LAKEWATCH database, our staff found that the 95% confidence limit for the phosphorus-chlorophyll empirical model example used for **My Lake** (pg. 18) ranges from **30% to 325%.**

In other words, there is a 95% confidence that the predicted chlorophyll (of 10 µg/L) will fall somewhere between 30% and 325%. We can translate this percentage range into real numbers and check to see if this is true by doing a couple of calculations.

Calculate this yourself

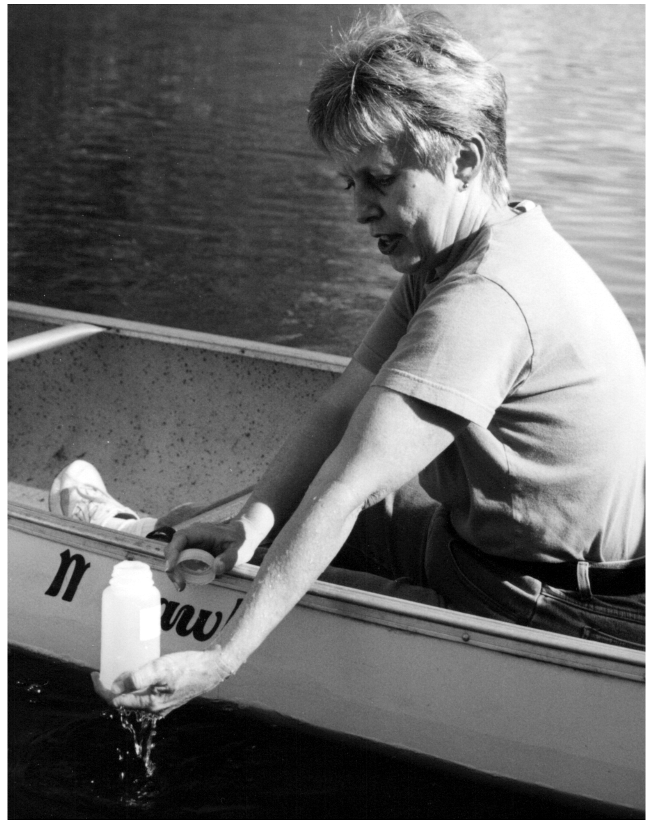
Using the phosphorus-chlorophyll empirical model example from page 18, we know that a chlorophyll concentration of 10 µg/L was predicted. We can use this predicted chlorophyll concentration of 10 µg/L along with the 95% confidence limit range of 30% to 325%, to do the following calculations:

30% of **10 µg/L** is **3 µg/L**

and

325% of **10 µg/L** is approximately **33 µg/L**.

In other words, the actual chlorophyll value for this sample lake (**My Lake**) should be somewhere between 3 µg/L and 33 µg/L for 95% of the time.



Joe Richard

Before water chemistry data can be used in empirical models or for lake management plans, water samples must first be collected and analyzed. Florida LAKEWATCH volunteer Phyllis Brumfeld collects a "grab sample" of lake water that will be analyzed in a UF/IFAS water chemistry laboratory at the Department of Fisheries and Aquatic Sciences in Gainesville.

Empirical Models and Their Limitations

While the confidence limit for the phosphorus-chlorophyll model may seem large (30% to 325% is a rather expansive range), it's not unusual. The confidence limit of even the most reliable empirical model can yield a broad range of chlorophyll values — particularly in Florida.

This broad range of confidence limits, based on Florida LAKEWATCH lakes, truly reflects the variability of chlorophyll concentrations found in waterbodies in this state. As you can see in Figure 1 (page 8), chlorophyll concentrations found in Florida lakes range from as little as 2 µg/L all the way up to 500 µg/L.

Such variability makes predictions from all empirical nutrient-chlorophyll models somewhat uncertain, particularly when only small changes occur in nutrient concentrations.

Use of a 95% confidence limit also reflects the desire of professionals to have their predictions correct 95% of the time. Confidence limits, however, can be smaller when the degree of certainty does not need to be as stringent (e.g., 80% confidence limit or 90% confidence limit).

