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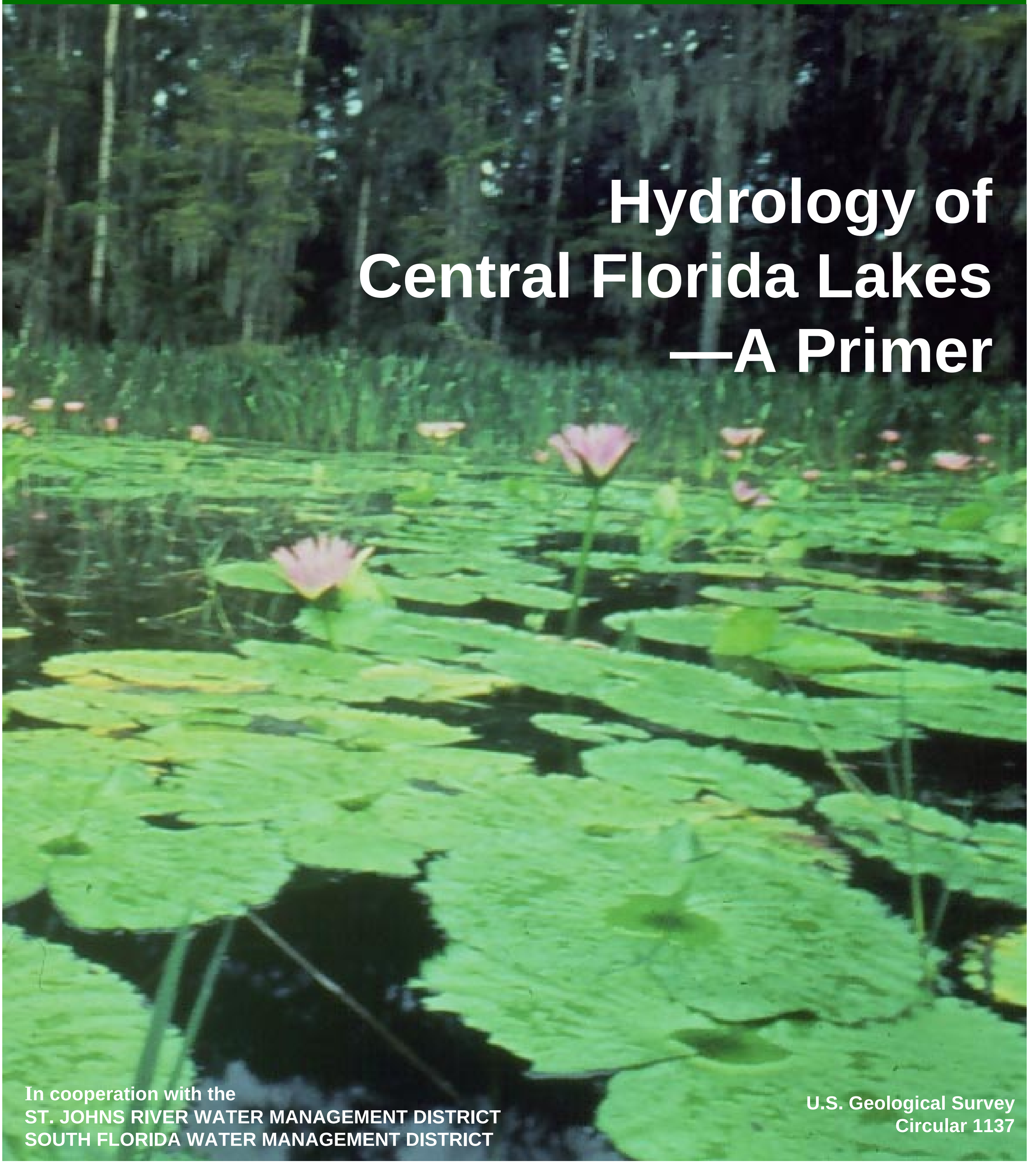
Hydrology of Central Florida Lakes —A Primer



In cooperation with the
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SOUTH FLORIDA WATER MANAGEMENT DISTRICT

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GLOSSARY

Alkalinity: 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 which ground water in a well rises above the top of the water-bearing formation that is tapped by the well.

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 outlet.

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 below the land surface in the zone of saturation.

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 then, 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 the water at any given point in a body of water at rest.

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: The branch of hydrology pertaining to the study of lakes.

Overburden: The loose soils, sand, gravel, or other unconsolidated materials overlying a rock stratum.

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 acidic 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: An imaginary surface that represents the height to which water will rise in a tightly cased well.

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-water 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 property of water to conduct a current of electricity. Specific conductance is commonly used as an indicator of the dissolved solids content of water.

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: The zone between land surface and the water table where the pores in the soil matrix are filled with air and water.

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

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

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

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 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 and the South Florida Water Management District. 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 (fig. 1) and 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. 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,

Many lakes in central Florida are used for recreation. (Photograph provided by St. Johns River Water Management District.)

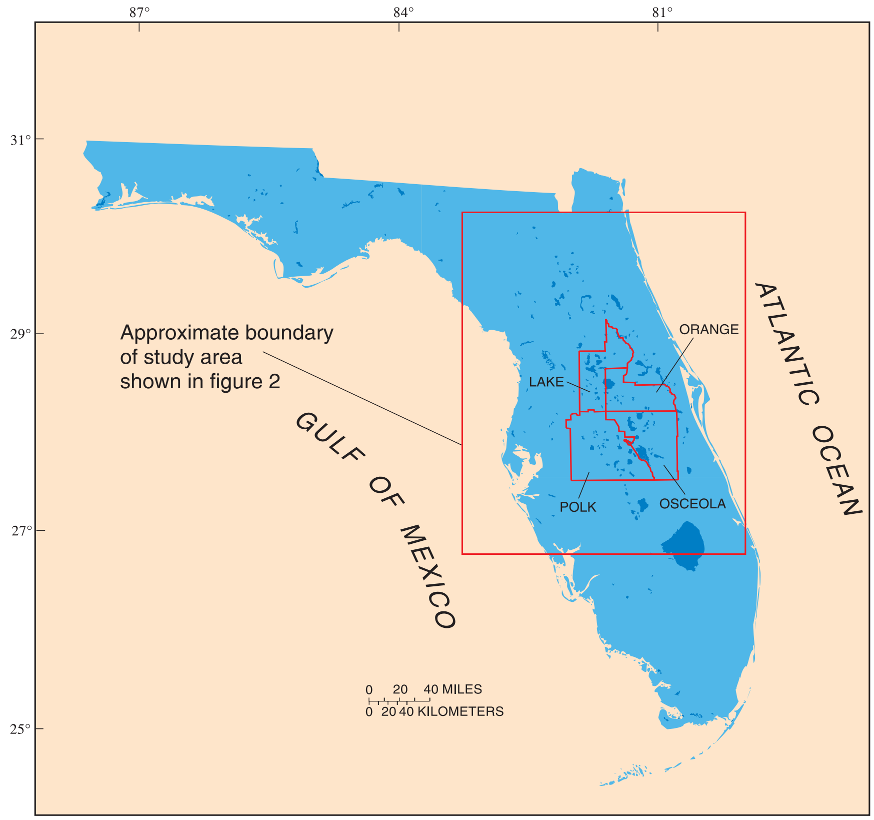


Figure 1. *Approximate geographic area covered by this report and distribution of lakes (dark blue) in Florida. Outlined counties contain 35 percent of the lakes in Florida.*

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 are defined in the glossary.

The classification of some water bodies as lakes is highly subjective. 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 saw grasses to cypress trees.

Lakes may be naturally formed or manmade; however, the distinction between naturally formed and manmade lakes is not always 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.

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, eagles, ducks, and herons. Because Florida lakes are used and enjoyed by many, they need to be appreciated, understood, and managed for the benefit of all.

Alligators are common in Florida lakes, although their population varies from one lake to the next. (Photograph provided by South Florida Water Management District.)

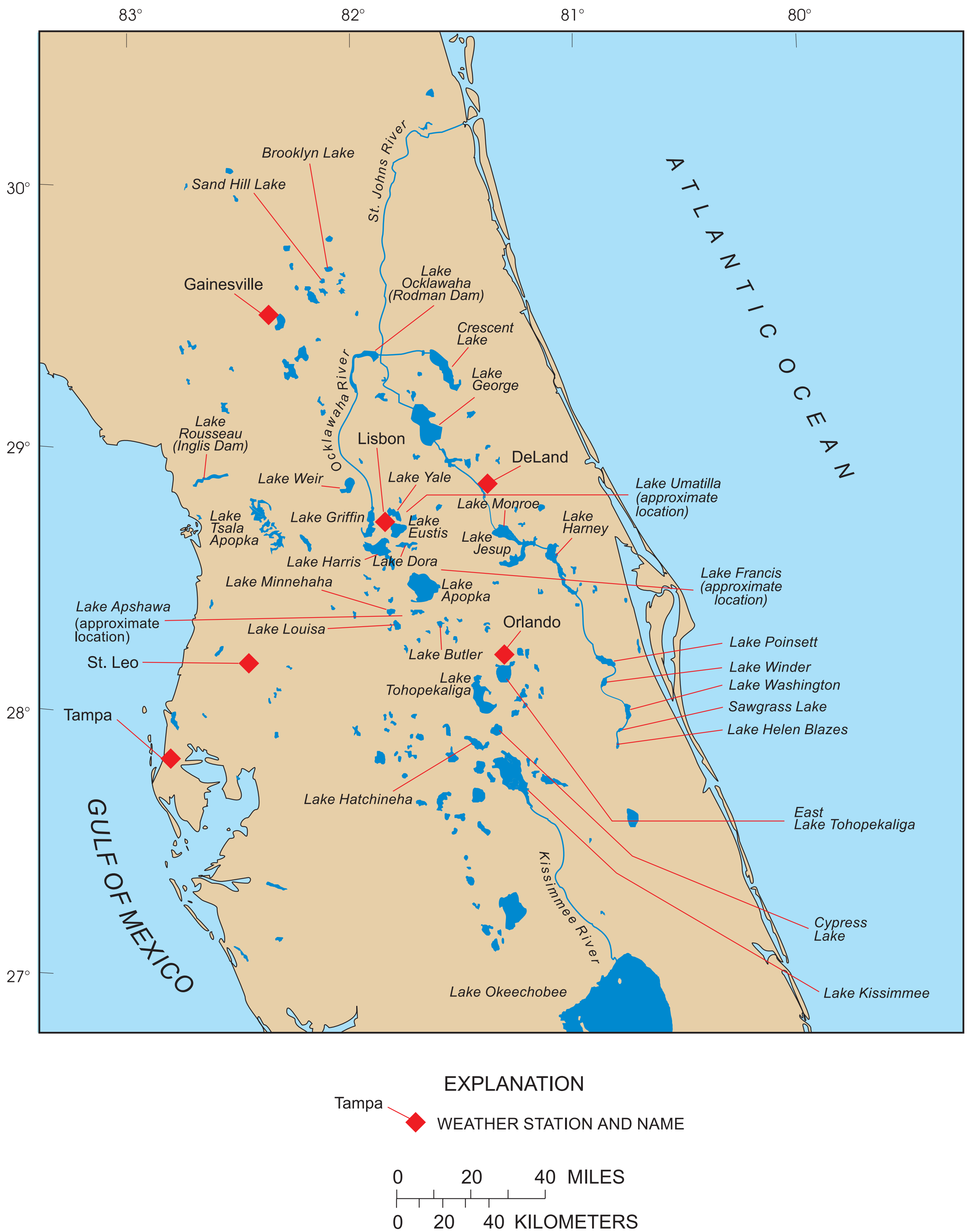


Figure 2. *Lakes and weather stations in this report.*

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, 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 land-locked, 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.

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 commonly are classified by geologists according to the physiographic region in which the lakes are located. Many lakes in Florida were formed by sinkhole activity and thus 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 of and visitors to central Florida have added their own classification system by describing a particular lake as a good fishing or water-skiing lake.

