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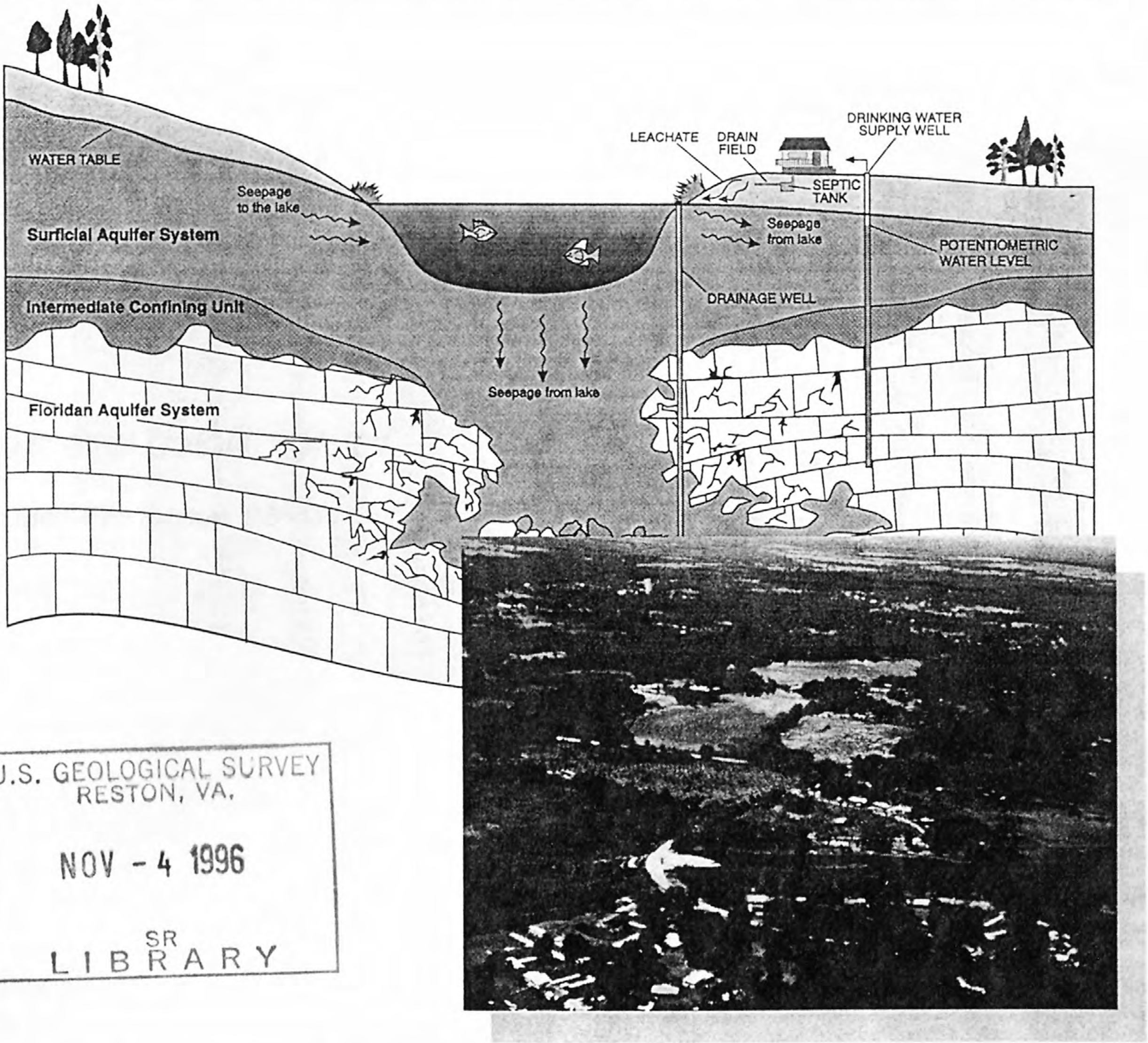
Hydrology Of Central Florida Lakes—A Primer



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Prepared in cooperation with the
St. Johns River Water Management District
South Florida Water Management District

Hydrology of Central Florida Lakes—A Primer

By D.M. Schiffer
Illustrations by Rafael Medina

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Prepared in cooperation with the
ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Tallahassee, Florida
1996

U.S. DEPARTMENT OF THE INTERIOR
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CONTENTS

FIGURES

Photographs

GLOSSARY

(Sources: Langbein, W.B., and Iseri, K.T., 1966; Fernald, E.A., and Patton, D.J, 1984; and Lane, Ed, ed., 1994)

Alkalinity: The alkalinity of water is a measure of the capacity of the water to neutralize acids.

Aquifer: A geologic formation, group of formations, or part of a formation that contains sufficient saturated, permeable material to be able to yield significant quantities of water to wells and springs.

Artesian: A condition in ground water in which water is under pressure, rising in a well tapping the aquifer until the water surface is in equilibrium with the atmosphere.

Buffered: The resistance of water to a change in pH.

Carbonates: Rock composed chiefly of carbonate minerals (calcium, magnesium); examples are limestone and dolomite.

Condensation: The process by which water changes from the vapor state into the liquid or solid state.

Conductivity: *See specific conductance.*

Dissolved oxygen: Atmospheric oxygen that is dissolved and held in solution in water. Only a fixed amount of oxygen can be dissolved in water at a given temperature and atmospheric pressure.

Dissolved solids: The sum of all the dissolved constituents in a water sample. Major components of dissolved solids are the ions of the following: calcium, magnesium, sodium, postassium, bicarbonate, sulfate, and chloride.

Drainage basin: A part of the surface of the earth that drains to a body of water by way of overland flow or stream flow.

Drainage lake: A lake that has a surface-water inlet, outlet, or both.

Evaporation: The process by which water is changed from the liquid state into the gaseous state through the transfer of heat energy.

Evapotranspiration: The sum of water lost from a given land area during any specified time by transpiration from vegetation and building of plant tissue; by evaporation from water surfaces, moist soil, and snow; and by interception (rainfall that never reaches the ground but evaporates from surfaces of plants and trees).

Flushing rate: The rate (volume per unit time) at which water leaves a lake, either through a surface-water outlet or through ground-water seepage.

Geomorphology: The study of the configuration and evolution of land forms.

Ground water: Water that is present in the pores of soils or limestone. Generally refers only to the layers that are saturated (all pores are filled with water).

Hydraulic gradient: The difference in water levels at two points divided by the distance between the two points. Either horizontal or vertical hydraulic gradients can be measured.

Hydrologic budget: An accounting of the inflow to, outflow from, and storage in a drainage basin.

Hydrologic cycle: A term denoting the circulation of water from the ocean, through the atmosphere, to the land; and thence, with many delays, back to the ocean by overland and subterranean routes, and in part by way of the atmosphere; also includes the many paths by which water is returned to the atmosphere without reaching the ocean.

Hydrology: The science of the water of the earth.

Hydrostatic pressure: The pressure exerted by water under equilibrium (balanced) conditions.

Infiltration: The flow of water into the surface of the earth through the pores of the soil at land surface. Distinct from percolation (see definition).

Interception: The process and the amount of rain stored on leaves and branches of vegetation that eventually evaporates back to the atmosphere.

Limnology: That branch of hydrology pertaining to the study of lakes.

Overburden: The sediments and water contained in the unsaturated zone, surficial aquifer system, and intermediate confining unit.

Nitrogen: An essential plant nutrient. High concentrations can lead to excessive plant growth and water-quality problems.

Pan coefficients: Mathematical ratios that relate lake evaporation to measured pan evaporation.

Percolation: Flow of water through a porous substance, usually in a vertical direction (downward). Rainfall, as it reaches the land surface, first infiltrates the surface, then percolates downward.

pH: A measure of how acid or alkaline water is, based on the concentration of hydrogen ions in the water.

Phosphorus: An essential plant nutrient. High concentrations can lead to excessive plant growth and water-quality problems.

Potential Evapotranspiration: The maximum amount of water that would be evaporated and transpired if there was no deficiency of water in the soil at any time for the use of vegetation.

Potentiometric surface or level: The height to which water will rise in a tightly cased well that is open to a confined or partially confined aquifer.

Precipitation: The discharge of water, in liquid or solid state, out of the atmosphere, generally upon a land or water surface. It is the common process by which atmospheric water becomes surface or subsurface water. Precipitation includes rain, hail, sleet, and snow.

Residence time: The time necessary for the total volume of water in a lake to be completely replaced by incoming water.

Retention Pond: A pond constructed for the purpose of retaining stormwater runoff. Water in retention ponds evaporates or infiltrates the bottom of the pond, eventually recharging the underlying ground water. If there is a surface outlet to another body of water, the pond is called a **detention pond**.

Seepage: The process of water moving slowly through the subsurface environment, or the actual water involved in the process of seepage.

Seepage lake: A lake that has no surface inflow or outflow; a landlocked lake.

Seiche: The free oscillation of the bulk of water in a lake and the motion caused by it on the surface of the lake.

Sinkhole: A funnel-shaped depression in the land surface that connects with underground passages or caverns.

Solution Processes: The chemical processes by which rock is dissolved by interactions with water.

Specific Conductance: A measure of the ionic concentration based on the property of natural water to conduct a current of electricity.

Spring: Site at which ground water flows through a natural opening in the ground onto the land surface or into a body of surface water.

Surface-runoff: That part of precipitation that does not infiltrate the land surface, but travels along the land surface.

Surface Water: Water that is present on the land surface, generally referring to lakes and streams.

Transpiration: The process by which plants take water from the soil, use it in plant growth, and then transpire it to the atmosphere in the form of water vapor. Evaporation and transpiration are often combined in one term, *Evapotranspiration*.

Unsaturated zone: A term used to describe the zone between land surface and the water table, where the pores in the soil matrix are filled with a combination of water and air.

Water table: The upper surface of the zone of saturation in the ground. The water table is at atmospheric pressure.

Zone of saturation: The zone in which the soil or rock is saturated with water under hydrostatic pressure.

Hydrology of Central Florida Lakes—A Primer

by Donna M. Schiffer

INTRODUCTION

Lakes are among the most valued natural resources of central Florida. The landscape of central Florida is riddled with lakes—when viewed from the air it almost seems there is more water than land. Florida has more naturally formed lakes than other southeastern States, where many lakes are manmade, created by building dams across streams. The abundance of lakes on the Florida peninsula is a result of the geology and geologic history of the State. An estimated 7,800 lakes in Florida are greater than 1 acre in surface area. Of these, 35 percent are located in just four counties (fig. 1): Lake, Orange, Osceola, and Polk (Hughes, 1974b). Lakes add to the aesthetic and commercial value of the area and are used by many residents and visitors for fishing, boating, swimming, and other types of outdoor recreation. Lakes also are used for other purposes, such as irrigation, flood control, water supply, and navigation. Residents and visitors commonly ask questions such as "Why are there so many lakes here?", "Why is my lake drying up (or flooding)?", or "Is my lake spring-fed?" These questions indicate that the basic hydrology of lakes and the interaction of lakes with ground water and surface water are not well understood by the general population.

Because of the importance of lakes to residents of central Florida and the many questions and misconceptions about lakes, this primer was prepared by the U.S. Geological Survey (USGS) in cooperation with the St. Johns River Water Management District (SJRWMD) and the South Florida Water Management District (SFWMD). The USGS has been collecting hydrologic data in central Florida since the 1920's, obtaining valuable information that has been used to better understand the hydrology of the water resources of central Florida, including lakes. In addition to data collection, as of 1994, the USGS had published 66 reports and maps on central Florida lakes (Garcia and Hoy, 1995).

The main purpose of this primer is to describe the hydrology of lakes in central Florida, the interactions between lakes and ground- and surface-waters, and to describe how these interactions affect lake water levels. Included are descriptions of the basic geology and geomorphology of central Florida, origins of central Florida lakes, factors that affect lake water levels, lake water quality, and common methods of improving water quality. The geographic area discussed in this primer is approximate—it includes west and east-central Florida, extending from the Gulf of Mexico to the Atlantic Ocean coastlines, northward into Marion, Putnam, and Flagler Counties, and southward to Lake Okeechobee (fig. 1). The information presented here was obtained from the many publications available on lakes in central Florida, as well as from publications on Florida geology, hydrology, and primers on ground water, surface water, and water quality. Many publications are available that provide more detailed information on lake water quality, and this primer is not intended as an extensive treatise on that subject. The reader is referred to the reference section of this primer for sources of more detailed information on lake water quality. Lakes discussed in this report are identified in figure 2. Technical terms used in the report are shown in bold italics and in the glossary.

The classification of some water bodies as lakes is highly sub-

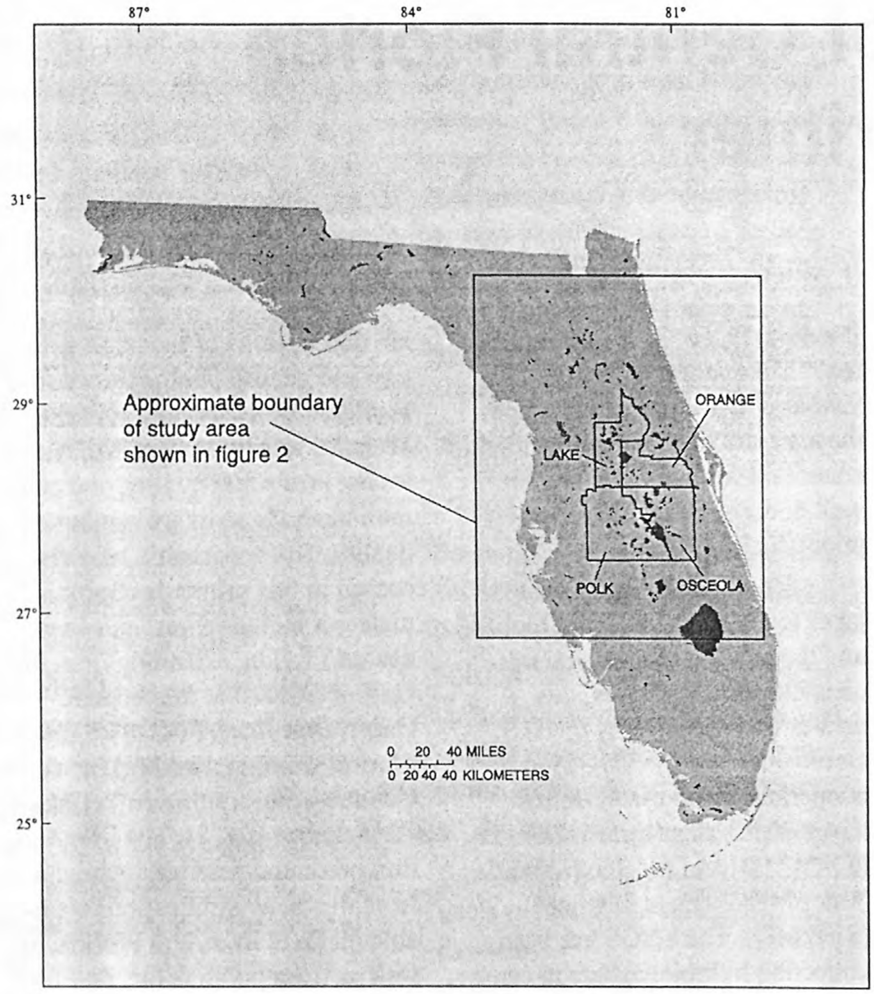


Figure 1. Approximate geographic area covered by this report and distribution of lakes in Florida.

jective. What one individual considers a "lake" another might consider a "pond." Generally, any water-filled depression or group of depressions in the land surface could be considered a lake. Lakes differ from swamps or wetlands in the type and amount of vegetation, water depth, and some water-quality characteristics. Lakes typically have emergent vegetation along the shoreline with a large expanse of open water in the center. Swamps or wetlands, on the other hand, are characterized by a water surface interrupted by the emergence of many varieties of plant life, from sawgrasses to cypress trees.

Lakes may be naturally formed or manmade; however, in some situations the distinction between naturally formed and manmade lakes is not clear. For example, retention ponds, which are required for the treatment of stormwater, can be constructed so that they serve multiple purposes of stormwater treatment and aesthetic enhancement of property. Larger retention ponds sometimes are used by residents for boating and fishing, and are considered by some to be lakes.

Hydrologic characteristics of central Florida lakes vary widely. The surface areas of lakes can range from several hundred square miles, such as Lake Okeechobee, to less than an acre. Water levels in some lakes may vary by 10 feet or more, whereas in other lakes, the water level may vary by only 1 or 2 feet. The quality of water among lakes in central Florida also is variable, ranging from pristine lakes such as Lake Butler in west Orange County to the pea-green colored waters of Lake Apopka, a short distance to the north in Orange and Lake Counties (although the clarity of water is not necessarily an indication of the quality of the water). Some lakes have natural surface-water inlets and outlets. Other lakes are landlocked, receiving water only from rainfall and losing water only from evaporation and seepage into the surrounding soils. This great variety in hydrologic characteristics is one of the reasons why water levels vary among lakes and why lakes respond differently to rainfall.