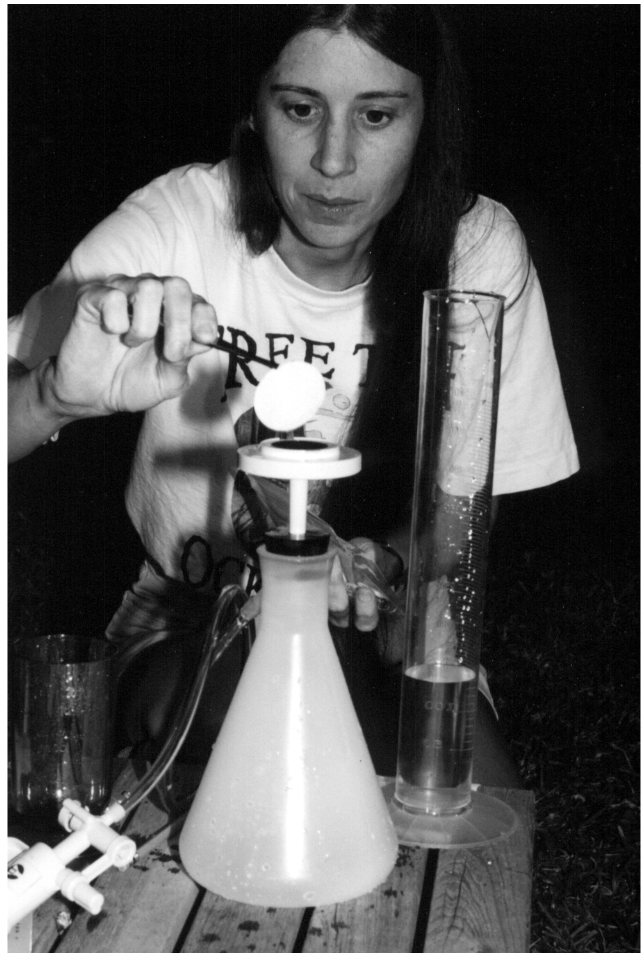
Also, keep in mind that in dealing with real waterbodies, as opposed to hypothetical ones, there is a broad range of possible chlorophyll concentrations that can occur based on any specific amount of nutrients in the system. It's difficult to predict precise quantities when dealing with real-world scenarios – and all the possible factors that can come into play.

In the case of water management, empirical models are used frequently because they have a proven record of providing inexpensive, reasonable results in a short time. Some scientists argue that more complicated experimental models are better than empirical models. However, experimental models are often very time consuming and expensive.

Because other environmental factors, such as local climate, can influence algal biomass (chlorophyll), managers may make their predictions more accurate by using empirical models developed for waterbodies in their local geographic region. When developing these empirical models, a basic understanding of how waterbodies function in that area should be combined with all the best available data.

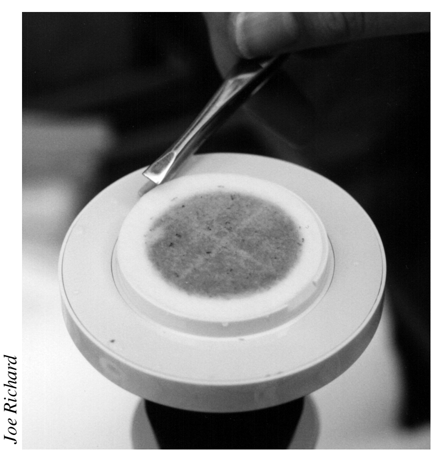
Of course there are instances when an individual lake may fall outside the predictions found while using any empirical model. When this happens, it's important for that lake to be studied independently of others in its region to determine what is "driving" the basic productivity of the lake.

While there are several empirical models currently being used throughout the state, we strongly suggest that lake managers and/or citizens consider using the models provided in this circular. These models are based on a large number of Florida lakes and offer a good starting point for determining the most appropriate management options for a waterbody.



Joe Richard

Florida LAKEWATCH volunteer Susan Wright (above) prepares to filter lake water from Clear Lake. As the water is pumped through the special glass filter (see photo below), algae are trapped on the surface. The filter will then be processed and analyzed in a water chemistry laboratory for chlorophyll (algae) concentrations. These chlorophyll data can then be used as baseline information for Clear Lake, as well as an effective tool for developing management strategies.



Joe Richard

Lastly, it's important to remember that empirical models merely provide a framework for evaluating the potential effects on algal biomass of changing nutrient concentrations in a waterbody. They provide a guide, not absolute answers.

Part 4
Limiting Environmental Factors Other Than Nutrients


Marilyn Bachmann

Limiting environmental factors are factors whose presence or absence causes the growth of aquatic plants and/or algae to be restricted. Often the management of a waterbody is focused solely on the manipulation of *nutrients* as a strategy for controlling growth of algae and/or plants, and the potentially limiting environmental factors are overlooked. A skilled manager will evaluate *all* the potentially limiting environmental factors along with the limiting nutrients and consider all the possibilities. Several important limiting environmental factors are described below:

♦ **Suspended solids** (tiny particles stirred up from the bottom sediments or washed in from the watershed) can reach concentrations high enough that the growth of algae is limited because sunlight is blocked out. This is a common situation in shallow lakes, especially those with heavy wave action such as Lake Okeechobee in south Florida.