Lakes in Florida and elsewhere commonly are classified by drainage characteristics; it is these characteristics that differentiate Florida lakes from lakes in other parts of the country. This general classification divides lakes into one of two major types—seepage and drainage lakes. Although there are many other hydrologic characteristics associated with each type (fig. 3), perhaps the most easily

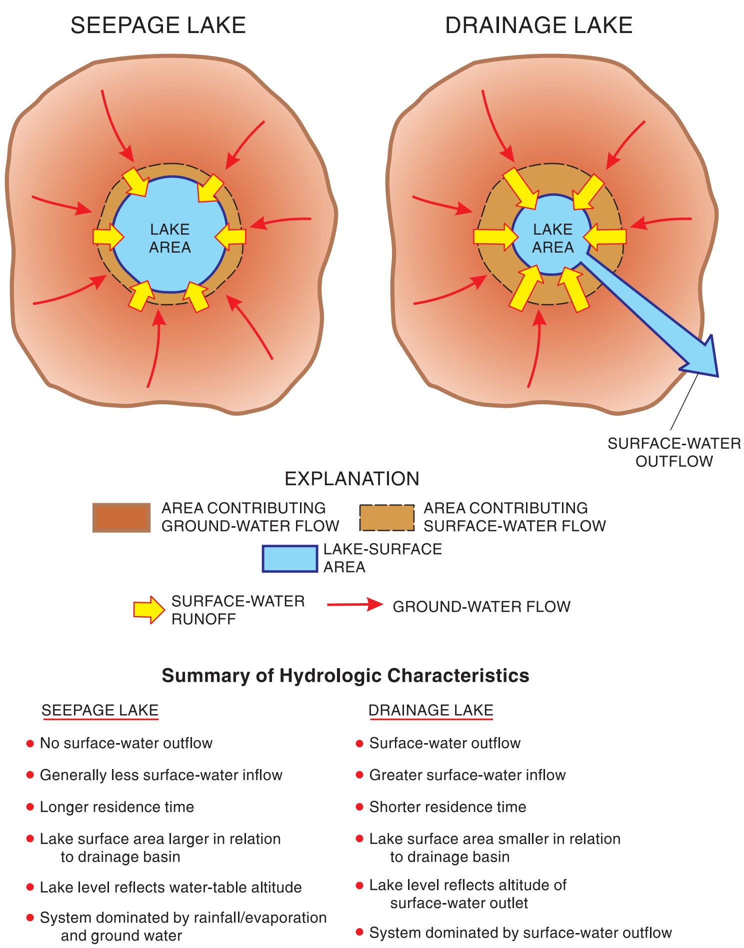


Figure 3. *Hydrologic characteristics of seepage and drainage lakes.*

recognized property used to distinguish between seepage and drainage lakes is the absence or presence (respectively) of surface-water outflow. Lakes that have no surface-water outflow lose water primarily through the ground-water system or through evapotranspiration and are called ***seepage lakes***. Lakes that lose water primarily through a surface-water outlet are called ***drainage lakes*** (Wetzel, 1975). Most Florida lakes are seepage lakes—nearly 70 percent of the lakes in Florida have no surface-water streams flowing into or out of them (Palmer, 1984). The drainage basin of a seepage lake commonly is referred to as a closed basin because of the lack of surface-water outflow from the basin; however, there is outflow from the basin through ground-water seepage. The drainage basins of drainage lakes are commonly referred to as open-drainage basins.

Florida has numerous wading birds that make use of the many lakes here. (Photographs provided by South Florida Water Management District.)

The dominance of ground-water flow over surface-water flow in much of Florida makes the hydrology of lakes here different from that of lakes in other parts of the country. The well-drained porous soils and rocks that are characteristic of the karst landscape of Florida are what make this difference. One difference between Florida lake hydrology and that of other parts of the country is expressed in the classical definition of a drainage basin. A drainage basin or watershed (the area contributing water) of a lake commonly refers to the land surface area draining to a water body as defined by topography. However, because most of the inflow to seepage lakes in Florida is from ground water, the ground-water basin must be considered part of the contributing drainage basin. Ultimately, however, the most significant difference between seepage and drainage lakes is not the source of the water, but the controlling factors affecting lake water volume (ground-water or surface-water outflows).

Most Florida lakes are seepage lakes—nearly 70 percent of the lakes in Florida have no surface-water streams flowing into or out of them.

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

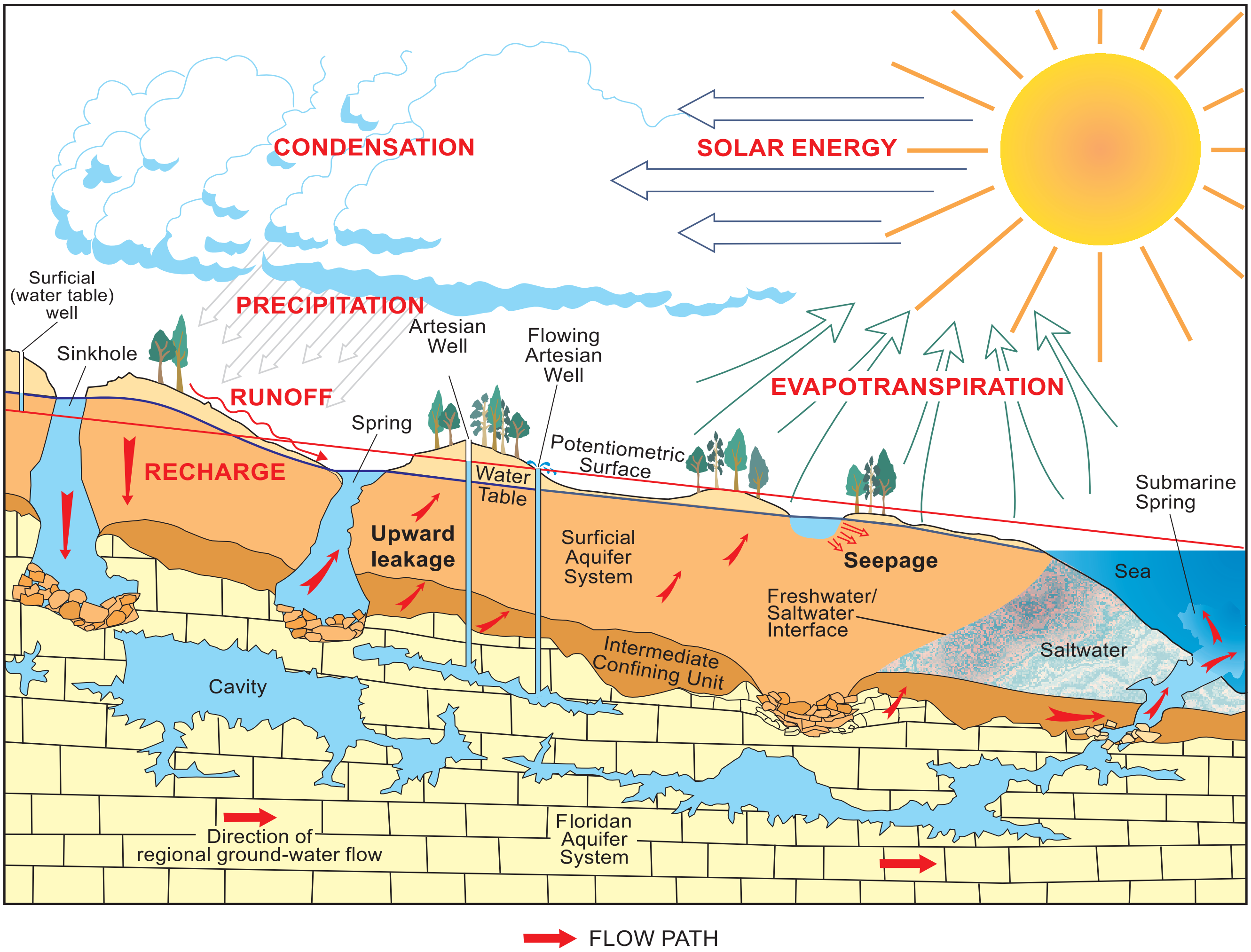


Figure 4. *Hydrologic cycle. (Modified from Fernald and Patton, 1984.)*

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, 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.

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.

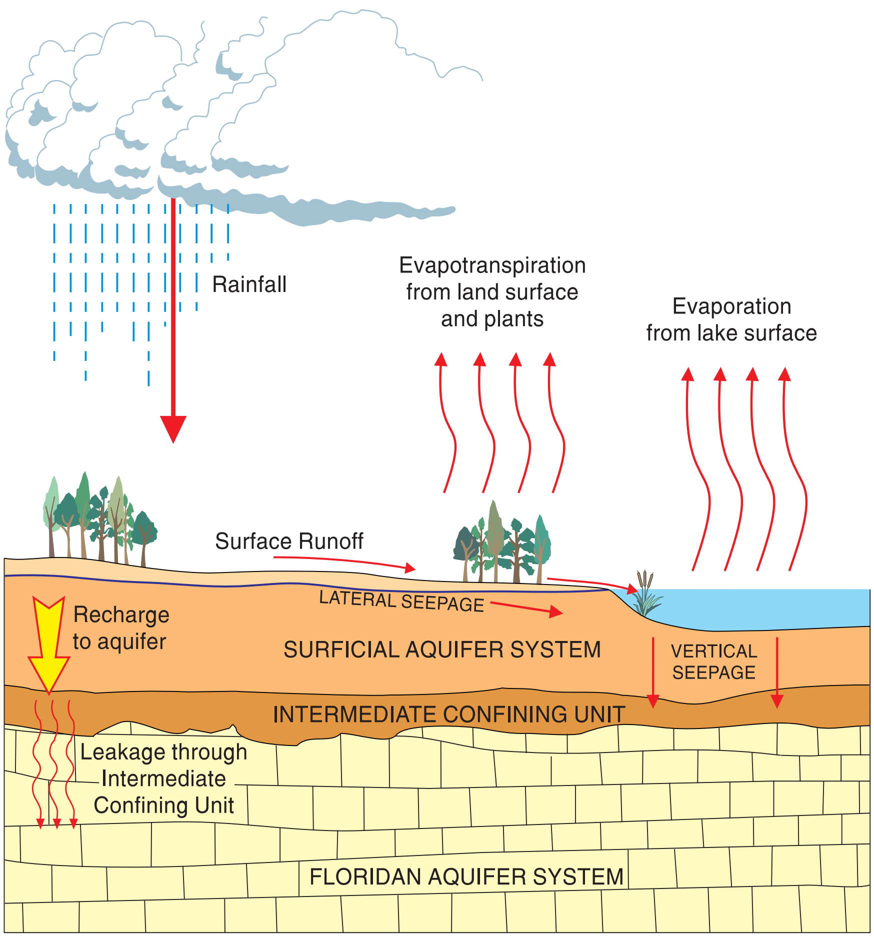


Figure 5. *Major components of the hydrologic budget for a central Florida lake in a ground-water recharge area.*

Some of the differences in lake water levels, particularly during summer months, can be the result of local differences in rainfall amount or intensity.

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 for 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

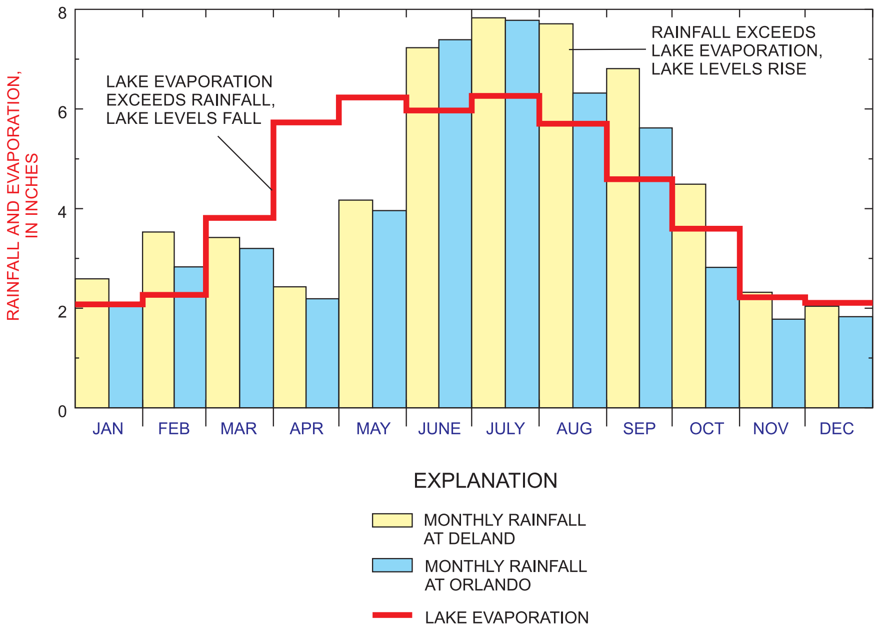


Figure 6. *Mean monthly rainfall at DeLand and Orlando for the period 1961–90 and lake evaporation based on pan evaporation (1960–88).*

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 open water surfaces such as lakes. Evaporation from a lake surface is referred to specifically as lake evaporation. The evaporation 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.