In addition to aesthetic value and recreational uses, lakes in central Florida are extremely important as habitats for fish, alligators, turtles, and birds, such as hawks

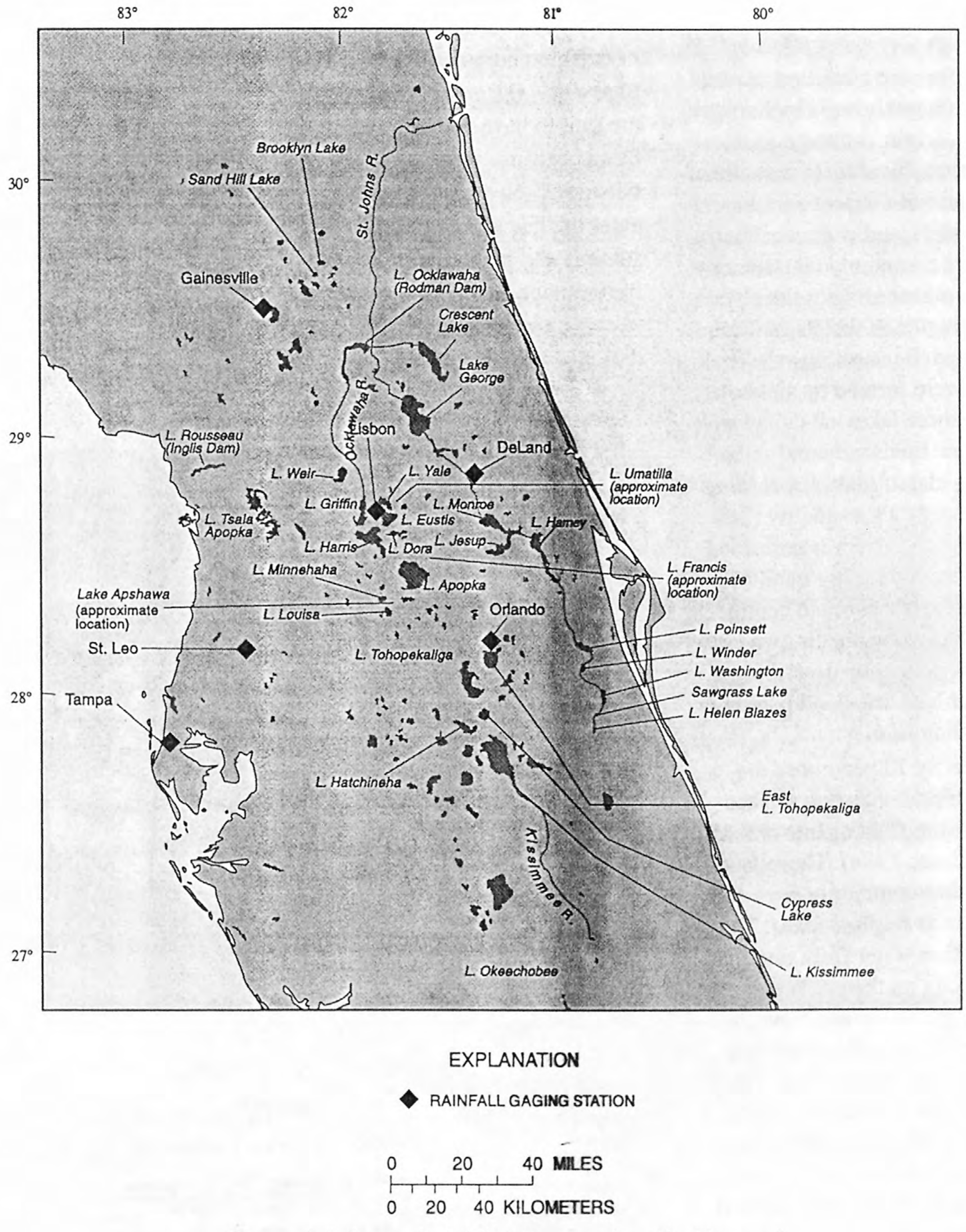


Figure 2. Lakes and rainfall stations mentioned in this report.

and eagles. Because Florida lakes are enjoyed and used by many, they need to be appreciated, understood, and protected.

CLASSIFICATION OF LAKES

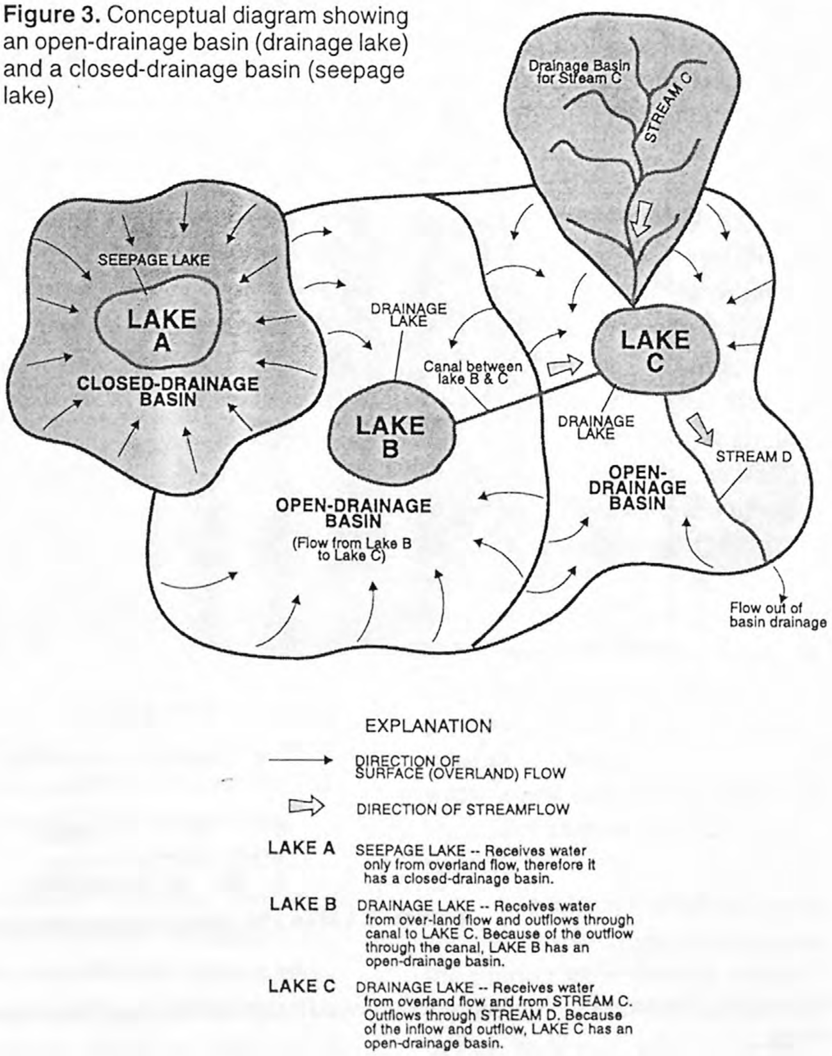
Lakes are classified according to different criteria including location, origin, drainage characteristics, trophic state (a measure of the amount of nutrient enrichment of the water), and water chemistry. Lakes are commonly classified by geologists according to the physiographic region in which the lakes are located. Because many lakes in Florida were formed by sinkhole activity, these lakes are called sinkhole lakes. Environmental scientists may classify lakes according to the state of water quality (this classification system is described in the section on water quality). Residents and visitors to central Florida have added their own classification system by describing a particular lake as a good fishing or water-skiing lake.

Nearly 70 percent of the lakes in Florida have no surface-water streams flowing into or out of them (Palmer, 1984). These landlocked lakes commonly are referred to as ***seepage lakes***. These lakes receive water from rain that falls directly on the surface of the lake and from overland flow (rainfall that reaches the ground and flows overland to the lake). The land area that contributes overland flow to the lake is called the drainage basin of that lake. For a landlocked lake, the drainage basin is referred to as a "closed" basin because the only surface water entering the lake is from surface runoff, and no water enters the lake from outside of the drainage basin.

Lakes that have distinct, channelized surface-water inflows or outflows commonly are referred to as ***drainage lakes***. These lakes are said to have "open" drainage basins because water originating outside of the drainage basin can enter the lake through inflow streams and lake water can leave the drainage basin through outflow streams. Conceptual drawings of a drainage lake (open-drainage basin) and a seepage lake (closed-drainage basin) are shown in figure 3.

Some central Florida lakes are connected by canals. Many of these canals were dug in the 1800's, before the arrival of the railroad, when Florida's lakes and rivers formed a major transportation network. Some of these canals were dug to lower the water levels and provide more usable land adjacent to the lakes because the land

Figure 3. Conceptual diagram showing an open-drainage basin (drainage lake) and a closed-drainage basin (seepage lake)



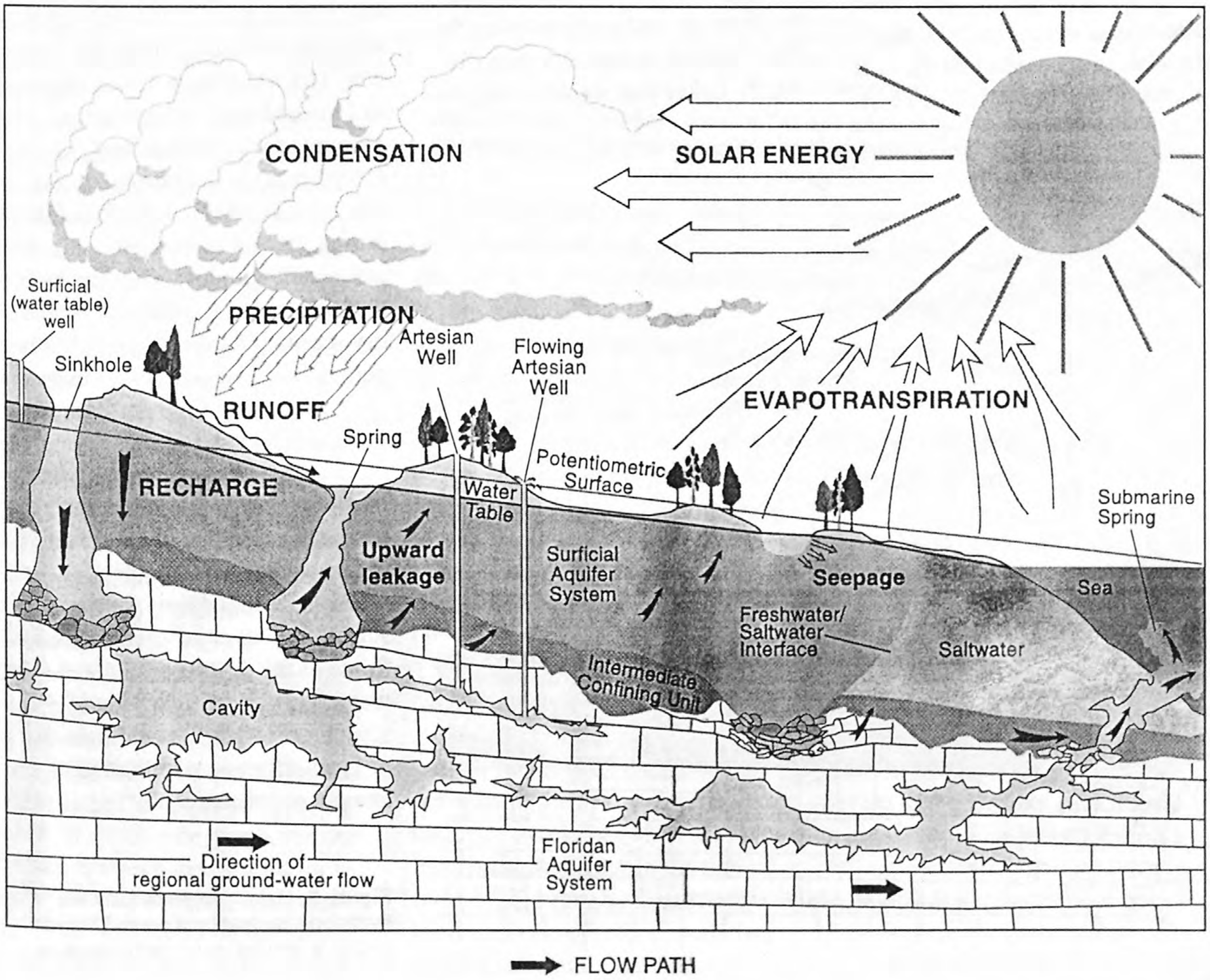
was valuable for farming and citrus cultivation. The construction of canals between lakes in effect changed former seepage lakes to drainage lakes. An example of this is shown in figure 3. Lake B in figure 3 originally was a seepage lake, but the construction of a canal to Lake C provided a surface outlet; the canal in effect changed the "type" of lake to a drainage lake with an open-drainage basin.

THE HYDROLOGIC CYCLE

Water in the environment moves from the atmosphere, to the *land surface, to the ground-water* system, and back to the atmosphere in a cycle called the hydrologic cycle (fig. 4). In this section, the components of the hydrologic cycle are described to provide the necessary background for an understanding of lake hydrology.

The primary components of the hydrologic cycle in central Florida are rainfall, runoff, infiltration (including recharge), evaporation, transpiration, and condensation. When rain falls, some of the water infiltrates the ground and recharges aquifers, some of it is intercepted by plants, and some of it flows over the land surface (surface runoff or overland flow). Beneath the land surface,

Figure 4. The hydrologic cycle.



water moves through the aquifers toward areas of discharge such as the ocean or streams. Water returns to the atmosphere through the processes of evaporation and plant transpiration (collectively labeled "evapotranspiration" in fig. 4). Once in the atmosphere as water vapor, the hydrologic cycle is completed when this vapor condenses and forms rain droplets that subsequently fall on the land surface again.

Some of the components of the hydrologic cycle can be quantified by using measuring devices to collect data, and a "water budget" of a lake (an accounting of the total volume of water entering and exiting the lake) can be determined from these data. Much of the research on Florida lakes has focused on water budgets in an effort to better understand the complex hydrologic system of a lake, and to determine how each component of the hydrologic cycle affects lake water levels and water quality. A schematic of the components of a lake water budget is shown in figure 5. Lakes receive water from rain falling on the surface of the lake, from surface runoff within the drainage basin, from streamflow, and from ground water entering the lake (labeled as lateral seepage in fig. 5). Lakes lose water to evaporation, seepage through the bottom, and streamflow (in lakes with surface-water connections). Rainfall and streamflow are relatively easy to measure, but recharge, evaporation, and seepage are much more difficult to determine accurately. The components of the hydrologic cycle are discussed in more detail in the following sections.

Rainfall

The climate of central Florida is subtropical, with warm, wet summers and mild, fairly dry winters. The wet season, which begins in June and ends in September, accounts for more than half (56 percent) of the rainfall during the year (Schiner, 1993). Rainfall during the wet season generally is associated with local showers and thunderstorms. Rainfall during the dry season (October through May) generally is associated with frontal systems moving from northern latitudes southward. Rainfall during the wet season can be highly localized, with heavy thunderstorms producing significantly more rain in some areas than in others, whereas rainfall during the dry season affects larger geographic areas. Some of the differences in lake water levels, particularly during summer months, can be the result of local differences in rainfall amount or intensity.

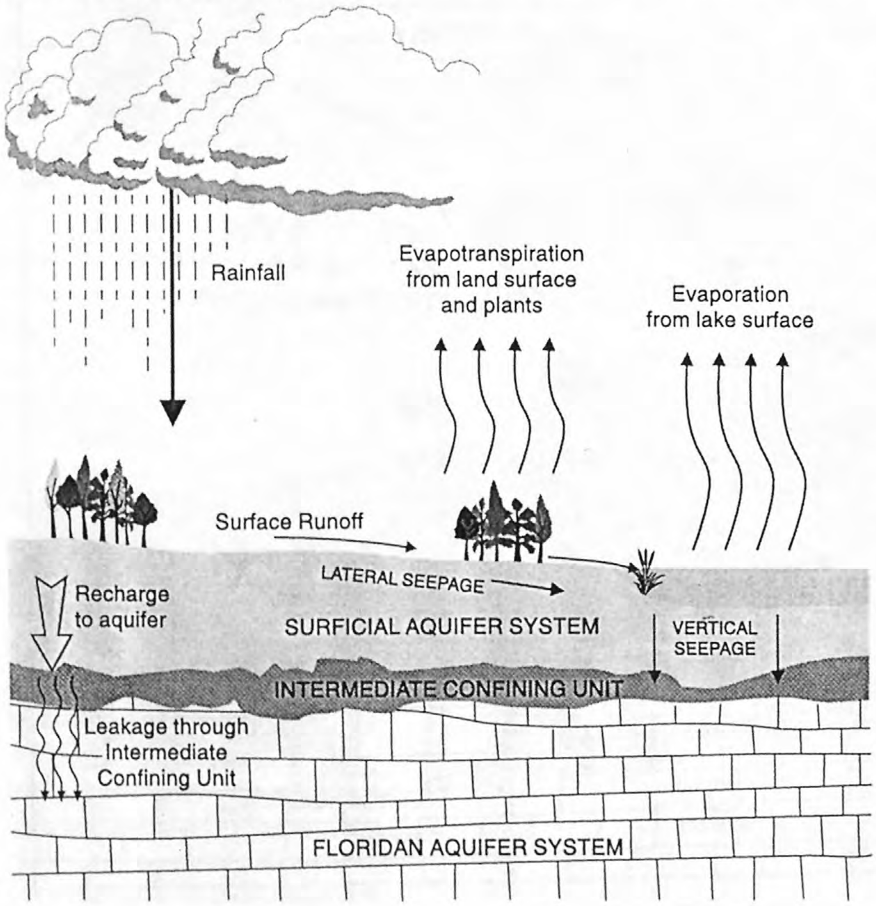


Figure 5. Major components of the hydrologic budget for a central Florida lake in a ground-water recharge area.

Total monthly or annual rainfall also is variable from location to location. For example, the average annual rainfall, based on 30 years of record (1961-90), ranges from 43.92 inches in Tampa to 54.09 inches in St. Leo (see fig. 2 for station locations). The variability from one location to another is indicated by the average monthly rainfall during a 30-year period (1961-90) at two rainfall stations in DeLand and Orlando (fig. 6, locations shown in fig. 2). Both stations are inland and are only about 30 miles apart, so one might expect similar rainfall amounts. Total rainfall at these two stations is similar for some months, but the rainfall at DeLand tends to be greater than the rainfall at Orlando, particularly during the months of August, September, and October, illustrating regional variability. Mean annual rainfall at DeLand (56.05 inches) is nearly 8 inches greater than mean annual rainfall at Orlando (48.11 inches) for the period 1961-90, indicating that long-term rainfall patterns can differ significantly even at locations that are relatively close and in similar settings.

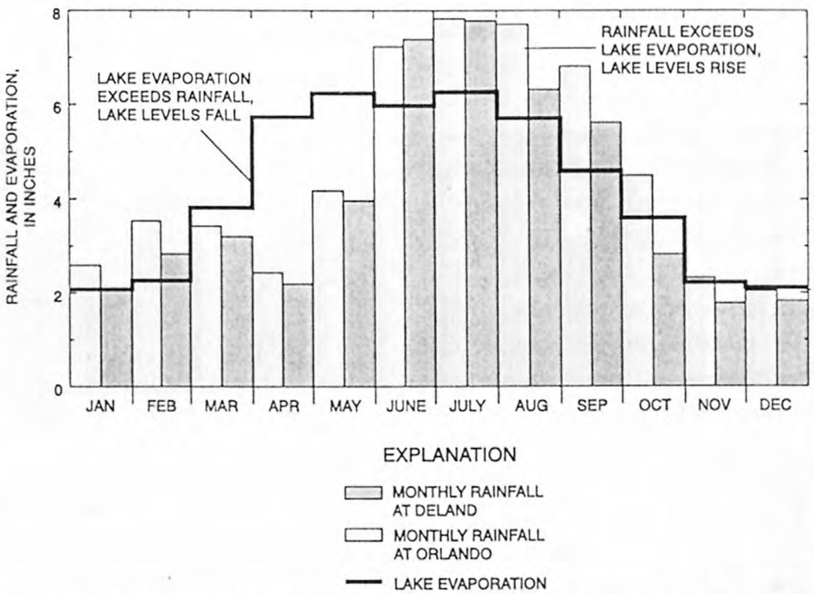


Figure 6. Mean monthly rainfall at DeLand and Orlando for the period 1961-90 and lake evaporation based on pan evaporation (1960-88).

