HYDROLOGIC CYCLE

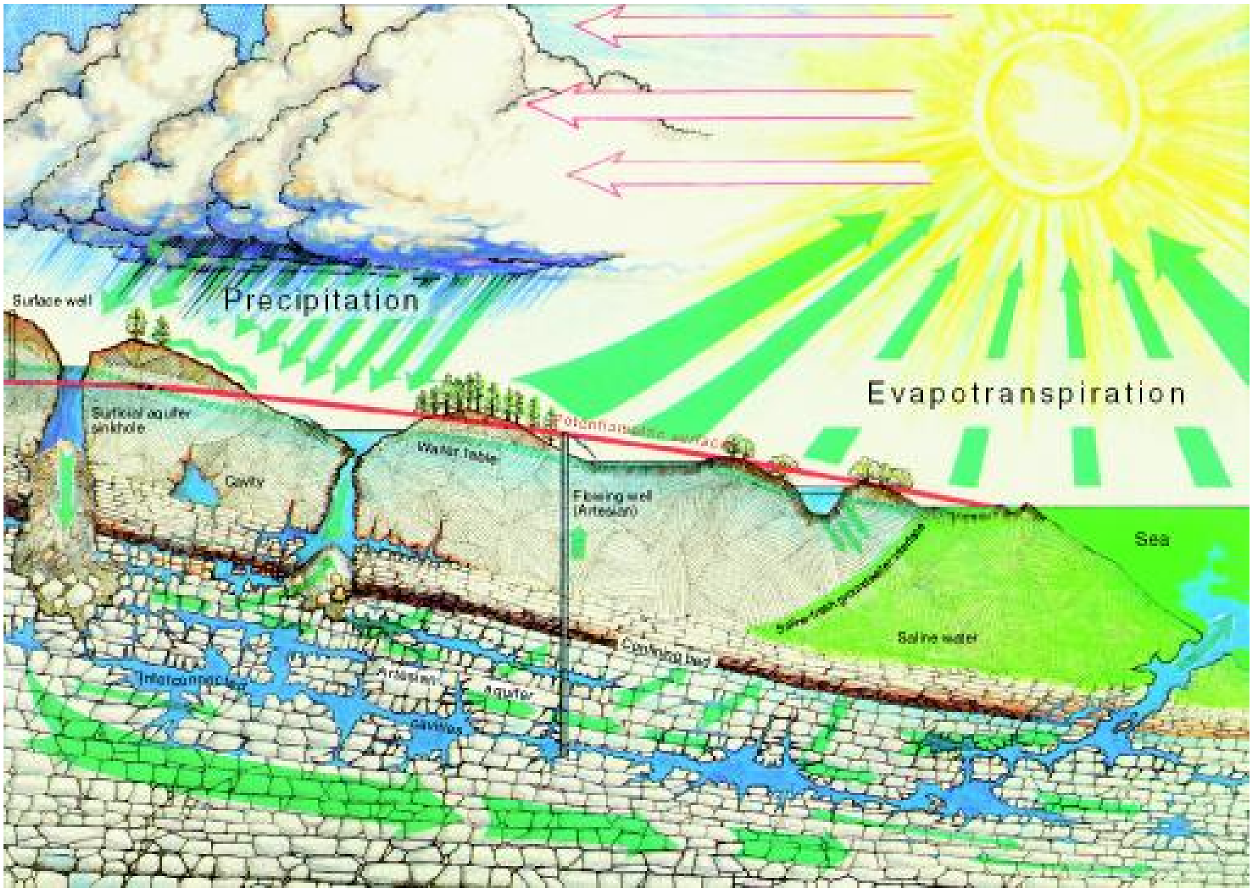
The hydrologic cycle is essentially a closed system with regard to water. The same water circles endlessly through its different phases, moving from sea to atmosphere to the land and back to the sea. Approximately 80,000 cubic miles of water evaporate annually from the world's oceans. The power source for the hydrologic cycle is solar energy, which induces evaporation. Although annual incoming radiant energy from the sun is greatest in the equatorial zone, the solar radiation reaching the earth's surface is reduced by the high cloudiness of that zone, and this reduced solar radiation, in addition to the high humidity, reduces evaporation. Highest evaporation occurs in the zones of highest solar radiation intensity at the earth's surface which are located to the north and south of the equator in the subtropical high pressure and trade-winds belts. King (1962) identified 20½N and 10½S as the latitudes with the highest levels of evaporation.