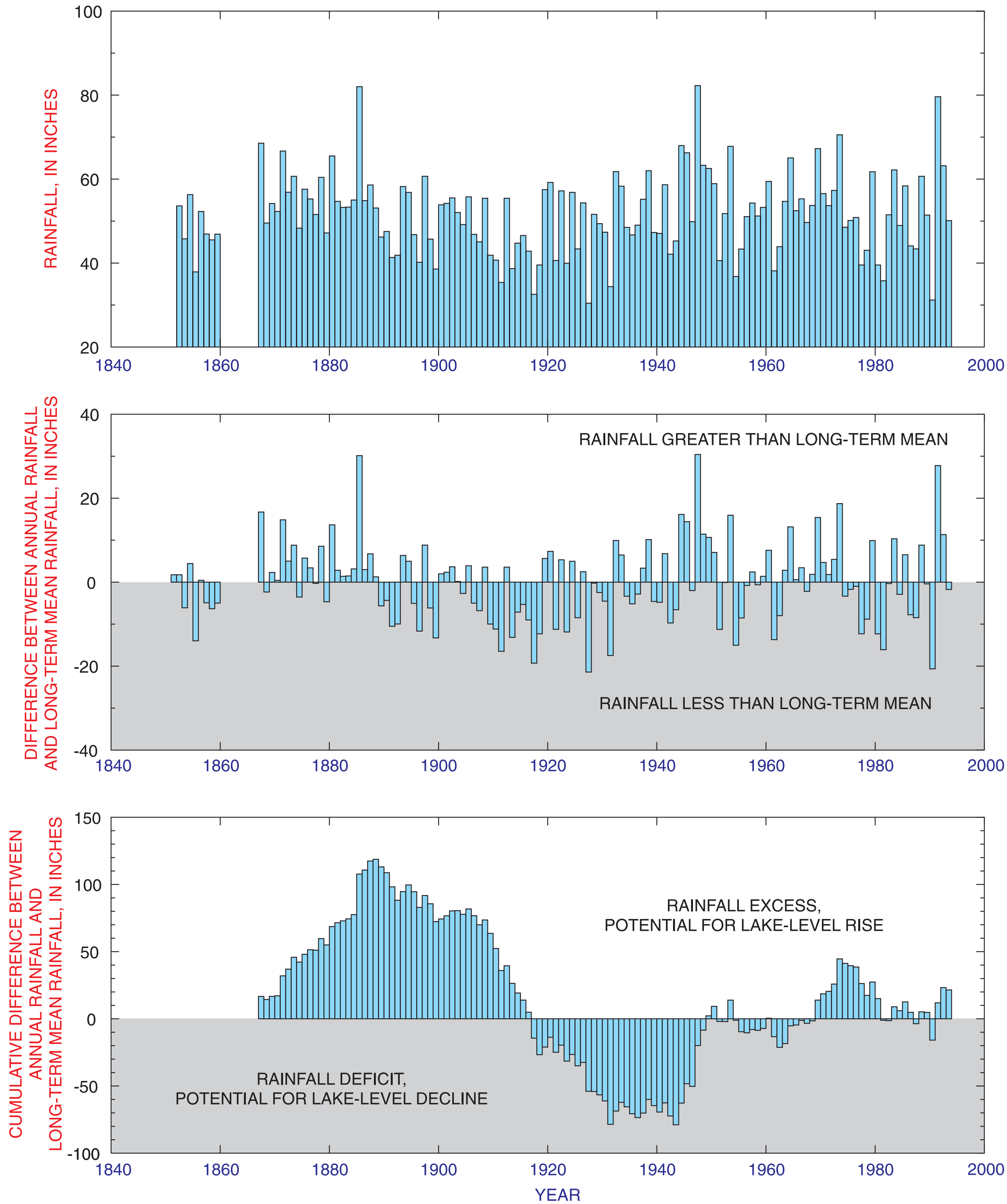


Figure 7. *Annual rainfall at Jacksonville, the station with the longest record in Florida.*

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 eventually reaches a lake or stream. Surface runoff refers to water flowing over the land surface and to water in streams and rivers. Surface runoff is a significant component of the hydrologic budget of drainage lakes. In seepage lakes, however, ground-water inflows and outflows dominate the hydrologic budget, and the component represented by surface runoff is relatively small.

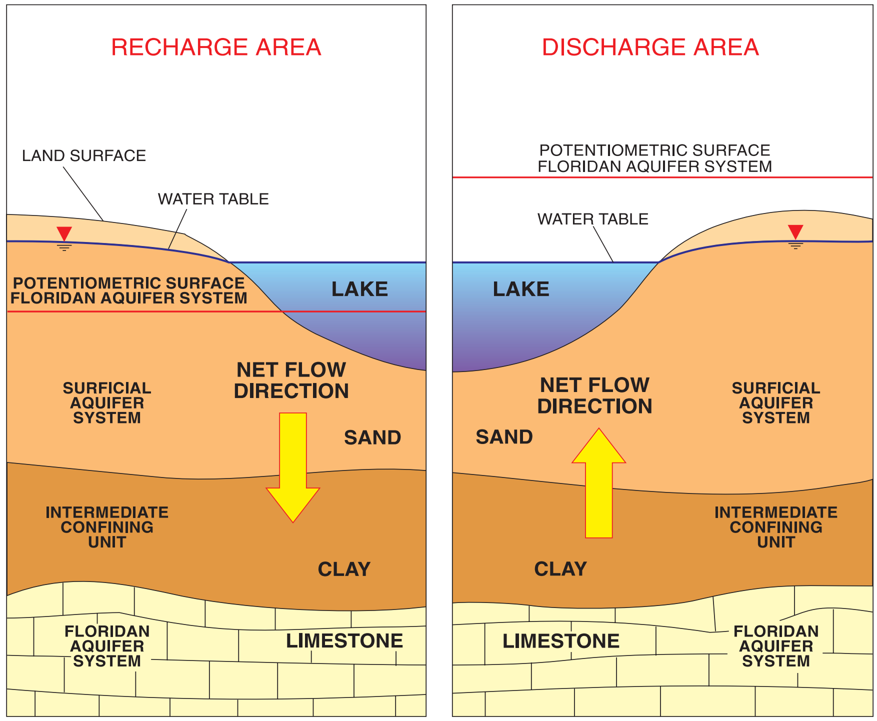


Figure 8. *Ground-water movement in recharge and discharge areas.*

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 table of the surficial aquifer system is 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 at a higher altitude than the water table of the surficial aquifer that 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 carbonates. Subsequent fluctuations of sea level during episodes of glaciation have 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 shown in figure 9, which also shows the hydrogeologic units, or aquifers and confining units, corresponding to the geology. Underlying the deepest rocks shown in the diagram in figure 9 are several thousand feet of igneous, metamorphic, and sedimentary rocks that form the foundation of the peninsula. Above these 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 Group, deposited about 25 million years ago, represents a transition between marine-derived and land-derived sediments. The lower layers of the Hawthorn Group 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 Group generally restrict ground-water movement. Overlying the Hawthorn Group 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 Group, 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 Group were deposited on top of this irregular, eroded limestone surface. Therefore, the thickness of the Hawthorn Group varies depending on the original altitude of the surface where it was deposited. In those areas where the sediments of the Hawthorn Group are thin, more surface water can penetrate to the underlying rock of the Ocala and Suwanee Limestone Formations and continue the erosional process. These are areas prone to sinkhole development. In those areas where the Hawthorn Group is thicker, the underlying rock is more shielded from the effects of continued erosion, and sinkholes are less common.

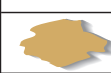
APPROXIMATE NUMBER OF YEARS AGO	SYSTEM	SERIES		GEOLOGIC UNIT	DESCRIPTION	GEOHYDROLOGIC UNIT		PATTERN USED IN ILLUSTRATION
Present - to 2,000,000	Quaternary	Recent and Pleistocene		Undifferentiated deposits	Unconsolidated materials including sand, clay, marl, shell, and phosphorite	Surficial aquifer system		
2,000,000 - to 65,000,000	Tertiary	Pliocene		Undifferentiated deposits	Silty to sandy clay, thin shell beds, and basal limestone beds of variable thickness, phosphatic	Intermediate confining unit		
		Miocene		Hawthorn Group	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 9. *Generalized summary of geologic and geohydrologic units in central Florida. (Modified from Miller, 1986; Tibbals, 1990; Bradner, 1994; Phelps, 1987; Lopez and Fretwell, 1992.)*

GROUND WATER

In this section of the primer, the ground-water system in central Florida is described to provide the background for understanding lake formation, water levels in lakes, and the quality of water in lakes 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 yield 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. 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).

In central Florida, the aquifer nearest the land surface is the surficial aquifer. 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 from 50 feet or more below land surface to above land surface in wetlands and lakes. (Because the water surface of a lake is the water table, and the land surface is actually the submerged lake bottom, the water table is above land surface in lakes.)

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

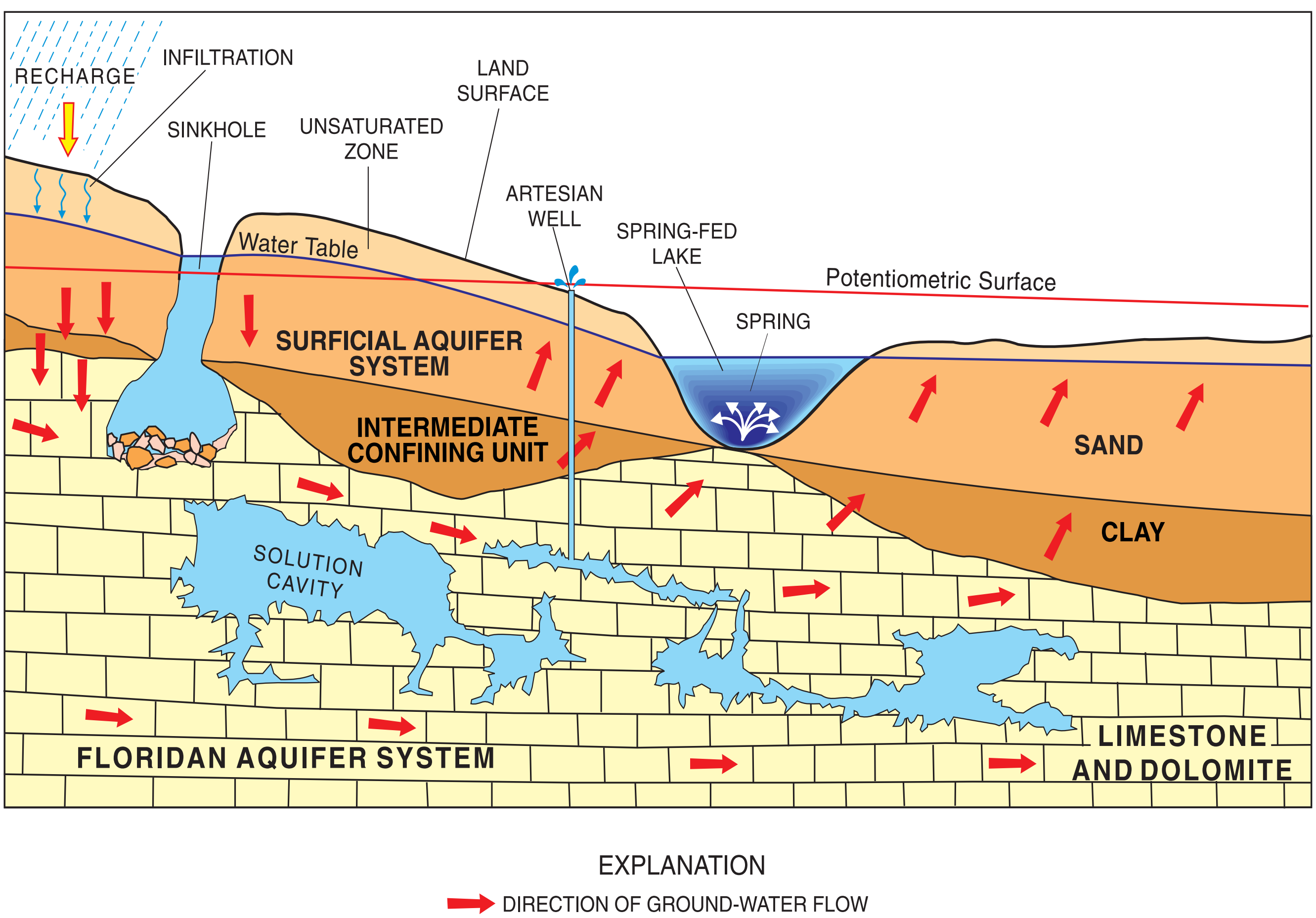


Figure 10. *Geology and major aquifers in central Florida.*

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.