The annual rainfall for Jacksonville, the site with the longest rainfall record in Florida, is shown in figure 7. Rainfall record-keeping started in 1851, but there is a break in the otherwise continuous record from 1861-66. Total annual rainfall is shown in the upper graph of figure 7. In the middle graph, the difference between the rainfall for each year and the long-term average is shown (based on the period 1866-1993). Just as daily rainfall varies from one day to the next, total annual rainfall varies from one year to the next. The difference between annual rainfall and the long-term average annual rainfall is called the "departure" from average for that year. These annual departures from the average can have a cumulative effect on lake water levels. For example, a series of years with less than average rainfall may result in lake water levels that are lower than the long-term average level for that lake. The bottom graph of figure 7 illustrates how the difference between annual rainfall and the average rainfall, when accumulated from one year to the next, can produce trends of excess or deficit rainfall. Excess rainfall early in the period, from 1866 through about 1889, produced enough of a cumulative surplus of rainfall (bars shown above the zero line) that it was 25 years before lower-than-average annual rainfall produced a deficit (bars shown below the zero line, beginning in 1917).

Evaporation and Transpiration

Most of the rain that falls is returned to the atmosphere by evaporation and by transpiration from plants. Commonly, evaporation and transpiration are considered together and called evapotranspiration. Water that is in the soil near the land surface can return to the atmosphere through evaporation. The highest evaporation rate is from water surfaces such as lakes. Evaporation from a lake surface is referred to specifically as lake evaporation. The evap-

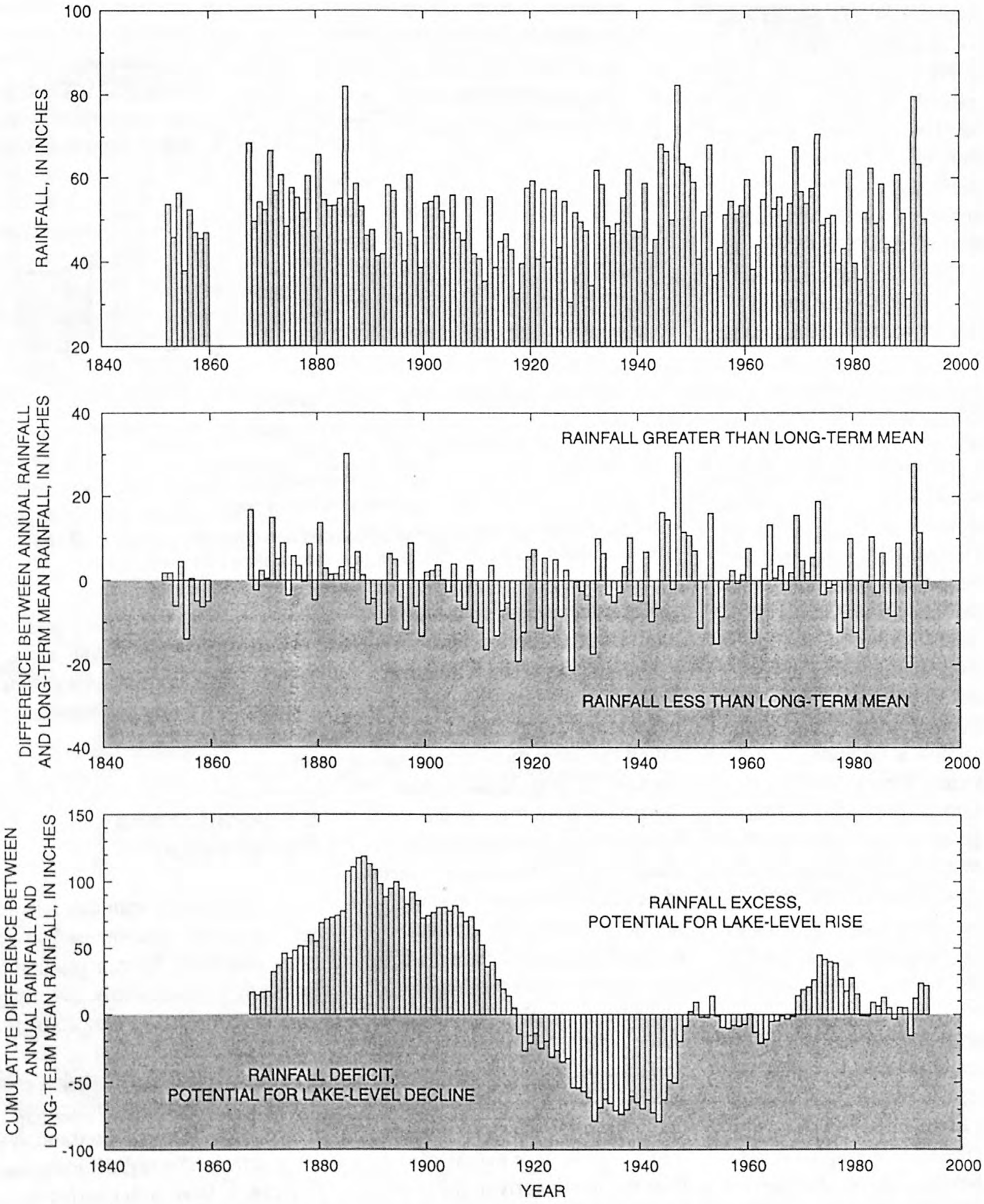


Figure 7. Annual rainfall at Jacksonville, the station with the longest record in Florida.

oration rate is affected by several variables such as the amount of moisture in the air (humidity), the amount of sunlight, wind, and temperature. Thus, evaporation rates are variable; in central Florida, evaporation rates have been estimated to be as low as 25 inches per year and as high as 50 inches per year (Tibbals, 1990).

One way that lake evaporation is estimated is from evaporation measured using a standard 4-foot diameter, shallow metal pan. Pan-evaporation rates are greater than lake-evaporation rates and must be corrected using pan coefficients, which are mathematical ratios that relate lake evaporation to pan evaporation.

Annual lake evaporation for the central Florida area was estimated to be about 51 inches, based on 28 years (1960-88) of pan-evaporation data recorded at the Lisbon and Gainesville weather stations (locations shown in fig. 2) and pan coefficients determined in studies at Lake Hefner, near Lake Okeechobee, by Kohler (1954). Other estimates of annual lake evaporation reported by researchers in central Florida have ranged from 47 inches (Phelps and German, 1996) to 58 inches (Lee and Swancar, 1994). The annual lake-evaporation rate of 51 inches is greater than the average yearly rainfall at Orlando (48.11 inches, based on rainfall from 1961-90); however, lake evaporation represents the maximum possible rate of evaporation. The actual evaporation rate over a large region is considerably lower than the lake-evaporation rate because the water is evaporating from land surfaces as well as water surfaces. Although the actual evaporation in the drainage basin of a lake can be estimated for a water budget, the computation can be complex because it requires information about land use, depth to the water table, and other hydrologic variables.

Surface Runoff

Rainfall that has not infiltrated the soil and has not been returned to the atmosphere by evapotranspiration flows over the land surface and is commonly referred to as surface runoff. This surface runoff replenishes the water supply of lakes but also carries with it sediment, fertilizers from lawns, petroleum products from road surfaces, and other contaminants. Runoff also can enter a lake indirectly, by entering streams or canals that contribute water to the lake.

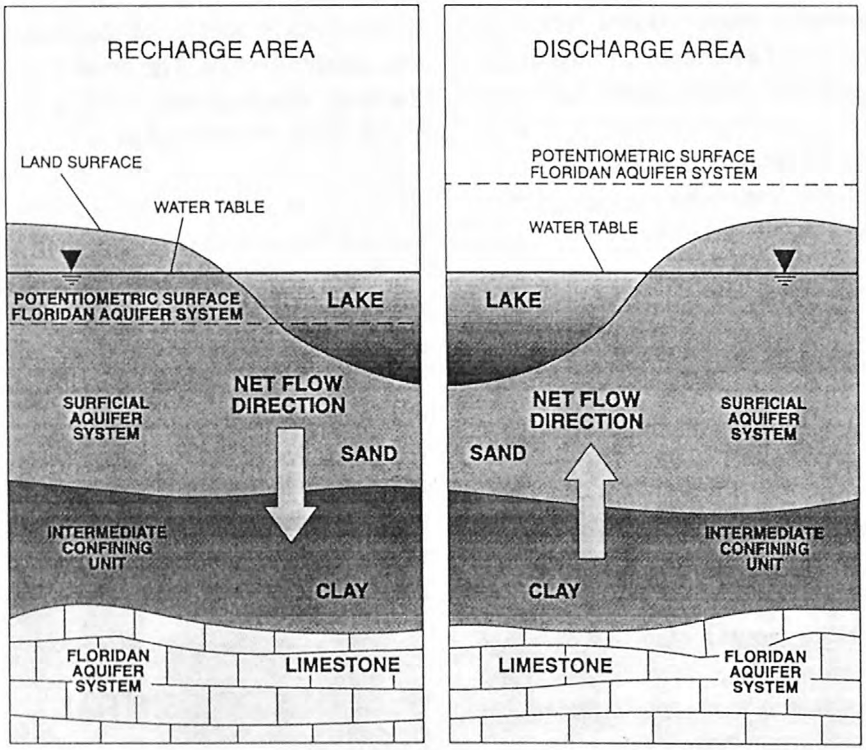
Infiltration and Ground-Water Recharge and Discharge

Part of the rainfall that reaches the land surface infiltrates the soil, where it gradually percolates downward until it reaches the surficial aquifer system (fig. 8). This water replenishes the surficial aquifer system which in turn replenishes or "recharges" the Floridan aquifer system. This downward movement can occur only where the water levels in the surficial aquifer system are higher (at a greater altitude) than the potentiometric surface of the Floridan aquifer system. The areas in the State where ground water is replenished are referred to as recharge areas. In areas where the potentiometric surface of the Floridan aquifer system is greater than the water level of the surficial aquifer which overlies it, water moves upward toward the land surface. These areas are referred to as discharge areas or areas of artesian flow (fig. 8). The many springs in Florida are located in discharge areas. Lakes in central Florida are present in both recharge and discharge areas

GEOLOGY OF CENTRAL FLORIDA

The Florida peninsula is composed of carbonate rock (limestone and dolomite) that was deposited over a period of about 100 million years. For about 75 million years, during the Cretaceous Period (138 to 63 million years ago), Florida was covered by relatively deep oceans. Later, from about 63 to 38 million years ago, the Florida peninsula was a shallow carbonate reef. Sea level then receded and rose several times, eroding and depositing carbonates, until about 5 million years ago. Since that time, land-derived sediments such as sand, silt, and clay have been deposited, rather than marine carbonate sediments. Subsequent fluctuations of sea level during episodes of glaciation have

Figure 8. Ground-water movement in recharge and discharge areas.



eroded, reworked, and transported the unconsolidated sand, silt, and clay sediments.

The Florida peninsula is a product of sedimentary processes and Florida's geology reflects these processes. The geology of central Florida is depicted graphically in figure 9, which also shows the hydrogeologic units, or aquifers and confining units, corresponding to the geology. Basement rocks (not shown in fig. 9) form the foundation of the peninsula. These rocks are several thousand feet below the surface and can be igneous, metamorphic, or sedimentary rocks. In central Florida, the basement rocks consist primarily of the igneous rock granite (Arthur and others, 1994, p. 11). Above these basement rocks are the Cedar Key, Oldsmar, and Avon Park Formations, and the Ocala and Suwanee Limestones (fig. 9). These formations consist of limestone, dolomite, anhydrite, and gypsum and were deposited when most of the Florida peninsula was below sea level. The total thickness of these formations ranges from 5,500 to 12,000 feet (Tibbals, 1990). The overlying Hawthorn Formation, deposited about 25 million years ago, represents a transition between marine-derived and land-derived sediments. The lower layers of the Hawthorn Formation generally are marine-derived and contain limestone, whereas the upper layers of clay, fine sand, and silt are land-derived. These upper layers of the Hawthorn Formation generally restrict ground-water movement. Overlying the Hawthorn Formation and continuing upward to the present land surface are unconsolidated sediments generally consisting of quartz sand, clay, and some organic material.

The thickness of the Hawthorn Formation, which varies greatly in central Florida, is a key element in the lake formation process (described in a later section). When rocks of the marine-formed Ocala Limestone and Suwanee Limestone Formations were exposed at land surface, the rock was eroded by wind, rain, flowing water, and thermal changes (expansion and contraction due to seasonal temperature change). Because the erosional process is not necessarily uniform from one location to another, the eroded surface of the limestone can be very irregular. Later in geologic time, the sediments of the Hawthorn Formation were deposited on top of this irregular, eroded limestone surface. Therefore, the thickness of the Hawthorn Formation varies depending on the original altitude of the surface where it was deposited.In those areas where the sediments of the Hawthorn Formation are thin, more surface water can penetrate to the underlying rock and continue the erosional process. These are areas prone to sinkhole development. In those areas where the Hawthorn Formation is thicker, the underlying rock is more shielded from the effects of continued erosion, and sinkholes are less common.

GROUND WATER

In this section of the primer, the ground-water system in central Florida is described in order to provide the background necessary for the understanding of lake formation, water levels in lakes, and the quality of water in lakes that are discussed in subsequent sections. Florida's ground water is contained in ***aquifers***. An ***aquifer*** is a layer or a combination of several layers of permeable soils or rocks that contain usable quantities of water. The major aquifers in central Florida are identified in figure 9 under the column labeled "Geohydrologic Unit" and in the generalized cross-section shown in figure 10. In central Florida, the aquifer nearest the land surface is the surficial aquifer, or water-table aquifer. The term "system" is used to indicate the presence of more than one water-bearing layer or aquifer; for regional analysis these multiple layers of aquifers are collectively considered as a single geohydrologic unit (fig. 9).

The ***water table*** refers to a surface below which all the openings or spaces in the soil or rock are filled with water (saturated). Pores in the soil between the land surface and the water table are filled with both water and air; this uppermost layer above the water table is referred to as the ***unsaturated zone***. The term ***ground water*** refers to water below the water table. The water table is in contact with the atmosphere through the unsaturated zone; therefore, the water table is at atmospheric pressure. The depth to the water table can range

Figure 9. Generalized summary of geologic and hydrogeologic units in central Florida.

APPROXIMATE NUMBER OF YEARS AGO	SYSTEM	SERIES		GEOLOGIC UNIT	DESCRIPTION	GEOHYDROLOGIC UNIT		PATTERN USED IN ILLUSTRATION
11,000	Quaternary	Recent and Pleistocene		Undifferentiated deposits	Unconsolidated materials including sand, clay, marl, shell, and phosphorite	Surficial aquifer system		
500,000 - 63,000,000	Tertiary	Pliocene		Undifferentiated deposits	Silty to sandy clay, thin shell beds, and basal limestone beds of variable thickness, phosphatic	Intermediate confining unit		
		Miocene		Hawthorn Formation	Dolomite, sand, clay, and limestone; silty, phosphatic			
		Oligocene		Suwanee Formation	Limestone, phosphatic	Floridan aquifer system	Upper Floridan aquifer	
		Eocene	Late	Ocala Limestone	Limestone, chalky, foraminferal, dolomitic near bottom			
			Middle	Avon Park Formation	Limestone and hard brown dolomite		Middle semiconfining unit	
			Early	Oldsmar Formation	Dolomite and limestone with intergranular gypsum		Lower Floridan aquifer	
		Paleocene		Cedar Key Formation	Dolomite and limestone with beds of anhydrite	Sub-Floridan confining unit		

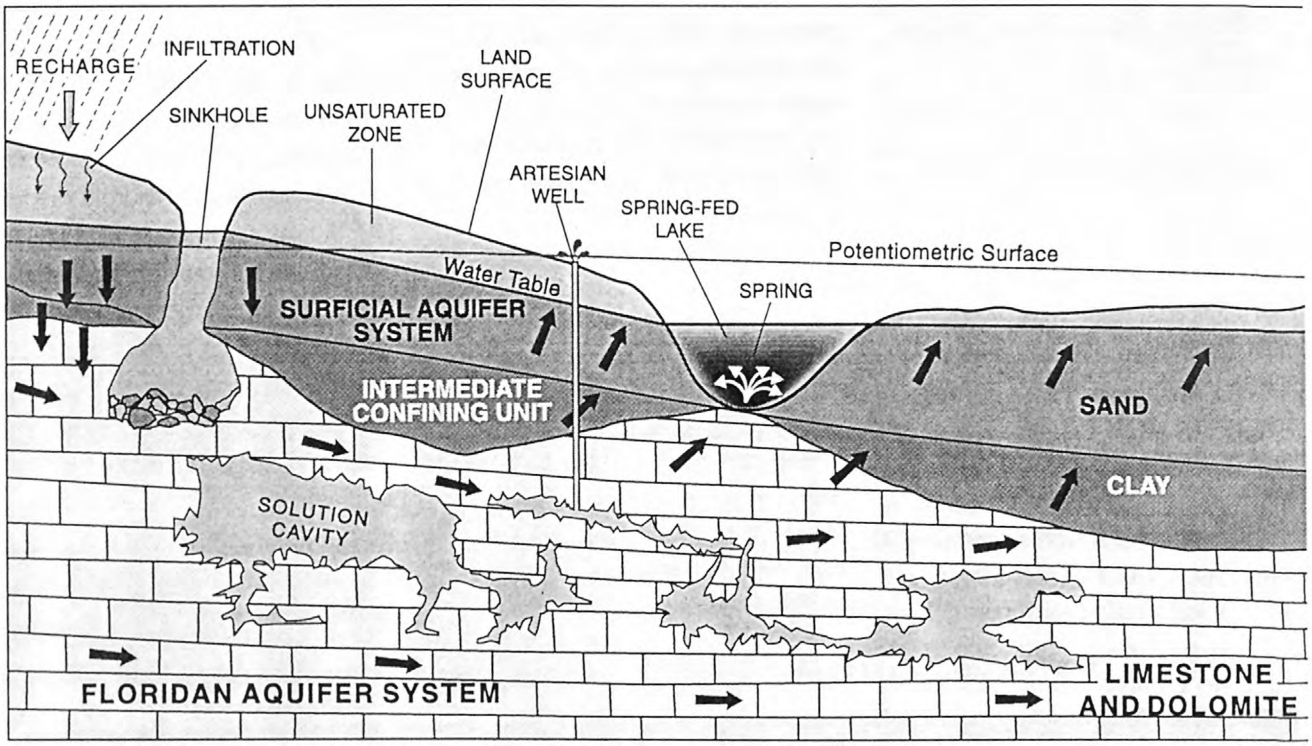


Figure 10. Geology and major aquifers in central Florida.

from only a few inches to 50 feet or more below land surface.

Beneath the surficial aquifer system lies the intermediate confining unit, which is composed of layers of clays, fine silts and, in some areas, limestone beds. The materials that make up the intermediate confining unit in most of central Florida generally are not very permeable, thus, this unit restricts the movement of water from above and below. In some areas, the lower part of the intermediate confining unit may consist of highly fractured limestone and dolomite, which can produce usable quantities of water; however, in most areas the intermediate confining unit is not used for water supply.