♦ The color of **dissolved substances,** though translucent, can block sunlight and retard the growth of aquatic plants and sometimes limit algal abundance. Many of Florida's lakes are tea-colored (reddish or reddish-brown) because of dissolved organic substances in the water. Even when tea-colored lakes are rich in nutrients, the growth of algae and submersed aquatic plants can be limited.

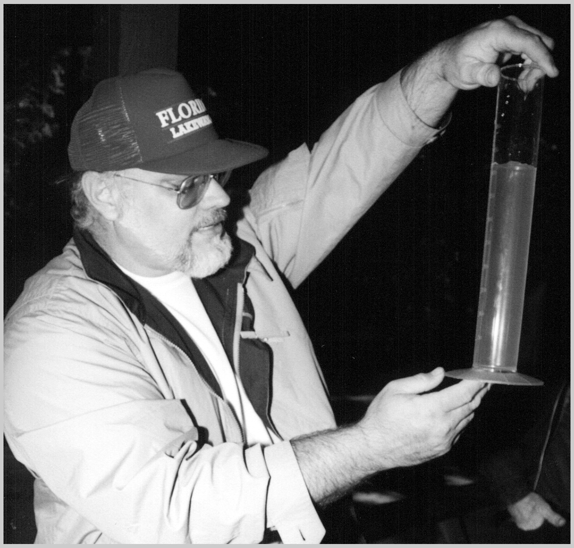
♦ The **hydraulic flushing rate** is the rate at which water flows out of a waterbody. The flushing rate can influence algal growth significantly. Waterbodies with high flushing rates (such as many of Florida's springs, reservoirs, and lakes that are actually just wide spots in rivers) have low algal levels even though they may have high nutrient concentrations.

This seemingly paradoxical condition exists because algae are flushed out of the system before they have the time to grow to their maximum potential.

Florida's famous Silver Springs provide a good example. Water samples taken from the springs are initially crystal clear and yet when analyzed in a water chemistry laboratory, they contain tremendously high levels of phosphorus concentrations. However, that same crystal clear water turns green with algae when left sitting in a jar, for a period of time.

♦ **Aquatic macrophytes** should also be considered as a limiting environmental factor, because their presence may limit the growth of free-floating algae in Florida waterbodies indirectly. If macrophyte coverage (PAC or "percent area covered") is less than 30% of a waterbody, the presence of macrophytes does not appear to influence open-water algal levels.

However, lakes with aquatic macrophytes covering over 50% of their bottom area typically have reduced algal levels and clearer water.



Amy Richard

Suspended solids can reach concentrations great enough that the growth of algae is limited because sunlight is blocked out.

Marilyn Bachmann

The color of dissolved substances, such as tannins released from cypress trees, can block sunlight and retard the growth of aquatic plants and sometimes limit algal abundance.

Amy Richard

Waterbodies with high flushing rates, such as many of Florida's springs have low algal levels even though they may have high nutrient concentrations.

Marilyn Bachmann

Lakes with aquatic macrophytes covering over 50% of their bottom area typically have reduced algal levels and clearer water.

One explanation is that either aquatic macrophytes, or perhaps the algae attached to them, use the available phosphorus in the water, competing with the free-floating algae for this necessary nutrient. Another explanation is that the macrophytes anchor the nutrient-rich bottom sediments in place, buffering the action of wind, waves, and human effects, and thereby deprive the free-floating algae of nutrients contained in the sediments that would otherwise be stirred up.

♦ Macrophytes also provide calm water conditions within their beds. This lack of water movement keeps algal cells from being suspended in the water column.

☛ See Appendix B for more information on **Aquatic Macrophytes.**

Appendix A
Logarithmic Scales

Scientists often use graphs to illustrate relationships between two different measures. In this example, graphs are used to compare phosphorus and chlorophyll in lakes.

Figure 1

Such a plot is shown in Figure 1 (page 26) with a “best fit” line that can be used to estimate the amount of chlorophyll when the total phosphorus measurement is known.

A problem with this type of graph is that we have trouble distinguishing the points for very low levels of phosphorus and chlorophyll. In Figure 1 the phosphorus concentrations range from a low of about 3 to a high of 350 and there are 51 points with concentrations of 10 or less. However, the distance on the scale from 0 to 10 takes up only 1/40th of the distance for the phosphorus axis; so the points are squeezed together.

Figure 2

In Figure 2 we have expanded the scale and cut it off at 100 instead of 400, in order to spread out the points; but they are still packed together, and we can no longer see the points for lakes with higher values of phosphorus and chlorophyll.

Figure 3

A common solution to this problem is shown in Figure 3. Rather than plotting the actual phosphorus concentrations, we can plot the ***logarithms*** of the concentrations.✪ This allows us to see more individual points that otherwise would be crowded in the lower corner of the graph.