The Floridan aquifer system is the primary source of nearly all the drinking water in central Florida.

Water in the Floridan aquifer system is under pressure in much of central Florida because the overlying clays and silts of the Hawthorn Group act to confine the water (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, above land surface (fig. 10). The level to which the water rises is referred to as a ***potentiometric surface***. Wells that tap the Floridan aquifer system in ground-water discharge areas 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 and there are no confining sediments, water in the aquifer is not under pressure; in these areas, 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. 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 is 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

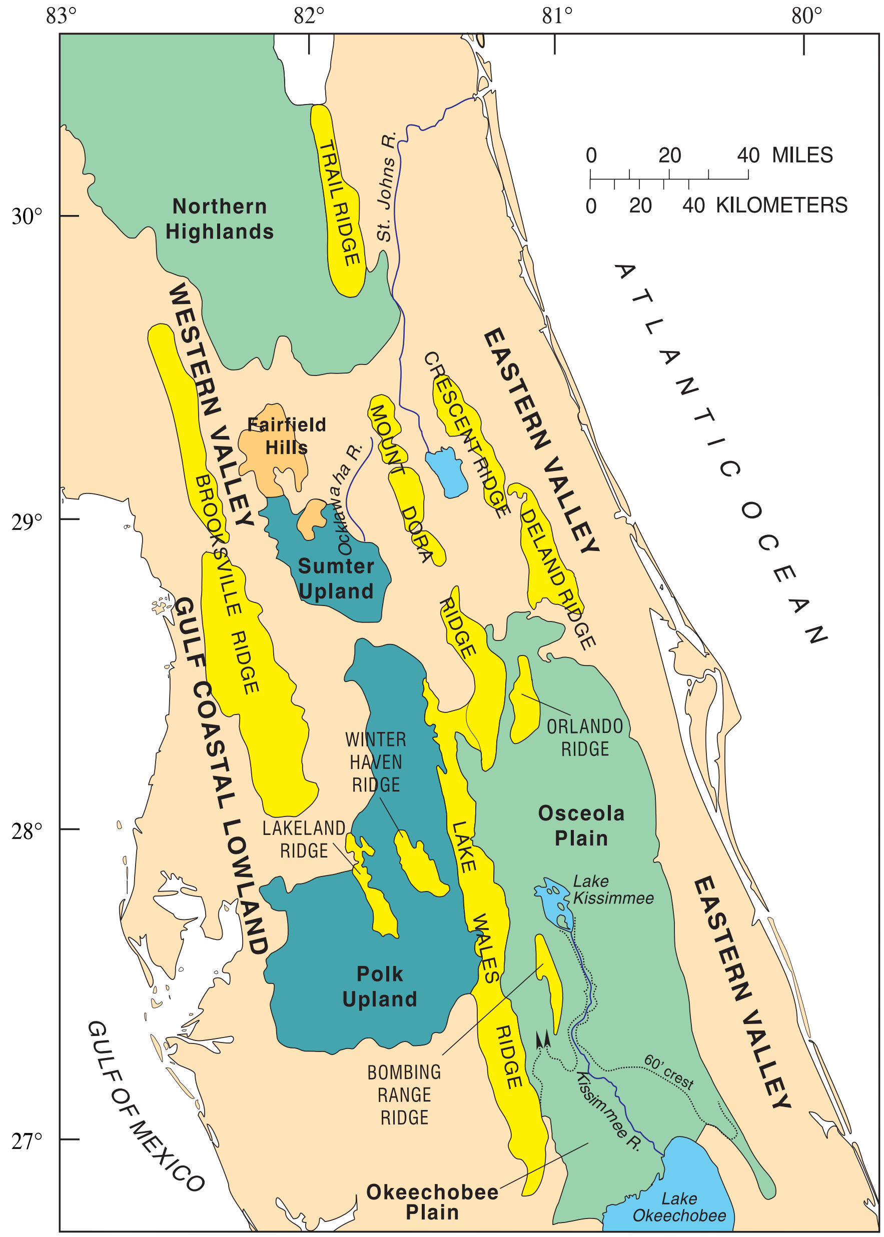


Figure 11. *Major physiographic regions of central Florida. (Modified from Cooke, 1945.)*

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 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 and soil zone 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 water in the aquifer is confined, less water from the surface reaches the limestone and sinkholes are not as common.

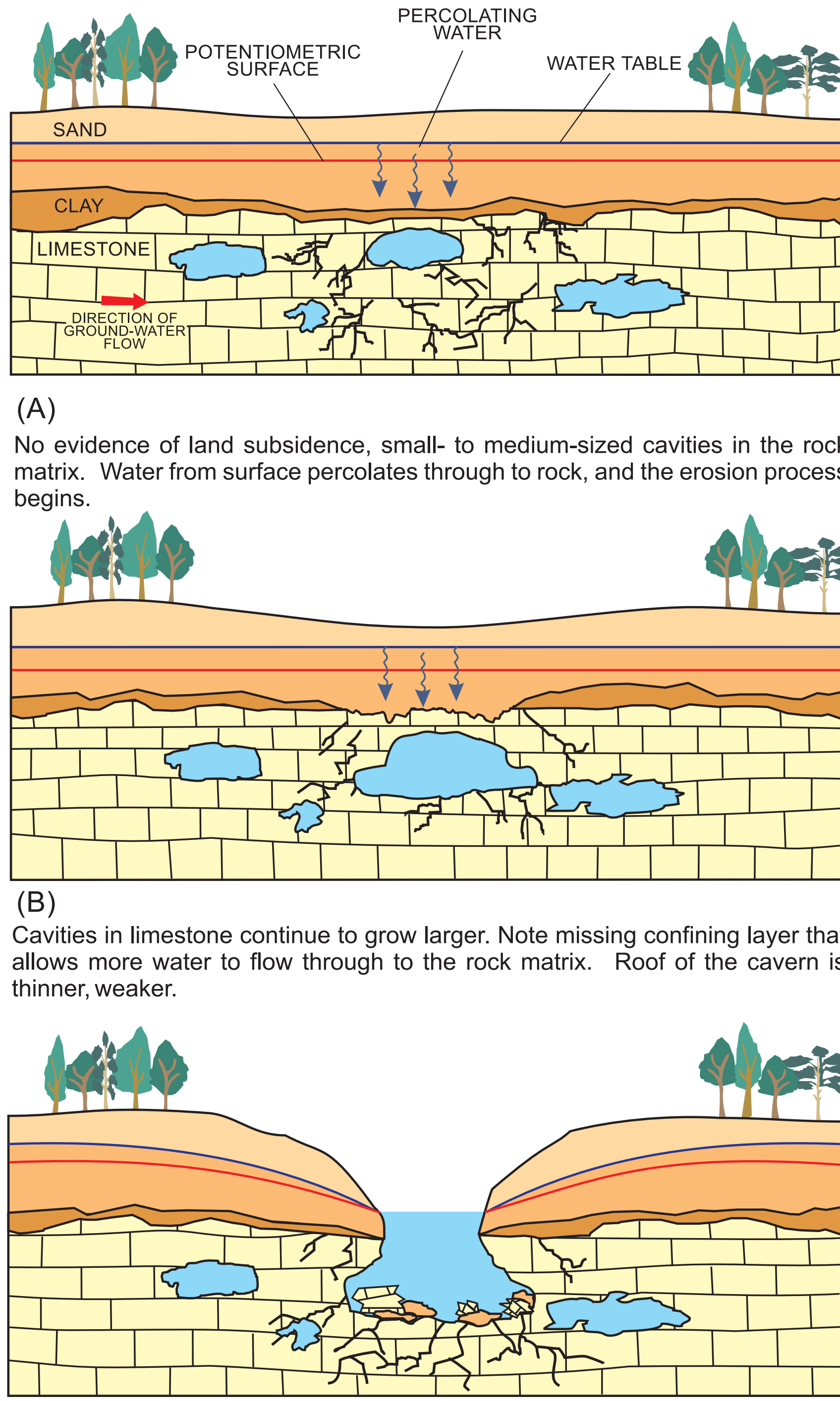
By far, the most common origin of Florida's lakes is by solution processes.

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 (see photo, p. 17) 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 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.



(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.

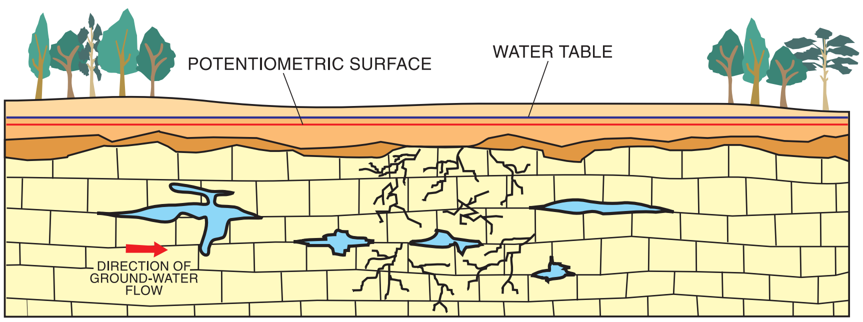
(C)
As ground-water levels drop during the dry season, the weight of the overburden exceeds the strength of the cavern roof, and the overburden collapses into the cavern, forming a sinkhole.

Figure 12. *Formation of a collapse sinkhole.*

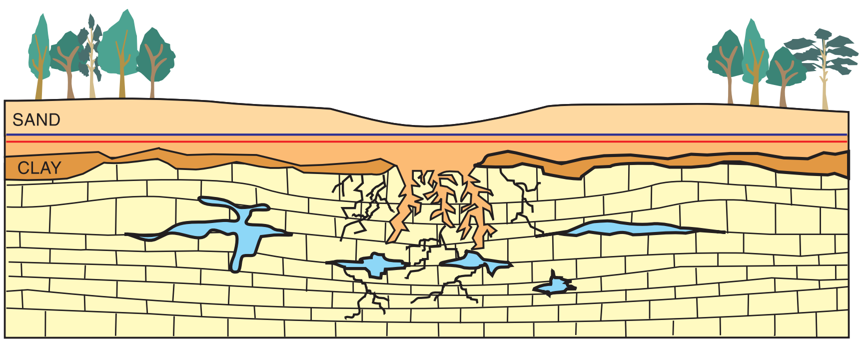
The progression of a subsidence sinkhole is shown in figure 13. Rainwater percolates through overlying sediments and reaches the limestone, dissolving the rock and gradually weakening its structural integrity. As the limestone continues to dissolve, the unconsolidated sediments above the limestone are carried downward with the percolating water and occupy the spaces formed by the dissolving limestone. With time, the movement of sediments into the openings in the limestone causes the formation of 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 (see photo, p. 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 shows 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 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.

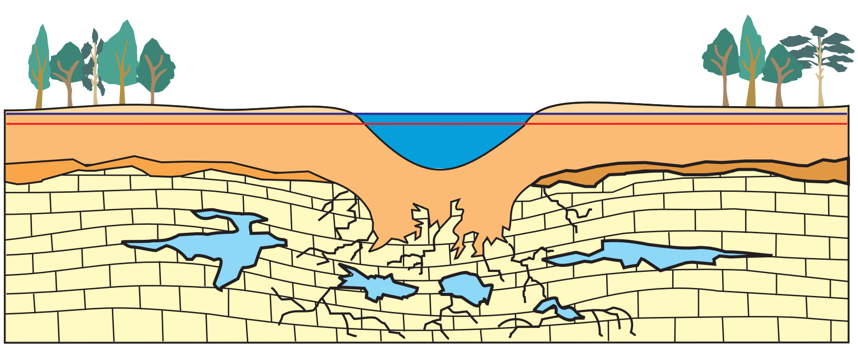
Not all lakes in central Florida were formed by solution processes. Some central Florida lakes originally were natural depressions in the ancient sea floor. These depressions formed as a result of scouring and redepositing of material by wave action and water currents. Freshwater eventually filled these depressions when sea level fell.