The Floridan aquifer system underlies the intermediate confining unit and is the primary source of nearly all the drinking water in central Florida. The rock that contains the Floridan aquifer system generally consists of highly permeable limestone and dolomite. The top of the aquifer is at or near land surface in west-central Florida (including Marion and Sumter Counties) and can be as deep as several hundred feet below land surface in other areas of central Florida. The Floridan aquifer system is further divided into the Upper Floridan and Lower Floridan aquifers (fig. 9). The Upper Floridan aquifer is the primary source of drinking water, although the Lower Floridan aquifer is used in some areas.

Water in the Floridan aquifer system is under pressure in much of central Florida because the overlying clays and silts of the Hawthorn Formation act to "confine" the limestone (thus the name "intermediate confining unit"). This condition is commonly called "artesian" because water levels in wells drilled into the aquifer rise above the top of the aquifer, and in some places rise above land surface (fig. 10). The level to which the water rises is referred to as a *potentiometric level.* Wells that tap the Floridan aquifer system are commonly referred to as artesian wells, particularly if the potentiometric level in the well is greater than the land surface; where this occurs, water will flow out of the well as shown in figure 10. In areas where the limestone of the Floridan aquifer system is at or near land surface, there are no confining sediments and the aquifer is not under pressure; thus, the aquifer is not artesian.

GEOMORPHOLOGY AND THE ORIGIN OF CENTRAL FLORIDA LAKES

The geomorphology of the Florida peninsula provides clues to geologic history and the origin of lakes. Physical features of the land surface of central Florida have been used to define physiographic regions, some of which are associated with the abundance of lakes. The physical features of Florida are quite varied, although compared to other parts of the country the State is rather flat and featureless. Physical features of central Florida range from highlands, ridges, and upland plains, to lowlands and coastal marshes. Cooke (1945) described two major physiographic regions in central Florida: the Central Highlands and the Coastal Lowlands. Land elevations in the Central Highlands region range from about 40 to 325 feet above sea level. The Coastal Lowlands border the entire coast of Florida and land elevations generally are less than 100 feet (Cooke, 1945).

The central Florida area is characterized by discontinuous highlands separated by broad valleys. One of the effects of the rise and fall of sea level was the formation of relict shoreline features such as beach ridges, which parallel the present-day Atlantic coastline (fig. 11). These beach ridges have had an effect on the shape, location, and orientation of lakes in central Florida. Swales between the beach ridges (shown as "plains" in fig. 11) are areas where surface water collected when sea level dropped, causing a decline in the water table and increasing the downward movement of water.

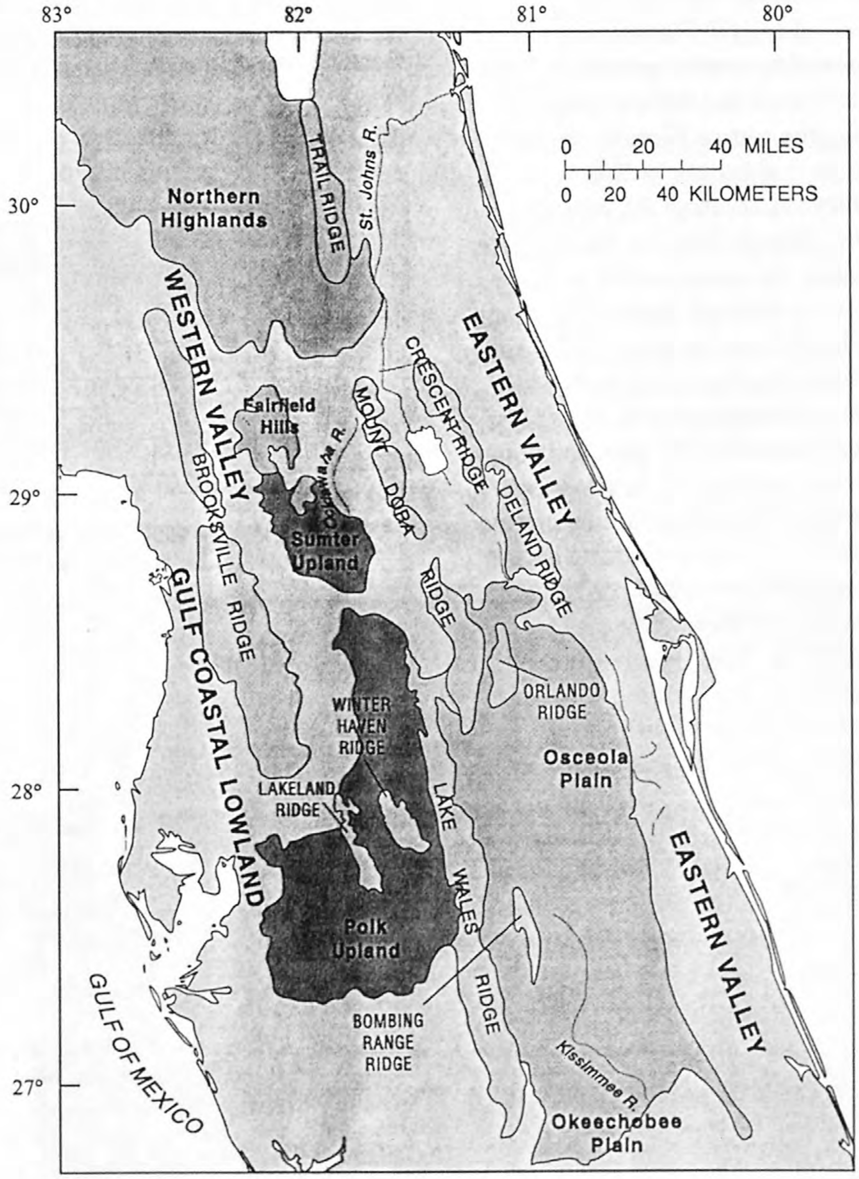
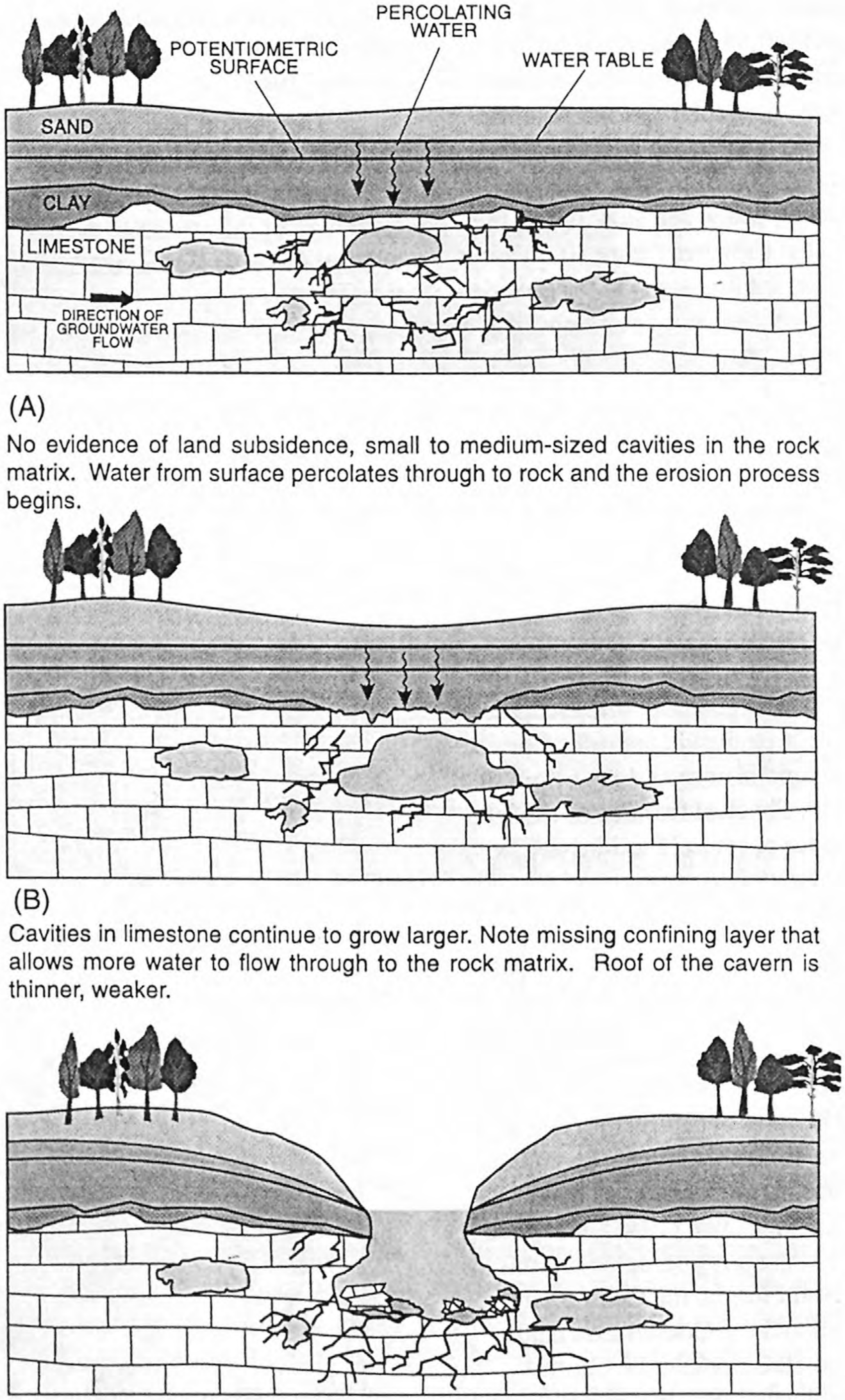


Figure 11. Major physiographic regions of central Florida

This increase in vertical water movement in turn accelerated the lake formation processes, which partly explains the abundance of lakes in central Florida. Within the Central Highlands of the Florida peninsula lies the most extensive area of closely spaced lakes in North America. The nearest counterparts to the lake district of Florida are in Canada and in the northern United States from Minnesota to Maine

Lakes in Florida were formed by several processes. The limestones and dolomites that underlie central Florida are "soft" rocks that are easily dissolved by rainwater entering the subsurface environment from the land surface and by the ground water moving through the rock matrix. The chemical processes by which rock is dissolved by interactions with water are commonly referred to as ***solution processes***. The past and continuing solution of the limestone beneath the land surface by ground water results in a landform called ***karst***. Common characteristics of a karst landform include a lack of surface drainage (nearly all the rainfall infiltrates into the ground and few drainage channels or streams develop), and the presence of sinkholes (depressions in the land surface), springs, circular-shaped lakes, and large cavities in the limestone and dolomite rocks.

By far, the most common origin of Florida's lakes is by solution processes. Solution processes



(A)
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.

(B)
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.

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

Figure 12. (At right) Formation of a collapse sinkhole.

are the underlying cause of sinkholes, which over time become lakes. Sinkholes are most common in areas where the intermediate confining unit between the unconsolidated materials of the surficial aquifer system and the underlying limestone of the Floridan aquifer system is thin, breached, or absent. With few exceptions, sinkholes form in areas of recharge to the Floridan aquifer system. In these areas, ground water easily moves downward from the land surface to the limestone. Carbon dioxide from the atmosphere is carried with the ground water and forms carbonic acid, a weak acid that dissolves the limestone, eventually forming cavities and caverns. In contrast, in areas where the intermediate confining unit is intact and the aquifer is more confined, less water from the surface reaches the limestone and sinkholes are not as common.

The three general types of sinkholes—subsidence, solution, and collapse—in central Florida generally correspond to the thickness of the sediments overlying the limestone of the Floridan aquifer system. The sediments and water contained in the unsaturated zone, surficial aquifer system, and intermediate confining unit collectively are termed overburden in the following description of sinkhole formation. Collapse sinkholes are most common in areas where the overburden is thick, but the intermediate confining unit is breached or absent. Subsidence sinkholes form where the overburden is thin and only a veneer of sediments is present overlying the limestone. Solution sinkholes form where the overburden is absent and the limestone is exposed at land surface.

Collapse sinkholes are the most dramatic of the three sinkhole types; they form with little warning and leave behind a deep, steeply sided hole. Collapse occurs because of the weakening of the rock of the aquifer by erosional processes and is often triggered by changes in water levels in the surficial and Floridan aquifer systems. The progression of a collapse sinkhole is shown in figure 12. A small cavity in the limestone of the Floridan aquifer system gradually grows larger as the rock is dissolved by the ground water flowing through it. The weight of the overburden above the cavity is supported by the roof of the cavity and is partly supported by pressure from the water in the aquifer. As the cavity grows larger, the rock that forms the roof of the cavity becomes progressively thinner. As water levels decline during dry periods or because of pumping, water pressure in the limestone cavity decreases and the weight of the overburden overcomes the structural integrity of the cavity roof. At this point, the roof and overburden collapse into the cavity forming the surficial "pothole" that is associated with sinkholes and karst terrain. The "Winter Park sinkhole" that formed in May 1981 (photo 1) probably is the best known collapse sinkhole in central Florida.

Although collapse sinkholes generally form during dry periods, they also can form as a result of heavy rainfall during an extended period of time. The rise in the water table of the surficial aquifer system as a result of the increased rainfall causes an increase in the weight of the overburden. A collapse occurs when the weight of the overburden on the roof of a limestone cavity

Photo 1. Winter Park sinkhole. Photo taken shortly after it formed in May 1981. (Photo by A.S. Navoy, USGS)

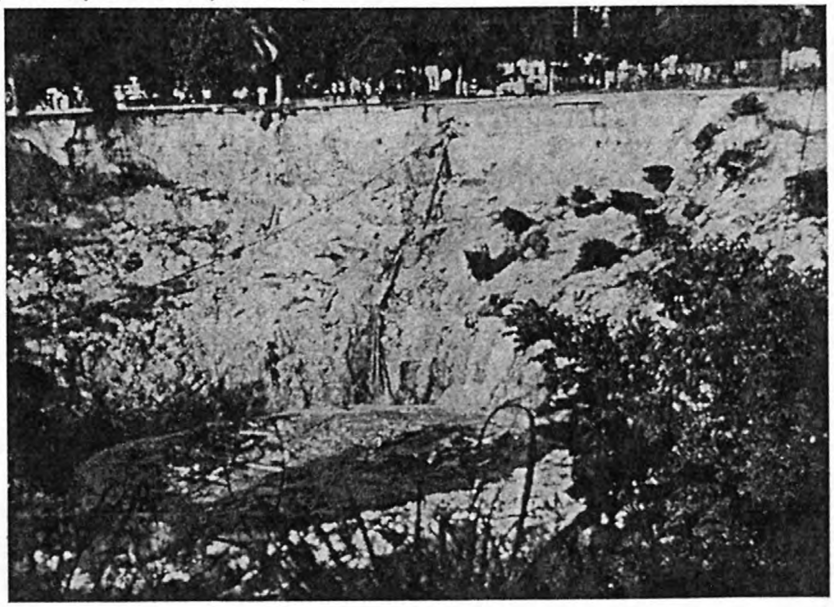
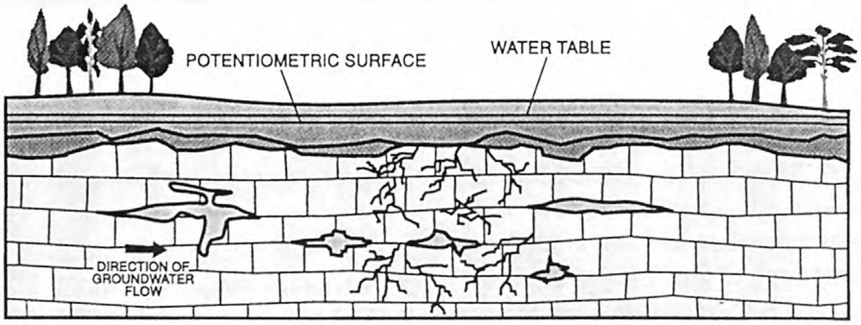
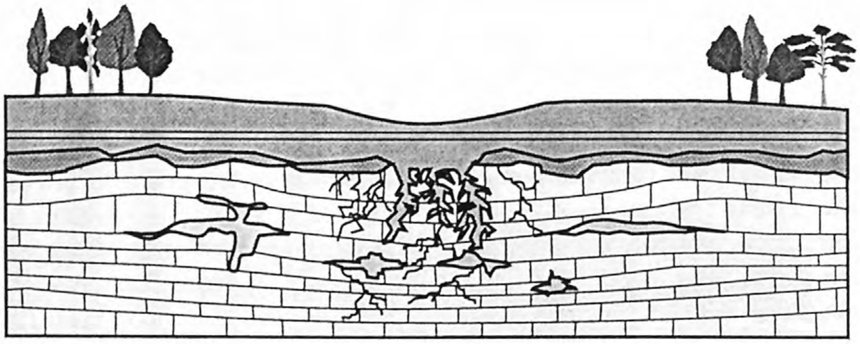


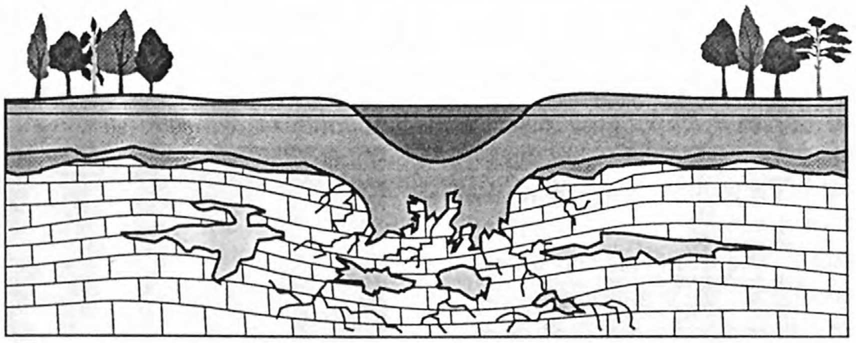
Figure 13. (At right) Formation of a subsidence sinkhole.



(A)
Initially the limestone contains fractures but no subsidence has occurred. Potentiometric surface may coincide with the water table.



(B)
Small cavities and cracks grow larger as time progresses and water moving through the rock erodes the rock matrix.



(C)
The rock matrix has been weakened by the continual erosion, and the overlying materials have settled into the depression formed by the compression of the rock. Water collects in the depression formed at land surface, creating a lake.

increases more rapidly than the water pressure in the cavity that is partially supporting the cavity roof and exceeds the structural strength of the roof.