For example, by using logarithms we are able to stretch out the scale at the lower end so that the distance between 2 and 7 is the same at the distance between 20 and 70 higher up on the scale. This is evident by comparing Figure 2 with Figure 3.

There are two other benefits. For many measurements the variability or sampling error increases as the value of the measurement increases. Notice in Figure 1 how the points are very close to the “best fit” line at low values of phosphorus and chlorophyll and show a much greater scatter as the values increase.

✪ *Recall that common logarithms are the exponents of the number 10. For example: $10^2 = 100$, so the logarithm of 100 is 2. And using the equation $10^3=1000$, we can see that the logarithm of 1000 is 3. Similarly the logarithm of 10 would be 1. [Note: Tables or computer programs can be used to find logarithms of other numbers that are not exact multiples of 10.]*

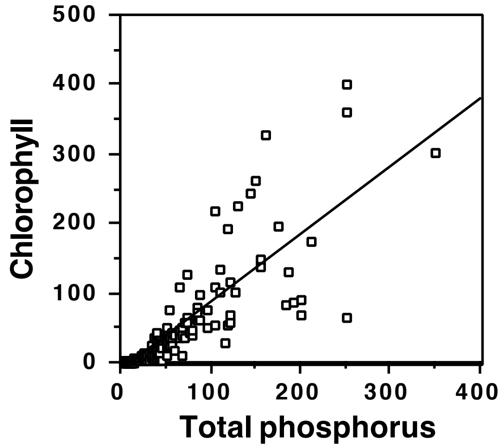


Figure 1.

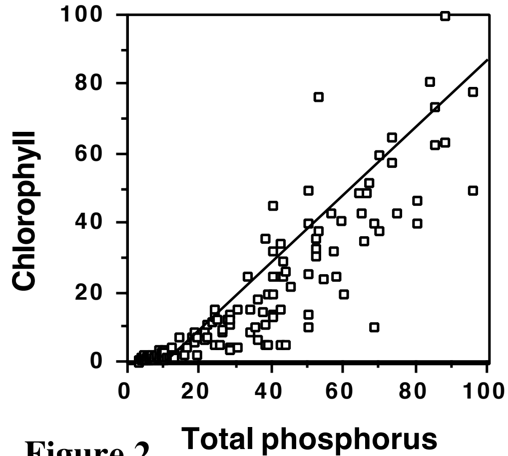


Figure 2.

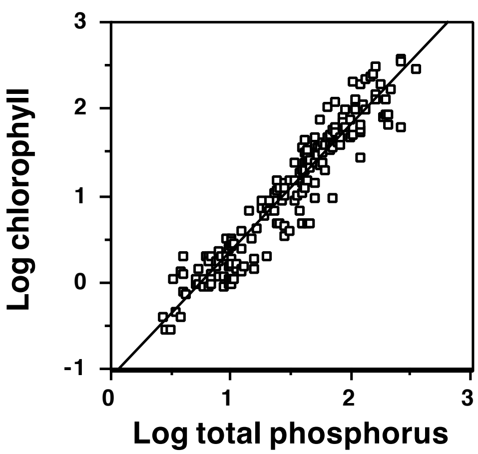


Figure 3

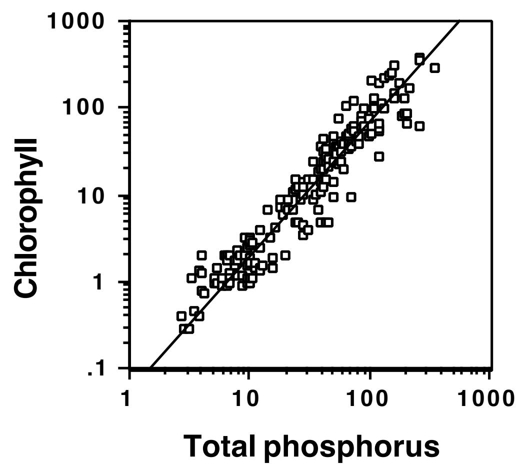


Figure 4

In the logarithmic plot in Figure 3 the scatter of the points along the line is more even from the low to the high end of the scale. It can be shown that in this case the per cent error is more or less constant. Lastly, we can often use a logarithmic plot to fit a straight line to data that form a curve on a direct plot. Note in Figure 2 that there is an upward curve to the points. This is straightened out in the logarithmic plot in Figure 3. This property makes it easier to find a mathematical relationship between the two measurements.

Figure 4

To make our plots easier to understand, we often use a logarithmic *scale* rather than the actual logarithms, which was done in Figure 3. Note how much easier it is to find the values for a point in Figure 4 when a logarithmic scale is used.