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

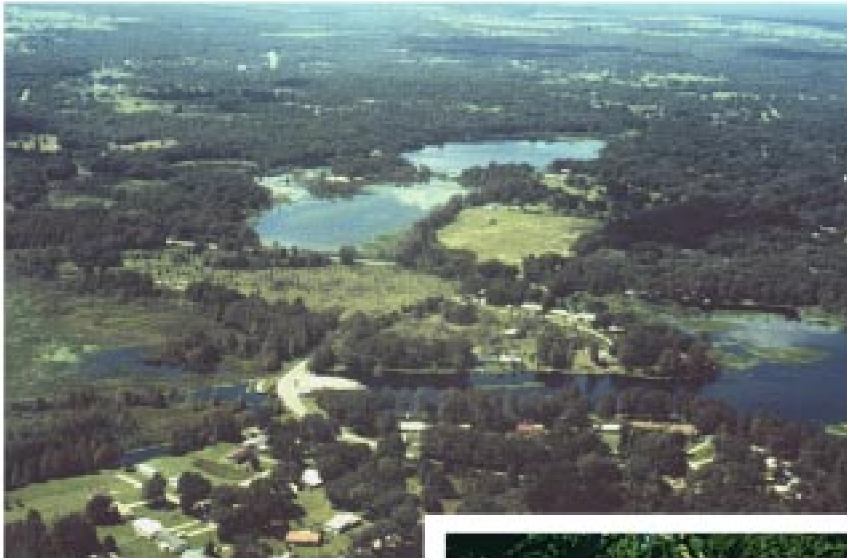


(B)
Small cavities and cracks grow larger as time progresses, and water moving through the rock erodes the rock matrix. Sediments carried by the water fill the voids in the rock.



(C)
Sediments from the upper layers continue to fill in the openings in the limestone, causing a depression at the land surface. If water collects in the depression, a new lake is formed.

Figure 13. *Formation of a subsidence sinkhole.*



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. (Photograph by L.A. Bradner, U.S. Geological Survey.)

The top photograph shows the Winter Park sinkhole shortly after it formed in May 1981. (Photograph by A.S. Navoy.)

In the bottom photograph, the sinkhole is shown 13 years later, in October 1994. (Photograph by L.A Bradner, U.S. Geological Survey.)

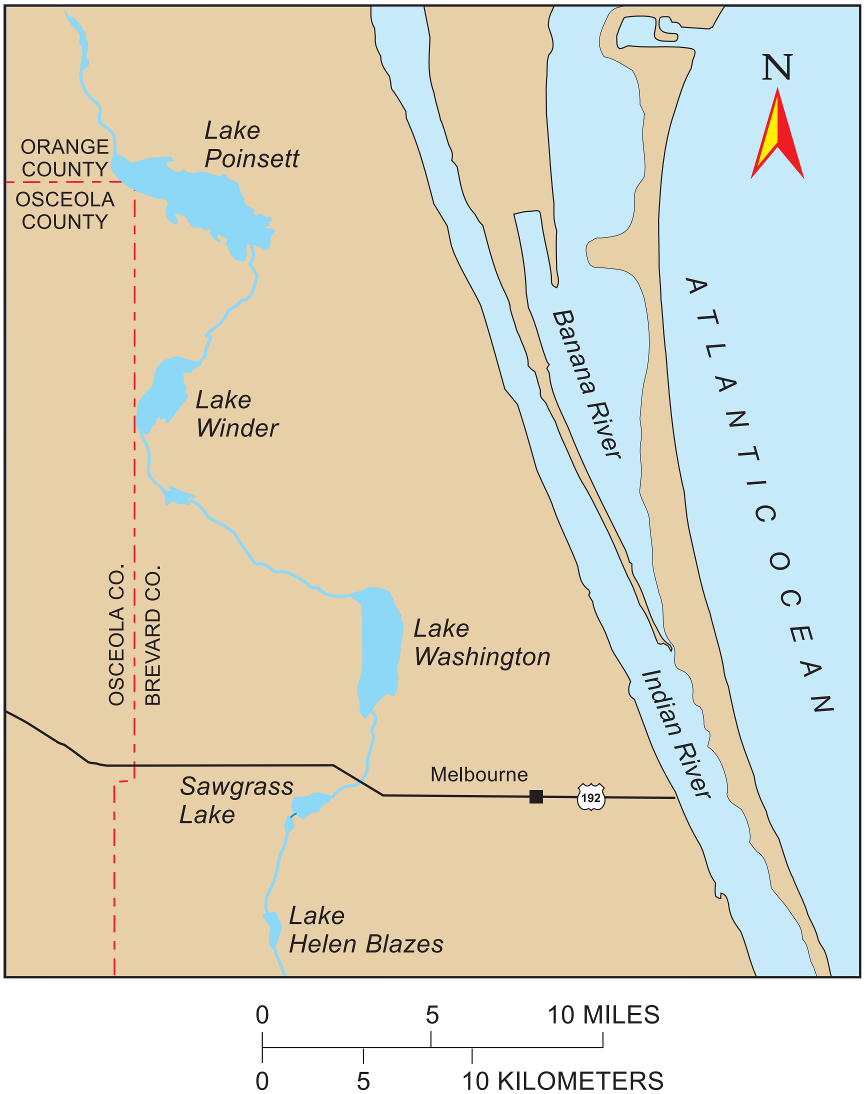


Figure 14. *Present-day lakes formed when sea level fell and freshwater filled depressions in the sea floor (Upper St. Johns River chain of lakes).*

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.

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.

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, and Yale (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

Although the unnamed lake in this aerial photograph taken in an area near Sebring, Florida, has a nearly perfect circular shape indicating its sinkhole origin, most solution-formed lakes do not have this perfect a shape! (Photograph by E.P. Simonds, U.S. Geological Survey.)

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.

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 constructed in the 1960's to connect the Atlantic Ocean and the Gulf of Mexico for shipping purposes but was halted after concerns about environmental impacts arose.

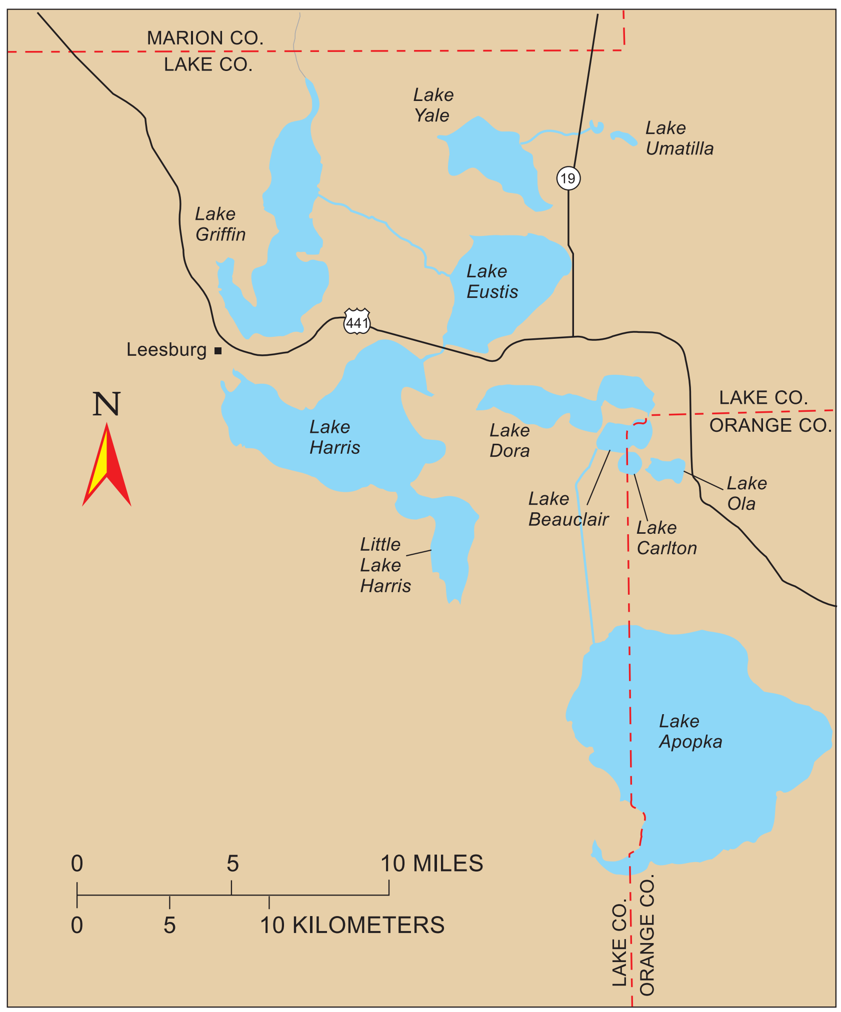


Figure 15. *Lakes formed by solution processes (Ocklawaha River chain of lakes).*

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.

WHAT CAUSES LAKE WATER-LEVEL FLUCTUATIONS

Water levels in lakes can vary over a wide range of time scales, from short-term, storm-related rises over a period of days, to long-term fluctuations caused by seasonal variations during the year. Water levels also can vary as a result of long-term trends in rainfall—patterns in rainfall may vary over periods of 20 to 30 years. For many people, the "normal" level of a lake is the level at which they first observed the lake. However, the normal or average water level of a lake must be defined for a particular period of time. The average water level in a lake during the 20-year period 1950–70 may be quite different from the average for 1970–90, for example, and the difference in the averages may be primarily due to the difference in rainfall during those periods. Thus, the average or normal water level for any lake can change with time.

For many people, the "normal" level of a lake is the level at which they first observed the lake.

Water levels in Florida lakes, though driven by inflows (rainfall, runoff, and ground-water seepage), ultimately are determined by outflows. In drainage lakes, outflows generally increase and decrease rapidly with small changes in water levels. Although the water levels fluctuate frequently, the fluctuations fall within a narrow range. Seepage lakes are characterized by less frequent water-level fluctuations within a greater range. The long-term fluctuations in seepage lakes reflect the larger seasonal and annual variations in rainfall and the altitude of the potentiometric surface. Examples of these water-level fluctuations are presented in this section of the report.

The variability in lake water levels is a function of the hydrologic budget of the lake. The balance of inflows and outflows in the hydrologic budget of a lake is reflected in the water levels. 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 driving factor affecting water levels in lakes. When rain falling on the surface of a lake or on the land surface within the drainage basin exceeds outflows from the lake, an increase in the volume of water in the lake causes a rise in water levels. 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 inflows from rainfall.

Evaporation from the lake surface causes 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 during low-rainfall periods is most pronounced in seepage lakes, where evaporation is a primary output; in drainage lakes or in lakes where water levels are controlled, the effects of high evaporation losses are less noticeable because they are masked by other, larger water losses.

The cumulative difference between rainfall and evaporation over time affects long-term seasonal and annual lake water levels, particularly in seepage lakes. Lake Umatilla in Lake County (fig. 2), for example, 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. The lag in the response of the lake water level to the cumulative difference between rainfall and lake evaporation (fig. 16) is the result of the storage of water in the hydrologic system. Inflows of this stored water sometimes mask the effects of high or low rainfall.

