A Beginner's Guide to Water Management —

Lake Morphometry

Information Circular 104

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

September 2001
2nd Edition

UNIVERSITY OF FLORIDA
IFAS

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LAKEWATCH

Edward L. Amerson

A lake is the landscape's most beautiful and expressive feature. It is the earth's eye looking into which the beholder measures the depth of his own nature.

—Henry David Thoreau
Walden

Introduction

If asked to describe a lake, most of us would probably begin by discussing the waterbody's more obvious characteristics such as its size, water clarity, aquatic plant growth, the color of the water, or fishing potential — whichever characteristics are most important to us as lake users. However, there are several other less visible lake characteristics that are just as significant, yet rarely discussed: namely the shape and structure of a lake basin.

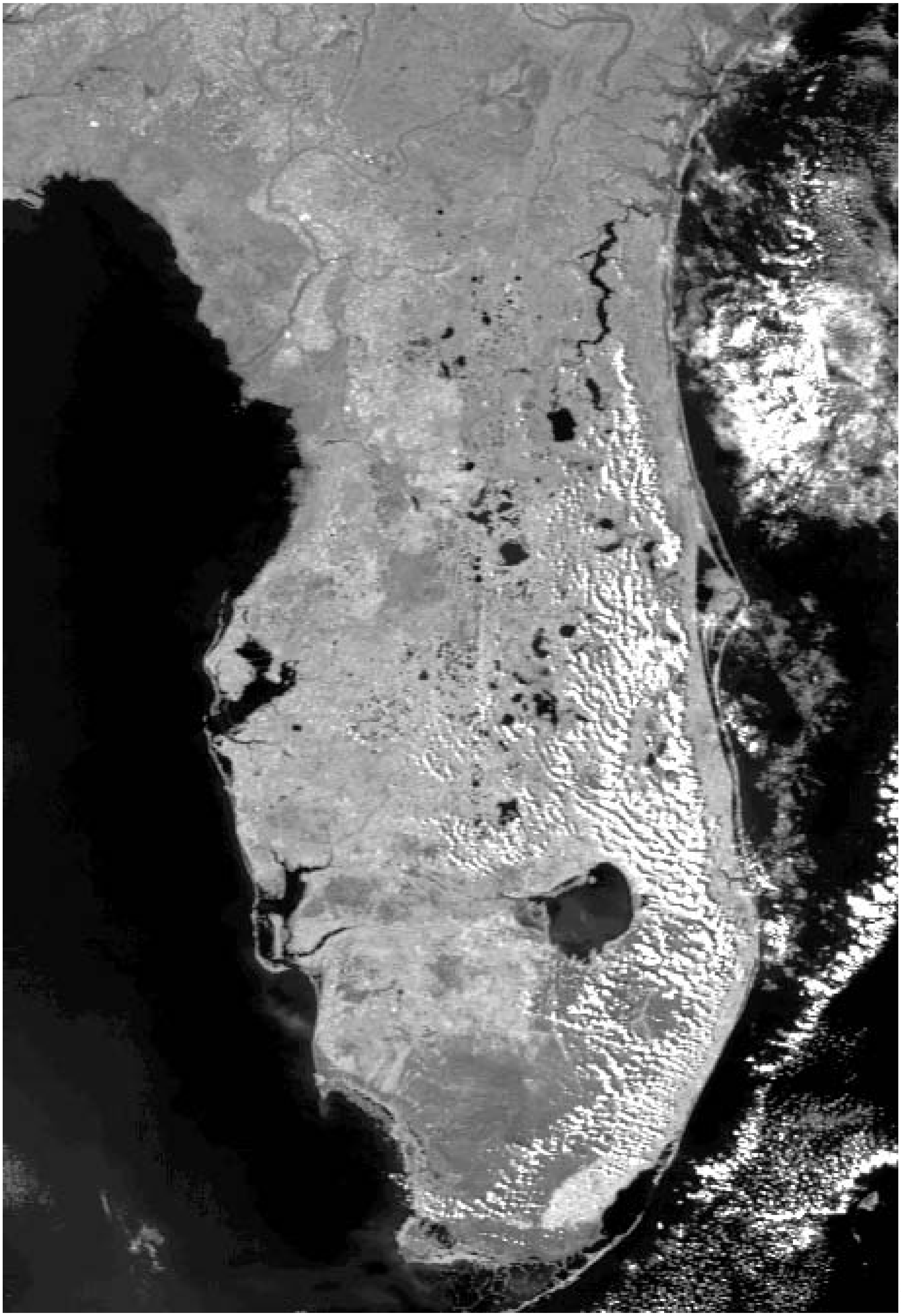
The study of these lake basin features is known as **lake morphology** and familiarity with the subject is as important to lake management professionals as human anatomy is to a physician. Just as physicians rely on their knowledge of human anatomy to understand a patient better, lake management professionals (and anyone else) can learn a great deal about how a lake functions by studying its **morphometric** characteristics. For example, when we know the shape and structure of a lake basin, we can sometimes predict how weather conditions or human-induced events may affect water levels in that system. This is important because, as many lake residents already know, changes in water levels can influence the water quality of their lake including the amount of algae and/or aquatic plants growing in the water, fish species and abundance, and water clarity. It can even play a role in determining the types of birds and wildlife that are attracted to a waterbody.

From a scientist's or lake manager's standpoint, this type of information can be helpful in anticipating changes in a lake system and predicting how it might affect the lake's inhabitants — increasing the chances of mitigating any undesirable impacts with carefully planned management techniques.

Lake residents can use their knowledge of lake morphometry when deciding where to build a lakefront home, boathouse, or dock. Some people have even learned to foresee changes in their lake and use them to enhance their own personal management goals. For instance, by anticipating drought-induced low water levels in his lake, one homeowner took advantage of the circumstances and applied for muck removal permits for his beachfront. Being able to plan ahead and obtain permits before conditions changed was a real advantage as the permitting process had traditionally proven to be a lengthy and time-consuming endeavor.

Lastly, studying lake morphometry can also help us appreciate lakes for what they are and manage them with more realistic expectations. For example, residents living on a large shallow lake in central Florida might find it useful to know that the size and shape of their lake makes it more susceptible to wave action, which stirs up bottom sediments and often results in low water clarity. With this insight, they may decide to create man-made islands to help buffer the effects of the wind or they may choose to do nothing, content with the idea that the lake has naturally limited water clarity. Whatever they decide, knowledge is an effective tool for the decision making process.

Because lake morphometry can play such a critical role in the dynamics of a lake system, we encourage anyone who is interested in learning more about their lake to become familiar with the following terminology and techniques currently used to study lakes. Such information will provide a solid basis for comparison with other waterbodies, as well as invaluable tools for developing a lake management plan for your lake, or others in your area.



NASA

Part 1

How Lakes Are Formed


Central Florida Visitors & Convention Bureau

Lakes are formed in a variety of ways, depending on their geographic location and the geological and biological forces at work within that region. In some instances, they are the result of catastrophic events such as earthquakes, volcanoes, landslides, or even meteorites.[1] Others were formed by more gradual processes such as glacial activity, changes in a river's course, wind action, solution processes, or the scouring effects of underwater currents in an ancient sea.[2] Even the accumulation of decaying organic materials has been attributed to the formation of some lakes. For example, it's thought that Lake Okeechobee, an enormous shallow bowl-shaped lake in Florida, was largely the result of erosion caused by ocean currents from long ago when the sea covered the area. But some scientists speculate that an accumulation of decaying organic materials around the rim of the lake (i.e., aquatic organisms, plants, and sediments) complemented its development by helping to contain water within its shores early in its formation.[3]

The majority of lakes in the northern regions of the United States and Canada are glacier-related: the result of large ice flows that scoured the land's surface, creating and removing great quantities of loose material and leaving behind thousands of depressions or basins that eventually became lakes. In some instances, lakes are formed simply from the accumulation of ice in pre-existing depressions within the landscape. Further south and throughout much of the continental United States, a majority of lakes are man-made, created for flood control, the generation of hydroelectric power, recreation, agriculture, or drinking water storage. In many cases, small reservoirs were created to reduce soil erosion.

Florida, however, is a major exception with more than 7,800 naturally formed bodies of water that are as diverse as the creatures inhabiting them. Some lakes are nearly circular in shape, appearing to have been cut out of the landscape with an immense cookie cutter. Many resemble shallow bowls, and others are contained within meandering shorelines that change seasonally with water levels and shoreline vegetation. They vary in size as well. While the majority are less than 30 acres in size, one waterbody, Lake Okeechobee, spans more than 450,000 acres. Its surface area is larger than some counties!

Of course, such an abundance and diversity of lakes is closely linked to Florida's watery geologic history. Fossilized seashells and coral fragments found many miles inland from today's coastline are a sure clue that, for a time, much of the state was submerged. As the oceans receded and the peninsula gradually began to rise out of the water, it became a shallow reef for an estimated 25 million years. During that time, warm ocean currents deposited materials such as limestone and phosphates and then later scoured and re-worked the porous carbonate rock, transporting and redepositing sand, silt, and clay sediments many times over. Eons later, after Florida emerged as a land mass, the resulting limestone formation has proven to be particularly susceptible to solution processes, the most common origin of Florida lakes.[4] It's important to note however, that most Florida lakes are likely the result of numerous geological and biological forces that occurred over a period of years, often centuries, and continue even today. The following is a discussion of these processes.

1 *Listed respectively: Lake Tahoe in California, Crater Lake in Oregon, Lost Lake in California, Chubb Lake in Quebec.*
2 *Listed respectively: the Great Lakes, Catahoula Lake in Louisiana, Hatfield Lake in New Mexico, Lake Jackson in Florida, and Lake Okeechobee in Florida.*
3 *Hutchinson, G.E., 1957.*
4 *The solution process is a chemical process by which rock is dissolved by interactions with water.*

Solution (Sinkhole) Lakes

USGS

Sinkhole lake in Sebring, Florida.

Florida's karst[5] geology is unique in that a large portion of the state is comprised of major deposits of limestone (i.e., calcium and magnesium carbonates) that are particularly susceptible to solution processes.

Rainwater tends to become slightly acidic as it mixes with carbon dioxide from the atmosphere and soils. As it percolates down from the surface or flows horizontally as groundwater,[6] small pockets of Florida's limestone rock matrix are continually being dissolved. As a result, underground cavities and/or caverns are sometimes formed. Under certain conditions, the roofs of these caverns eventually collapse and the resulting sinkhole can, over time, fill with water, creating a **solution lake** (a.k.a. sinkhole lake). *See Figure 1-1 on page 3*.

Florida has the largest concentration of solution lakes in North America. Many are nearly circular, but others are irregular in shape because adjacent sinkholes or additional ground subsidences allow cavities to fuse together to form compound depressions. Solution lakes are still being formed today!

*See **North Florida's Famous Disappearing Lakes** on page 4.*

Depression lakes

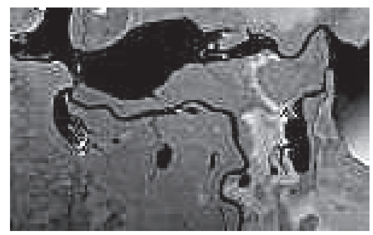
Although the majority of lakes in Florida are the result of solution processes, there are a few other varieties. For example, there are large shallow bowl-shaped waterbodies, only a few meters deep, known as **depression lakes**. While a number of these lakes were carved out of the seafloor by wave action or underwater currents, others are the result of land subsidence or even earthquake activity. For instance, Long Pond in Levy County is thought to have been formed along a fault line, caused by earthquake activity several thousand years ago.

Depression lakes are often different in shape and size from solution lakes. Due to the scouring action of underwater currents and waves, some depression lakes are elongated or appear threaded together like a string of pearls, often along coastal areas or near rivers.

Examples of depression lakes can be found along Florida's Upper St. Johns River, including Lakes Helen Blazes, Washington, Winder, and Poinsett in Brevard County — all remnants of an ancient estuary.[7]

Lake Okeechobee is another example of a depression lake and is thought to have originated as a rather large dip in the Pliocene seabed.[8] Scientists believe that additional biological and geological forces (i.e., solution processes, wind and wave erosion, and sedimentation) helped to modify the lake over time.

River lakes

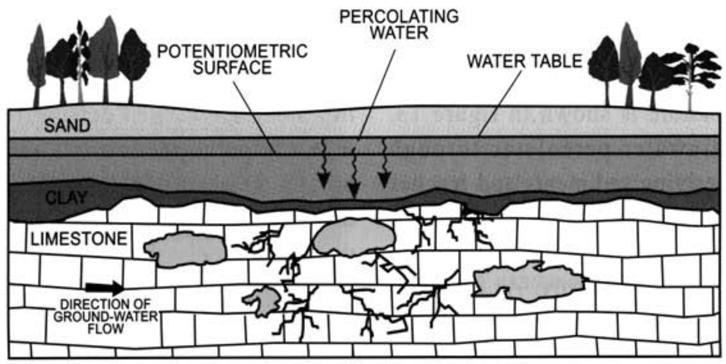


USGS

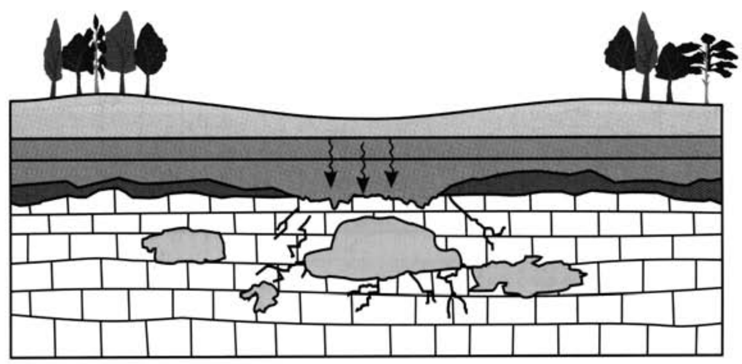
A few lakes in Florida are the result of rivers carrying and delivering large loads of sediment along their borders and creating natural levies that eventually separate newly formed lakes from the river. Similar to depression lakes, **river lakes** are typically elongated in shape and appear to be threaded together. Some are even connected as a series or "chain" of lakes. The Tsala-Apopka Chain-of-Lakes in Citrus county is an example of this type of lake system. Created years ago when the Withlacoochee River was much wider than it is today, numerous lakes (e.g., Floral City, Freds, Hernando, and Henderson) were formed, in part, as the result of changes in the river's course. River lakes are similar to oxbow lakes, but are generally wider and larger than ox-bow lakes, which are typically U-shaped.