Appendix B
Description of Terms
Excerpts from Florida LAKEWATCH Information Circular 101

Aquatic Macrophytes

are aquatic plants that are large enough to be apparent to the naked eye. In other words, they are larger than microscopic aquatic plants. The general term "aquatic plants" usually refers to aquatic macrophytes, but some scientists use it to mean aquatic macrophytes and algae.

Aquatic macrophytes characteristically grow in water or in wet areas and are quite a diverse group. For example, some are rooted in the bottom sediments, while others float on the water's surface and are not rooted to the bottom. Aquatic plants may be native to an area, or they may have been imported (referred to as *exotic*).

Some aquatic macrophytes are vascular plants, meaning they contain a system of fluid-conducting tubes, much like human blood vessels. Cattails, waterlilies, and hydrilla are examples. Large algae such as *Cladophora*, *Lyngbya*, and *Chara* are examples of non-vascular plants that are also included in the category of aquatic macrophytes.

Even though they are quite diverse, aquatic macrophytes have been grouped into three general categories:

♦ emergent aquatic plants are rooted in the bottom sediments and protrude up above the water's surface;

♦ submersed aquatic plants primarily grow completely below the water's surface; and

♦ floating-leaved aquatic plants can be rooted to the waterbody's bottom sediments and also have leaves that float on the water's surface.

Aquatic macrophytes are a natural part of waterbodies, although in some circumstances they can be troublesome. The same plant may be a desirable aquatic plant in one location and a nuisance weed in another. When exotic aquatic plants have no natural enemies in their adopted area, they can grow unchecked and may become overly abundant.

In Florida for example, millions of dollars are spent each year to control two particularly aggressive and fast-growing aquatic macrophytes: **water hyacinth**, an exotic aquatic plant that is thought to be from Central and South America, and **hydrilla**, an exotic aquatic plant that is thought to be from Africa.

The term "weed" is not reserved solely for exotic aquatic plants. In some circumstances, our native aquatic plants can cause serious problems, too. When assessing the abundance of aquatic plants in a waterbody, scientists may choose to measure or calculate one or more of the following:

♦ **PVI** (Percent Volume *Infested* or Percent Volume *Inhabited*) is a measure of the percentage of a waterbody's volume that contains aquatic macrophytes;

♦ **PAC** (Percent Area Covered) is a measure of the percentage of a waterbody's bottom area that has aquatic plants growing on or over it;

♦ **frequency of occurrence** is an estimate of the abundance of specific aquatic plants; and

♦ **average plant biomass** is the average weight of several samples of fresh, live aquatic plants growing in one square meter of a lake's area.

The Role of Aquatic Macrophytes in Waterbodies:

Aquatic macrophytes perform several functions in waterbodies, often quite complex ones. A few are briefly described below.

♦ Aquatic macrophytes provide habitat for fish, wildlife, and other aquatic animals.

♦ Aquatic macrophytes provide habitat and food for organisms that fish and wildlife feed on.

♦ Aquatic macrophytes along a shoreline can protect the land from erosion caused by waves and wind.

♦ Aquatic macrophytes can stabilize bottom sediments by dampening the wave action.

♦ The mixing of air into the water that takes place at the water's surface can be obstructed by the presence of floating plants and floating-leaved plants. In this way, they can cause lower oxygen levels in the water.

♦ Floating plants and floating-leaved plants create shaded areas that can cause the growth of submersed plants beneath them to be slowed.

♦ When submersed aquatic plants become more abundant, these plants can cause water to become clearer. Conversely, the removal of large amounts of submersed aquatic plants can cause water to become less clear.

♦ When aquatic macrophytes die, the underwater decay process uses oxygen from the water, which can become severely oxygen-poor if massive amounts of plants die simultaneously.

♦ Decayed plant debris (dead leaves, etc.) contributes to the buildup of sediments on the bottom.

Chlorophyll

is the green pigment found in plants and found abundantly in nearly all algae. Chlorophyll allows plants and algae to use sunlight in the process of photosynthesis for growth. Thanks to chlorophyll, plants are able to provide food and oxygen for the majority of animal life on earth.

Scientists may refer to **chlorophyll *a***, which is one type of chlorophyll. **Chlorophyll *b*** and **chlorophyll *c*** are two other types.

A measurement of all three of these types combined is known as **total chlorophyll**. Chlorophyll can be abbreviated CHL and total chlorophyll can be abbreviated TCHL.

The Role of Chlorophyll in Waterbodies:

Measurements of the chlorophyll concentrations in water samples are very useful to scientists. For example, they are often used to estimate algal biomass in a waterbody and to assess a waterbody's biological productivity.