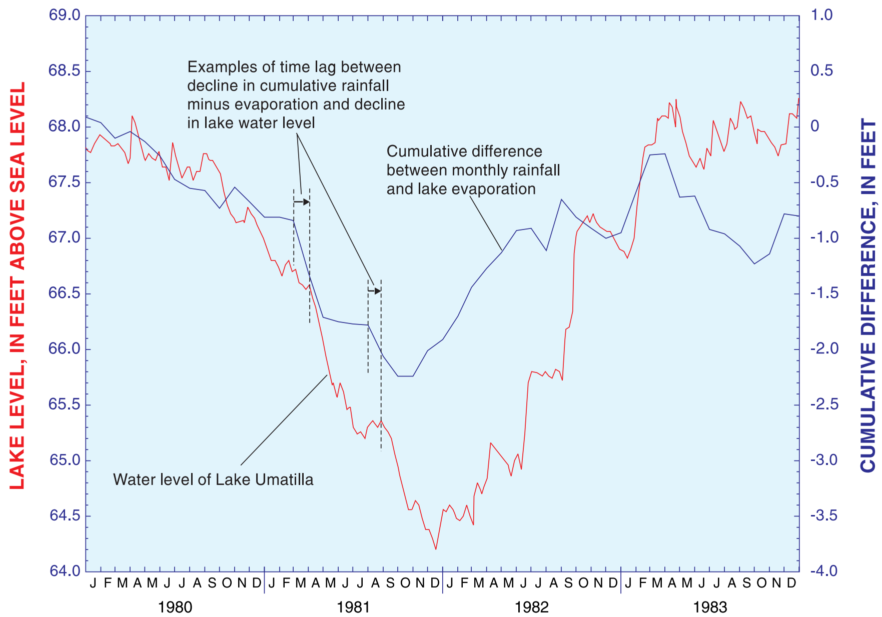


Figure 16. *Water level in Lake Umatilla, Lake County, and the cumulative difference between rainfall and lake evaporation.*

The cumulative difference between rainfall and evaporation over time affects long-term seasonal and annual lake water levels, particularly in seepage lakes.

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 lakes in Florida are seepage lakes and thus are not subject to the effects caused by directly connected surface-water inflows and outflows. 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, even in many drainage lakes, water levels generally 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 position of the water surface of the lake relative to 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 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 the 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 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.

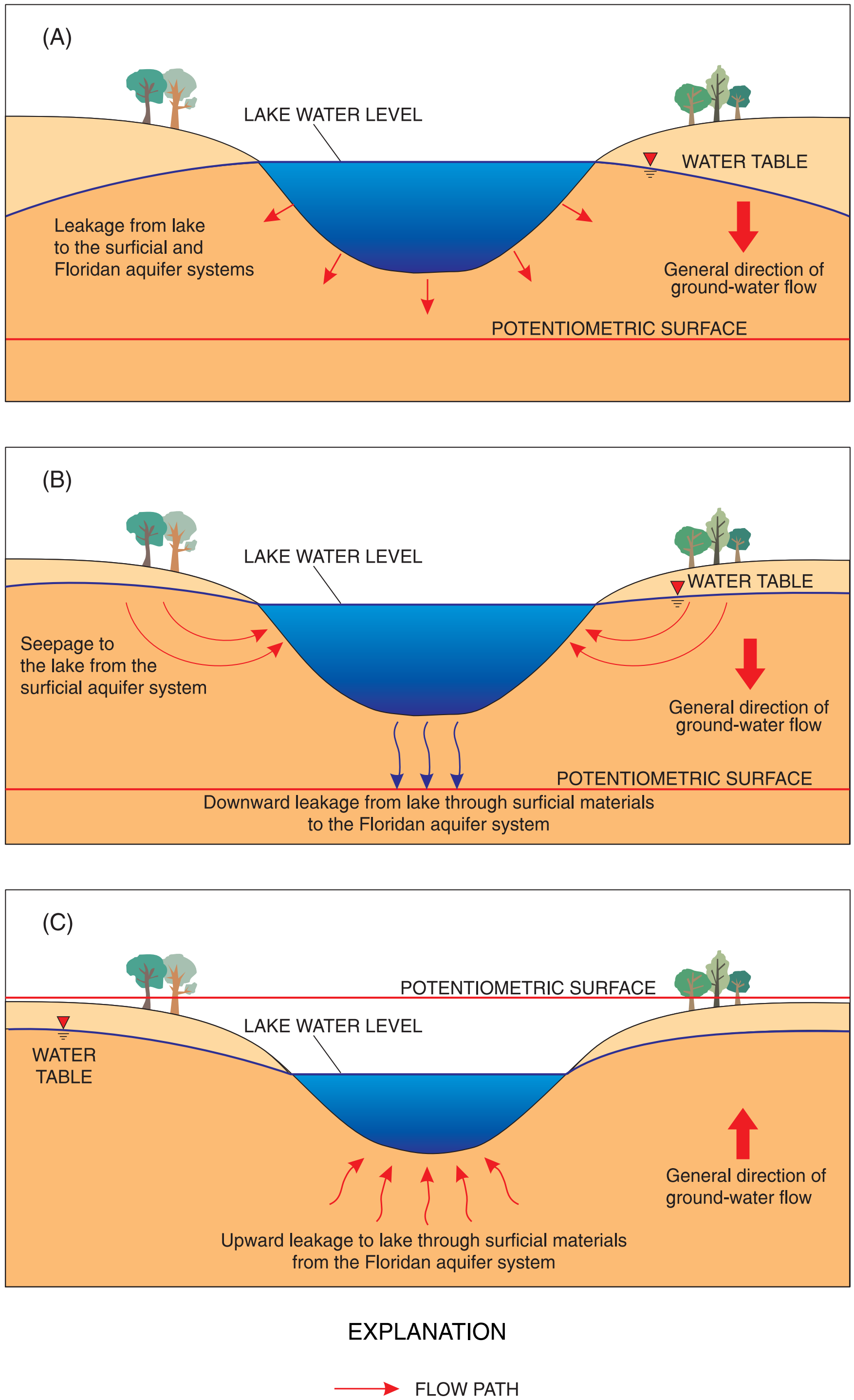


Figure 17. *Interactions between ground-water and lake water levels. (Note: Only surficial materials are illustrated.)*

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.

Because so many lakes in central Florida were formed by solution processes, there is a strong link between lakes and ground water.

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).

One 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

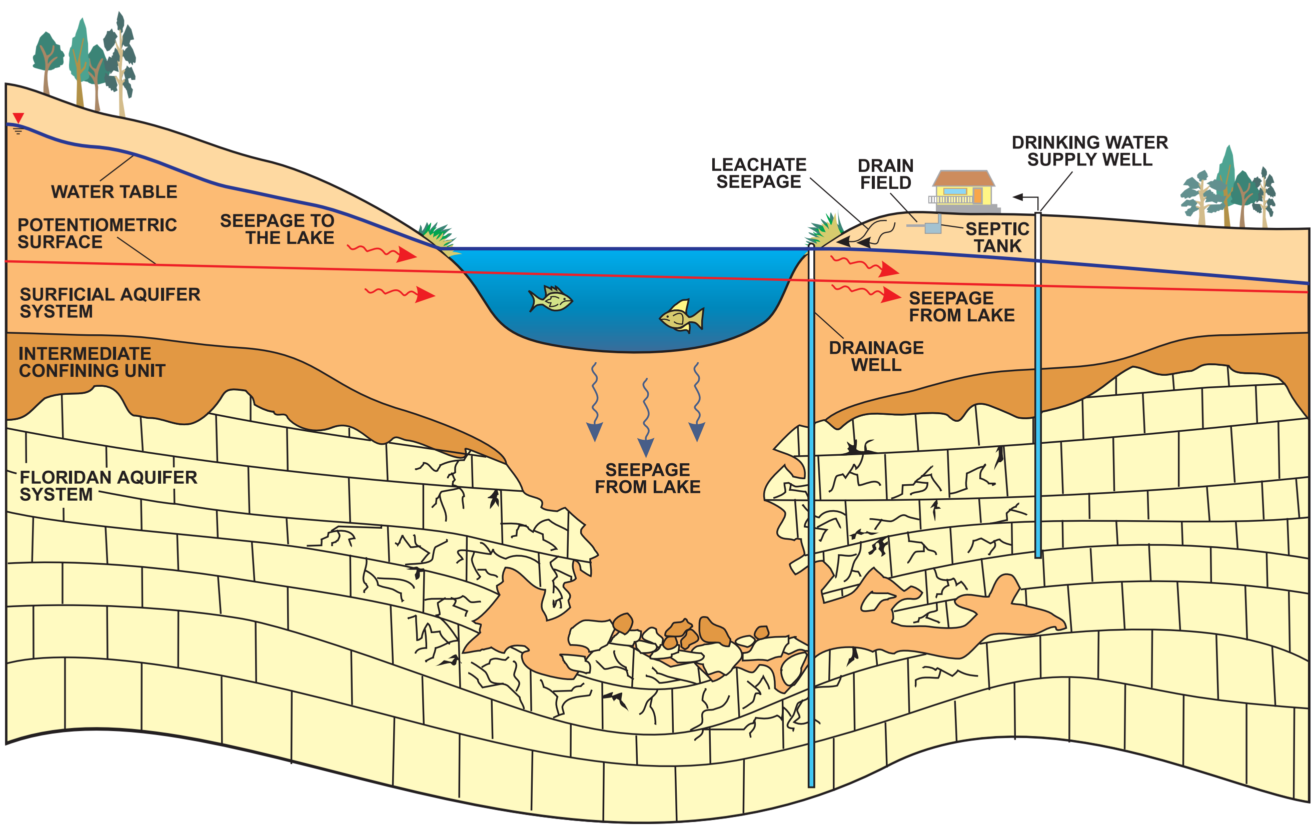


Figure 18. *Cross section through a sinkhole lake showing ground-water seepage.*

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

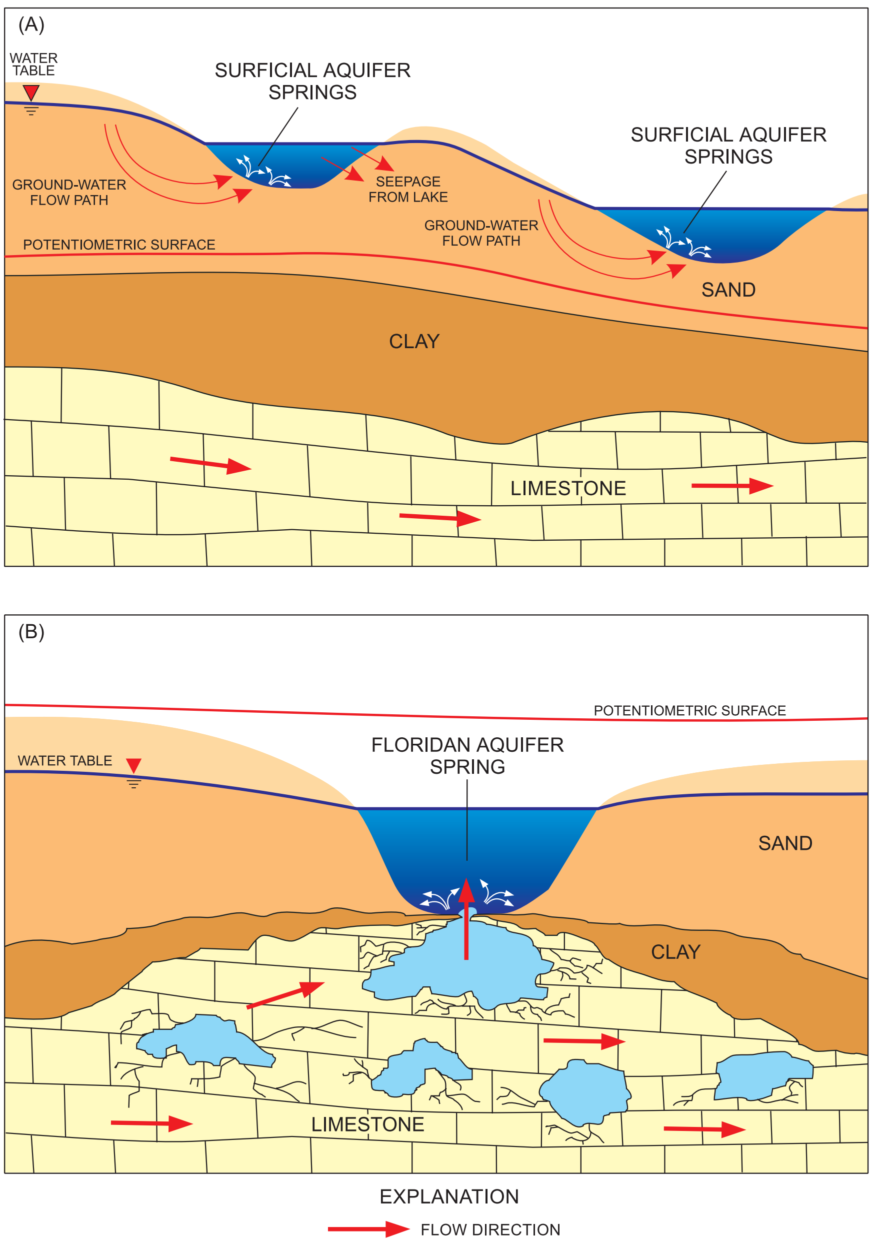


Figure 19. *Surficial-aquifer spring flow (A) and Floridan-aquifer spring flow (B) to a lake.*

How Human Activities Affect Lake Water Levels

Many Florida lakes have been modified to decrease the range of fluctuation in lake levels and reduce the risk and extent of flooding around lakes. Natural drainage systems have been altered, for example, through the addition of canals or by the dredging or straightening of existing outflow channels. Many of the canals connecting lakes in Florida were constructed during the 1800's, before the arrival of the railroad, when Florida 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 was valuable for farming and citrus cultivation. The effect of this type of modification of natural drainage is the reduction in the overall surface area of the lake and in the range of lake level fluctuations, particularly for natural seepage lakes.