5 *Karst refers to limestone and dolomite rock formations beneath the land surface that have been altered by solution processes that continue even today. Karst landforms typically lack major surface drainage such as rivers and streams. Instead, nearly all rainfall filters down through the porous rock.*
6 *Groundwater is the water below the land surface in the zone of saturation.*
7 *White, William A. 1970, pages 102-104.*
8 *Hutchinson, G.E., 1957.*

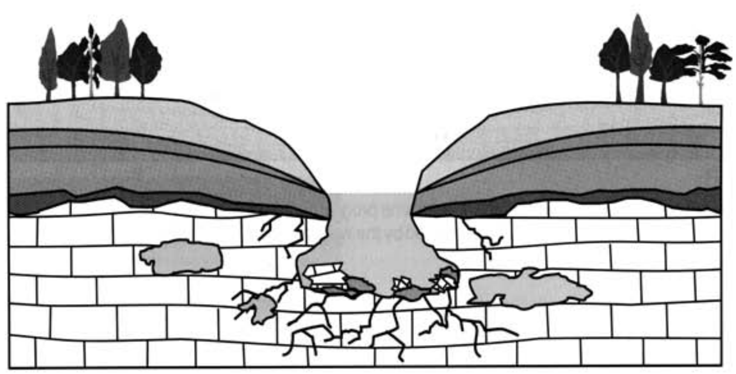
How Sinkholes Are Formed



No evidence of land subsidence, small- to medium-sized cavities in the rock matrix. Water from surface percolates through to rock, and the erosion process begins.



Cavities in limestone continue to grow larger. Note missing confining layer that allows more water to flow through to the rock matrix. Roof of the cavern is thinner, weaker.



As ground-water levels drop during the dry season, the weight of the overburden exceeds the strength of the cavern roof, and the overburden collapses into the cavern, forming a sinkhole.

Courtesy of USGS / Hydrology of Central Florida Lakes — A Primer

Figure 1-1 Formation of a collapse sinkhole.

Solution Lakes:

North Florida's Famous Disappearing Lakes


UF/IFAS Center for Aquatic and Invasive Plants

Paynes's Prairie in Gainesville was once known as Lake Alachua, after locals plugged up a nearby sinkhole.


Jess Van Dyke / Florida DEP

Porter Sink that drained Lake Jackson in September 1999.


Jess Van Dyke / Florida DEP

A brave Jess Van Dyke, with Florida DEP, descends into Porter Sink to explore underneath Lake Jackson after its infamous disappearing act in September 1999.

The north central region of Florida is dotted with numerous examples of solution lakes. However, there are several that are particularly interesting as they have a rather disconcerting habit of disappearing.

Alligator Lake in Lake City, Lake Alachua (i.e., Payne's Prairie) in Gainesville, and Lake Jackson in Tallahassee, are all known to have done this at various times in the past and they have at least one morphological characteristic in common. Their lake beds are situated *above* local groundwater levels and as a result, they are even more susceptible to solution processes and the formation of sinkholes. *See Figure 1-1 on page 3*.

Lake Jackson performed its most recent disappearing act in September of 1999 and May 2000. Due to drought conditions and steadily dropping groundwater levels, a portion of the lakebed collapsed into an eight-foot wide sinkhole that drained the entire central portion of the lake. Six months later, a second sinkhole opened up in a different section of the lake. And "though shallow pools still occurred in portions of the lake, more than 90% of the 4,000-acre lake had vanished!" (Jess Van Dyke, *Aquatics*, Summer 2000).

This type of activity has been documented several times since the late 1800s and always coincides with long-term drought conditions.

Not to worry, once the sinkhole becomes blocked with sediment and debris and rainfall resumes, the lake will probably fill up again.

Reservoirs and other man-made lakes

Reservoirs are generally formed by building a dam or weir across a body of flowing water and allowing water to fill up a valley or low lying area. People have been building these structures for more than 3,000 years to supply drinking water, hydroelectric power, fish and other aquatic products, aids to navigation, even defense. While many lakes in Florida were formed naturally, thousands of small reservoirs can be found throughout the state, as well as several larger ones, including:

• Manatee Lake in Manatee County was built to serve as a drinking water supply;

• Lake Talquin in Gadsden County is used primarily for recreational activities;

• Lake Seminole, which spans across the Florida/ Georgia border into both Jackson and Seminole Counties, is used for barge traffic/access, via the Apalachicola River, to Georgia and Alabama;

• Lakes Karick and Hurricane in Okaloosa County, and Bear lake in Santa Rosa County are managed as fishing lakes by the Florida Fish and Wildlife Conservation Commission;

• Lake Rousseau in Citrus County was originally created to help generate hydroelectric power for the phosphate industry there. It is now surrounded with many lakefront homesites and is also a popular fishing lake.

Central Florida Visitors and Convention Bureau

• Lake Ocklawaha (a.k.a. Rodman Reservoir) in Putnam County is a remnant of the now defunct Cross-Florida Barge Canal project from the 1960s.[9] Since then, it has become a popular fishing lake.

Aside from reservoirs, hundreds of thousands of **stormwater retention lakes** exist throughout the state. Some were built for stormwater treatment, while others were made for the diversion of floodwaters, and/or landscape enhancement. Many are managed for a variety of recreational uses including fishing, water gardening, bird watching, and boating.

Florida is also possibly the nation's leader for **real estate lakes**, the majority of which are found in south Florida in areas that were mined for fill dirt. The remaining pits were turned into lakes and surrounded by homes.

Coastal Dune Lakes

Lawrence Jackson

Coastal dune lakes are most likely the result of several forces. Some are the result of longshore currents flowing along a stretch of coastline, depositing sediments across some irregularity or indentation of the coast, such as an inlet or bay. Eventually, a newly formed sandbar becomes large enough to cut off the inlet or bay from the ocean, and a lagoon or saltwater lake is created. Years later, after the development of additional sand hills or dunes, the lake becomes increasingly landlocked, with less influence or intrusion of saltwater. Occasionally, these lakes can become saline due to surrounding dunes opening up again.

In the Florida panhandle there is a prominent area of coastal dune lakes. Examples include lakes Big Red Fish, Camp Creek, Draper, Eastern and Western, to name a few. Depending on hurricane activity and rainfall, they oscillate between being saline and freshwater lakes.

9 *The canal project was an attempt to connect the Atlantic Ocean with the Gulf of Mexico in North Florida.*

Part 2

Bathymetric Maps and What They Tell Us About Lakes

Amy Richard

When planning a trip to unfamiliar territory, the first thing many of us will do is reach for a map of the area. If traveling by car, one might use a road map. However, if traveling "off road," a topographic map would be especially helpful as it would provide details about the actual terrain such as distances and elevations of mountain ranges, as well as the location of rivers and streams.

Bathymetric maps are similar to topographic maps, in that they provide details about the terrain of a landscape. In the case of a bathymetric map, the terrain that is described is underwater.

As you can see in Figure 2-1 on page 7, a bathymetric map is generally depicted as a grouping of concentric contour lines, with the outermost contour line representing the shoreline of the lake at a given point in time. Lines within the map are obtained by recording water depths throughout the lake and connecting the recorded points of equal water depth. Contour lines drawn close together indicate rapid changes in water depth and lines that are far apart indicate water depths that change gradually.

The contour lines are only estimates of water depth between two points of a known depth. There may be discrepancies in any given map depending on the number of depth measurements taken. To put it simply, the more depth measurements one is able to record, the more accurate the map will be.

It's also important to note that the outermost contour line, as well as the rest of a lake's bathymetry, is subject to change depending on rainfall patterns and resulting lake levels.

Bathymetric maps are the primary method used to describe a lake's physical characteristics.

Once we have a bathymetric map, we can calculate several measurements that are crucial to understanding how a lake system functions, including surface area, maximum length, mean width, maximum width, mean depth, maximum depth, shoreline length, shoreline development, and volume. These measurements are discussed in greater detail in Part 3.

*See **Part 3 Commonly Measured Morphometric Features and What They Tell Us About Lakes** on page 10 for detailed information about these features.*

The following are a few examples of how bathymetric maps may be useful to scientists or anyone interested in learning more about a lake:

Anatomy of a Bathymetric Map

Figure 2-1 below is an example of a bathymetric map made by LAKEWATCH staff.

Notice how the outermost line delineates the lake's shoreline. Lines within that outline are called contour lines. They are obtained by recording water depths throughout the lake and connecting the recorded points of equal water depth.

Contour lines drawn close together indicate rapid changes in water depth and lines that are far apart indicate water depths that change gradually. All of these contour lines are estimates of water depth and so there may be discrepancies in any given map depending on the number of depth measurements taken to make the map. A general rule of thumb: the more depth measurements one is able to record, the more accurate the map will be.

It's also important to note that the map shown here documents the bathymetry of Lake Jackson for one particular date in time. Based on weather conditions, etc., the bathymetry of the lake is susceptible to change. For example, during a period of drought, it's likely that the lake's surface area could "shrink" in which case the outermost contour line and each of the depth contour lines would change right along with the water levels.

A well-made bathymetric map will usually include:

A The name, county and geographic location of the waterbody;

B An outline of the lake shoreline, drawn to a known scale;

C Depth contour lines drawn at known intervals;

D Symbol indicating geographic orientation (i.e., north);

E Name of the mapmakers and date.

While the map shown here is not designed for navigation purposes, it can be used to calculate important morphometric features of a lake such as:

surface area, maximum length, mean length, maximum width, mean width, maximum depth, mean depth, shoreline length, shoreline development, and volume.

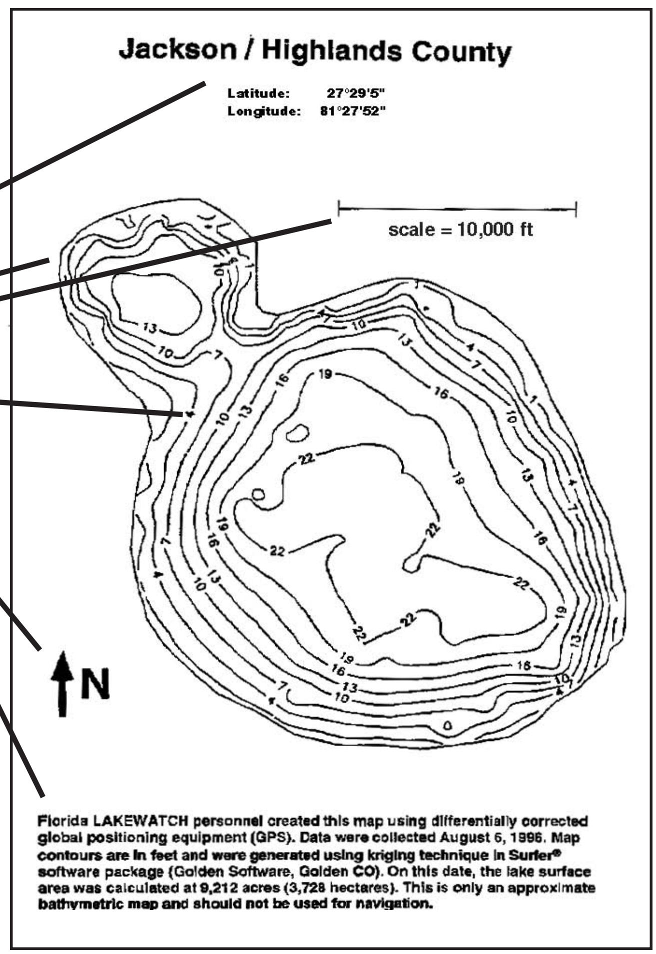


Figure 2-1


Joe Richard

Local residents of Lake Alice in Gainesville, Florida.

♦ Lake surface area can be calculated from a bathymetric map. This measurement determines the size of the lake and is usually expressed in acres or hectares.

*For more on this, see **Part 3 Commonly Measured Morphometric Features** on page 10.*

♦ Bathymetric maps can be used to help calculate lake volume, which is usually expressed in acre-feet or cubic meters.

*See **Hypsographic curves** on page 12, **Volume** on page 15, and **Appendix B** on pages 31- 32.*

♦ Bathymetric maps can also be used to calculate average depth, which can help predict biological productivity (i.e., shallow lakes tend to be more productive than deep lakes).

♦ Using the scale provided in a bathymetric map, one can calculate fetch distances from all directions.

*See **Fetch** on page 19.*

♦ The irregularity of a lake's shoreline, as depicted by bathymetric maps, can tell us much about a lake's potential for biological habitat (i.e., its ability to support animals such as fish, birds, alligators, etc.).

*See **Shoreline Development** on pages 18* .

♦ Mention bathymetric maps to an angler and he or she is likely to get starry-eyed at the prospect of finding a fishing "hotspot." Anglers use these maps to spot areas where lake depth changes rapidly; they know that larger predatory fish can often be found there.