In Florida:

Waterbodies in the Florida LAKEWATCH database analyzed prior to January 1998 had average chlorophyll concentrations which ranged from less than 1 to over 400 µg/L.

Using these average chlorophyll concentrations from this same database, Florida lakes were found to be distributed into the four trophic states as follows:

♦ 12% of the lakes (those with chlorophyll values less than 3 µg/L) would be classified as **oligotrophic**;

♦ about 31% of the lakes (those with chlorophyll values between 4 and 7 µg/L) would be classified as **mesotrophic**;

♦ 41% of the lakes (those with chlorophyll values between 8 and 40 µg/L) would be classified as **eutrophic**; and

♦ nearly 16% of the lakes (those with chlorophyll values greater than 40 µg/L) would be classified as **hypereutrophic**.

In Florida, characteristics of a lake's geographic region can provide insight into how much chlorophyll may be expected for lakes in that area. For example, water entering the waterbodies by stream flow or underground flowage through fertile soils can pick up nutrients that can then fertilize the growth of algae and aquatic plants. In this way, the geology and physiography of a watershed can influence a waterbody's biological productivity significantly.

Health Concerns:

Chlorophyll (algae) poses no direct threat to human health. There are some rare cases where algae can become high enough in abundance to cause concern. However, algae are generally not a health threat.

Color

in waterbodies has two components:
(1) **apparent color** is the color of a water sample that *has not* had particulates filtered out;
(2) **true color** is the color of a water sample that *has* had all particulates filtered out of the water.

The measurement of true color is the one most commonly used by scientists. To measure true color, the color of the filtered water sample is matched to one from a spectrum of standard colors. Each of the standard colors has been assigned a number on a scale of **platinum-cobalt units** (abbreviated as either **PCU** or **Pt-Co units**). On the PCU scale, a higher value of true color represents water that is darker in color.

The Role of Color in Waterbodies:

Dissolved organic materials (humic acids from decaying leaves), and dissolved minerals can give water a reddish brown "tea" color.

The presence of color can reduce both the quantity and quality of light penetrating into the water column. As a result, high color concentrations (greater than 50 PCU) may limit both the quantity and types of algae growing in a waterbody. Changing the quantity and quality of light reaching the bottom of a waterbody can also influence the depth of colonization and the types of aquatic plants that can grow there. In some waterbodies, color is the **limiting environmental factor.**

In Florida:

Waterbodies in the Florida LAKEWATCH database analyzed prior to January 1998 had average color values ranging from 0 to over 700 PCU. Over 75% of these waterbodies had color values less than 70 PCU.

Waterbodies that adjoin poorly drained areas (such as swamps) often have darker water, especially after a rainfall. Consequently, the location of a waterbody has a strong influence on its color. For example, lakes in the well-drained New Hope Ridge/Greenhead Slope lake region in northwestern Florida (in Washington, Bay, Calhoun, and Jackson Counties) tend to have color values below 10 PCU. While lakes in the poorly-drained Okefenokee Plains lake region in north Florida (in Baker, Columbia, and Hamilton Counties) tend to have values above 100 PCU.

Health Concerns:

There is no known direct health hazard of color. Consequently, an acceptable level of color depends on personal preference. Water transparency, however, may be reduced in highly colored waters (greater than 50 PCU) to the point where underwater hazards may be concealed, creating a potentially dangerous situation for swimmers, skiers, and boaters.

Humic acids

are produced when organic matter such as dead leaves decay. Humic acids can color water so that it appears reddish or reddish-brown, like tea. In some cases, the water can appear almost black.

Lake Region

is a geographic area in which lakes have similar geology, soils, chemistry, hydrology, and biological features. In 1997, using Florida LAKEWATCH data and other information, the United States Environmental Protection Agency divided Florida into 47 lake regions using these similarities as their criteria.

Lakes in an individual lake region exhibit remarkable similarities. However, lakes in one lake region may differ significantly from those in a different lake region. For example, most lakes in the New Hope Ridge/Greenhead Slope lake region in northwestern Florida (in Washington, Bay, Calhoun, and Jackson Counties) tend to have lower total nitrogen, lower total phosphorus, lower chlorophyll concentrations and higher Secchi depths when compared to other Florida lakes. While lakes in the Lakeland/Bone Valley Upland lake region in central Florida (in Polk and Hillsborough Counties) tend to have higher total nitrogen, higher total phosphorus, higher chlorophyll concentrations and lower Secchi depths when similarly compared.

Using descriptions of Lake Regions, waterbody managers can establish reasonable, attainable water management goals for individual lakes. Lake Region characteristics can also be used to help choose management strategies that are likely to be effective in achieving management goals. In addition, lakes with water chemistry that differs markedly from that of other lakes in the same lake region can be identified and investigated to determine the cause of their being atypical.