The progression of a subsidence sinkhole is illustrated in the drawings in figure 13. As rainwater percolates through overlying sediments and reaches the limestone, the water dissolves the rock and gradually weakens its structural integrity. As the limestone continues to dissolve, depressions form in the surface of the rock and the weight of the overburden causes the rock to become compressed in a process of gradual settling. Somewhat analogous to this settling is the effect observed when a corrugated cardboard box becomes wet—the water weakens the structural integrity of the cardboard so that any weight placed on it causes the cardboard surface to sag. Similarly, the weight of sediments and water overlying the limestone causes the erosion-weakened limestone to "sag." As the limestone dissolves, the overlying sediments fill in the eroded rock surface, resulting in a bowl-shaped depression at the land surface. As the depression enlarges with time, water begins to collect in the depression. Sand and clay are carried to the newly formed sinkhole in runoff from the surrounding land, eventually settling, lining the bottom of the depression, and restricting the flow of water through the bottom. As water continues to accumulate in the depression, a lake is formed. An example of a lake formed in this way is Lake Tsala Apopka, in Citrus County (photo 2, page 17) In this area of central Florida the limestone is covered with a veneer of unconsolidated sediments or is exposed at the land surface. Lake Tsala Apopka is actually a series of lakes and marshes; the aerial view shown in

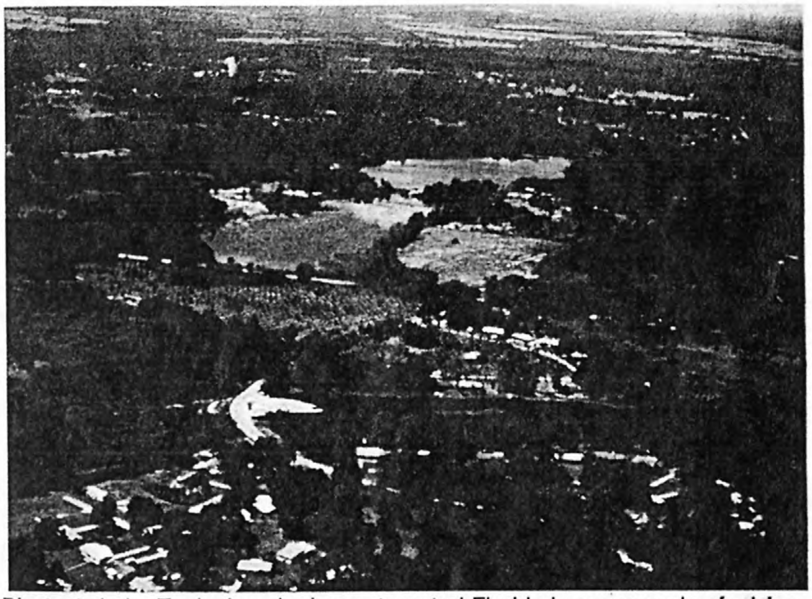


Photo 2. Lake Tsala Apopka in west-central Florida is an example of a lake formed by solution processes. The limestone in the area near this lake is commonly seen at land surface. (Photo by L.A. Bradner, USGS)

the photograph indicates the many depressions that together form the lake.

With the passing of time, the difference in appearance of lakes formed by these different types of sinkholes is less distinct. For example, the photograph of the Winter Park sinkhole on this page was taken in 1994, 13 years after the sinkhole formed. In the photo, the steep sides of the sinkhole are no longer visible because the water level has risen in the sinkhole and the "sink" looks very much like nearby lakes that may have been formed by other processes. Thus the specific type of sinkhole that caused the lake to form is not readily apparent.

Not all lakes in central Florida were formed by solution processes. Some central Florida lakes originally were natural depressions in the ancient sea floor. These depressions formed as a result of scouring and redepositing of material by wave action and water currents. Freshwater eventually filled these depressions when sea level fell. Examples of lakes that were formed in this way are the lakes that form a chain along the Upper St. Johns River, including Lakes Helen Blazes, Washington, Winder, and Poinsett in Brevard County (fig. 14). These lakes, through which the Upper St. Johns River flows, are remnants of an ancient estuary (White, 1970, p. 103).

Probably the least common origin of lakes in Florida is by fluvial, or riverine processes. More commonly fluvial processes combine with other lake-formation processes to enlarge or change the shape of lakes. For example, although Lakes Harney, Monroe, and George (fig. 2) all originated from depressions in the ancient sea floor, riverine processes have continued to enlarge these lakes.

Photo 3. The Winter Park sinkhole in October 1994, about 13 years after it formed. (Photo by L.A. Bradner, USGS)

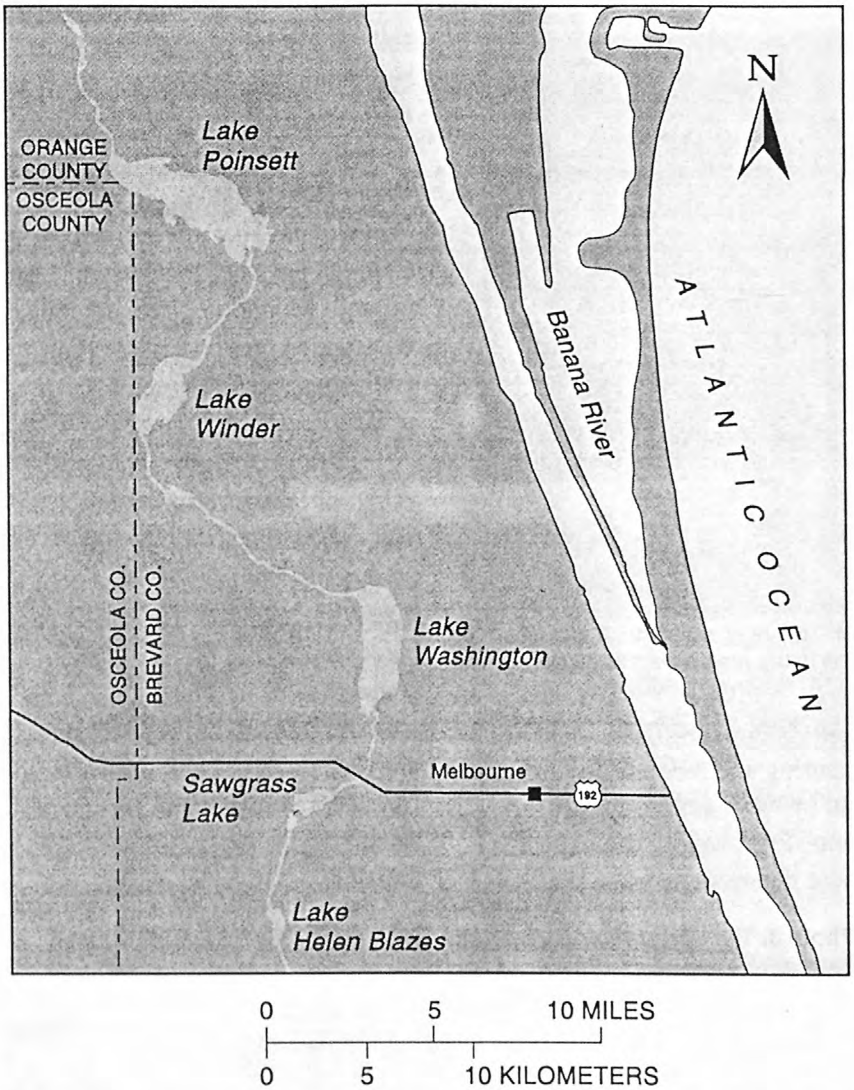


Figure 14. Present-day lakes formed when sea level fell and freshwater filled depressions in the sea floor (Upper St. Johns River chain of lakes).

Lakes formed in ancient sea floor depressions or by riverine processes differ in shape, grouping, and orientation of inlets and outlets from lakes formed by solution processes. For example, the lakes that form the Upper St. Johns River chain of lakes are elongated in the direction of the river flow, so that the lakes appear to be threaded together by the river (fig. 14). The inlet and outlet of each lake line up with the river and are oriented along the long axis of the lake. Solution-formed or sinkhole lakes tend to appear in groups or clusters, rather than in linear chains as in the Upper St. Johns River lake chain. An example of solution-formed lakes are the lakes of the Ocklawaha chain: Apopka, Harris, Griffin, Dora, Eustis, Yale, and Weir (fig. 15). The inlets and outlets of these lakes tend to be randomly oriented with respect to their long axes. Regardless of the orientation of inlets and outlets of central Florida lakes, a group of connected lakes are commonly referred to as a chain of lakes.

Manmade lakes in Florida often are created for practical as well as aesthetic reasons. Sometimes these lakes are referred to as "real-estate lakes," and are used in housing developments for stormwater treatment and for enhancement of the natural landscape. Lakes of this type usually are not named, even though some are quite large. One type of manmade lake is formed by building a dam across a river. Examples of this type of lake are Lake Rousseau in west-central Florida (located along the county lines of Levy, Marion, and Citrus Counties), which was created when the Inglis Dam was built in 1969, and Lake Ocklawaha in Putnam County, which was created when the Rodman Dam was built in 1968 (fig. 2). Both of these impoundments were created as part of the Cross-Florida Barge Canal, which was partially completed in the 1960's and was to connect the Atlantic Ocean and the Gulf of Mexico for shipping purposes, but was halted after concerns about environmental impacts arose.

PHYSICAL CHARACTERISTICS OF LAKES

Some of the physical characteristics of lakes include shape (length, width), depth, surface area, and total volume. As described in the last section, the shape of a lake, which may be circular, elliptical, or irregular, is the result of the process by which it was formed and the environment in which it has existed since it was formed. Because the environment of a lake is dynamic, physical characteristics may change with time, either as a result of natural environmental processes or because of human activity.

Lakes formed in ancient sea floor depressions or by riverine processes differ in shape, grouping, and orientation of inlets and outlets from lakes formed by solution processes.

The physical characteristics of lakes in Florida differ from those of lakes in other parts of the country, primarily because of differences in how they were formed and in local geology. Many lakes in the northern United States, such as the Great Lakes, the Finger Lakes of New York and the numerous lakes in Minnesota and Wisconsin, were formed by glacial processes. Lakes of glacial origin can be very deep, with steeply sloped sides and an irregular shape. Florida's lakes tend to be very shallow (7-20 feet deep), with gently sloping sides. Sinkhole lakes generally are circular, but can be irregularly shaped if a number of circular depressions coalesce.

The physical characteristics of a lake also are related to the age of the lake. A recently formed sinkhole lake may be quite deep and have steeply sloped sides, but gradually the lake fills in with sediments carried into the lake by runoff, and the side slopes become more gradual and stabilize as a result of erosional processes. As a lake continues to age it may resemble a marsh or wetland rather than a lake. Eventually, the lake may become little more than a broad open field (or prairie), sometimes with a stream running through what once was the deepest part of the lake. An example of this can be seen in Payne's Prairie near Gainesville, Florida.

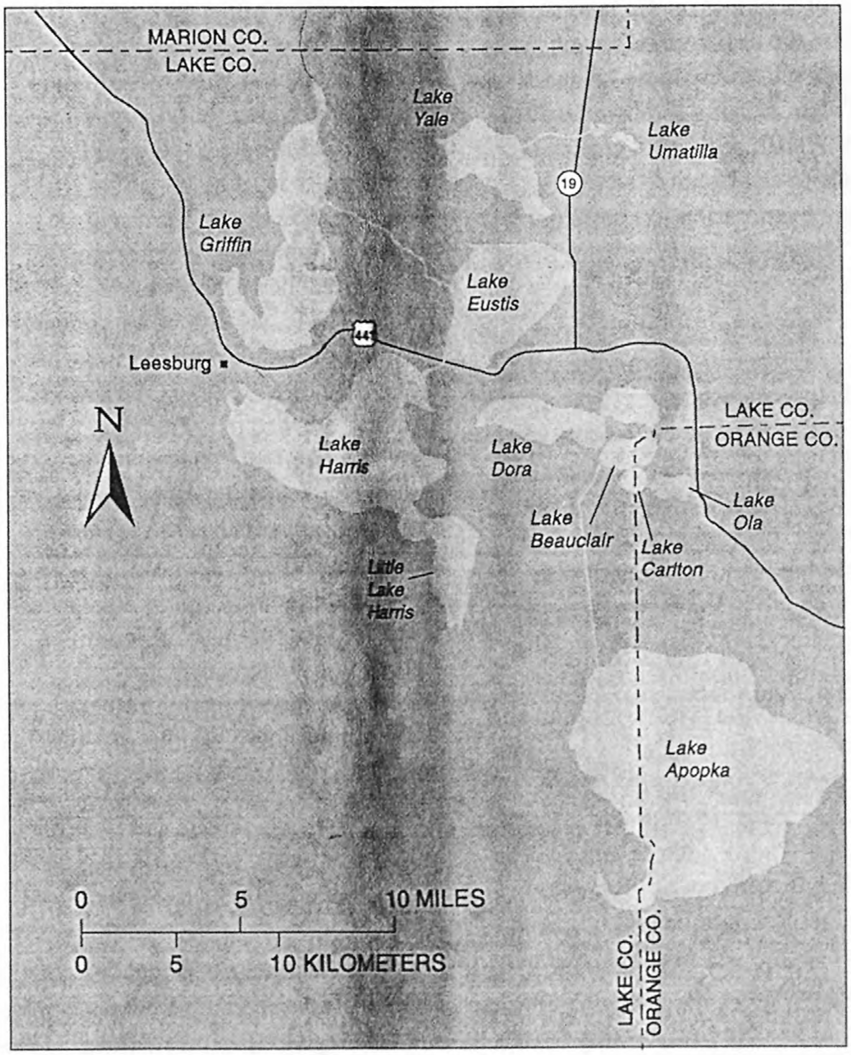


Figure 15. Lakes formed by solution processes (Ocklawaha River chain of lakes).

WHAT CAUSES LAKE WATER-LEVEL FLUCTUATIONS?

The volume and rate of water moving into and out of the drainage basin of a lake are the primary determinants of lake water level. This section presents a description of how each component of the hydrologic cycle affects lake water levels.

How Rainfall and Evapotranspiration Affect Lake Water Levels

Rainfall, either directly or indirectly, probably is the single greatest factor affecting water levels in lakes. Rain falling on the surface of a lake or on the land surface within the drainage basin causes an increase in the volume of water in the lake, causing the lake level to rise. A lack of rainfall causes lake levels to fall because water losses (from evaporation, seepage out of the lake, and pumping from the lake) are not balanced by water volume increases from rainfall.

Evaporation from the lake surface and evapotranspiration in the drainage basin cause lake levels to decline. Lake evaporation generally is greatest during May through July (fig. 6). Lower rainfall during April and May, combined with relatively high lake evaporation, result in greater water losses from lakes during these months. The losses resulting from lake evaporation and evapotranspiration during low-rainfall periods is most pronounced in seepage lakes; in drainage lakes or in lakes where water levels are controlled, the effects of high evaporation losses would be less noticeable because they are masked by other water losses.

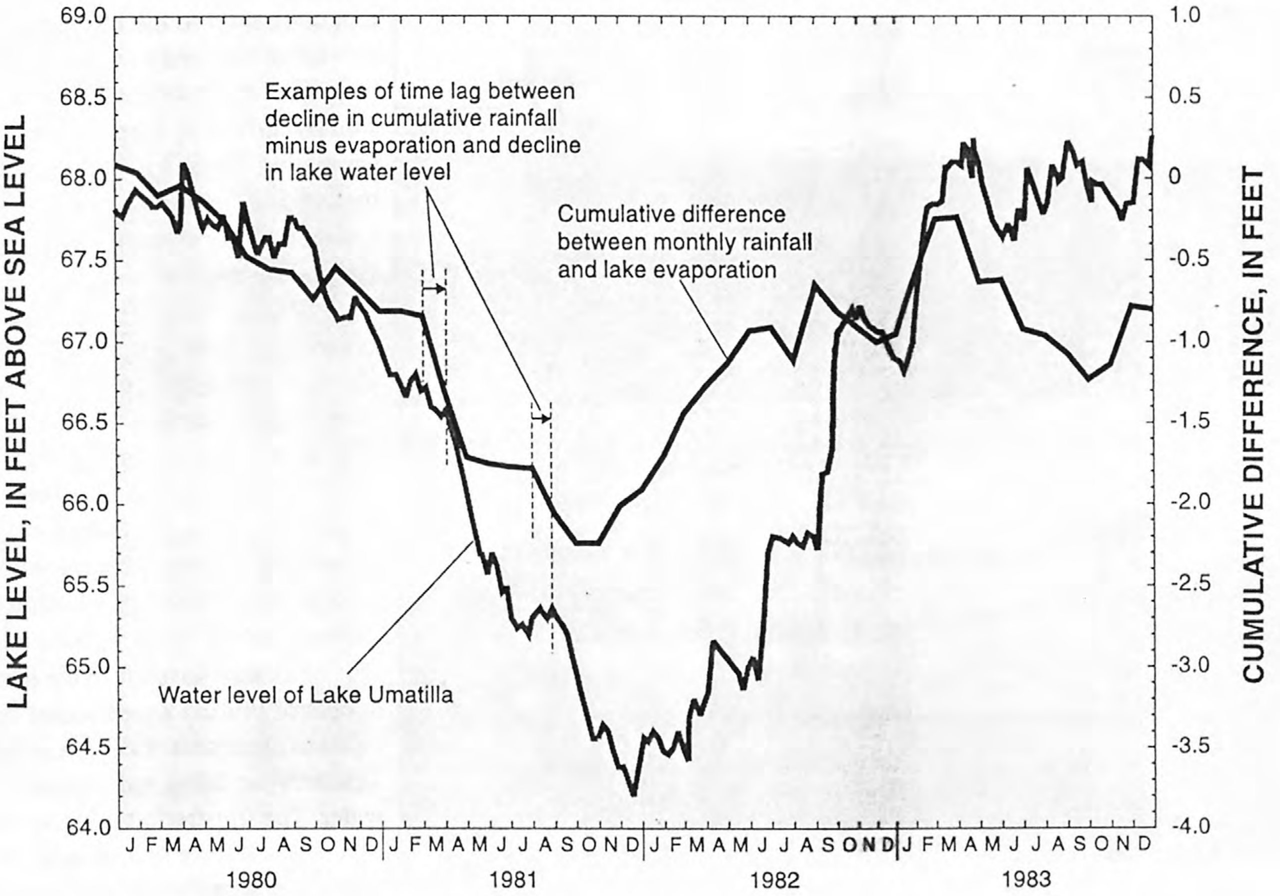
The cumulative difference between rainfall and evaporation over time affects lake water levels, particularly in seepage lakes. Lake Umatilla in Lake County (location shown in fig. 2) has characteristics of a seepage lake because it does not overflow except at extremely high water levels. Lake evaporation, in inches, was subtracted from monthly rainfall for a 4-year period; the result for each month then was accumulated. This cumulative difference is shown in figure 16 along with the weekly water levels in Lake Umatilla.The 4-year period shown represents a time when many lakes in central Florida reached record-low water levels (1981) because of a number of years of below-normal rainfall. Lake water levels began to rise as rainfall returned to normal levels in 1982-83 (fig. 16). The lag in the response of the lake water level to the cumulative difference between rainfall and lake evaporation is seen in several places in figure 16. Because lakes are part of a complex hydrologic system, effects from other elements of the hydrologic cycle sometimes mask the effects of rainfall.