Making a bathymetric map

Making a bathymetric map can be a simple process or a complex one. LAKEWATCH uses a technique that is somewhere in between. Regardless of their complexity, a well made bathymetric map generally consists of a line drawing of the shoreline, to scale, along with depth measurements taken at different areas of the lake.

*See **Anatomy of a Bathymetric Map** on page 7.*

Beyond that, the amount of detail in a bathymetric map depends on the amount of time and effort expended in making it, as well as consideration of its intended use. For example, some bathymetric maps are designed for navigation, requiring many, many data points or depth measurements.

Complex bathymetric maps are constructed by completing a survey of the shoreline using standard surveying methods and then combining the survey with electronically measured water depths at known locations throughout the lake. Lake water levels, in relation to mean sea levels, are often represented.

Water depth readings are collected with an electronic depth recorder (a.k.a. fathometer) and simultaneously linked with global positioning system (GPS) coordinates.[10] The procedure is repeated numerous times on the lake, generally following a grid pattern. This type of mapping procedure allows for more data points to be recorded and is considered to be very accurate.

It's important to point out however that not all bathymetric maps provide lake level data in relation to mean sea level (MSL). LAKEWATCH bathymetric maps, for example, provide data only for one point in time and not in relation to MSL.

Simple bathymetric maps can be made by sketching a general outline of a lake basin and then measuring and recording water depths at a number of locations within the lake.

The more depth measurements one is able to record, the more accurate the map will be. Water depths can be measured with an electronic depth recorder or something as basic as a weighted line, marked in increments of feet or meters.

This approach can be used by anyone with a boat and can be a valuable exercise, especially for those who live on or frequently use a lake.

While these maps may not be appropriate for navigation purposes, they are perfectly adequate for developing aquatic plant management strategies or planning a fishing trip.

10 *This type of system utilizes satellite technology to determine one's geographic location.*

LAKEWATCH Bathymetric Maps

Every summer since 1996, LAKEWATCH staff work with students and volunteers to create bathymetric maps for a limited number of LAKEWATCH lakes. The maps are designed to compliment LAKEWATCH data on individual lakes, providing a snapshot of the lake's bathymetry at a given time, and at a minimum of cost and effort.

LAKEWATCH uses a technique that involves the use of Global Positioning (GPS) equipment in coordination with a depth recorder (i.e., echosounding equipment). The depthfinder is used for recording actual lake depth measurements, while the GPS equipment simultaneously determines and records the location of each depth measurement. Bathymetric maps are completed with a computer software program that merges the information together and "draws" the lake's contours.

A good number of these bathymetric maps (200+) are available on the Florida LAKEWATCH web site:

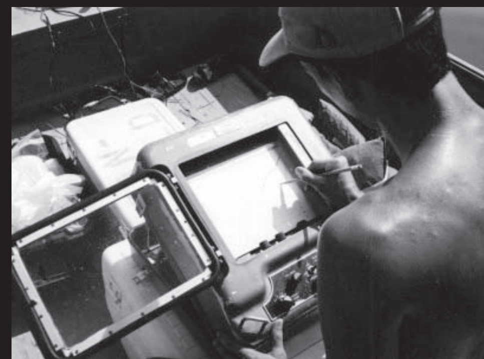
http://lakewatch.ifas.ufl.edu

Amy Richard

*See **Figure 2-1** on page 7 for an example of a **LAKEWATCH Bathymetric map**.*

Part 3

Commonly Measured Morphometric Features and What They Tell Us About Lakes



Mark V. Hoyer

As we learned in Part 2, bathymetric maps are essential tools for anyone interested in learning about a lake system. The following is a continuation of this discussion, as we will now introduce the various lake features that are commonly associated with bathymetric maps. Note: These terms and concepts are not listed alphabetically but are instead presented in the order of their significance to the lake management process.

Surface area —

refers to the size of a lake and is generally expressed in units of acres or hectares (abbreviated **ha**). *Note: One hectare equals 2.47 acres. A square that is 100 meters on a side would have an area of 1 hectare.*

In Florida, the majority of lakes have small surface areas. About 80% of the named lakes have surface areas less than 100 acres (40 ha) and only 31 lakes have surface areas greater than 5,000 acres (2,024 ha). Florida's largest lake is Lake Okeechobee, with a surface area of 450,000 acres (183,000 ha).

Don Missett

This photo of Lake Hampton in Citrus County is a good example of how drastically a lake shoreline can change. Obviously, when a lake's shoreline "shrinks" this much, its surface area has been reduced as well.

> ***Surface area** is often represented in scientific literature as the symbol* **A**.

It's important to remember that the water level and surface area of many Florida lakes can change dramatically with drought and/or flood conditions. This can be a shocking realization for homeowners who bought lakefront property during a lake's high water stage, and later find themselves living hundreds of feet from the water's edge due to drought-induced shrinkage of the lake.

Surface area is one of the most important morphometric parameters of a lake because it not only describes the size of a lake, but also plays a major role in a lake system in the following ways:

Lake surface area can be used to help predict the potential effects of wind on a lake.

In general, lakes with more surface area are subject to larger waves during windy conditions. This is significant because larger waves have the ability to mix water at greater depths, in some instances reaching all the way to the bottom of the

Central Florida Visitors and Convention Bureau

Lake Eloise at Cypress Gardens, Florida. Lakes with more surface area are generally subject to larger waves during windy conditions.

lake. Waves can also result in extensive shore erosion.

The ability to create mixing at the bottom of a lake is extremely important because it can result in the resuspension of sediments, and/or the disturbance of submersed aquatic plants. As a result, other lake characteristics, such as water clarity and the availability of nutrients, can be affected.

A lake's surface area also influences the dilution capacity a lake may have.

Consider two lakes, one small and one large, but with the same average water depth (i.e., mean depth). Visualize an equal amount of nutrients, let's say 100 kg, are introduced into each lake over the course of a year. Although the amount entering both lakes is the same, the larger lake, with a greater surface area and volume of water, will have a reduced concentration of the material than the smaller lake. In other words, the larger lake simply has more water available to dilute materials coming into the lake.

The ability of a lake to dilute materials, whether they be naturally occurring from the watershed or from a human-induced spill, is known as **dilution capacity.**

In general, lakes with a greater surface area will have a greater dilution capacity than lakes with a smaller surface area. If a lake has a greater dilution capacity, it is less likely to be affected by nutrients or other substances that may be introduced from human activity. In this instance, the adage "the solution to pollution is dilution" rings true.

Consideration of a lake's surface area is also useful when trying to choose the appropriate type of boat to use on a lake.

If you've ever been on a large lake during windy conditions, it doesn't take long to figure out that lakes with more surface area are generally capable of generating larger waves. And when winds do increase, you don't want to be caught out in the middle of the lake in a small boat.

*See **Fetch** on page 19.*

Some boats are even designed to fit the dynamics of the waterbody that they are used in. For example, commercial fishermen who spend a lot of time fishing on Lake Okeechobee have designed, and continue to build, custom fishing boats with a high prow and tapering gunnels in an effort to lessen the effects of choppy waves that are common on Lake Okeechobee. These boats provide a smoother ride and a safer boat during windy conditions.

Now that bathymetric maps and lake surface area are fresh in our minds, it's a good time to introduce another lake management tool that has proven to be invaluable to lake managers, scientists and lake residents — anyone interested enough to "do the math." (See below.)

Hypsographic curves —

are graphs used to provide a visual representation of the relationship between the surface area of a lake basin and its depth. With these graphs, we can be more accurate in predicting how a lake's surface area could change based on changes in water depth. *See Figure 3-2on page 13.*

To help explain this concept, let's refer a LAKEWATCH bathymetric map: When looking at the bathymetric map in Figure 3-1, we have a "bird's eye" view of Lake Denton. From this perspective, it's easy to picture how the lake would look if it were full of water, right up to its outermost contour line. It's also relatively easy to picture what the lake would look like if water levels were to shrink down to the 6-, 11- or 16-foot depth contours. Notice that if the lake were to shrink down to the 21–foot depth contour line, its surface area would be reduced to about half its original size.

But this approach gives us a visual estimation only. If we were to calculate the surface area within each one of the contour lines in Figure 3-1 and then plot them on a graph, we'd have a hypsographic curve — a visual image that can give us accurate information at a glance.

*See **Drawing Hypsographic Curves** on page 13 for more about how we make these graphs.*

Interpreting hypsographic curves

Using the "gauge" provided in the vertical y-axis of Figure 3-2, we can choose a hypothetical change in lake level and then compare it with the horizontal x-axis for an estimate of what the lake's surface area would be under those circumstances. For example, let's say that we want to know what the surface area of Lake Denton would be if the water level were to drop 10 feet.

To do this, we would draw a horizontal imaginary line across the graph in Figure 3-2 from the 10 unit mark. As you can see, it would intersect the hypsographic curve at about the 45 unit mark along the x-axis. This means that if the lake level were to drop 10 feet, the lake's surface area would be reduced to approximately 45 acres.

Notice that a larger drop in the water level would have an even more profound effect. For instance, if the lake level were to drop 30 feet, the surface area of the lake would be reduced to 25 acres.

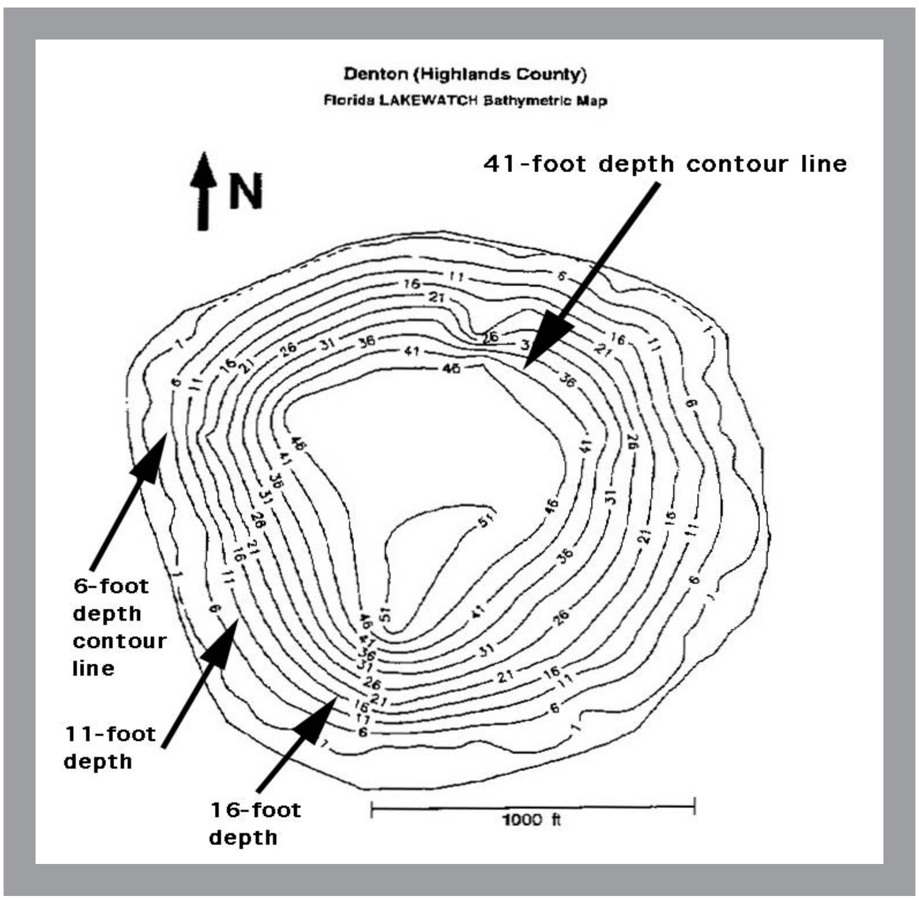


Figure 3-1 *A bathymetric map created by Florida LAKEWATCH.*

Drawing hypsographic curves

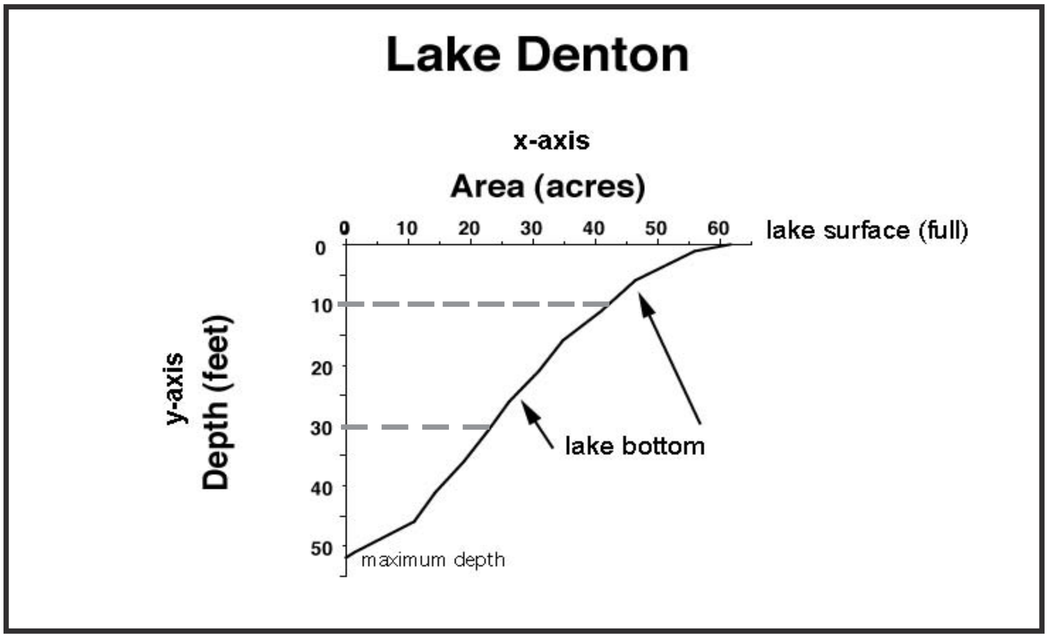


Figure 3-2 *A hypsographic curve drawn for Lake Denton. Notice that the x-axis is located at the top of the figure. This is a common format for this type of graph as it allows depth measurements to be displayed in a downward direction.*

One way to explain hypsographic curves is to describe the steps that were taken to draw one. To do this, we'll need to revisit what we know about bathymetric maps. Why? Because hypsographic curves are based on lake bathymetry and it works like this:

1 While looking at the bathymetric map in Figure 3-1, we can see that the outermost contour line of the map is used to represent the lake's shoreline at its high water level.