Other human activities that affect the water budget of lakes and thus, water levels, include urbanization, the use of lake water by residents for lawn irrigation (lowering lake levels), and the disposal of water from various sources to lakes (increasing lake levels). Urbanization increases the impervious surface area contributing runoff to a lake, causing a greater volume of water to reach the lake unless other provisions are made (retention facilities). Although some of the lake water used for irrigation returns to the lake through ground-water seepage, most of it is lost to evaporation and uptake by vegetation. Examples of water contributed to lakes through human activities include stormwater runoff, water from water-to-air heat-pump systems (which obtain water from ground-water sources), treated sewage effluent, and 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, increasing 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. As described previously, water-level fluctuations in seepage lakes (without artificial water-level controls) generally are less frequent but vary through a greater range 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. Lake level changes are more frequent in Lake Apopka than in Lake Francis, but 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.

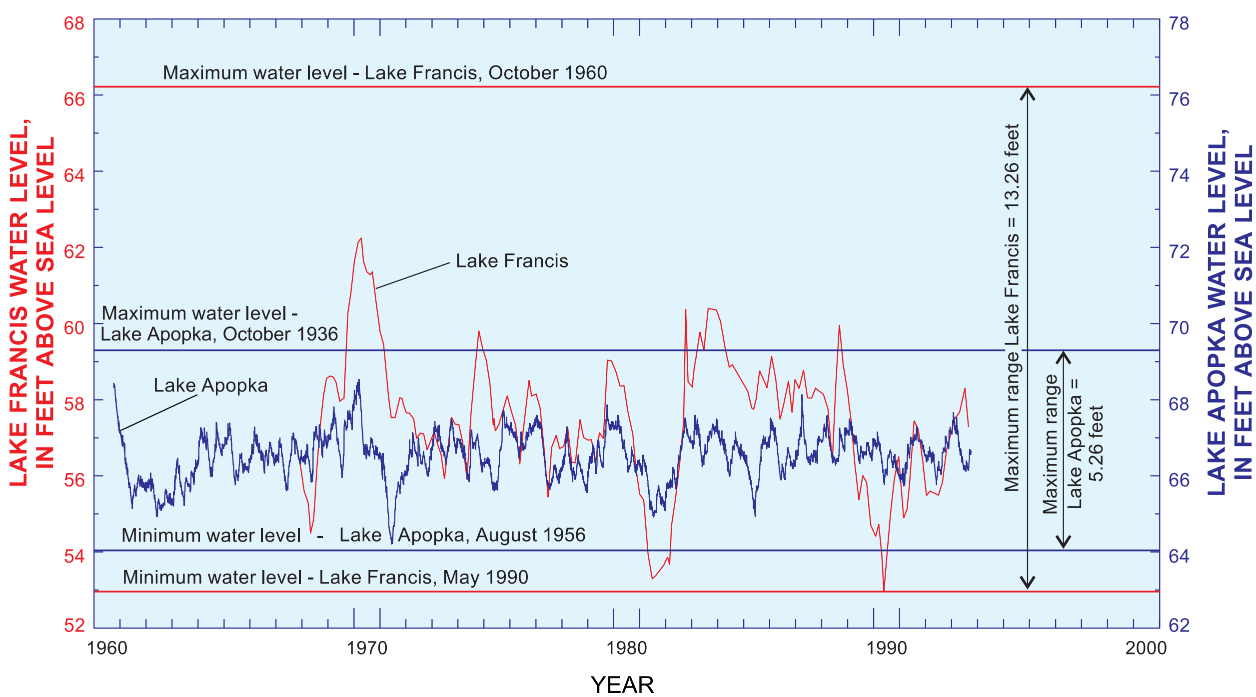


__Figure 20.__ Water-level fluctuations in a drainage lake (Lake Apopka) and a seepage lake (Lake Francis).

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 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 an 11-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).

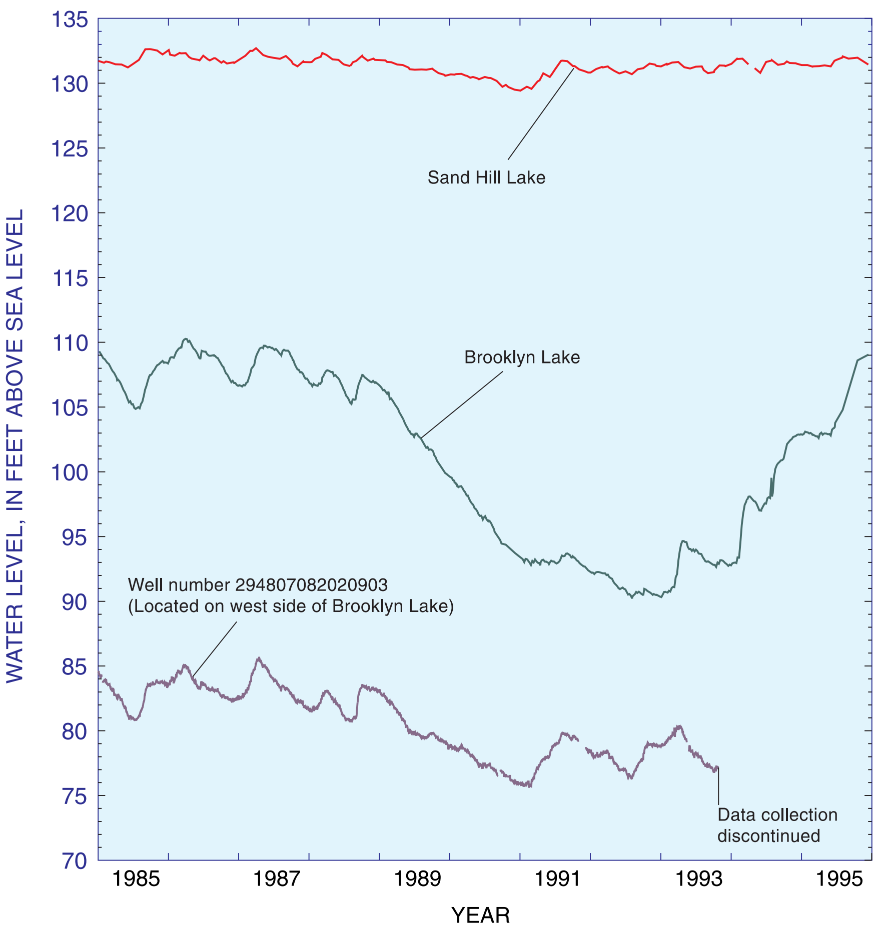


Figure 21. *Water level in Sand Hill Lake, Brooklyn Lake, and in a well near Brooklyn Lake.*

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

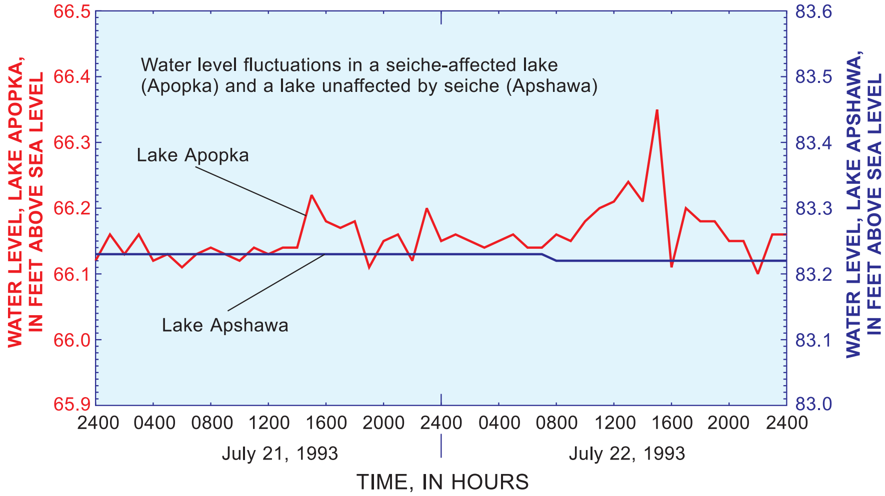


Figure 22. *Water levels in Lake Apopka and Lake Apshawa illustrating the effect of seiche on water levels.*

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 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 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. 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 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. For example, reducing the natural range of fluctuations in a lake decreases

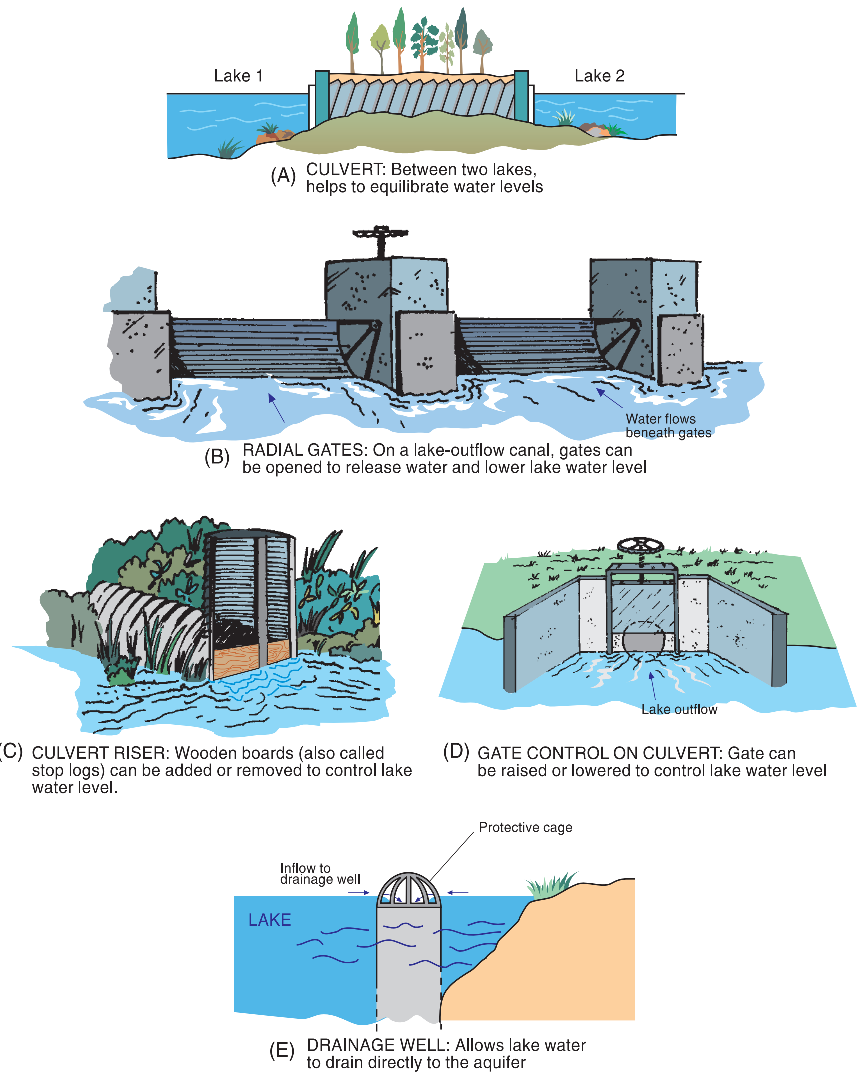


Figure 23. *Examples of lake water-level control devices.*

the area of vegetated flood plain and wetlands around many lakes, areas that serve as natural fish nurseries and nutrient filters (through plant uptake). The loss of fish habitat and increased nutrient enrichment resulting from the decreased range of water levels in controlled lakes has been detrimental to the overall recreational and ecological quality of these lakes. Greater variation in water levels is now allowed in most controlled lakes because of the recognized benefits to lake flora and fauna.