Once evaporated, water is carried through the atmosphere as clouds and vapor, forming an integral part of the earth's weather. When atmospheric conditions are right, water vapor condenses and falls as precipitation, such as rain, snow, sleet, or hail. Some precipitation bypasses part of the cycle and either evaporates while in the air or falls into the ocean. Other precipitation falls on the land.

Precipitation that falls on the land flows through many different pathways. Some precipitation will flow on the surface as runoff or overland flow. This water eventually makes its way to bodies of surface water, such as lakes, wetlands or rivers, where it will reside temporarily. Eventually, the surface water evaporates back into the atmosphere, makes its way to the ocean by way of a river system, or seeps through the lake, wetlands, or stream bottom into the underlying rocks or sediments.

Some precipitation seeps into the ground on which it falls, a process known as infiltration. As the water percolates downward through the soil, some may be removed by growing plants and recycled back into the atmosphere by transpiration from leaf surfaces. Some soil moisture will remain, clinging to the soil particles. Excess moisture is pulled downward by gravity until it reaches the zone of saturation or water table. Water below the water table is called groundwater. Much, but not all, groundwater flows beneath the land surface through layers of soil and rock until it reaches points of discharge, such as springs, wells, or seeps. Most groundwater discharges to streams and ultimately flows to the ocean, however long or deep the journey. Some of the very old groundwater, however, known as connate water, may stay beneath the land surface for millions of years. Connate water, which is highly mineralized because of its long contact with rock materials, is water that became trapped in sediments when they were deposited and subsequently was buried by younger sediments. Typically, however, the age of groundwater ranges from a few tens of years to tens of thousands of years (Bouwer 1978).

Water is added to the hydrologic cycle in minute amounts each year from deep within the earth by volcanic eruptions. This water is called juvenile water or primary water and is a component of deep rock and magma. This added water is balanced by water removed from the hydrologic cycle each year by combination with newly deposited hydrated minerals, such as gypsum, a mineral whose chemical formula contains water molecules.



References

King, C.A. 1962. An Introduction to Oceanography. New York, N.Y.: McGraw-Hill.
Bouwer, H. 1978. Groundwater Hydrology. New York, N.Y.: McGraw Hill.

Study Questions

1. Why are the areas of highest evaporation of water not found at the equator?
2. The subtropical regions of the earth have the highest evaporation rates. They are areas identified as latitudes 20.5 N and 10 S. These areas are characteristically blessed with high pressure and trade winds. Explain why high pressure and wind accelerate evaporation.
3. Using a dictionary, define water-table. Is groundwater found above or below the water-table?
4. What is connate water?
5. What is juvenile water?
6. Connate water and juvenile water are added to the hydrologic cycle every year, but accumulations are balanced through the removal of hydrologic water by what process?
7. Using only your words and arrows, draw the hydrologic cycle.