The lake regions are mapped and described in a report entitled ***Lake Regions of Florida*** (EPA/R=97/127). The Florida LAKEWATCH Program can provide a free pamphlet describing:

(1) how and why the Lake Regions project was developed;

(2) how to compare your lake with others in its Lake Region; and

(3) how the Lake Region Classification System can be useful to you.

Trophic State

is defined as the degree of biological productivity of a waterbody. Scientists debate exactly what is meant by "biological productivity," but it generally relates to the amount of algae, aquatic plants, fish and wildlife a waterbody can produce and sustain.

Waterbodies are traditionally classified into four groups according to their level of biological productivity. The adjectives denoting each of these trophic states, from the lowest productivity level to the highest, are ***oligotrophic***, ***mesotrophic***, ***eutrophic***, and ***hypereutrophic***. Aquatic scientists assess trophic state by using measurements of one or more of the following:

♦ total phosphorus concentrations in the water;

♦ total nitrogen concentrations in the water;

♦ total chlorophyll concentrations (a measure of free-floating algae in the water column); and

♦ water clarity (measured using a Secchi disc); and

♦ aquatic plant abundance.

Florida LAKEWATCH professionals base trophic state classifications primarily on the amount of chlorophyll in water samples. Chlorophyll concentrations have been selected by LAKEWATCH as the most direct indicators of biological productivity, since the amount of algae actually being produced in a waterbody is reflected in the amount of chlorophyll present. In addition, Florida LAKEWATCH professionals may modify their chlorophyll-based classifications by taking the aquatic plant abundance into account.

Trophic State Index (TSI)

is a scale of numbers from 1 to 100 that can be used to indicate the relative trophic state of a waterbody. Low TSI values indicate lower levels of biological productivity, and higher TSI values indicate higher levels. The use of TSI is an attempt to make evaluations of biological productivity easier to understand.

Using mathematical formulas, TSI values can be calculated using four parameters: total nitrogen concentrations, total phosphorus concentrations, total chlorophyll concentrations, and Secchi depth. Sometimes a single TSI value for a waterbody is calculated by combining selected individual TSI values.

The State of Florida has classified its waterbodies according to the designated uses the state has assigned to each. (See **Water Quality** in this Appendix, for a more detailed description.)

The Florida Department of Environmental Protection (FDEP) assesses water quality in Florida by evaluating whether each waterbody was able "to support its designated use." [The Florida Water Quality Assessment 305(b) Report 1996]. Their assessment is based solely on TSI values as follows:

♦ waterbodies with TSI values from 0 to 59 are rated as "good and fully support use";

♦ those waterbodies with TSI values between 60-69 are rated as "fair and partially support use"; and

♦ waterbodies with TSI values from 70 to 100 are rated as "poor and do not support use."

Individual TSI values may be further combined in a special type of averaging to produce an **Average Trophic State Index** (abbreviated TSI_{ave}). Government and regulatory agencies responsible for water management often use the average value, overlooking the fact that the designing author, Dr. Robert Carlson of Kent State University in Ohio, never intended TSI values to be reduced to a single number. TSI values for the individual parameters could differ markedly within any specific waterbody and this significant variation will be obscured when the TSI_{ave} is calculated.

Dr. Carlson has noted that TSI values should not be averaged, as consideration of the differences in *individual* TSI values in a waterbody can provide insight and a better understanding of its biological productivity.

The Florida LAKEWATCH Program does not use the TSI system (the TSI_{ave} or individual TSI values). Instead LAKEWATCH finds it more informative to use the individual values of the four measured parameters without transforming them into TSI values.

Water Clarity

is the transparency or clearness of water. While many people tend to equate water clarity with water quality, it's a misconception to do so. Contrary to popular perceptions, crystal clear water may contain pathogens or bacteria that would make it harmful to drink or to swim in, while pea-soup green water may be harmless.

Water clarity in a waterbody is commonly measured by using an 8-inch diameter Secchi disc attached to a cord. The disc is lowered into the water, and the depth at which it vanishes from sight is measured. Measured in this way, water clarity is primarily affected by three components in the water:

♦ free-floating algae called phytoplankton,

♦ dissolved organic compounds that color the water reddish or brown, and

♦ sediments suspended in the water (either stirred up from the bottom or washed in from the shore).

Water clarity is important to individuals who want the water in their swimming areas to be clear enough so that they can see where they are going. In Canada, the government recommends that water should be sufficiently clear so that a Secchi disc is visible at a minimum depth of 1.2 meters (about 4 feet). This recommendation is one reason that many eutrophic and hypereutrophic lakes that have abundant growths of free-floating algae do not meet Canadian standards for swimming and are deemed undesirable. It should be noted that these lakes are not necessarily undesirable for fishing nor are they necessarily polluted in the sense of being contaminated by toxic substances.