2 Using any one of the techniques from Appendix A on page 29 (i.e., Measuring Surface Area), the area within that outermost shoreline contour can be measured and calculated. In this instance, the surface area of Lake Denton in Figure 3-1 was found to be 60 acres.

Depending on whether you are using the English or Metric system, the unit of measure may be represented in square feet, square yards, acres, square miles OR square meters, hectares, or square kilometers.

3 Lake Denton's surface area measurement of 60 units was then plotted on the x-axis of the graph in Figure 3-2. Notice that it was plotted to correspond with a "0" value on the y-axis (i.e., depth). In other words, the surface area of the lake, at **0** units below the surface, is 60 acres.

Notice the value for the lake's maximum depth (i.e., 51 units) is plotted on the y-axis. If lake levels were to ever drop to this depth, the surface area would be a value of ***0*** *on the x-axis.*

4 By calculating and plotting surface area measurements for the remaining contour lines in Figure 3-1, we were able to complete the hypsographic curve for Lake Denton as shown in Figure 3-2 above.

Why are hypsographic curves important?

♦ Hypsographic curves are used for predicting the best time to implement various lake management strategies such as aquatic plant management, habitat restoration, muck removal activities, etc. From a lake resident's standpoint, being able to visualize and/or predict a lake's surface area during high, medium, or low water levels can certainly be helpful in planning the location for a new lakefront home or dock.

♦ Hypsographic curves are also useful for comparing lakes and explaining why some lakes are more susceptible to changes in lake surface area while others of similar size (i.e., surface area) may show very little change. For example, during dry weather conditions, property owners on a shallow lake basin often see a dramatic recession of water from what they considered to be the original shoreline. In contrast, those living on a deeper lake basin would probably notice very little change in lake surface area when lake levels drop.

If both the shallow and deep lakes happen to be located near one another, it can be quite confusing to the shallow lake property owners who are trying to figure out why their lake has so little water, while a neighboring lake seems unaffected. This scenario occurs on a regular basis in Florida and is cause for much concern to some lake residents.

Most of the time, such discrepancies can be explained simply by differences in lake morphometry (i.e., size, depth and shape).

Scientists use hypsographic curves for predicting two lake dynamics in particular:

(1) a lake's ability to dilute incoming materials,

*See **Surface Area** on pages 10-11 and **Volume** on page 15 for more about dilution capacity.*

(2) the potential for lake water mixing.

*See **Part 4 Wind, Waves and Water Mixing** on pages 20-27 for more about this dynamic.*

Archie Howell

Now you see it, now you don't. This boathouse and dock are high and dry after a prolonged period of drought. The structure of the lake basin, with a shallow sloping shoreline and an average lake depth of only 2 meters has contributed to the drastic loss of lake surface area.

Amy Richard

Deeper lakes, with steep bottom slopes, are often less affected by periods of low rainfall.

Both of these dynamics are particularly important because they have much to do with the concentration of nutrients in a lake and a lake's ability to support life — its biological productivity. For instance, it's been found that, in Florida shallow lakes tend to be more productive than deep lakes, meaning that shallow lakes often have greater concentrations of nutrients and also produce more fish and wildlife.

*See **Figure 3-3** on page 15 for examples of hypsographic curves drawn from both a shallow lake and a deep lake.*

Volume —

is the total amount of water in a lake basin, and it is usually expressed in units of acre-feet or cubic meters depending on which measurement system being used (i.e., English or Metric).

> ***Volume** is often represented in scientific literature with the symbol* **V**.

Lake volume data are available for only a limited number of lakes in Florida. As a whole, Florida lakes tend to have less volume than deeper lakes in the northern United States. It is also important to remember that lake volume can fluctuate dramatically depending on rainfall.

Lake volume is an important consideration to lake management, as it can influence a lake's dilution capacity.

As mentioned earlier in the Surface Area segment on pages 10-11, the ability of a lake to dilute materials, whether they be naturally occurring from the watershed or from human activity, is known as a lake's **dilution capacity**. Lakes with larger volumes of water have a greater ability to dilute materials coming into the lake basin.

♦ Dilution capacity is an important consideration when applying some herbicides to algae or aquatic plants in a lake. Extra care must be taken to apply the correct concentration of chemical based on the lake's volume as herbicides are absorbed by plants from the water column. If concentrations are too weak, they would be less effective and if the dosage is too strong, the herbicide application would cost more than it should. (Herbicide treatment for submersed aquatic weeds can cost as much as $300 – $400 per acre.)

♦ Scientists also consider lake volume when estimating nutrient loads or flushing rates, as both can impact algal populations in a lake.

There are several ways to measure the volume of a lake.

♦ Hypsographic curves are used to determine lake volume. In the graphs in Figure 3-3, the area between the x-axis, the y-axis and the curve itself is proportional to the lake's volume. Based on this knowledge, we can use several techniques to calculate volume.

> *See **Appendix B Measuring Lake Volume** on pages 31-32 for details.*

♦ If you happen to know the mean depth of a lake and also its surface area, volume can be found by multiplying the two:

Volume (**V**) = mean depth (**z**) × surface area (**A**)

> *See **surface area** on pages 10-11 and **mean depth** on page 16.*

Florida LAKEWATCH staff have created bathymetric maps for more than 200 lakes in Florida. A number of maps are created every year and can be obtained from our website —

http://lakewatch.ifas.ufl.edu

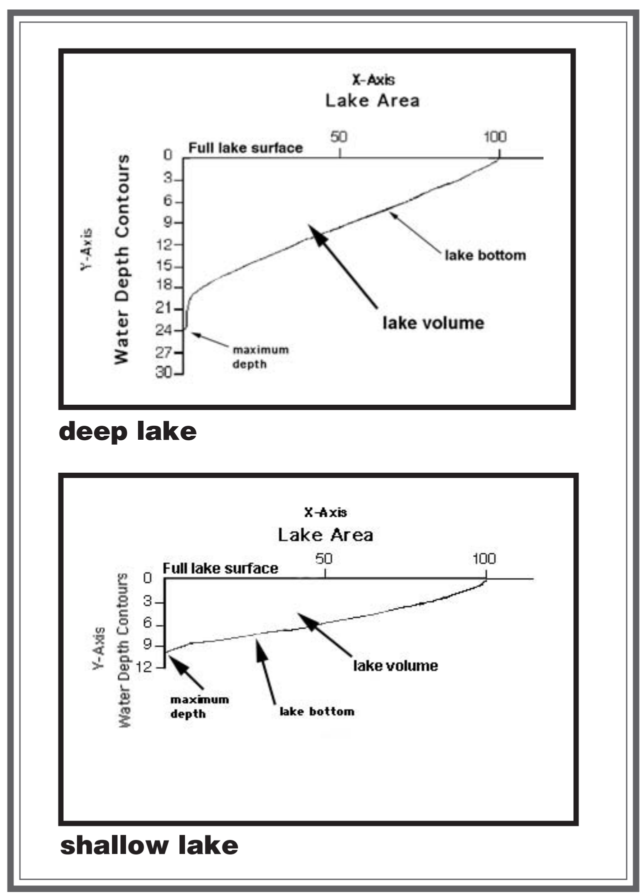


Figure 3-3
Hypsographic curves can be used to make comparisons between deep lakes and shallow lakes.

Maximum length —

is the distance, in a straight line, between the two farthest points on a lake. The distance must be measured without intersecting a land mass. *See Figure 3-5 on page 19.*

> ***Maximum length*** *is often represented in scientific literature by the symbol* L_{max}.

Maximum length is important because it can influence the depth at which waves can mix water and/or bottom sediments in a lake.

For example, if a lake should happen to have a sizable maximum length, with no landform to disrupt the wind, waves have the potential to grow quite large under windy conditions, influencing boating safety and shoreline erosion.

In contrast, when a lake has a small maximum length, waves are prevented from becoming very large and lake water mixing is reduced.

As a general rule, the larger the maximum length, the larger the waves, and the greater potential there is for mixing or disruption of bottom sediments. Of course, there are exceptions. For instance, deep lakes are less likely to experience disruption of bottom sediments and oxbow lakes are usually less affected by wind-induced wave action due to their narrow shape. A lake's orientation to prevailing winds is another consideration.

> *For more on waves and their potential to mix or disrupt bottom sediments, see* ***Part 4 Wind, Waves and Water Mixing in Lakes*** *on page 20.*

Mean width —

is calculated by dividing a lake's surface area by its maximum length. This measurement is also used to predict the amount of water mixing that can occur in a lake during strong winds. *See definition of maximum length.*

Maximum width—

is the maximum distance between the two widest points of a lake, that can be measured without crossing land, and at a right angle to the maximum length. In other words, the lake's maximum width must be measured at a 90º angle to the lake's "axis." *See Figure 3-5 on page 19.*

Maximum width is also important to consider when determining the potential for waves to mix water and/or sediments at the bottom of a lake.

Mean depth —

is the average water depth of a lake.

> ***Mean depth*** *is often represented in scientific literature by the symbol* $\mathbf{z}$ *or* $\bar{\mathbf{z}}$.

Professionals calculate mean depth by dividing the volume of a lake by its surface area. However, if lake volume and surface area measurements are not available, one can simply collect numerous lake depth measurements and then average them. This technique can be useful for smaller waterbodies though it will be less accurate than the first method described.

> *See* ***Appendix A Measuring Lake Surface Area*** *on pages 29-30 and* ***Appendix B Measuring Lake Volume*** *on pages 31-32.*

Mean depth is important because early studies of algae, aquatic invertebrates, and fish populations have shown that shallow lakes are generally more productive than deep lakes.

Mean depth also has much to do with the potential for waves to disrupt bottom sediments. For example, lakes with greater mean depths usually don't experience as much mixing of bottom sediments, as wave action is less likely to reach the bottom.

Maximum depth —

is the greatest depth of a lake. The location of a lake's maximum depth is sometimes (but not always) indicated in bathymetric maps with an "X." *See Figure 3-5 on page 19.*

> ***Maximum depth*** *is often represented in scientific literature by the symbol* $\mathbf{z}_{max}$.

Maximum depth cannot be estimated, and can only be obtained by locating and actually measuring the deepest point in a lake.

Maximum depth is important because it can influence the movement of fine organic sediments found on the bottom of a lake.

For example, water currents or waves can move sediments along the bottom of a lake or resuspend them into the water column. If a lake has deep areas or holes, the sediments usually find their way into these areas first. However, if the holes were to eventually become filled-in with sediments, there is no place for new and/or remaining sediments to go except back and forth across the lake bottom or into the water column.

*See **A Lake Mystery** on page 17.*

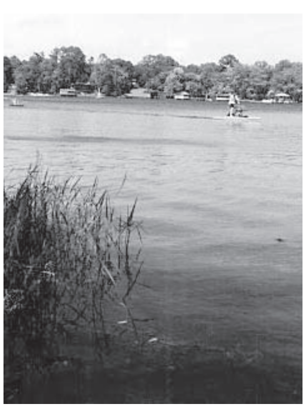
Shoreline —

is the area where a body of water meets the land. On a bathymetric map, it is represented by the outermost contour line of the map. *See Figure 2-1 on page 7.*

A lake's shoreline is important because it defines the area where a waterbody interfaces with the land.

In Florida, this area of interface can change considerably depending on rainfall and lake levels. Lakefront property owners also need to be aware of the fact that, in Florida, land below the high water mark typically belongs to the state. This is important for planning various activities such as aquatic plant removal, muck removal, or dock construction, as some of these activities require permits.

Changes in a lake shoreline can also be significant to aquatic plant management. For instance, at high water levels, and depending on the slope of the land, a lake may have small amounts of aquatic vegetation along its shoreline. However, if water levels were to fall, the reduction in water depth along the lake's shoreline could result in a dramatic increase in aquatic plant growth. Why?



Joe Richard

Because when the water becomes shallow, sunlight may be able to reach larger areas of the lake bottom, providing the necessary energy for plants to grow.

Art & Luceen Sullivan

A Lake Mystery

In the 1960s, many Florida lakefront homes were built on sand mounds that were dredged from the near-shore waters of lakes. This activity created many deep holes in the lakes. In some waterbodies, the holes constituted the lake's maximum depth. Over the years, they have acted as depositories for fine sediments. Forty years later, residents on some lakes began noticing that their white sandy beaches had suddenly disappeared under layers of fine gray-brown silt. How did this happen?

In some instances, it may simply be a case of the deep holes having filled up, and now that there's no place for the sediments to go, they are being carried along the lake bottom, all the way to the shoreline and beach. A solution?

While dredging is not always a popular activity, it could be helpful in this instance.

Shoreline length —

is the linear measurement of a waterbody's entire perimeter, at a given water level. In Florida, shoreline lengths fluctuate considerably, depending on rainfall and lake levels.

Shoreline length is important because it provides a measurement of the actual amount of interface between a waterbody and the surrounding land.