CLIMATE AND WEATHER

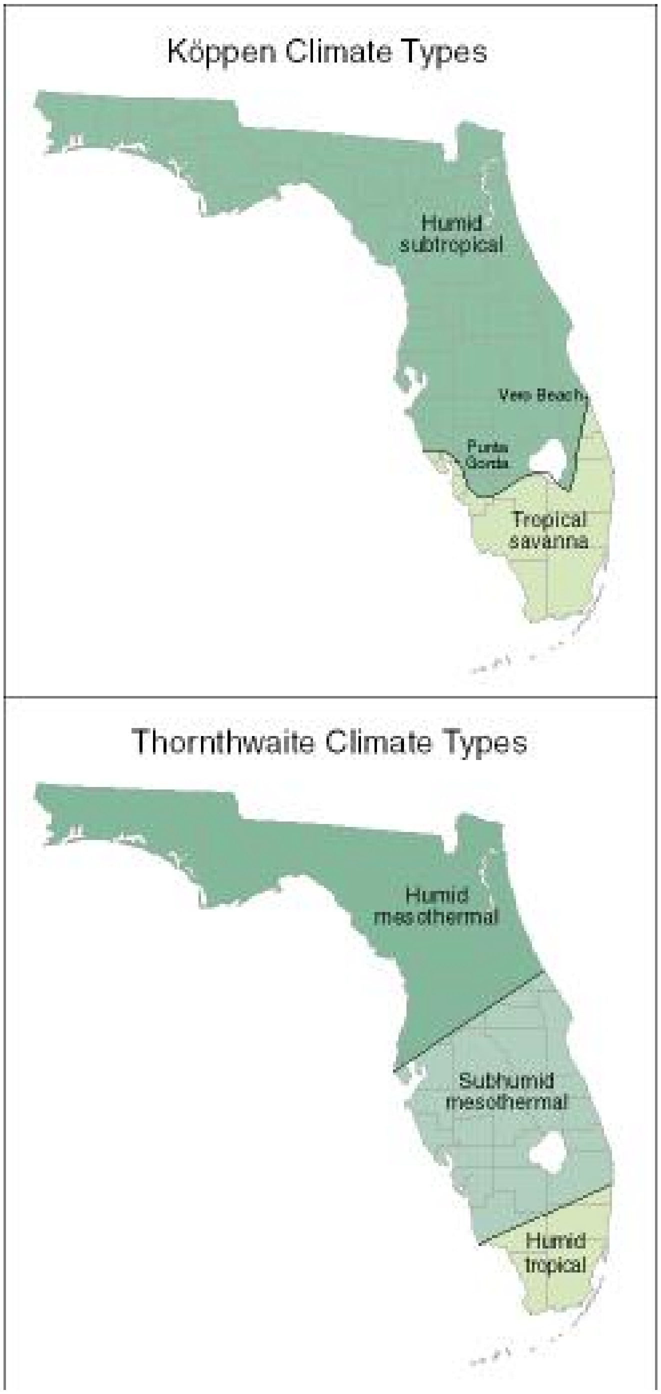
Climate is often stated to be one of Florida's most important resources. Although the state is located at the same latitude as some of the world's major deserts, Florida is one of the wettest states in the country. Its average rainfall per year is 53 inches; only Alabama has this same amount, and both are exceeded only by the 55-inch average of Louisiana. Florida has many unique rainfall characteristics in addition to being one of the wettest states. For example, it is first or tied for first in the nation in the following categories: proportion of summer versus winter rainfall; percentage of the months of June through September in which rainfall exceeds four inches; rainfall in the average wettest month; difference in rainfall between the average wettest and driest months; and maximum expected 30-minute rainfall.

Despite the fact that Florida is a low peninsula with a relatively homogeneous topographic nature, extending over just six and one-half degrees of latitude, it is not uniform in rainfall characteristics, or even in general climate types. The most commonly used climate classification, developed by Wladimir Köppen, divides the state into two major climate types. A tropical savanna, also called a tropical wet-and-dry climate, occurs in the southern portion of the peninsula and the Keys. Here all months average above 64½F and pronounced wet and dry seasons occur. The rainy season, typically June through September, has frequent afternoon thunderstorms and some months exceed 10 inches of rainfall. The dry season, winter, may have very little or no rainfall for weeks, occasionally for months. Extending along the coast from about Ft. Pierce to Miami is a transitional tropical climate, which has a relatively short dry season. The northern three-quarters of the state has a humid subtropical climate; this type covers much of the southeastern portion of the country. This climate is subtropical rather than tropical because some months have an average temperature of less than 64½F. Also, this part of Florida does not experience such a pronounced dry season as the tropical southern section.

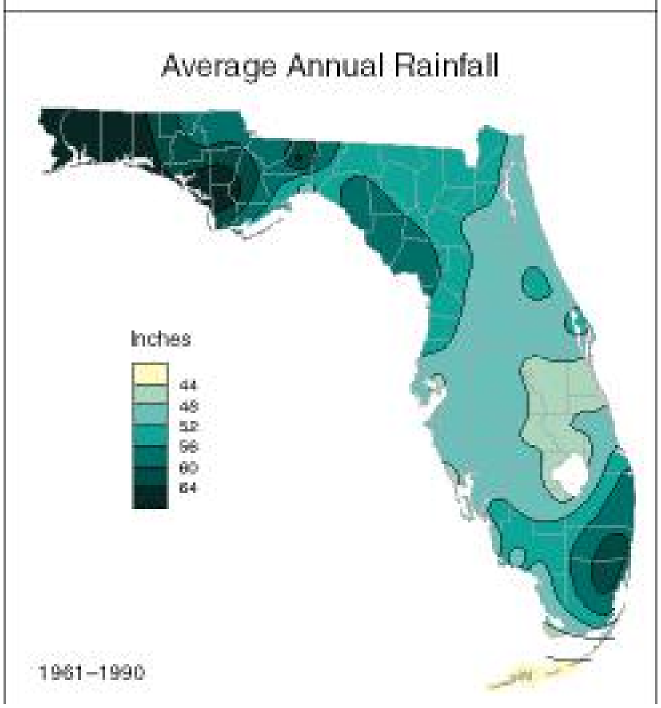
Another climate classification, called the Thornthwaite system, is used frequently by water resource scientists and divides Florida into three types, rather than two. This system includes an indicator of precipitation effectiveness, which considers evapotranspiration as well as rainfall, and it is this indicator (not the humidity of the air) that determines the boundary between humid and subhumid climate types. As can be seen in the figure, the humid tropical class of the Thornthwaite system corresponds approximately with the tropical savanna of the Köppen system.