How Surface Water Affects Lake Water Levels

Surface-water inflows to lakes include overland flow within the drainage basin; inflow from contributing streams; inflow (from other lakes or ponds) through surface-water connections such as canals, streams, or pipes; and stormwater transported through storm sewers. Surface-water connections generally allow more rapid inflow and outflow of water than ground-water connections; for this reason, these inflows and outflows can affect lake levels and water quality more rapidly than can similar volumes of inflow and outflow of ground water. Most (about 70 percent) of the lakes in Florida are seepage lakes (Palmer, 1984) and thus are not subject to the effects caused by directly connected surface-water inflows and outflows.However, in drainage lakes in central Florida, the inlets and outlets may not function for periods ranging from a few months to many years because water levels are below the level of the inlet or outlet (Deevey, 1988), thus water levels in many of these lakes probably are affected more by rainfall and ground water than by surface water.

How Ground Water Affects Lake Water Levels

The interaction between lakes and ground water can be very complex. Flow direction and volume are functions of the relative positions of the water surface of the lake, the water table of the surficial



aquifer system, and the potentiometric surface of the Floridan aquifer system. The ***hydraulic gradient*** is a term used to refer to the difference or change in water level over a given distance; for example, the difference in altitude between the water table of the surficial aquifer system and the potentiometric surface of the Floridan aquifer system, divided by the vertical distance between the two water surfaces, would be the vertical hydraulic gradient.

Some "typical" configurations of lake- and ground-water levels in recharge and discharge areas that also illustrate the effects

Figure 16. Water level in Lake Umatilla and the cumulative difference between rainfall and lake evaporation.

of the hydraulic gradient are presented in figure 17. A lake in a ground-water recharge area is shown in figure 17(A and B). In figure 17A, water moves out of the lake and into the adjacent and underlying aquifer because the lake water level is higher than the water table of the surficial aquifer system, perhaps because of recent rainfall. During periods of intense rainfall the lake water level may rise above the local water table and the general flow direction will be away from the lake. This condition usually is temporary. As the rain enters the soil and recharges the surficial aquifer system, the water table near a lake rises above the lake water level (fig. 17B), the direction of flow reverses, and lake receives seepage from the surficial aquifer system.

A lake in a ground-water discharge area is shown in figure 17C. In this illustration, the potentiometric surface of the Floridan aquifer system is above the lake water surface (and the water table of the surficial aquifer system); thus, the hydraulic gradient and the direction of flow is upward. Water from the Floridan aquifer system moves

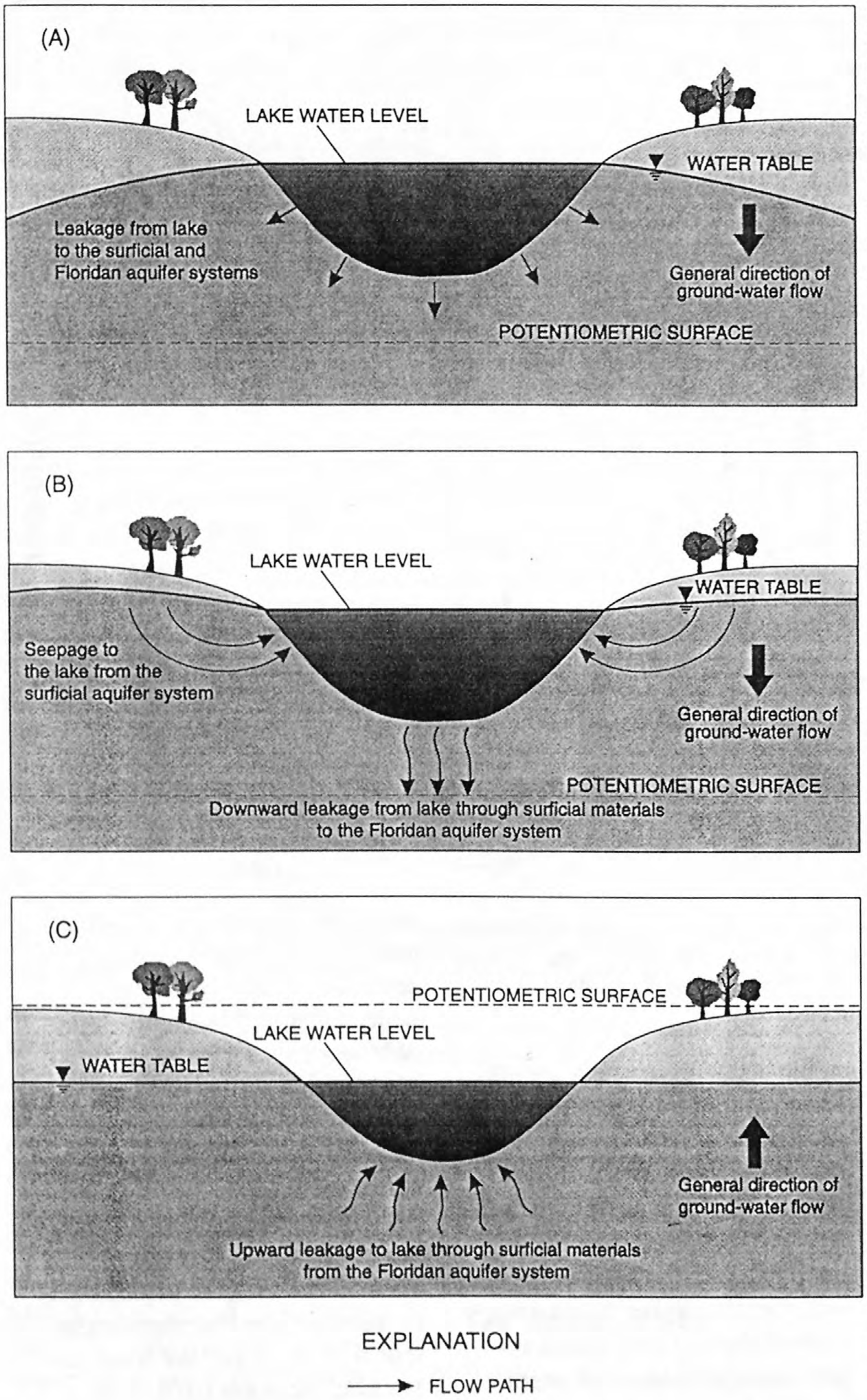


Figure 17. Interactions between ground-water and lake water levels.

upward to the surficial aquifer system or directly to the lake bottom, providing a source of water to the lake. The water moves under pressure by diffuse upward leakage (migrating through the pores of the rock and soil), through fractures, or through a large opening, such as a spring.

Water levels in lakes located in recharge areas generally fluctuate more than levels in lakes in discharge areas (Hughes, 1974b). This may be because a lake in a discharge area receives a fairly constant supply of water from the underlying aquifer, whereas the leakage of water out of a lake in a recharge area is more variable.

Because so many of the lakes in central Florida were formed by solution processes, there is a strong link between lakes and ground water. The illustration in figure 18 of a sinkhole lake in a ground-water recharge area shows some of the pathways of ground-water movement. The lake shown in figure 18 is underlain by sand and organic material from the collapse that formed the lake; these materials provide an avenue for water to move easily from the lake to the underlying Floridan aquifer system. Also shown in figure 18 is the "flow-through" condition that exists in many central Florida lakes. Ground-water flows into the lake along one shoreline and out of the lake along the opposite shoreline, in the direction of the positive hydraulic gradient of the water table of the surficial aquifer system.

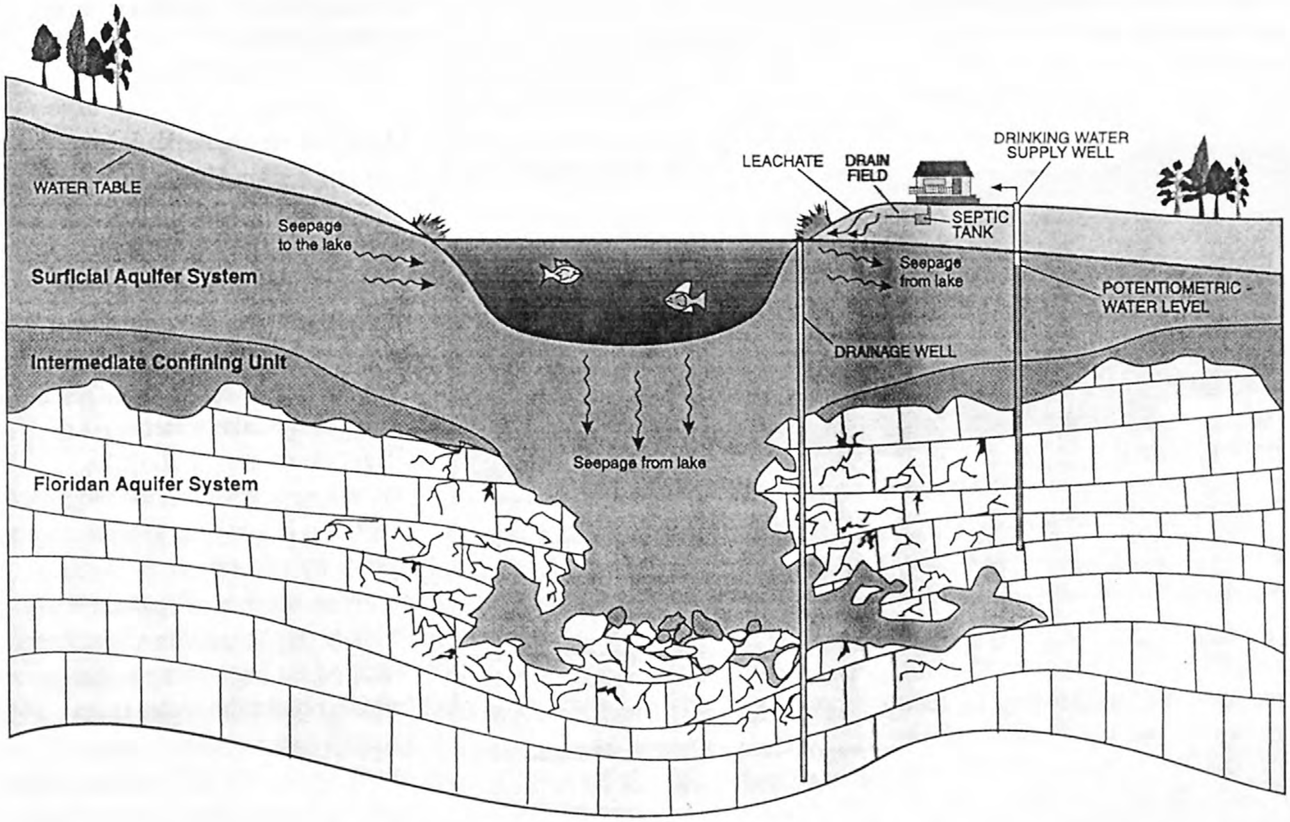


Figure 18. Cross-section through a sinkhole lake showing ground-water flow paths.

The rate and volume of ground-water flow also depends on the permeability of the materials in which the lake exists, and the thickness and characteristics of the intermediate confining unit beneath the lake. For example, ground water moves very slowly through a thick intermediate confining unit, thus slowing the rate and reducing the volume of water entering or leaving the lake. The rate of leakage from a lake increases with increasing permeability of the soil. Lakes with high rates of leakage generally will have greater ranges of water levels than lakes with low rates of leakage (Hughes, 1974b).

A common misconception about lakes in central Florida is that many of them are spring-fed. Many lakes *are* spring-fed, but the origin of the water of the spring is not necessarily the Floridan aquifer system, the same aquifer that supplies the major springs for which Florida is known. Observed springs in lakes commonly are specific locations in the lake bottom where water is entering the lake from the adjacent surficial aquifer. Some lakes are directly connected to the Floridan aquifer system through fractures in the underlying rock or through the remains of the original sinkhole that formed the lake. Such connections provide a path for water from the Floridan aquifer system to enter the lake, and springs of sufficient magnitude to be detected are manifestations of these connections. The cross-sections in figure 19 show the conditions of spring flow from the surficial aquifer system (fig. 19A) and the Floridan aquifer system (fig 19B) to lakes. Examples of lakes that receive spring flow from the Floridan aquifer system are Lake Apopka in Orange County

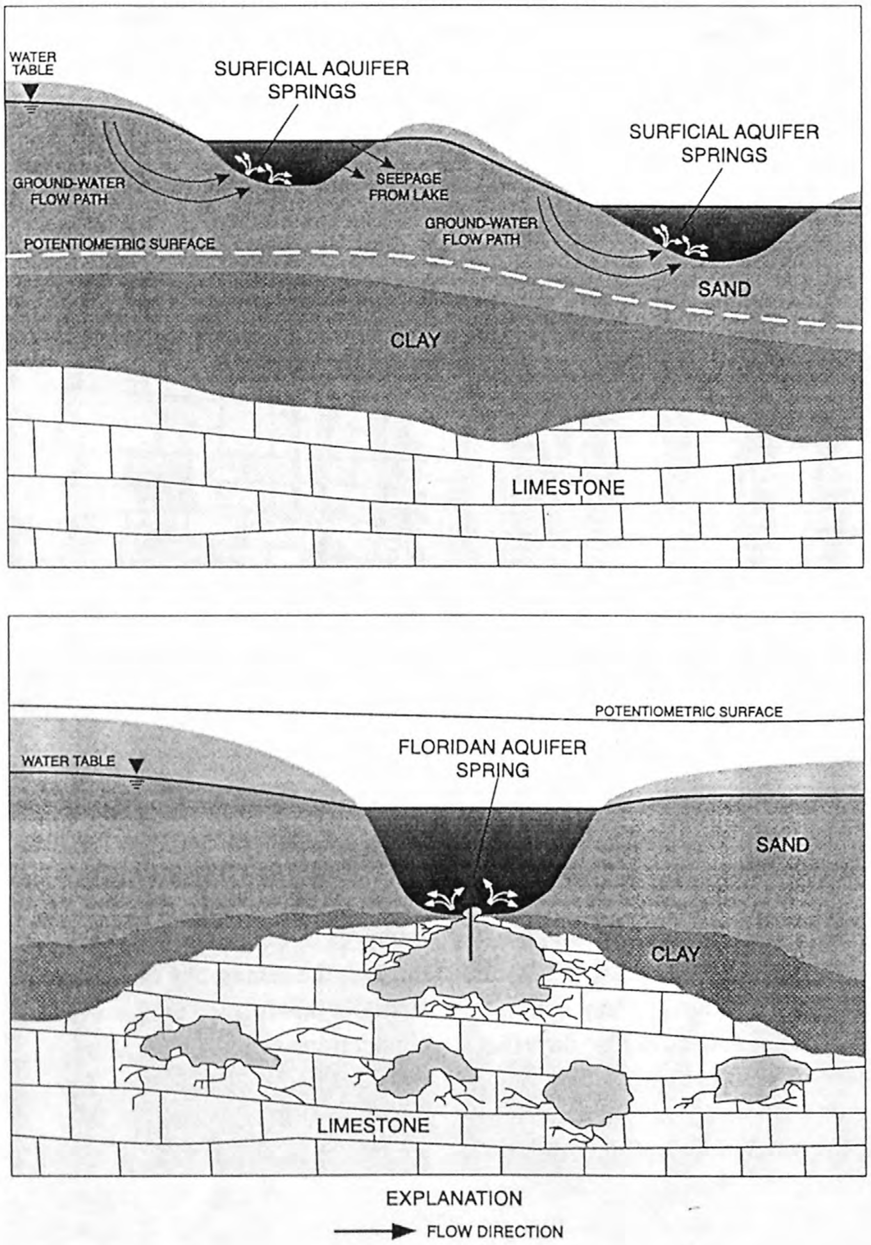


Figure 19. Surficial-aquifer spring flow (A) and Floridan-aquifer spring flow (B) to a lake

(Apopka Spring), and Lake George in northwestern Volusia County (Croaker Hole).

How Human Activities Affect Lake Water Levels

Water levels in lakes are affected by human activities in the drainage basin. The pumping of lake water for lawn irrigation can lower water levels in small lakes. Some of the lake water used for irrigation returns to the lake through ground-water seepage, but most of it is lost to evaporation and uptake by vegetation. Some less-common sources of surface water to lakes might include water from water-to-air heat-pump systems (which obtain the water from ground-water sources), treated sewage effluent (although usually only on larger lakes), or discharge water from agricultural activities. Recent regulations pertaining to discharging of treated wastewater to lakes and streams have led to development and implementation of alternative disposal methods and, in some cases, have reduced or eliminated these inflows to lakes.

Ground-water interactions with lakes also are affected by human activities. For example, one source of ground water to lakes is water (leachate) from drainfields of septic tanks (shown in fig. 18). Other activities cause declines in lake water levels. Water pumped for irrigation or other applications from the surficial aquifer system near a lake reduces the natural seepage to the lake by lowering the water table, which may cause a decrease in lake water level. Pumping water from the Floridan aquifer system in ground-water recharge areas can lower the potentiometric surface of the aquifer, which would increase the hydraulic gradient between the lake water level and the potentiometric surface. This increase would in turn induce more seepage from the lake, thus lowering the lake water level.

Examples of Lake Water-Level Fluctuations

The range of water-level fluctuations can vary significantly among lakes. Water-level fluctuations in landlocked seepage lakes (without artificial water-level controls) generally are greater than water level fluctuations in drainage lakes. To illustrate this, water levels for two lakes are shown in figure 20: one is a seepage lake (Lake Francis, in northwestern Orange County) and the other is a drainage lake with a controlled outlet (Lake Apopka, in Orange and Lake Counties). Although the water levels are at different elevations, the lake levels are shown to the same relative scale. The scale for Lake Francis is shown on the left axis of the graph and the scale for Lake Apopka is shown on the right. The range in water levels for Lake Francis is much greater than the range in water levels for Lake Apopka. Observed water levels in Lake Francis range from about 53 feet (May 25, 1990) to about 66 feet (October, 1960), which represents a range of 13 feet. Observed water levels in Lake Apopka range from about 64 feet above sea level (August 13, 1956) to about 69 feet above sea level (October 12, 1936), which represents a range of water level of 5 feet. Thus, the water level in landlocked Lake Francis has varied by as much as 8 feet more than the water level in Lake Apopka.