There are several approaches one can use to measure shoreline length:

♦ Using an aerial or topographic map of the waterbody, trace around the image of the lake with a cartometer (a mapmaker's device that measures distances as drawn on a map). If you don't have a cartometer, trace around the waterbody using a piece of string. Compare the cartometer measurement or the length of string with the map's scale to convert the measurement to the actual shoreline length.

♦ If the lake has a perimeter road that is in close proximity to the lakeshore, it might be possible to drive the perimeter in a car and measure the distance with an odometer, and then estimate shoreline length using that distance.

♦ Using electronic navigation instrumentation, such as a GPS,[11] measure the distance while traveling close to the shoreline in a boat.

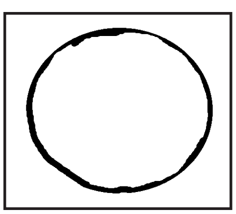
♦ If the waterbody is small enough, the distance can be manually paced off by walking the perimeter. (One average stride is generally equal to about three feet.)

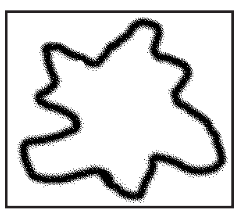

Joe Richard

Shoreline development —

refers to the length of a lake's shoreline relative to a circle of the same area. In other words, lakes with longer, irregularly shaped shorelines are considered to have more shoreline development, while circular lakes are considered to have less shoreline development. See the following explanation:

> ***Shoreline development*** *is often represented in scientific literature by the symbol* **SLD**.


Lake A


Lake B

Consider Lakes A and B above. Both lakes have the same surface area. Notice how Lake B on the right has an irregularly shaped shoreline and Lake A on the left is more circular in shape. If you were to trace the entire perimeter of each lake with a piece of string, you would find that the string used to trace Lake B would be longer than that of Lake A.

Determining a lake's shoreline development is important because it helps us assess the amount of potential wildlife habitat available for a lake.

For example, if Lake B has a greater amount of shoreline development, there is more of an interface between the water and surrounding land (i.e., coves and peninsulas). This interface often translates into more habitat for fish, birds, and other wildlife to raise their young.

How does one determine a lake's shoreline development?

The mathematical equation provided below can be used to calculate the shoreline development of a lake. The higher the number, the greater the shoreline development.

Note: a lake in the shape of a perfect circle will always have a shoreline development value of 1.

shoreline development (SLD) $= \dfrac{L}{2\sqrt{\pi A}}$

L *= Shoreline length* ***A*** *= surface area of the lake*

11 ***GPS*** *is an acronym for Global Positioning System — a navigation device that utilizes satellite technology for determining one's geographic location.*

Fetch —

is the distance that wind can travel over water before intersecting a landmass. We can use fetch distances to predict the depth at which wave energy extends below the water's surface.

These predictions are made based on the relationship between wind velocity and the amount of fetch distance that a lake may have.

Fetch is also an important consideration when boating, as wind exerts the greatest amount of energy when there is no landmass in the way to "break" its effect. The greater the fetch distance, the greater potential there is for large waves — and increasingly dangerous boating conditions.

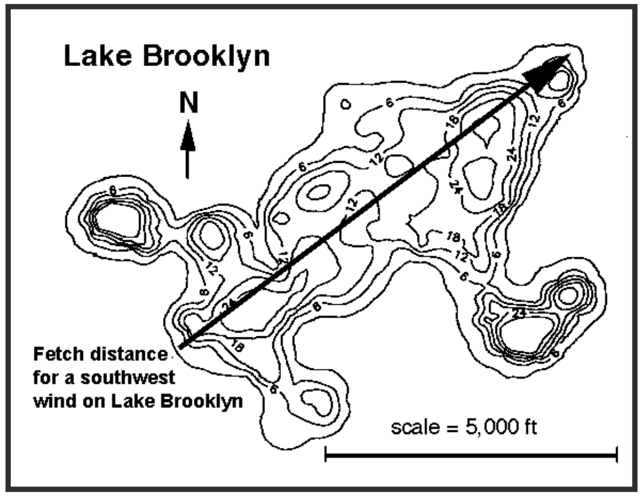


Figure 3-4 *Using the map's scale, fetch distances can be calculated from any direction. Both the depth contour lines and the scale in this map are recorded in feet.*

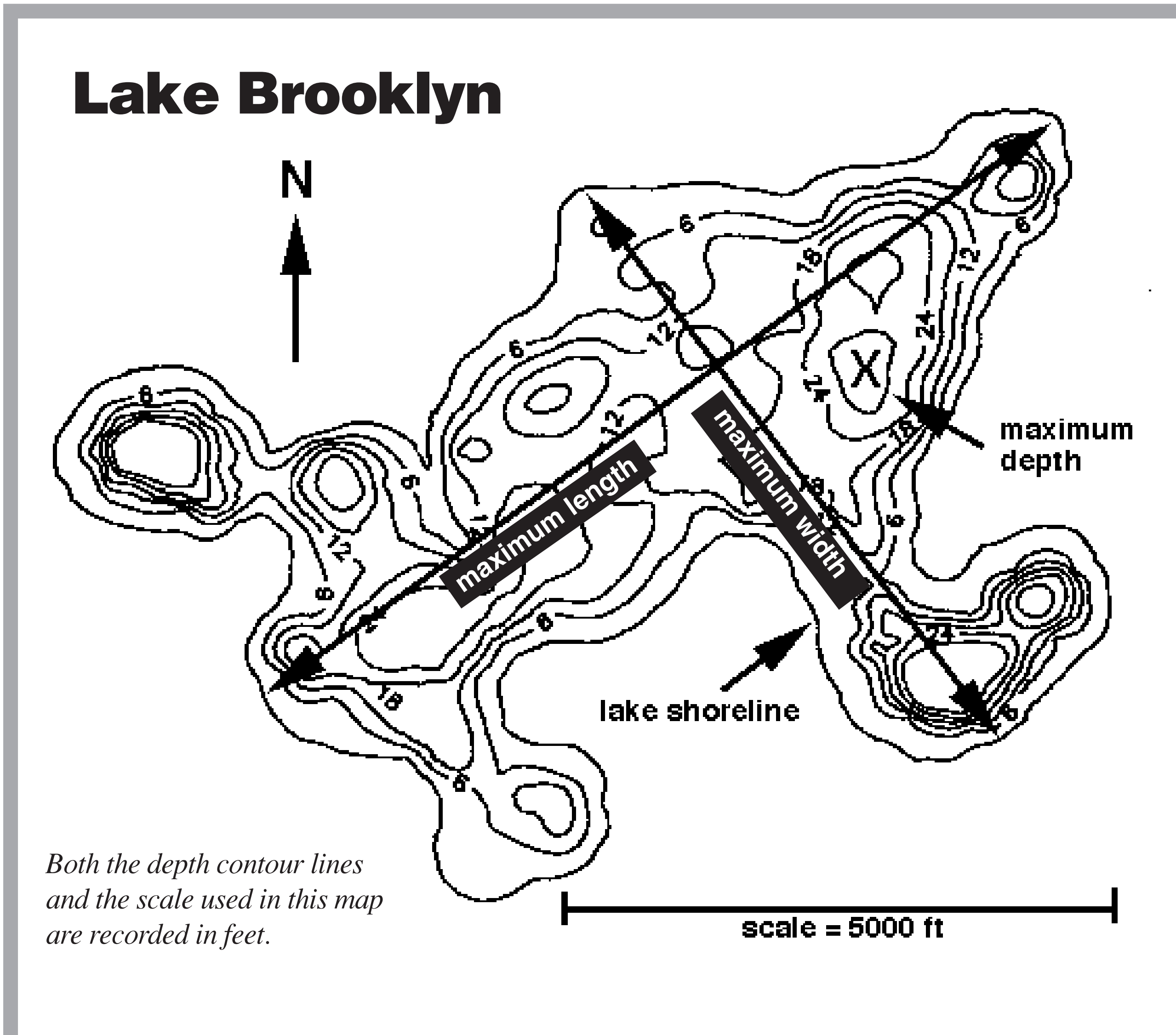
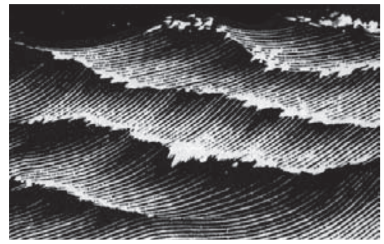


Figure 3-5

Part 4

Wind, Waves, and Water Mixing In Lakes



Now that we've been introduced to some of the basic concepts and terminology related to lake morphometry, we can turn our attention toward a dynamic that is extremely important to lake management and yet often overlooked: wind mixing (a.k.a. water mixing) in lakes.

In the following pages, we'll explore the influence that wind and waves can have on the movement and/or mixing of water within a lake, as well as the role that lake morphometry plays.

Wind

As any boater soon learns while navigating across open water, there is a strong correlation between wind and waves (i.e., the stronger the wind, the larger the waves). However, aside from wave activity on the surface, there are other types of water movement occurring below the waves that we never see. For instance, underwater **currents** tend to move water particles horizontally through the water column. At the same time, water particles are also being distributed in an irregular swirling motion known as **turbulence**. It works like this:

Currents

Winds blowing across the surface of a lake interact with lake water and cause the water to move in a downward direction. The resulting water currents can move across the lake with the wind, or they can move along the shore when the winds approach the shoreline at an angle.

If the wind blows from one direction for a while, it can cause the water to pile up along the downwind shore, so that the water level is actually higher on one side of the lake than another — usually by a fraction of an inch, but sometimes much more in a large lake.

An extreme example of this dynamic was seen in 1928 when hurricane winds piled water upon Lake Okeechobee's northern shore, causing the city of Lake Okeechobee to flood. As water piled up along the north shore of the lake, waters receded substantially along the southern shoreline. Hours later, when the hurricane force winds changed direction, lake waters then returned to the southern shore and caused massive flooding there as well, resulting in hundreds of deaths. This single event prompted the call for the construction of what is now known as the Hoover Dike.

Under normal conditions however, the difference in water elevation across a lake is minimal — just enough to generate water currents. These currents move water back to the other side of the lake to even out the elevation difference. Sometimes the currents flow along the shore, but often the water flows as a return current below the surface of the lake. Thus the wind may be moving a surface layer of water in one direction and the return current moves a layer of water in the opposite direction. (Anglers sometimes notice that the direction of the current changes as they lower their baited hook down through the water column.)

Turbulence

In most lake currents, the water does not flow smoothly, but rather tends to move in a more chaotic, irregular manner known as **turbulent flow**. It is like the motion of smoke as it comes out of a large, industrial smokestack. While the dominant movement might be in one direction, the particles within the flow are moving in a series of swirls of different sizes.

The importance of turbulent flow is that it results in the mixing of the water mass. Among other things, turbulent flow keeps plankton (i.e., algae and zooplankton) in suspension, it moves dissolved oxygen from the surface of the lake to deeper waters, it evens out water temperatures in the upper part of the lake, and distributes dissolved substances like plant nutrients throughout the lake.

Waves

While water currents tend to move particles in one direction, simple surface waves are rhythmic movements of water particles that in theory end up in the same place that they start. These water particles rotate at the surface in circular orbits, completing one circle in the time that it takes for one wave crest to be replaced by another (i.e., the wave period). The radius of these orbits gets smaller as they move downward in the water column and become negligible at a depth of about one-half the wavelength.

There are other factors that come into play as well. For example, the longer the fetch distance, the greater the wavelengths and wave heights will be. Likewise, the greater the wind speed, the greater the wavelengths and wave heights.

*See **Fetch** on page 19, **Figure 4-1 Anatomy of a Wave** below, and **Table 4-1** on page 25.*

As waves get larger, they are able to exert energy to greater depths, resulting in significant water movements. As a rule-of-thumb, if the water depth is less than one-half the wavelength, waves can potentially have a scouring effect on a lake's bottom sediments. Lake scientists often refer to this scouring effect as **resuspension.**

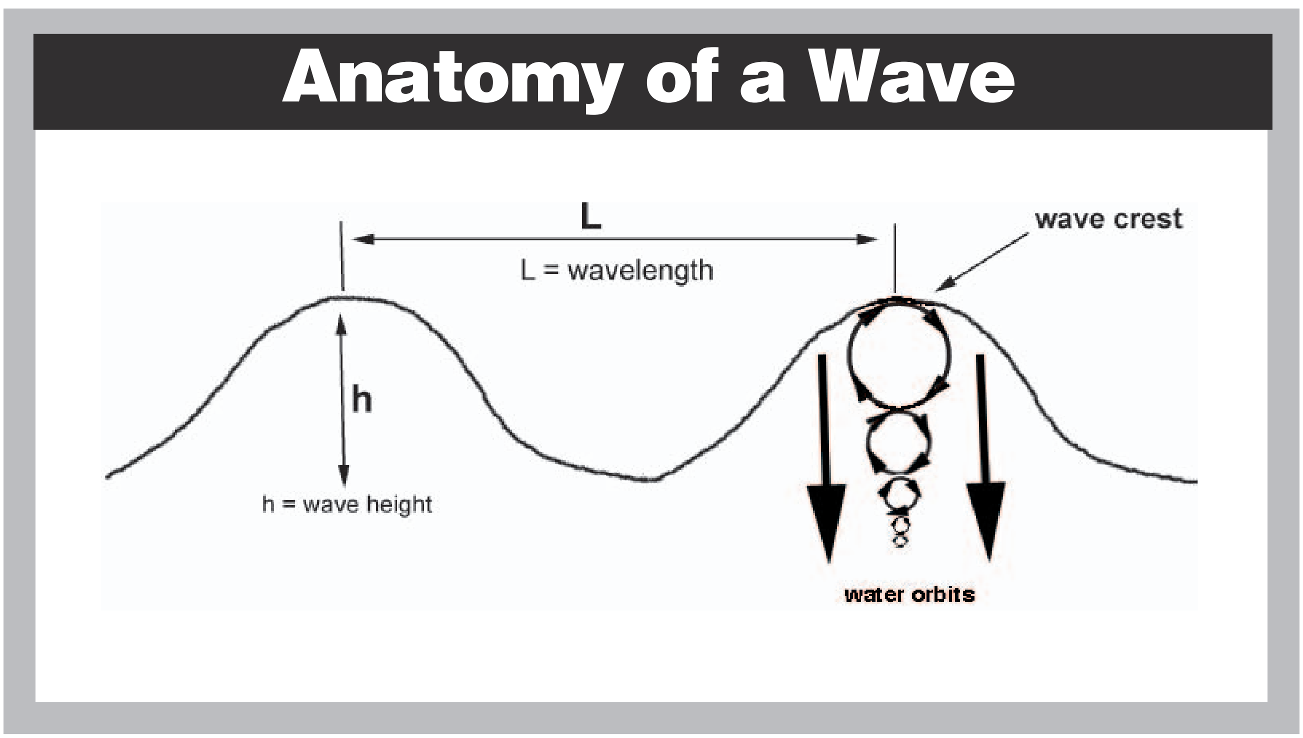


Figure 4-1 *Aside from the energy that waves exert on the surface of a lake, there is also a substantial amount of energy exerted below the surface. Notice that the radius of the downward orbits is reduced as one moves downward in the water column. At a depth of about one-half the wavelength distance, the orbits become negligible. A rule-of-thumb: if the water depth is less than one-half the wavelength, the waves have the potential to disturb and resuspend bottom sediments.*

Based on the dynamics just described, it is possible to use standard engineering equations to calculate the sizes of surface waves for various combinations of wind speed and fetch. Once the size of a wave is known, one can then use the one-half wavelength rule mentioned earlier to determine the depths at which waves can be expected to disturb or resuspend fine bottom sediments in a lake. We have provided this information for quick reference in the Table 4-1 on page 25.