A third way of denoting regional climate distinctions is the climatological division scheme. Each division is, as nearly as possible, a region of relatively uniform climate within a state. The divisions, of which there are 344 in the conterminous states, are primarily modifications of the old U.S. Department of Agriculture crop reporting districts. Florida has seven climatological divisions, the names of which relate to their geographical location in the state. This approach yields boundaries that are very different from the Köppen and Thornthwaite classifications.

Although some rainfall data are reported on a climatological division basis, such as certain drought indices, nearly all data are for individual stations. Values for 95 stations in Florida are used to describe the climate of the state, emphasizing rainfall characteristics. To facilitate comparison of general climatic maps, international agreement has led to the use of what is called a climatic normal, which is an average of a climatic element, such as rainfall, over a 30-year period, ending with a decade. The averages are computed from the data for the preceding three decades. For some aspects, such as extremes and long-term trends, it is preferable to use all data available for the entire period of collection for each station. Most stations in Florida have nearly complete records since 1948.




Climatological Divisions
Northwest
North
North Central
South Central
Everglades and SW Coast
Lower East Coast
Keys


Average Annual Rainfall
Inches
44
48
52
56
60
64
1961–1990

Study Questions

1. States that border on the Gulf Coast from Louisiana to Florida receive some of the highest amounts of annual rainfall in the United States. Can you think of another area in the conterminous United States that is known for its high amounts of annual rainfall?
2. What is the criteria used by the Koppen Climate Type model?
3. What is the criteria used by the Thornthwaite Climate Control model?
4. Look at the map of "Average Annual Rainfall." Which of the models is most like the annual rainfall map? Explain your answer.

GROUNDWATER

Groundwater is one of Florida's most valuable natural resources. Usable quantities of potable groundwater can be obtained throughout the state, with the exception of a few places, most of which are near the coasts. About 93 percent of Florida's population depends on groundwater for drinking water. Florida ranked fifth in the nation in the use of fresh groundwater in 1995. Because of its abundance and availability, groundwater is the principal source of freshwater for public supply and domestic (rural) and industrial uses. Of the total freshwater used in Florida in 1995, 60 percent was groundwater.

All of Florida is in the Coastal Plain physiographic province, a region of low relief underlain by unconsolidated to poorly consolidated sediments and hardened carbonate rocks. Florida is covered nearly everywhere by sands that overlie a thick sequence of limestone and dolomite. Together, the surficial sands and the limestone and dolomite form an enormous groundwater reservoir that provides more available groundwater than any other state (McGuinness 1963).

Hydrologists have estimated that the total quantity of fresh groundwater in Florida is more than a quadrillion gallons—about one-fifth as much as in all of the five Great Lakes, 100 times that in Lake Mead on the Colorado River, and 30,000 times the daily flow to the sea of Florida's 13 major coastal rivers (Conover 1973).

Nearly all of Florida's groundwater originates from precipitation. Annual precipitation (1951–95) averages over 50 inches per year. Part of this precipitation percolates to the water table and recharges the groundwater reservoir. Annual recharge to groundwater ranges from near zero in some perennially wet, lowland areas to greater than 20 inches per year or more in well-drained upland areas. In much of the state, most of this recharge moves through the surficial sands and discharges downward to deeper aquifers (groundwater reservoirs) or laterally to nearby lakes and streams.