Extreme water-level fluctuations in some lakes in Florida have been a matter of great concern among residents. For example, water levels in Brooklyn Lake, located in Clay County in north-central Florida have ranged from 90 feet above sea level (recorded in 1992) to 118 feet above sea level (reported in 1948 by a local resident), a range of 28 feet. In contrast, Sand Hill Lake, about 2.5 miles northeast of Brooklyn Lake, historically has fluctuated through a range of only 3.3 feet (fig. 21). Brooklyn Lake receives surface inflow, but surface outflow

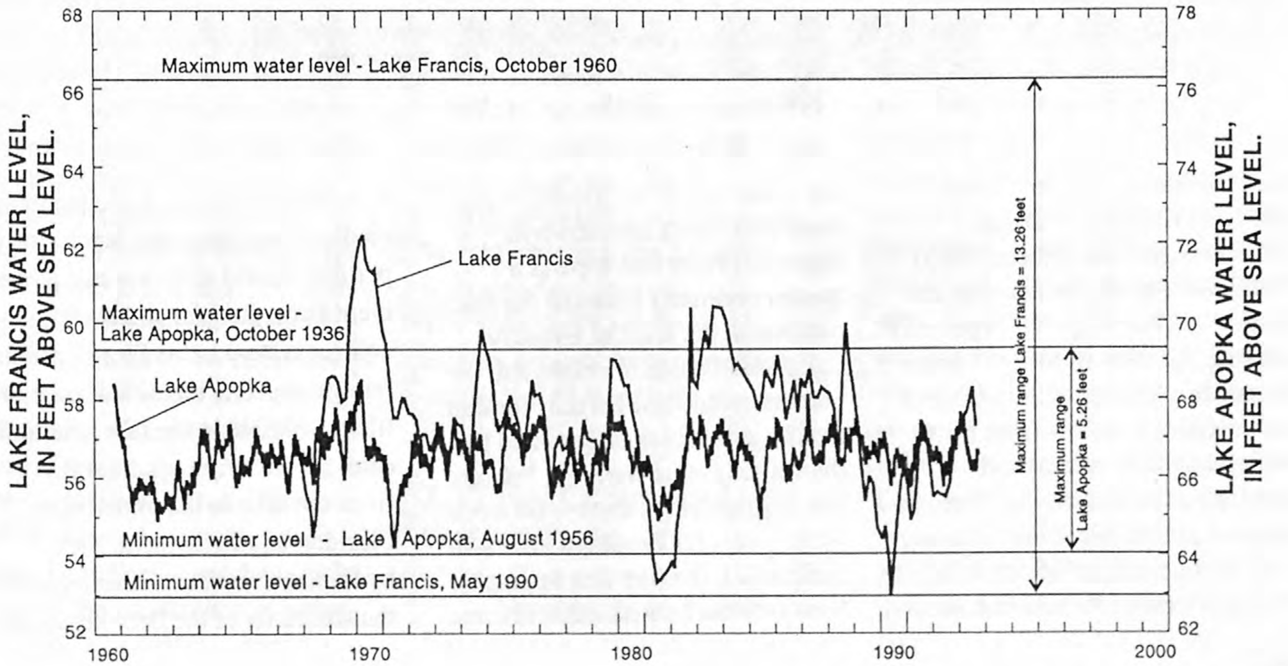


Figure 20. Water-level fluctuations in a drainage lake (Lake Apopka) and a seepage lake (Lake Francis).

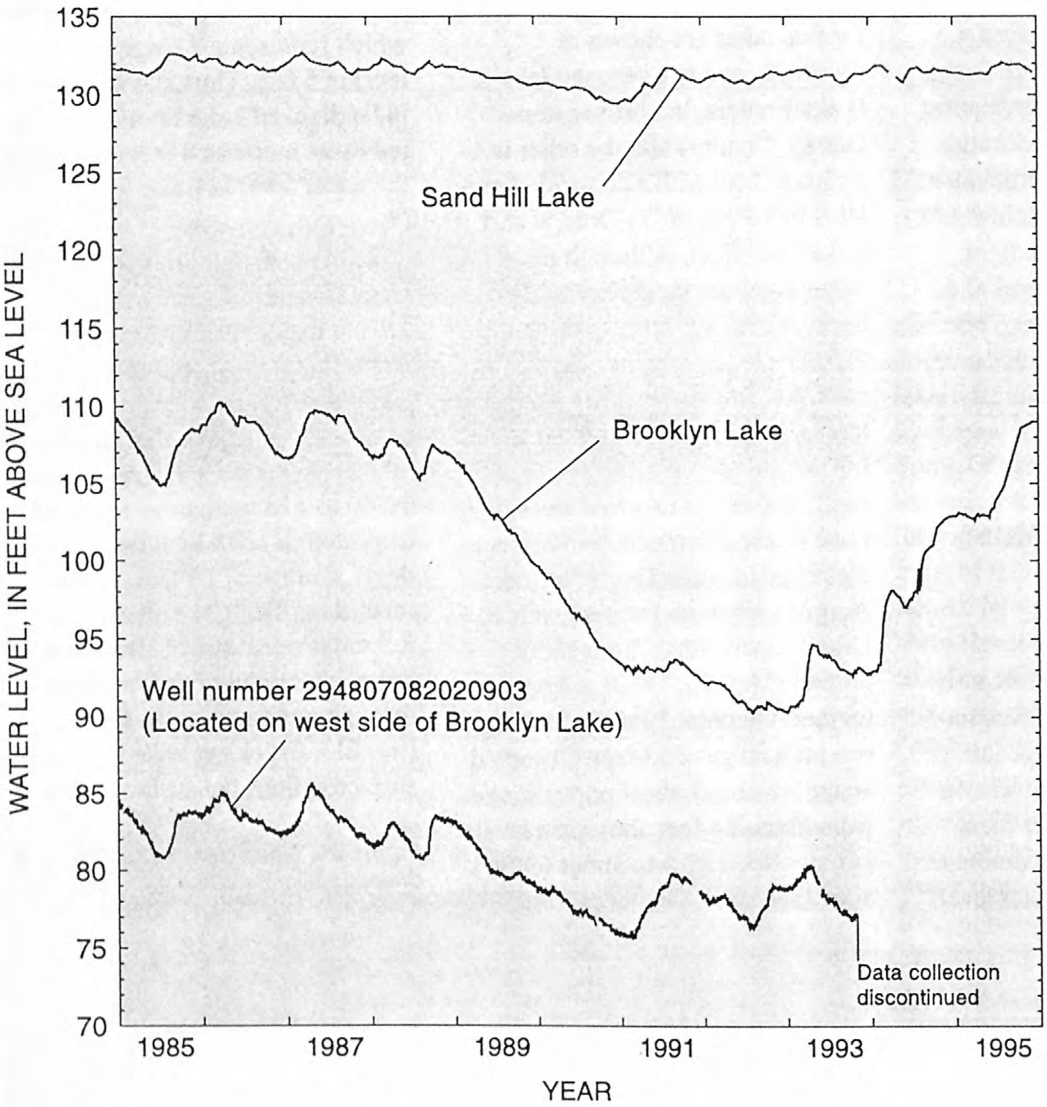
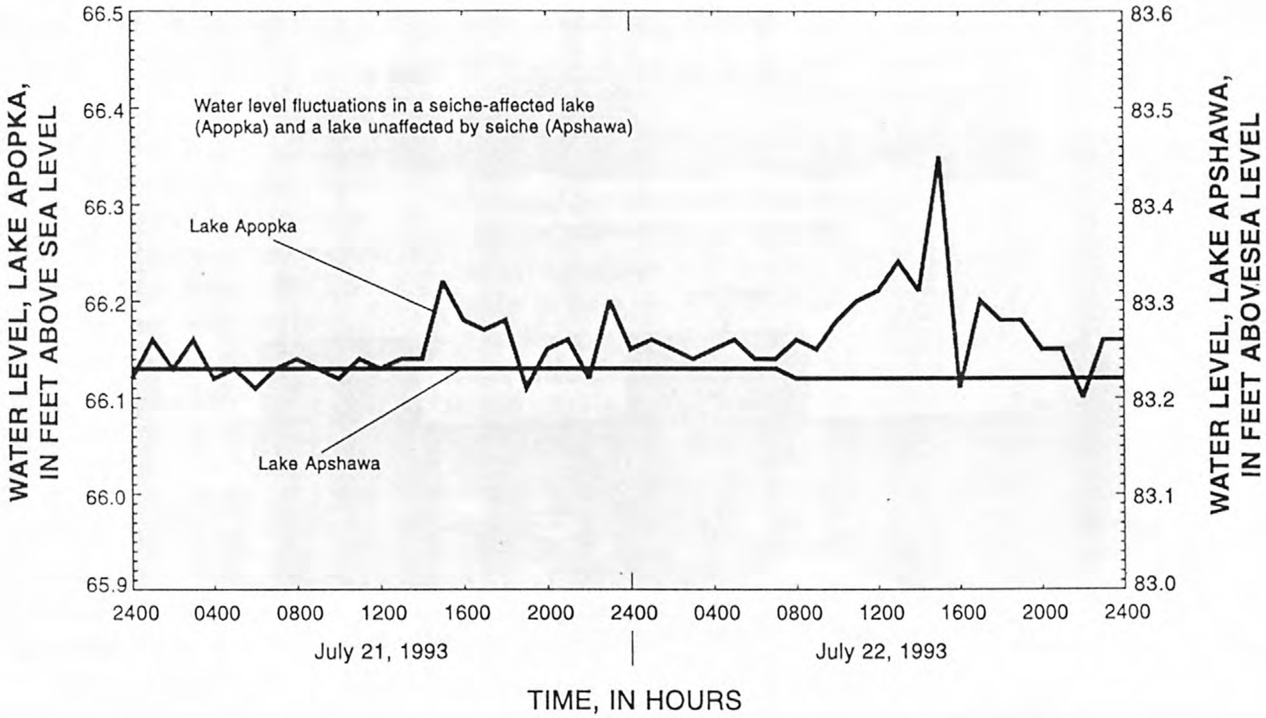


Figure 21. Water level in Sand Hill Lake, Brooklyn Lake, and in a well near Brooklyn Lake.

from the lake occurs only when the lake level rises above about 115 feet (Clark and others, 1963). Thus, water-level fluctuations are similar to what might be expected in a seepage lake. Brooklyn Lake is located in a ground-water recharge area, receiving inflow from the surficial aquifer system and recharging the underlying Floridan aquifer system. Water levels during a 10-year period (1985-95) in a well just west of Brooklyn Lake and water levels for Brooklyn and Sand Hill Lakes are shown in figure 21. Note that there is a greater similarity between the fluctuations in the level of Brooklyn Lake (middle line in graph) and the potentiometric level of the Floridan aquifer system (as represented by the water level in the well, bottom line in graph) than there is between water levels for Brooklyn Lake and Sand Hill Lake (top line in graph). Research has indicated that in some areas near Brooklyn Lake the intermediate confining unit is relatively permeable and allows water movement from the lake and surficial aquifer system to the Floridan aquifer system. The identification of a filled sinkhole in the lake also indicates a path of preferential flow from the lake to the underlying Floridan aquifer system. This hydraulic connection is reflected in the similarity of the Brooklyn Lake



water levels and ground-water levels shown (fig. 21).

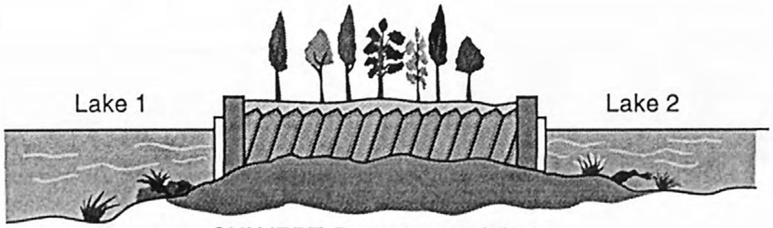
Lake water levels may fluctuate because of the effect of wind on the water surface and sometimes because of tidal effects. ***Seiche*** is a term applied to a wave that oscillates in a water body, causing periodic water-level fluctuations that can vary in time from a few minutes to several hours. Seiche is caused by seismic or atmospheric disturbances and is aided by wind and tidal currents. The effect of seiche is related to the physical dimensions of a lake (surface area and depth); large lakes will exhibit more of the effects of seiche than will small lakes, and shallow lakes will be affected more than deep lakes. The effect of seiche is indicated by the oscillations in water levels in Lake Apopka during a

Figure 22. Water levels in Lake Apopka and Lake Apshawa illustrating the effect of seiche on water levels.

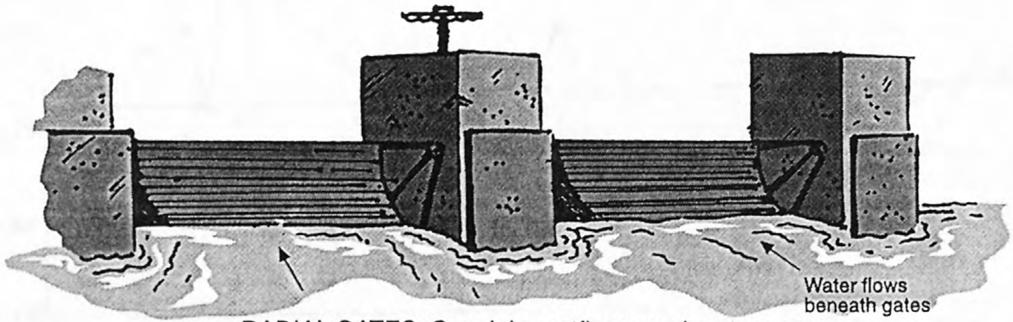
48-hour period (fig. 22). Lake levels for the same time period are shown for Lake Apshawa, which is near Lake Apopka and thus subject to similar wind patterns. Lake Apopka has a surface area of 30,630 acres (47.9 square miles). Water levels in Lake Apshawa, with a surface area of only 110 acres (0.17 square mile), indicate no noticeable seiche effect during the 48-hour period.

Artificial Control of Lake Water Levels

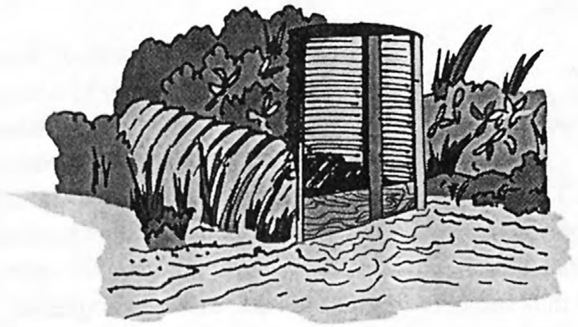
Water levels in drainage lakes may be artificially controlled by increasing the volume of water entering or leaving the lake through the use of control structures, which can be fixed or adjustable. Water levels in some lakes are artificially maintained at higher than normal levels by pumping ground water into the lake. Some examples of fixed control structures include canals, dams, and drainage pipes (culverts). These fixed controls can be made adjustable by the addition of devices that can be raised or lowered. Examples of devices used to artificially control lake water levels are shown in figure 23. A culvert connects two lakes (fig. 23A) and allows water to flow in either direction until the levels of the two lakes are equal. Canals can be fitted with gates that can be adjusted to allow more or less flow out of (or into) a lake, which in turn affects the lake



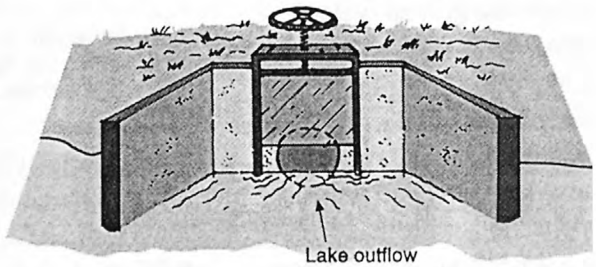
(A) CULVERT: Between two lakes, helps to equilibrate water levels



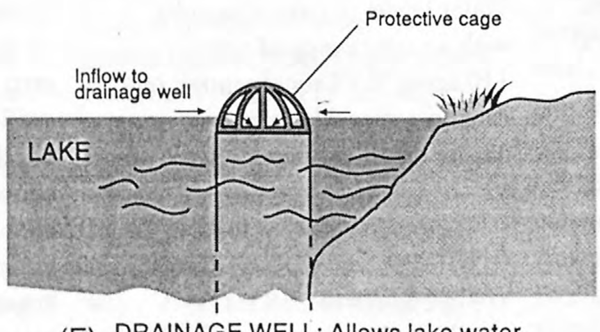
(B) RADIAL GATES: On a lake-outflow canal, gates can be opened to release water and lower lake water level



(C) CULVERT RISER: Wooden boards (also called stop logs) can be added or removed to control lake water level.



(D) GATE CONTROL ON CULVERT: Gate can be raised or lowered to control lake water level



(E) DRAINAGE WELL: Allows lake water to drain directly to the aquifer

Figure 23. (At left) Examples of lake water-level control devices

water level. Radial gates, shown in figure 23B, are used in many canals and can be set at a fixed opening size to allow only a certain amount of water to flow beneath the lower edge of the gate. A culvert riser is a way of controlling inflow or outflow to or from a culvert using boards, or stop-logs which are removed or added to control flow (fig. 23C). A screw-type gate on a culvert (fig. 23D) can be adjusted to regulate the volume of water flowing into or out of a lake (depending on the flow direction).

Lake drainage wells (fig. 23E), which allow lake water to flow directly into the aquifer (usually the Floridan aquifer system), have been used to control lake water levels in central Florida, particularly in the Orlando area, since 1904. The volume of water that can leave a lake through a drainage well is primarily a function of the diameter of the well; debris is prevented from entering the well by a protective cage over the top of the well. If the drainage-well structure is not regularly maintained by removing debris from the protective cage, the buildup of debris causes a restriction in flow, resulting in higher lake water levels. Drainage wells, used primarily on seepage lakes, significantly affect lake water levels and reduce the risk of flooding by providing rapid drainage. However, the direct connection between lake water and water in the Floridan aquifer system increases the risk of contaminating the aquifer. A drainage well on a seepage lake performs the same function that a surface outlet performs on a drainage lake. Thus, the range of water-level fluctuations in a seepage lake that has a drainage well may be similar to those of a drainage lake.

The range of water-level fluctuations in artificially controlled lakes tends to be smaller than the range of levels in "uncontrolled" lakes. Many of these controls were built in the past when it was considered desirable to control lake levels for aesthetic reasons and for flood control. In more recent years, however, the negative effects on water quality caused by minimizing the natural rise and fall of lake water levels has been recognized, and greater variation in water levels is now allowed in controlled lakes because of the recognized benefits to lake flora and fauna.

QUALITY OF WATER IN CENTRAL FLORIDA LAKES

The basic characteristics of lake water quality include the physical, chemical, and biological characteristics of a lake. Lake water quality is complex, and the diversity of plants and animals that can be supported in a lake is closely related to the relative amounts of individual chemical constituents in the water. Relative concentrations of selected chemical constituents can be indicators of the source of the water to the lake, because of differences in the chemistry of water from these sources. As an example, water from the Floridan aquifer system is higher in concentrations of calcium and bicarbonate ions than water from the surficial aquifer system or surface waters.