Note: The possibility for resuspension also depends upon the characteristics of the sediments and the roughness of the bottom. For instance, heavy particles like sand are less likely to be resuspended than are smaller particles like silts and clays.

Water Mixing

Scientists are particularly interested in the energy that waves set in motion below the surface because they know that this type of water movement or **water mixing** has the potential to influence one or more of the following processes:

Oxygen in the water column

Turbulent water movements that are generated by waves assist the movement of oxygen from the air into the water. In fact, this is one of the main sources of oxygen in lakes. As mentioned earlier, it can help to move oxygen from surface waters to deeper waters.

It should be mentioned however, that even with the help of turbulent water movements distributing oxygen from the air, there are times when the respiration of organisms within a lake (i.e., bacteria, macrophytes, and animals) can consume so much oxygen that a fish kill can occur. This is common after several consecutive ***calm*** cloudy days when the loss of sunlight prevents algae and macrophytes from making their usual contribution of oxygen to the water column, via photosynthesis.

Joe Richard

Water temperature changes

In shallow lakes, water movements can keep the temperature uniform from the surface of the lake to the bottom. In deep lakes, warm water will float on top of the cold water isolating deeper waters from the atmosphere — its major source of oxygen (i.e., stratification). This can have a detrimental affect on fish by reducing the availability of oxygen, particularly after a sudden thunderstorm.

Nutrient transport within the water column

Nutrients are distributed vertically by turbulence in much the same way that oxygen and water temperatures are mixed. This can facilitate the recycling of nutrients from the sediments and deeper waters and, in some instances, result in an increase in biological productivity.

Disruption of bottom sediments

Several studies have shown that the resuspension of sediments by wind-driven waves can play a significant role in affecting water quality in large shallow lakes — particularly in Florida where shallow lakes are abundant.

Water quality problems caused by sediment resuspension

♦ Resuspended sediments increase the turbidity of the water and reduce light penetration. This reduces the depth at which algae and aquatic plants can grow in a lake.

♦ Nutrients stored in bottom sediments are often introduced back into the water column resulting in an increase in the growth of algae. This may or may not be desirable, depending on the intended use of the lake.

♦ In some shallow lakes, there is a layer of algae that grows on the surface of the sediments. These algae are resuspended along with the sediments during strong wind events and can result in significant increases in the amount of algae in the lake water.

♦ The resuspension process, along with the effects of the waves themselves, can form a layer of fluid-like sediments on the lake bed that is too unstable to allow for the rooting of aquatic plants. This can prevent the reestablishment of aquatic plants in a lake that previously had plants.

Interaction between lake morphometry and bottom sediments


No one told Earl that there was an easier way to learn about lake morphometry.

As we've discussed before, wind-driven waves often can cause enough turbulence in shallow waters to resuspend fine sediments. Some of these particles will be suspended in the water column and can move about the lake with water currents. Eventually, they will settle back to the lakebed when the water becomes calm. If they settle in a shallow area with exposure to the wind, they will be resuspended again at some time in the future.

On the other hand, particles settling in deep areas of the lake may be protected from resuspension and will remain undisturbed. In such a lake, the fine particles may go through several cycles of settlement and resuspension but in time they will end up being trapped in the deep holes. As a result, shallower exposed areas will tend to have sediments dominated by larger particles such as sands. Deep areas will contain fine particles like silts, clays, and fragments of dead plants and animals.

In a shallow lake, there may not be a place that can remain undisturbed by water motions developed by surface waves. As a result, fine sediments can cover the entire lakebed and sediment resuspension may be a frequent event.


UF/IFAS Center for Aquatic and Invasive Plants

Aquatic plants and bottom sediments

Large beds of aquatic plants can alter sedimentation patterns in a lake in several ways:

♦ The plants themselves greatly reduce the amount of turbulence within the plant beds, resulting in an accumulation of fine particles in shallow areas that are dominated by plants. This can happen even though there may be deep areas within the lake.

♦ Plant beds can interfere with the development of waves in a lake. Thus, shallow lakes filled with plants may not develop large waves and the fine sediments will be protected from resuspension. Such plant-dominated lakes tend to appear clear due to a lack of turbulence that would otherwise keep fine particles and algae in suspension.

The effect that plants can have on a lake is demonstrated effectively when, for one reason or another, a plant-dominated lake loses its aquatic plants. This might happen when plants are removed on purpose with the use of grass carp or herbicides or when they are lost due to increased water levels or ripped up by hurricane-force winds. If any of these events should occur, the usual effect is for the water to become more turbid as wind-driven waves are able to resuspend sediments and algae are able to grow due to lack of competition from large plants and associated algae.

How can we estimate if lake bottom sediments are subject to resuspension?

1 If we want to know if a particular spot in a lake is subject to resuspension, we can use the information provided in Table 4-1.

First, we would use a map to find the fetches in all directions and then find the maximum fetch. Suppose the fetch was 10,000 feet in the north direction. If we look to see the effect of a 10 mile per hour (mph) wind from the north for that fetch in Table 4-1, we see that we might expect mixing to a depth of 6.0 feet. In other words, if the water depth at that point were 6 feet or less and the sediments were of a fine consistency, we might expect some of the sediments to be resuspended. If the wind were say 25 mph, the table shows a mixing depth of about 16 feet.

Note: These calculations assume that there are no beds of aquatic plants along the fetch that might reduce the buildup of waves.

See ***Fetch*** *on page 19,* ***Table 4-1*** *on page 25 and* ***Figure 4-1 Anatomy of a Wave*** *on page 21.*

2 If we are interested in knowing how often sediments might be disturbed at one particular spot in a lake, we could start by finding the fetches for the four major compass directions.

If we know the depth of the water for that one location, we can estimate the minimum wind velocity from each direction that could cause sediments to be disturbed. For example, suppose our location on the lake was six feet deep and the east fetch was 8000 feet. From Table 4-1 we can see that a wind between 10 and 12 mph (11 mph would be pretty close) would produce waves sufficient to disturb the bottom at 6 feet.

Our next step would be to use wind records from a nearby recording station (i.e., an airport) to determine how often we could expect an easterly wind to exceed 11 mph. For example, if an east wind blew 11 mph or more for 2% of the time, then we would expect east winds to disturb the bottom 2% of the time.

We could then make the same calculations for winds from a north, south, and west direction. By adding all of these individual percentages together, we can obtain the per cent of time that we would expect winds to disturb the sediments at that point on the lake.

3 We can compare lakes for their extent of wave disturbance by looking at several points within a lake.

For example, as shown in Figure 4-2 on page 26, we made the above calculations for several points within two Florida lakes.

However, instead of using a table like the one in Table 4-1 we used engineering equations directly to find the minimum velocities. Also, instead of using the four basic wind directions mentioned earlier, we used 36 different wind directions to calculate the per cent of time that we would expect lake sediments to be disturbed by wind-driven waves.

The lakes used for our comparison in Figure 4-2 were chosen because they are so different from one another: one lake being large and shallow (Lake Istokpoga) and the other relatively smaller and deeper (Lake Thonotosassa). Notice that in Lake Istokpoga every single point on the lakebed is frequently disturbed by the waves (i.e., every number is greater than 0). In contrast, Lake Thonotosassa has a large area with no sediment disturbance (i.e., numbers are 0 or less than 1).

4 Another way to make comparisons between lakes is to summarize the calculated percents for all points in a lake.

For instance, we could determine what percent of the points or lake locations were disturbed 90% of the time or more, followed by the percent of points that were disturbed 80% of the time or more, and so on down to the percent of points disturbed 0% of the time or more.

These numbers can then be plotted on a graph, with percent of time on the horizontal axis and percent of the lake area on the vertical axis as we did in Figure 4-3 on page 27.

We can use the same approach to make comparisons of different water levels within an individual lake. For instance, the graph shown

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Depth of wave mixing in feet for various fetch distances and wind velocities

Fetch Distances in Feet	Wind Velocity in Miles Per Hour: 2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
2,000	0.4	1.1	1.7	2.3	2.9	3.5	4.2	4.8	5.4	6.0	6.6	7.3	7.9	8.5	9.1
4,000	0.5	1.4	2.3	3.1	4.0	4.9	5.7	6.6	7.5	8.4	9.2	10.1	11.0	11.8	12.7
6,000	0.6	1.6	2.7	3.7	4.8	5.9	6.9	8.0	9.0	10.1	11.2	12.2	13.3	14.3	15.4
8,000	0.6	1.8	3.0	4.2	5.5	6.7	7.9	9.1	10.3	11.6	12.8	14.0	15.2	16.4	17.7
10,000	0.6	1.9	3.3	4.6	6.0	7.4	8.7	10.1	11.4	12.8	14.2	15.5	16.9	18.3	19.6
12,000	0.5	2.0	3.5	5.0	6.5	8.0	9.5	11.0	12.4	13.9	15.4	16.9	18.4	19.9	21.4
14,000	0.5	2.1	3.7	5.3	6.9	8.5	10.1	11.7	13.4	15.0	16.6	18.2	19.8	21.4	23.0
16,000	0.5	2.2	3.9	5.6	7.3	9.1	10.8	12.5	14.2	15.9	17.6	19.3	21.0	22.7	24.5
18,000	0.5	2.3	4.1	5.9	7.7	9.5	11.3	13.2	15.0	16.8	18.6	20.4	22.2	24.0	25.8
20,000	0.4	2.3	4.2	6.2	8.1	10.0	11.9	13.8	15.7	17.6	19.5	21.4	23.3	25.2	27.1
22,000	0.4	2.4	4.4	6.4	8.4	10.4	12.4	14.4	16.4	18.4	20.4	22.4	24.4	26.4	28.4
24,000	0.4	2.4	4.5	6.6	8.7	10.8	12.9	15.0	17.0	19.1	21.2	23.3	25.4	27.5	29.6
26,000	0.3	2.5	4.7	6.8	9.0	11.2	13.3	15.5	17.7	19.8	22.0	24.2	26.4	28.5	30.7
28,000	0.3	2.5	4.8	7.0	9.3	11.5	13.8	16.0	18.3	20.5	22.8	25.0	27.3	29.5	31.8
30,000	0.2	2.6	4.9	7.2	9.6	11.9	14.2	16.5	18.9	21.2	23.5	25.8	28.2	30.5	32.8

Table 4-1

Using the table above, we can quickly determine the depth at which a wave's energy is felt below the surface based on wind speed and fetch. The table was assembled using the one-half wavelength rule in combination with standard engineering equations to calculate the sizes of surface waves for numerous combinations of wind speed and fetch.

Note: When evaluating the fetch distances shown here, remember that 1 mile is equivalent to 5,280 feet.