Lake drainage wells, which allow lake water to flow directly into the aquifer, have been used to control lake water levels in central Florida, particularly in the Orlando area, since 1904.

QUALITY OF WATER IN CENTRAL FLORIDA LAKES

The quality of water in Florida 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. Common lake classification systems, factors or hydrologic characteristics that affect lake water quality, and some of the methods used for water-quality improvement are discussed in the following sections.

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.

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 that 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

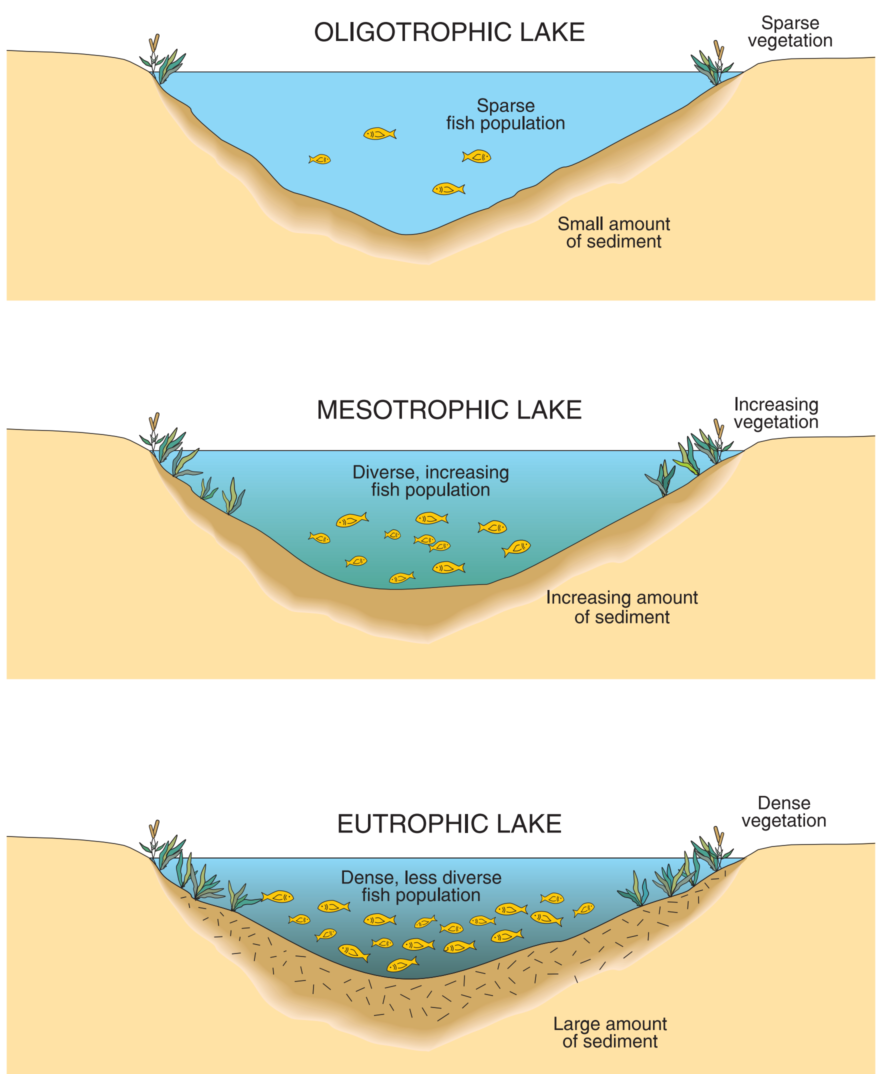


Figure 24. *Examples of an oligotrophic, mesotrophic, and eutrophic lake.*

Shoreline vegetation can provide aesthetic value as well as habitat for wildlife. (Photograph provided by St. Johns River Water Management District.)

chemistry of the water gradually changes to that of a mesotrophic lake. As the lake continues to age, 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 quality of water in Florida lakes generally is controlled by two important properties—the quality of the water entering the lake, and the rate at which lake water is replenished. These two properties are related—the effects of poorer quality inflow water can be mitigated by the rapid replacement of water in a lake. Conversely, the quality of water in a lake in which the water is replenished slowly (as in seepage lakes) can be maintained if the inflow water quality is good. In this section, the effects from inflow water from various sources are discussed.

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 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.

One important factor that has a direct effect on the response of the lake to the addition of nutrients is the residence time of water in the lake.

Water Quality: A Function of Residence Time

How much the water from the various sources described in the last section 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 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.

Because seepage lakes tend to have long residence times, they are more likely to be affected by the addition of nutrients or changes in chemistry than are drainage lakes.

Residence time is significant to the water quality of seepage and drainage lakes. Residence times in seepage lakes tend to be naturally long due to slow rates of ground-water outflow. The long residence time provides time for aquatic plants to use the nutrients in the water, encouraging plant growth and settling of nutrient-rich sediments on the lake bottom. Residence times in drainage lakes are shorter than in seepage lakes. In lakes with short residence times, the nutrients are not available in the water for plant uptake for as long as in lakes with long residence times. Thus drainage lakes generally are able to receive a greater nutrient load than seepage lakes without excessive aquatic plant growth. Because seepage lakes tend to have long residence times, they are more likely to be affected by the addition of nutrients or changes in chemistry than are drainage lakes. One study of 20 Florida lakes indicated that lakes in northern States (of comparable volume to the lakes in the study) were flushed five to ten times more rapidly than Florida lakes (Brenner and others, 1990, p. 372). The long residence time of most Florida lakes makes them more vulnerable to the effects of relatively small amounts of pollutants.

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

When aquatic vegetation grows to nuisance levels, chemical methods may be employed for control. This type of control can lead to problems with water quality when the plants begin to decompose after they are killed, releasing nutrients into the water, and encouraging more vegetative growth. (Photograph provided by St. Johns River Water Management District.)

The scene above shows the variety of vegetation that is found in and near lakes. (Photograph provided by South Florida Water Management District.)

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 farther in the lake, contributes to the clarity of lake water. However, generally more than one-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 lack of light 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

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. 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

Many central Florida lakes are surrounded by private homes and docks. (Photograph by E.R. German, U.S. Geological Survey.)

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. Aeration 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 a 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 a 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 a 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 some central Florida lakes to control aquatic vegetation (Canfield and others, 1983).

Aeration of lake water increases oxygen in the water, improves water circulation, and also has aesthetic value.

Lakeshore vegetation is important for nutrient uptake and provides habitat for wildlife. (Photograph provided by South Florida Water Management District.)

The drawdown or lowering of the water level in an urban lake sometimes is used to improve water quality by exposing the lake bottom for sediments to become oxygenated. Here, Lake Eola in downtown Orlando is shown, August 1994.

Another management method is the use of dry-retention basins, which can be incorporated into the landscape of lakeside parks. Shown above is a dry-retention basin near Lake Eola in downtown Orlando, Florida.

It is not uncommon to find the natural shoreline of a lake altered such as is shown above. (Photograph by E.R. German, U.S. Geological Survey.)

Probably 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 and visitors can help protect lakes by being aware of human activities that affect 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. Florida residents can help prevent water-quality problems in neighborhood lakes 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.

Probably the most effective way to protect the quality of water in lakes is through education and prevention of problems before they occur.

SUMMARY

One of the most common sights in central Florida are the numerous lakes dotting the landscape. Lakes enhance the beauty of the landscape, are important for wildlife, and are a treasured natural resource, used by Florida residents and visitors for recreation and appreciated for their beauty.

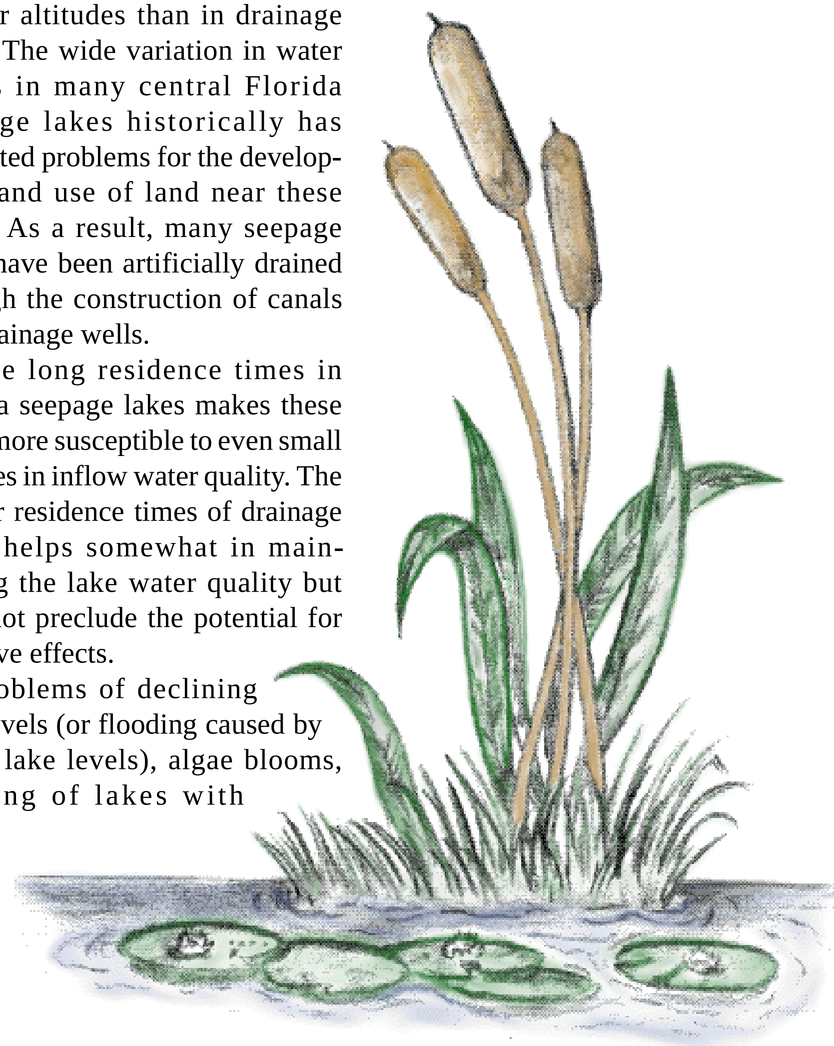
Lakes in Florida are special because of the hydrologic characteristics that set these lakes apart from lakes in most other States. Florida’s karst landscape has provided a setting for numerous landlocked, shallow seepage lakes that are closely tied to the ground-water resources of the State. In addition to these seepage lakes, some lakes in central Florida are drainage lakes, which drain through surface-water connections to other lakes or to streams or rivers.

Lakes in Florida are special because of the hydrologic characteristics that set these lakes apart from lakes in most other States. Florida’s karst landscape has provided a setting for numerous landlocked, shallow seepage lakes that are closely tied to the ground-water resources of the State.

Water levels are of great concern to many, and the complexity of the hydrologic system governing these lake levels is not commonly understood. Lake levels are a product of the balance of the hydrologic budget—inflows (rainfall, runoff, seepage) minus outflows (evaporation, seepage, surface-outflow). The water level response to the components of the hydrologic budget differs between seepage and drainage lakes, primarily in the timing of the fluctuations of lake levels and in the range of lake levels. Water levels in drainage lakes can change rapidly because the surface-water outflows allow for a large volume of water to leave the lake in a relatively short time period. However, a small change in lake level can produce a large volume of outflow from the lake, thus the water levels rise and fall within a very narrow range. Seepage lakes, however, lose water much more gradually through evaporation and seepage, and the volume of water exiting is much smaller, so water levels rise to greater altitudes than in drainage lakes. The wide variation in water levels in many central Florida seepage lakes historically has presented problems for the development and use of land near these lakes. As a result, many seepage lakes have been artificially drained through the construction of canals and drainage wells.

The long residence times in Florida seepage lakes makes these lakes more susceptible to even small changes in inflow water quality. The shorter residence times of drainage lakes helps somewhat in maintaining the lake water quality but does not preclude the potential for negative effects.

Problems of declining lake levels (or flooding caused by rising lake levels), algae blooms, choking of lakes with aquatic weeds, and many other problems, do not have simple or quick solutions. Many problems are the natural consequence of climatic changes; others are the result of many decades of development. The importance of education, improved understanding through research, and cooperation cannot be understated. Through the combined efforts and cooperation of individuals, communities, and government, lakes in Florida can be preserved and continue to be a valuable natural resource for the benefit of all.



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