The Role of Water Clarity in Waterbodies:

Water clarity will have a direct influence on the amount of biological production in a waterbody. When water is not clear, sunlight cannot penetrate far and the growth of aquatic plants will be limited. Consequently aquatic scientists often use Secchi depth (along with total phosphorus, total nitrogen, and total chlorophyll concentrations) to determine a waterbody's trophic state.

Water clarity affects plant growth, but conversely, the abundance of aquatic plants can affect water clarity. Generally, increasing the abundance of submersed aquatic plants to cover 50% or more of a waterbody's bottom area may have the effect of increasing the water clarity. One explanation is that either the submersed plants, or perhaps the algae attached to aquatic plants, use the available nutrients in the water, depriving the free-floating algae of them. Another explanation is that the submersed plants anchor the nutrient-rich bottom sediments in place – buffering the action of wind, waves, and human effects – depriving the free-floating algae of nutrients contained in the bottom sediments that would otherwise be stirred up.

Because plants must have sunlight in order to grow, water clarity is also directly related to how deep underwater aquatic plants will be able to live. This depth can be estimated using Secchi depth readings.

In Florida:

Waterbodies in the Florida LAKEWATCH database analyzed prior to January 1998, had Secchi depths ranging from less than 0.2 to over 11.6 meters (from about 0.7 to 38 feet).

The trophic state of a waterbody is strongly related to the water clarity. Using these average Secchi depth readings from the Florida LAKEWATCH database analyzed prior to January 1998, Florida lakes were found to be distributed into the four trophic states as follows:

♦ approximately 7% of these lakes would be classified as **oligotrophic** (lakes with Secchi depths greater than 3.9 meters [about 13 feet]) ;

♦ about 22% of these lakes would be classified as **mesotrophic** (lakes with Secchi depths between

2.4 and 3.9 meters [between about 8 and 13 feet]) ;

♦ 45% of these lakes would be classified as **eutrophic** (lakes with Secchi depths between 0.9 and 2.4 meters [between about 3 and 8 feet]) ; and

♦ 26% of these lakes would be classified as **hypereutrophic** (lakes with Secchi depths less than 0.9 meters [about 3 feet]).

The location of a waterbody has a strong influence on its water clarity. For example, lakes in the New Hope Ridge/Greenhead Slope lake region (in Washington, Bay, Calhoun, and Jackson Counties) tend to have Secchi depths greater than 3.0 meters. While lakes in the Lakeland/Bone Valley Upland lake region (in Hillsborough and Polk Counties) tend to have Secchi depths less than 0.9 meters.

Health Concerns:

Water clarity is not known to be directly related to human health.

Water Quality

is a subjective, judgmental term used to describe the condition of a waterbody in relation to human needs or values. The phrases "good water quality" or "poor water quality" are often related to whether the waterbody is meeting expectations about how it can be used and what the attitudes of the waterbody users are. Water quality is not an absolute.

One person may judge a waterbody as being high quality, while someone with a different set of values may judge the same waterbody as being poor quality. For example, a lake with an abundance of aquatic plants in the water may not be inviting for swimmers but may look like a good fishing spot to anglers.

Water quality guidelines for freshwaters have been developed by various regulatory and governmental agencies. For example, the Canadian Council of Resource and Environmental Ministers (CCREM) provides basic scientific information about the effects of water quality parameters in several categories, including raw water for drinking water supply, recreational water quality and aesthetics, support of freshwater aquatic life, agricultural uses, and industrial water supply.

Water quality guidelines developed by the Florida Department of Environmental Protection (FDEP) provide standards for the amounts of some substances that can be discharged into Florida waterbodies (Florida Administrative Code 62.302.530). These FDEP guidelines provide different standards for waterbodies in each of five classes. They are defined by their assigned designated use as follows:

♦ Class I waters are for POTABLE WATER SUPPLIES;

♦ Class II waters are for SHELLFISH PROPAGATION OR HARVESTING;

♦ Class III waters are for RECREATION, PROPAGATION AND MAINTENANCE OF A HEALTHY, WELL-BALANCED POPULATION OF FISH AND WILDLIFE;

♦ Class IV waters are for AGRICULTURAL WATER SUPPLIES; and

♦ Class V waters are for NAVIGATION, UTILITY AND INDUSTRIAL USE.

All Florida waterbodies are designated as Class III unless they have been specifically classified otherwise (refer to Chapter 62-302.400, Florida Administrative Code for a list of waterbodies that are not Class III).