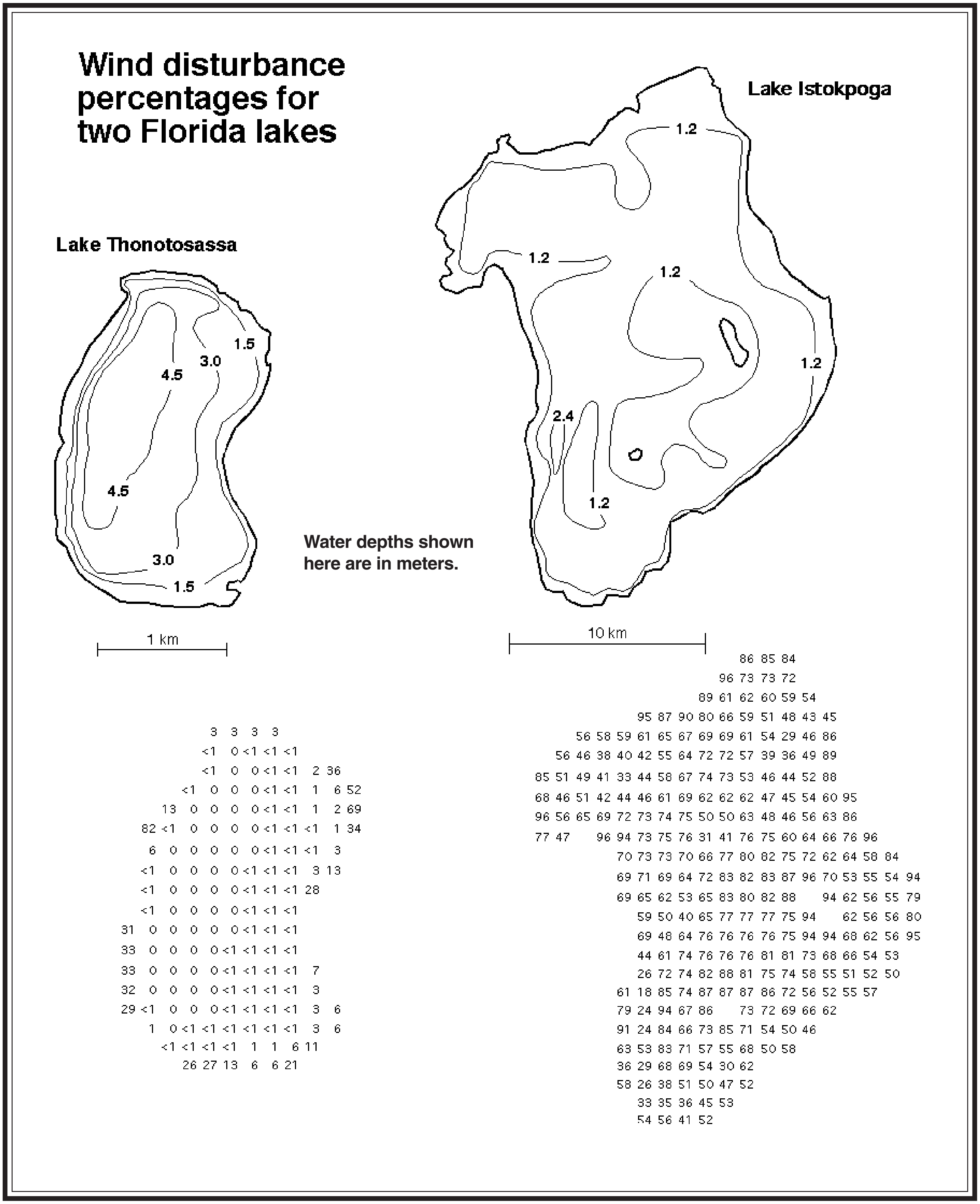


Figure 4-2 *The numbers shown here, within the lake shapes in the bottom portion of the figure, reflect the percentage of time that the lake's bottom sediments are disturbed by wind-driven waves at each of the individual locations. Notice that in Lake Istokpoga (on the right) all the points on the lakebed are frequently disturbed by the waves, while Lake Thonotosassa, a smaller and deeper lake, has a large area with no sediment disturbance.*

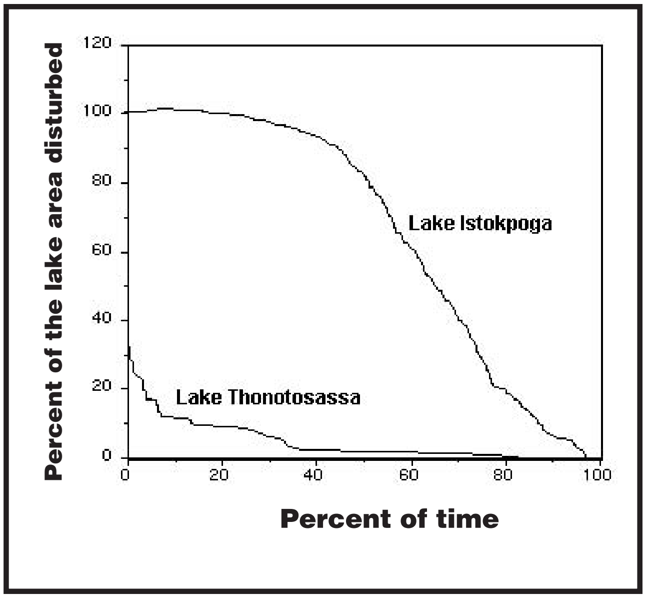


Figure 4-3 *A comparison of lakebed disturbance for all points in a lake. In this example, we've shown the lakebed disturbance on two Florida lakes that are quite different in both size and mean depth. Notice the difference between the lines for the two lakes. Lake Istokpoga is a rather large shallow lake and Lake Thonotosassa is smaller and deeper.*

here in Figure 4-4 shows the calculated effects that changes in water level might have on Lake Apopka in central Florida.

Notice that changes in lake level are indicated by the numbers in the center of the graph. The "0" curve represents Lake Apopka at its mean lake level and curves to the left of it represent lake level *increases* in 1-foot increments. Curves to the right of the "0" curve represent lake level *decreases* in one-foot increments.

The graph clearly illustrates that lowered lake levels can increase the extent of the lakebed that is susceptible to wave action, while increases in water levels can prevent waves from reaching the lakebed in areas where they could under normal lake levels. This is a good example of how important water level changes can be in shallow lakes.

Studies of several Florida lakes indicate that the percent of lake bottom subject to wave disturbance at one time or another ranges from 6% to 100%.

5 There is a shortcut method for estimating the impact of wave mixing on a whole lake.

First, we divide the square root of the lake area in units of square kilometers, by lake mean depth in meters. The resulting number is called a **dynamic ratio** and was originally developed by a lake scientist named Lars Håkanson for a different purpose. However, a recent study of Florida lakes found a relationship between the dynamic ratio and the percent of the lakebed that can be disturbed by waves.[12]

Lakes with dynamic ratios above 0.8 were subject to wave disturbance at all areas of the lakebed at least some of the time.

Note: This calculation is made on the assumption that there were not significant amounts of aquatic plants in the lake. If plants are present in large quantities, the wind disturbance could be substantially less than this calculation would indicate.

Lakes with dynamic ratio values below 0.8 showed a linear decrease in areas disturbed at one time or another. If for example the ratio were 0.4, only about 50% of the lakebed would be disturbed at one time or another.

12 *Roger W. Bachmann, Mark V. Hoyer and Daniel E. Canfield, Jr. 2000. The potential for wave disturbance in shallow Florida lakes. Lake and Reservoir Management 16(4): 281-291.*

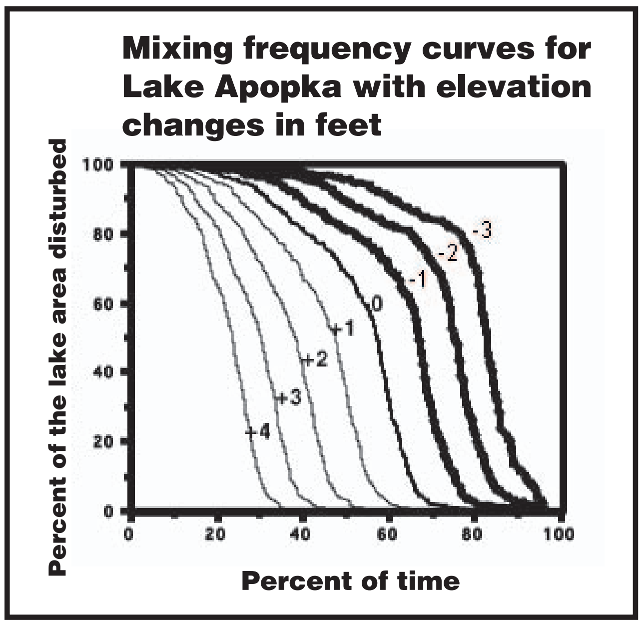
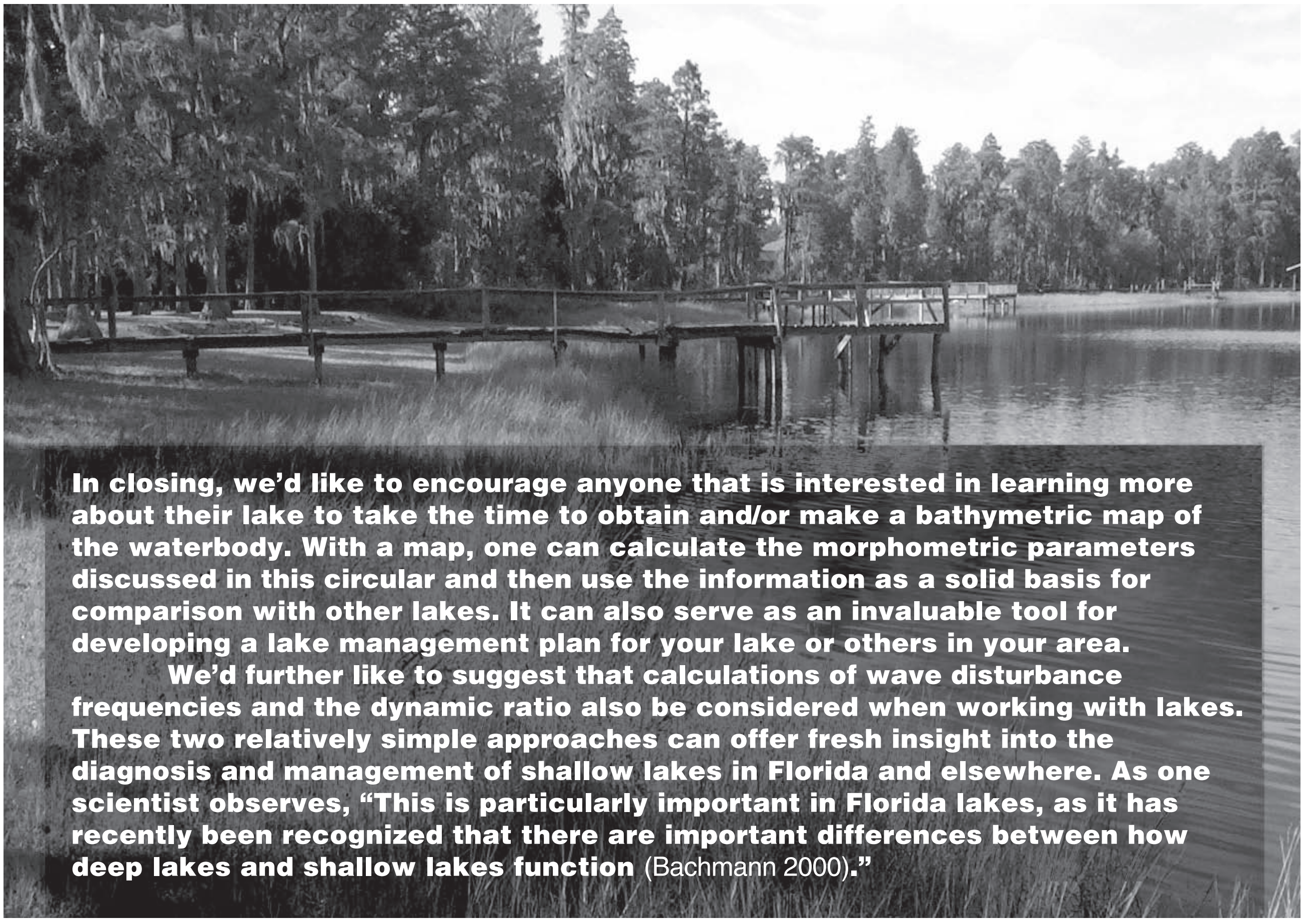


Figure 4-4 *This graph illustrates how changes in water level might affect Lake Apopka in Central Florida. The plus signs indicate increases in water depth and minus signs indicate decreases in water depth.*



In closing, we'd like to encourage anyone that is interested in learning more about their lake to take the time to obtain and/or make a bathymetric map of the waterbody. With a map, one can calculate the morphometric parameters discussed in this circular and then use the information as a solid basis for comparison with other lakes. It can also serve as an invaluable tool for developing a lake management plan for your lake or others in your area.

We'd further like to suggest that calculations of wave disturbance frequencies and the dynamic ratio also be considered when working with lakes. These two relatively simple approaches can offer fresh insight into the diagnosis and management of shallow lakes in Florida and elsewhere. As one scientist observes, "This is particularly important in Florida lakes, as it has recently been recognized that there are important differences between how deep lakes and shallow lakes function (Bachmann 2000)**."**

FCCDR/USF

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Appendix A

Measuring Lake Surface Area

Lake surface area can be measured with a bathymetric map using any of the following techniques:

1 One of the most accurate methods is to use a **planimeter** to trace the shoreline contour of a lake. This hand-held instrument is designed for measuring the area of a shape as drawn on a two-dimensional plane.

Using the tracer point of a planimeter, you can carefully follow the outermost contour of a bathymetric map. The planimeter calculates the area of the shape in ***planimeter units (PU)*** while tracing its outline. Once you have the area in planimeter units you can compare it with the scale of the map to convert the PU to the lake's actual surface area.