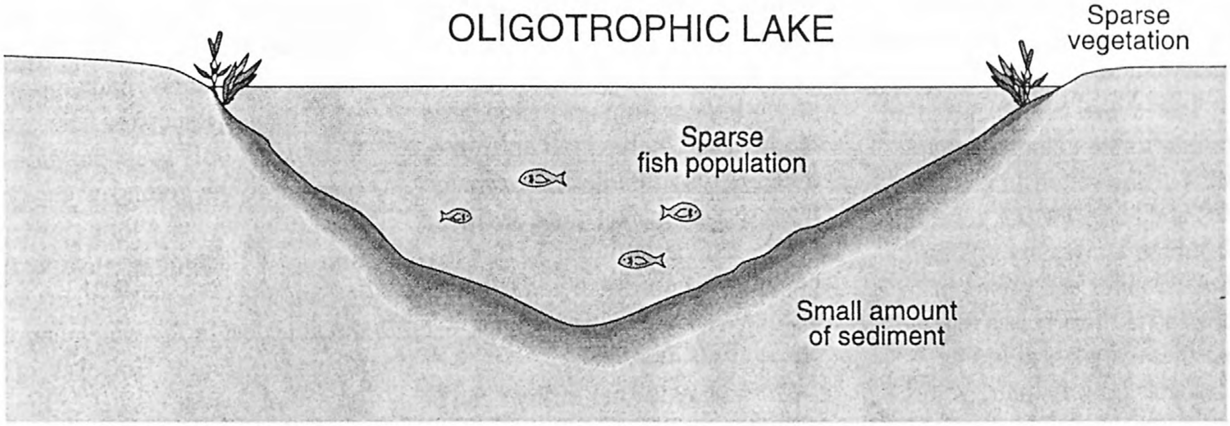
How "good" the quality of water in a lake is depends on who is asking the question! What is the intended use of the water? Is it "good enough" for one use, but not for another? A lake that contains a large number of aquatic plants and supports a large fish population may "look" unappealing to some for swimming or water-skiing, but a lake that is attractive for swimming, with low nutrient (nitrogen and phosphorus) concentrations, clear water, and a sandy bottom free of aquatic plants, will be of little use to someone who wants to catch fish. The quality of water sometimes is judged on the basis of its clarity—a strictly subjective opinion, based on an individual's perception of the clarity of the lake water. The quality of water in lakes is affected by many factors, including the sources of water to the lake, the quality and quantity of water from these sources, the length of time a volume of water remains in the lake (residence time), rainfall and runoff amount and quality, time of year, depth of the lake, and the type and amount of plants and animals in the lake.

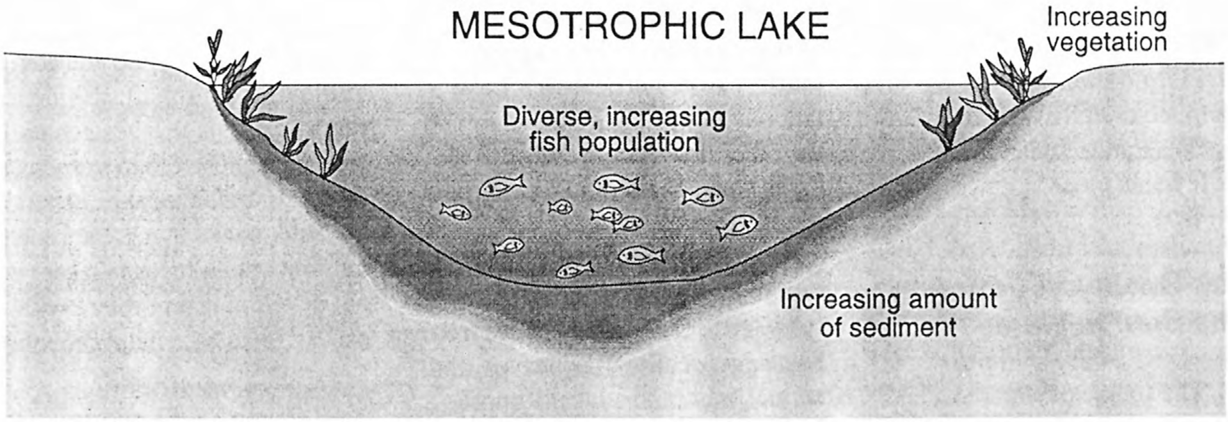
Lake Water-Quality Classification Systems

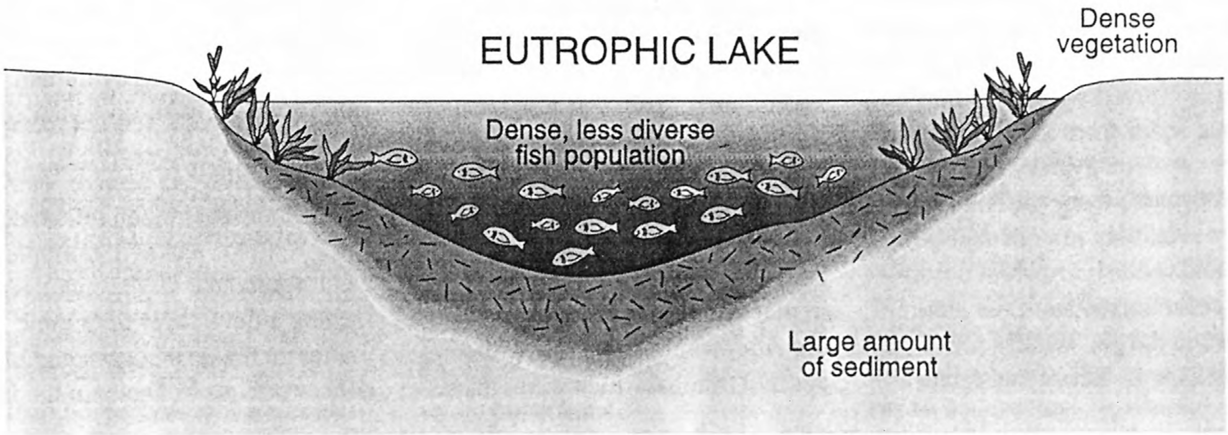
Scientists have devised different classification schemes to define the quality of lakes relative to one another. A common method of classifying lakes is by the trophic state of the lake. The trophic state refers to the degree or amount of enrichment (eutrophication) of the lake with nutrients in the water. Lakes can be classified as oligotrophic, mesotrophic, or eutrophic (fig. 24). ***Oligotrophic*** lakes have very low levels of nutrients, very little organic material along the lake bottom, and high levels of dissolved oxygen near the bottom. ***Mesotrophic*** lakes are moderately enriched and the natural processes of accumulation of sediments and growth of aquatic vegetation are occurring. ***Eutrophic*** lakes are highly enriched with nutrients, have an accumulation of organic sediments, and low levels of dissolved oxygen in water near the lake bottom. Eutrophic lakes typically have high concentrations of algae or aquatic vegetation, and also differ from oligotrophic and mesotrophic lakes in the type of vegetation and animal life which can exist in the lake. The trophic state also is a measure of the productivity of a lake; lakes that are enriched are more "productive" in that they have large populations of aquatic plants and animals, though the diversity of the organisms may be low. Low-productivity (oligotrophic) lakes have much smaller, but more diverse, populations of flora and fauna than mesotrophic or eutrophic lakes. However, many species of fish and other aquatic animals cannot tolerate the conditions that exist in eutrophic lakes, where large fluctuations in concentrations of dissolved oxygen are common. Thus, there may be more fish in a eutrophic lake than in an oligotrophic lake, but far fewer species can survive in the eutrophic lake.

All lakes eventually become eutrophic as a part of the aging process. Although the process is natural, many factors can accelerate the process, including human influences. A newly formed, "young" lake will be oligotrophic. With time, sediments continue to enter the lake, plant and animal populations become established, and the chemistry of the water gradually changes to that of a mesotrophic lake. As the lake continues to age,

Figure 24. (At right): Examples of an oligotrophic, mesotrophic, and eutrophic lake.


OLIGOTROPHIC LAKE
Sparse vegetation
Sparse fish population
Small amount of sediment


MESOTROPHIC LAKE
Increasing vegetation
Diverse, increasing fish population
Increasing amount of sediment


EUTROPHIC LAKE
Dense vegetation
Dense, less diverse fish population
Large amount of sediment

or eutrophy, it gradually becomes a marsh and, eventually, an open field (as described in the section on physical characteristics of lakes).

Lakes also can be classified according to the chemical characteristics of the water. In the late 1960's and early 1970's, researchers from the University of Florida studied 55 lakes and ponds in north-central Florida and determined that the lakes could be divided into four distinct groups based on the following physical characteristics: alkalinity, specific conductance, color, and calcium concentration (Shannon and Brezonik, 1972). The four groups into which these 55 lakes in north-central Florida were placed are (1) acid, colored; (2) alkaline, colored; (3) alkaline, clear; and (4) soft water, clear.

Water Quality: A Function of the Source Water

The source of water to a lake can sometimes be determined from the chemical characteristics of the water. For example, lakes that receive water from surface-water sources or from the surficial aquifer system generally have low concentrations of dissolved solids when compared with lakes that receive water from the Floridan aquifer system. Water in lakes that receive runoff from wetlands may have a relatively low pH and be dark and reddish brown in color. This color comes from the natural tannins in the plants and soils of the wetland areas. Lakes that receive most of their water from ground-water sources and rainfall (seepage lakes) generally have little color. Seepage lakes are affected by ground-water seepage to and from the lake and by the land use immediately around the lake. Leachate from septic tank systems, fertilized lawns, and agricultural lands can potentially contribute additional nutrients such as nitrogen and phosphorus to the lake.

Surface-water inflows can be a significant source of water-quality problems to lakes. Water entering a drainage lake from a contributing stream can carry with it nutrients and pesticides from upstream sources. For example, outflow from nutrient-rich Lake Apopka enters Lake Beauclair and the other downstream lakes in the Ocklawaha chain of lakes. Surface runoff from streets can carry grease and oils from automobiles. Surface runoff from residential areas can carry fertilizers and pesticides from lawns, grass clippings, leaves, and animal wastes to a lake. Runoff from industrial areas may contain residual amounts of chemicals used for cleaning or degreasers that are washed into storm sewers.

How much the water from these various sources affects water quality in a lake is a function of several factors. One important factor that has a direct effect on the response of the lake to the addition of nutrients is the ***residence time*** of the nutrient-enriched water in the lake. Another term sometimes used in place of residence time is ***flushing rate***, which is the rate (volume per unit time) at which water leaves a lake, either through a surface-water outlet or through ground-water seepage. For a drainage lake, the flushing rate is much more rapid than in a seepage lake, which loses water only to evaporation and seepage to the ground-water system. If a lake has a long residence time (low flushing rate), more time is available for aquatic plants to use the nutrients in the water, and the plants proliferate. However, in a lake with a short residence time (high flushing rate), the nutrients are not in the water long enough for plant uptake. Seepage lakes tend to have long residence times and are more likely to be affected (than drainage lakes) by the addition of nutrients from runoff. Residence times in drainage lakes generally are much shorter than in seepage lakes, so drainage lakes generally are able to take in a greater load of nutrients (than seepage lakes) without developing a problem with excessive aquatic plant growth.

Water-Quality Problems

Central Florida lakes are subject to many influences, both natural and manmade. Although eutrophication is a natural process, it can be accelerated by human activities. One well-documented example of a lake in which eutrophication has been accelerated because of human influence is Lake Apopka, a classic example of a eutrophic lake that is characterized by a thick layer of organic matter on the lake bottom and high concentrations of algae. In the late

1800's, Lake Apopka was the second largest lake in Florida and supported a large population of bass. Beginning at the turn of the 20th century, dikes were built along the north shore of the lake and the part of the lake behind the dike was drained so that the rich organic soils of the lake bottom could be used for farming. This reduced the size of the lake, so that it is now only the fourth largest lake in the State. Nutrients from farms and citrus groves washed into the lake, and sewage effluent was discharged into the lake for many years. The lake was used for recreation including bass fishing competitions up to the 1940's, when a hurricane uprooted much of the vegetation in the lake, which further upset the natural balance of the lake and degraded the quality of the water. The uprooting of the vegetation, in combination with the added nutrients, contributed to the rapid decline of lake water quality.

Aquatic vegetation is necessary for the health of a lake, but some types of vegetation are desirable whereas others are considered nuisance plants. Shoreline plants provide habitat for water fowl and other animals and are considered beneficial because they remove nutrients from the water, thereby decreasing the nutrients available for algae growth. Aquatic vegetation, whether along the shore or further in the lake, contributes to the clarity of lake water. However, generally more than half of the lake bottom must have aquatic vegetation in order to cause the water to be clearer or to maintain water clarity (Canfield, 1992). However, this level of aquatic vegetation often is considered a nuisance level.

One aquatic plant that has created problems in Florida lakes and streams is the water hyacinth, a plant brought from Brazil to the United States in the late 1800's (Brenner and others, 1990, p. 382). Hyacinths float on the water surface and prevent light from penetrating through to the lake bottom. This in turn causes the decline of rooted aquatic vegetation on the lake bottom, which changes the vegetative characteristics of the lake and alters the natural balance of plant and animal life. Water hyacinths grow prolifically and affect the use of lakes for fishing and recreational purposes. Hydrilla is another aquatic plant, introduced through the aquarium trade in the early 1960's (Brenner and others, 1990, p. 382), that has spread to many Florida lakes. Hydrilla also can choke out native plant species and affect lake water quality.

Acid rain may affect lake water quality. Most of Florida's lakes have soft water (Shannon and Brezonik, 1972) and are poorly buffered (pH of the water is easily affected by changes in water chemistry), thus these lakes are more susceptible to the effects of acid rainfall. However, many Florida lakes are naturally acidic, and species of plants and animals in the lakes are naturally tolerant of more acidic conditions.

Water-Quality Solutions

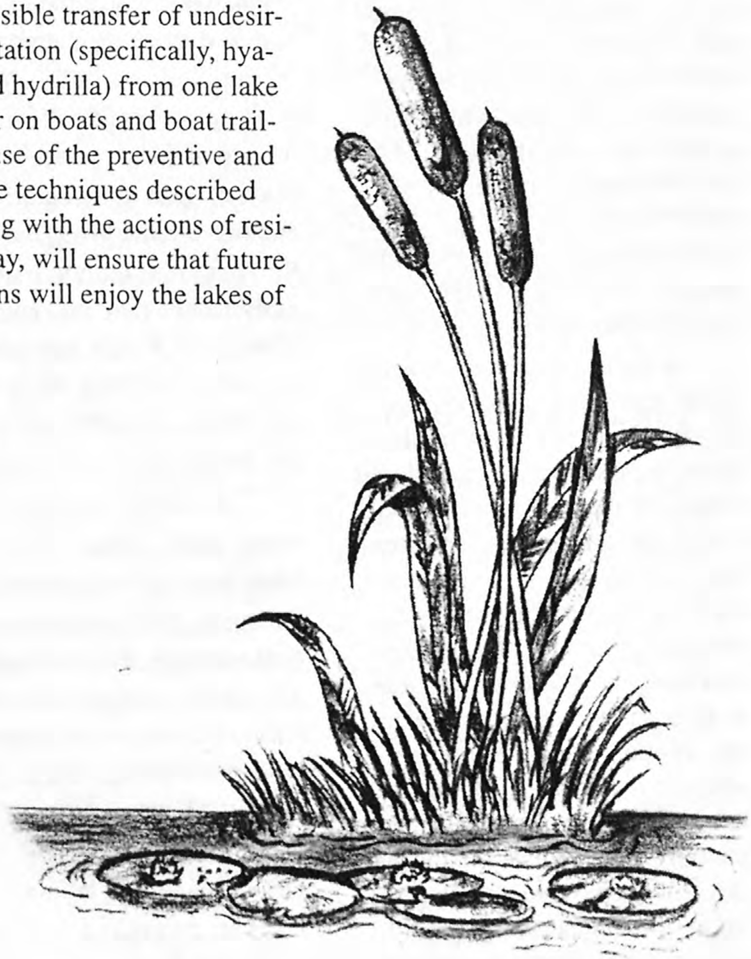
Techniques for solving lake water-quality problems are numerous, but never easy, because lakes are complex systems. The most common method of improving lake water quality is through the application of Best Management Practices, or BMPs, which include the following: aeration, pretreatment by detention of stormwater prior to its entering a lake, addition of alum, and more exotic techniques such as addition of Asiatic grass carp to the lake (Brenner and others, 1990, p. 383). Many BMPs are useful for all lakes, regardless of the lake water quality, to help prevent or delay water-quality problems. Some of the BMPs are preventive measures whereas others are more restorative in nature. Other methods of lake restoration include dredging and lake-level drawdown. These preventive and restorative methods are discussed briefly below.

Aeration of lake water adds oxygen to the water and aids in the mixing and distribution of the oxygen in the water. This helps prevent fish kills that result from low concentrations of oxygen. Other potential benefits of aeration include control of algal blooms and general improvement of the condition of the bottom sediments, which can be highly organic and anaerobic (without oxygen) in eutrophic lakes. Phosphorus is more soluble in water with low oxygen concentrations. The addition of oxygen through aeration causes phosphorus to be less mobile, which helps to keep the lake from becoming weed-choked or algal-rich. The addition of oxygen to the water provides a better environment for aquatic plants and animals, and the mixing that occurs during aeration helps distribute the oxygen through the water column.

Another common method of preventing water-quality degradation in lakes is the detention of stormwater prior to its entering the lake. Stormwater is known to be a source of contaminants and nutrients to lakes. By detaining the incoming stormwater, sediments and debris carried by the water can settle, improving the condition of the water before it enters the lake. Alum, a chemical compound with a high affinity for absorbing other chemicals, has been added to water in detention basins to remove nutrients from the water prior to release of the water to the lake. However, the alum and absorbed material eventually must be removed after it has settled and accumulated in the detention basin or lake bottom.

A more exotic method of lake restoration is the addition of specific species of fish known for their capacity to consume algae and aquatic plants. The Asiatic grass carp has been used successfully in certain central Florida lakes to control aquatic vegetation (Canfield and others, 1983).

The most effective way to protect the quality of water in lakes is through education and prevention of problems before they occur. All of Florida's residents can help protect lakes by being aware of what they do that affects lakes. People living on lakefront property can improve water quality by leaving aquatic vegetation along the shoreline. Removing the vegetation to create beaches interferes with the natural uptake of nutrients from the water by shoreline plants, and eliminates habitats for aquatic life. Another way in which Florida residents can help prevent water-quality problems in neighborhood lakes is by reducing the amount of fertilizer applied to lawns and landscape plants to that which is required for proper growth, so that excess fertilizer will not wash into lakes and streams. Boaters can help improve lake water quality by being aware of the possible transfer of undesirable vegetation (specifically, hyacinths and hydrilla) from one lake to another on boats and boat trailers. The use of the preventive and restorative techniques described here, along with the actions of residents today, will ensure that future generations will enjoy the lakes of Florida.



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