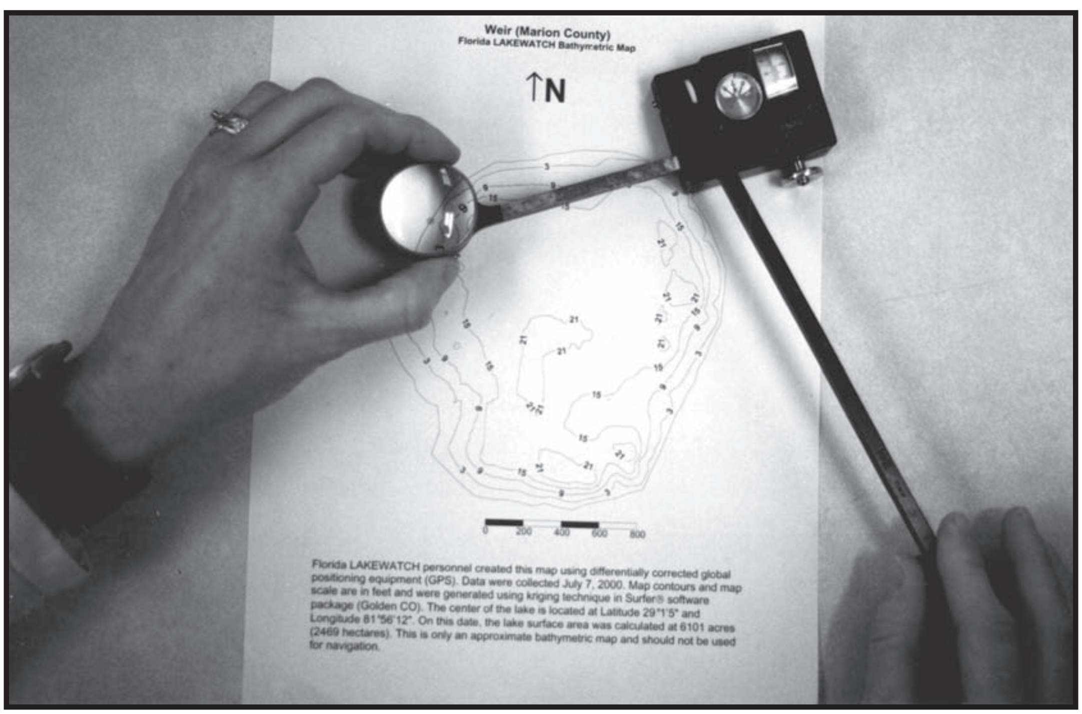
Note: For detailed information about how to do this, refer to a limnology methods manual.

2 Digital tablets or computer scanners can also be used to trace or scan a bathymetric map image. Once the image is digitally memorized (i.e., traced or scanned), computer mapping software can be used to calculate surface area.

3 Another method involves placing a grid pattern over a lake map and counting the squares (of a known dimension) from the grid, to determine lake surface area.

Step 1: Trace the lake map on a piece of graph paper or draw a square grid on top of a copy of the map, as illustrated in Figure A-1 on page 30.

Step 2: Count all the squares that fall within the shoreline of the lake. At the shoreline, count only those squares that are more than half inside the lake shoreline area. Do <u>not</u> count squares that are more than one-half outside the lake boundary.



Joe Richard

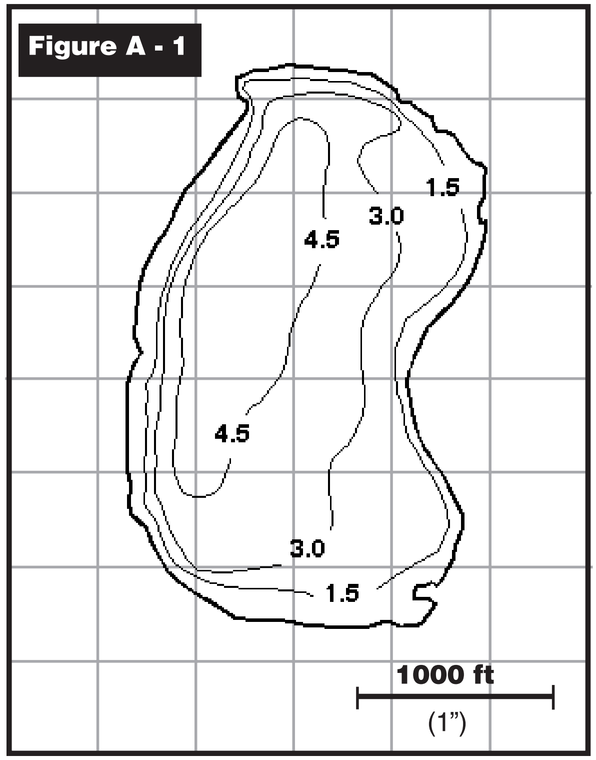
A planimeter can be used to trace the shoreline contour of a lake, in planimeter units.

Step 3: Using the map scale, determine the area represented by one square. For example, suppose the map scale shows that 1 inch represents 1000 feet and the squares of the grid are one-half inch on a side. Using this information, we can see that each square represents a measurement of 500 feet per side [**0.5 x 1000 = 500 ft.**]. Therefore, the area of one square would equal 250,000 square feet [**500 x 500 = 250,000 sq ft**].

Step 4: The area of the lake, in square feet, would be equal to the number of squares counted from the grid *(N)* **X** 250,000. To convert the area from square feet to acres, divide by 43,560.✪

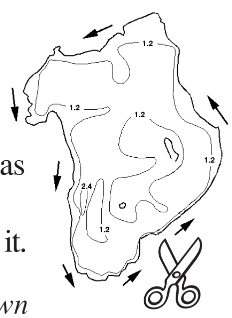
$$\frac{N \times 250{,}000}{43{,}560} = \text{lake surface area in acres}$$

✪ *43,560 is the conversion factor for converting square feet to acres.*



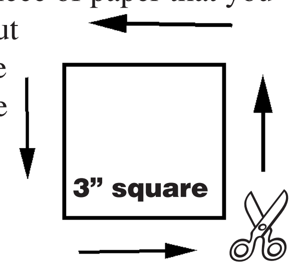
4 There is another way to calculate surface area that is relatively simple, but it does require a weight scale that is sensitive enough to weigh a piece of paper.

Step 1: Lightly trace an outline of the lake (from a bathymetric map or satellite map, for instance) onto a heavy grade of paper such as construction paper. Cut out your newly drawn lake shape and weigh it.



Note: The lake shape example shown here is much smaller than you should use. Your cutout should be closer in size to the lake map in Figure A-1 (or larger) for obtaining a weight on most laboratory scales.

Step 2: Using the same piece of paper that you cut the lake shape from, but from an area outside of the lake shape cutout, measure and cut out a square of known dimensions and weigh that too.



Note: The square cutout should be similar in size to the lake shape cutout. For this example, we'll use a 3-inch square cutout.

Step 3: Once weights are obtained for the lake shape and the square cutout, use the equation below to find the area of the lake in square feet.

Note: To convert the area from square feet to acres, divide by 43,560.✪

Find the AREA of the square paper cutout (to scale).
For instance, if the map's scale equates 1 inch with 1000 feet, then one side of the 3-inch cutout square represents 3000 feet. Consequently, that 3-inch square piece of paper represents 9,000,000 sq ft of surface area. (See below.)

3,000 ft X 3,000 ft = **9,000,000 sq ft**

Divide the number from above (i.e., 9,000,000 sq ft) **by the WEIGHT of that same 3-inch square piece of paper.**
If the weight of the square piece of paper was 0.25 oz, then your answer for this part of the equation would be 36,000,000. (See below.)

9,000,000 sq ft ÷ 0.25 oz = **36,000,000 sq ft/oz**

X

Multiply by the WEIGHT of the lake shape paper cutout.
If the lake shape cutout weighs 0.35 oz, then you would multiply 0.35 with the number from the bottommost portion of the equation at left:
0.35 oz X 36,000,000 sq ft/oz

=

AREA of a lake, as drawn on a map.
Using the numbers provided here, we found the area to be:
12,600,000 square feet

Appendix B

Measuring Lake Volume

There are several ways to calculate and/or estimate the volume of a lake:

1 The simplest way involves using basic algebraic equations for determining volume. To do this, one has to have the approximate dimensions of the waterbody such as average depth, length and width. *Note: This method is used as a quick way to determine volume for ponds or smaller lakes and is generally less accurate than the following methods.*

*See **A Quick Way of Estimating the Volume of a Lake in Acre-Feet** on page 32.*

2 For lake basins that are almost conical in shape and structure (i.e., some solution lakes), a rough estimate can be made using the same equation used for determining the volume of a cone:

$$\text{Volume } (V) = 1.047\ r^2h$$

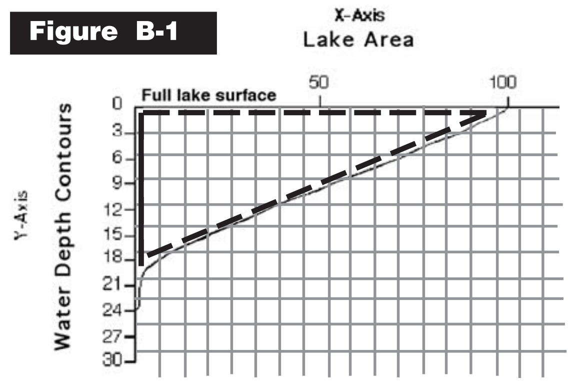
r is the radius of the top *(surface)* of the cone *(lake)*

h is the height *(maximum depth)* of the cone *(lake)*

3 Hypsographic curves can also be used. As you can see in Figure B-1, volume is proportional to the area between the x-axis, the y-axis and the curve itself. Based on this knowledge, we can determine the lake's volume using the following method:

Step 1: First, draw the hypsographic curve onto lined graph paper, as shown in Figure B-1. Then count the number of squares found between the x-axis, the y-axis and the curve itself. *Note: squares that are more than half-way inside this area are to be counted and squares that are more than half outside the area should not be counted.*

Figure B-1



Step 2: The lake volume represented by each square can then be found, and the total of all of these volumes will give us the lake's volume. To do this, multiply the area represented by one square along the x-axis times the depth represented by one square on the y-axis. This product is then multiplied by the number of squares counted within the hypsographic curve.

4 Bathymetric maps can be used to determine lake volume and it's done like this:

Step 1: Using the same technique of counting squares described in Appendix A Part 3 (see Figure A-1), place a grid of small squares on a bathymetric map of your lake and calculate the area found within the various individual contour lines. *Note: Using Figure A-1, you should have four separate area measurements: one for the surface area of the entire lake, one for the area within the 1.5 contour line, one for the 3.0 contour line and one for the 4.5 line.)*

Step 2: The next step is to calculate the volume of water layer by layer, starting with the top layer. (See Figure B-1.) You can do this by finding the **area** at

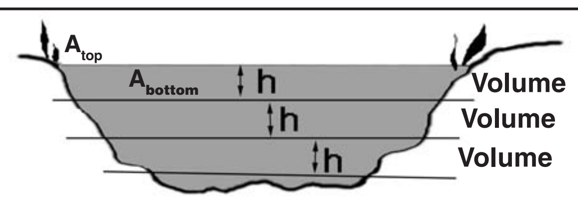


Figure B-1

the top of the first layer (A_{top}) and the area at the bottom of the first layer (A_{bottom}). Plug both numbers into the equation provided in Figure B-2. *Note: See Appendix A Part 3 for more on calculating a lake's surface area using a bathymetric map.*

Step 3: After finding the volume of the top layer, calculate the volume of the second deepest layer, using the same technique, and continue on down for each layer of the lake. (See Figure B-1.)

Step 4: Add the volumes of the respective layers to find the total volume for the lake.

Step 5: If the areas are in units of square feet and the depth interval is in feet also, the volume would be in cubic feet. If the areas are in acres and the depth interval in feet, then the area would be in units of acre-feet.

$$V = \frac{h\,(A_{top} + A_{bottom} + \sqrt{A_{top} \times A_{bottom}}\,)}{3}$$

Let: A_{top} = the area of the top of the layer

A_{bottom} = the area of the bottom of the layer

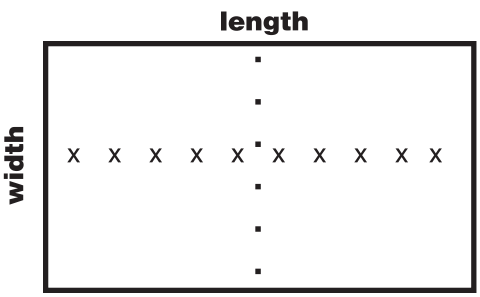
h = the distance between contour lines

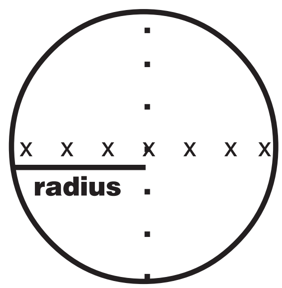
V = the volume of one layer

Figure B-2

Note: An acre-foot is one acre covered with one foot of water.

A quick way of estimating the volume of a small lake in acre-feet





Step 1: First determine the average depth of the lake. This is also referred to as its **mean depth**. You can find this number by collecting a series of water depth measurements at various locations in the waterbody, and then averaging them. An electronic fathometer, or something as simple as a weighted line, marked in increments of feet or meters, can be used to collect water depth measurements. Collect these measurements every 10 to 20 feet for both the long and short axis of the waterbody. Add all of these numbers together and then divide by the total number of readings that were taken to obtain the average depth.

Step 2: Once you've determined the average depth of the lake, you can use this number, along with the waterbody's length and width to solve the following equations. Notice that the equations are different, depending on the general shape of the waterbody:

If your lake or pond is rectangular in shape — multiply the lake's length, width, and average depth and divide by 43,560 to find its volume in acre-feet.

$$\frac{\text{length} \times \text{width} \times \text{average depth}}{43{,}560} = \_\_\_\_\_ \text{ acre-feet}$$

43,560 is the conversion factor used to convert cubic feet into acre-feet.

If your lake is circular in shape — use its radius, pi (π or 3.14), and average depth in the following equation:

$$\frac{3.14 \times r^2 \times \text{average depth}}{43{,}560} = \_\_\_\_ \text{ acre-feet}$$

43,560 is the conversion factor used to convert cubic feet into acre-feet.

As always, we welcome your questions or comments.