Florida is underlain virtually everywhere by aquifers capable of yielding at least small quantities of potable water to wells. Aquifers are defined on the basis of rock types, geologic confinement, and groundwater flow. An aquifer system consists of two or more hydraulically connected aquifers. A change in the condition of one aquifer affects the other aquifers in the system. In Florida three aquifer systems are used for water supply: the surficial aquifer system, the intermediate aquifer system, and the Floridan aquifer system. Two aquifers within the surficial aquifer system—the sand and gravel and the Biscayne aquifers—are important sources of supply where they occur.

Aquifers in Florida are composed of sedimentary rock units of varying composition and depositional history. These units are divided into geologic formations based on rock composition and physical characteristics. Many units are related by the similarities of the sediments while others may be defined on the sediment heterogeneity. Aquifer systems are defined as a body of rock that is sufficiently permeable to conduct groundwater and to yield economically significant quantities of water to wells and springs. They are identified independently from lithostratigraphic units and may include more than one formation or be limited to only a portion of a formation.

The stratigraphic and hydrogeologic framework of Florida has significant variability from north to south and west to east in the peninsula and the panhandle. The stratigraphic units that comprise the aquifer systems in Florida occur primarily as subsurface units with very limited surface exposures. As a result of the generally low relief of the state, most of the stratigraphic descriptions are from well cuttings and cores used to study the subsurface sediments and rocks.

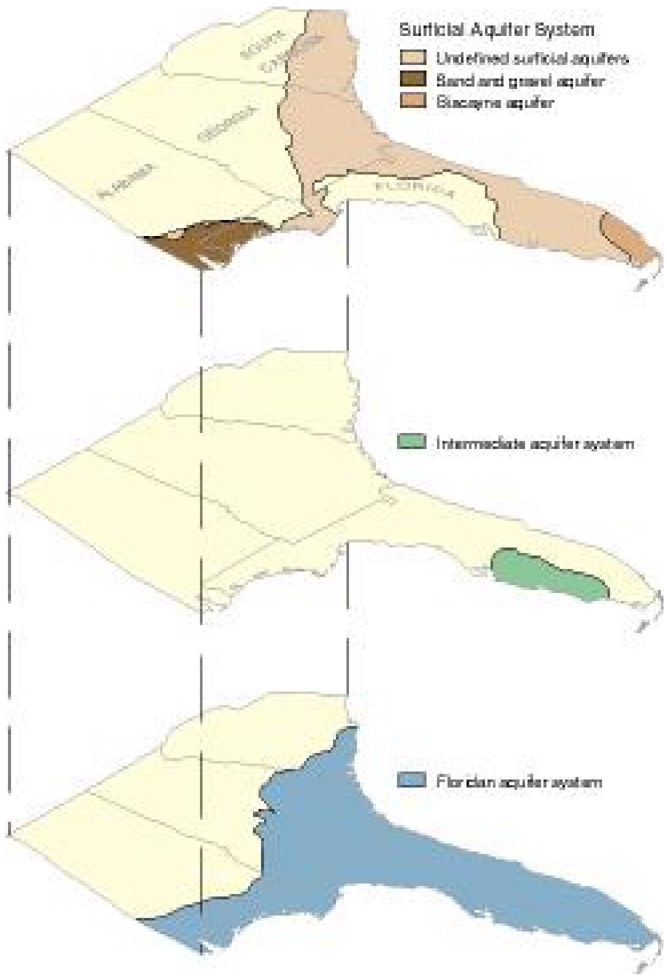
The following description of the stratigraphy of the various units associated with the aquifer systems is brief and generalized. More complete information concerning these groups and formations can be obtained by referring to Florida Geological Survey and U. S. Geological Survey publications relating to specific areas and/or specific aquifers.

The surficial aquifer system consists mostly of unconsolidated sand and includes the sand and gravel and the Biscayne aquifers and all the undefined aquifers present at the land surface. In Florida the surficial aquifer system is used by a few small municipalities as well as by large numbers of individual households. The sand and gravel and Biscayne aquifers are separately recognized parts of the surficial aquifer system that consist of distinct rock types. The sand and gravel aquifer is the major source of water in northwest Florida and the Biscayne aquifer is the major source of water in southeast Florida. Between the surficial aquifers and the Floridan aquifer system in some parts of the state is the intermediate aquifer system. The intermediate aquifer system is an important source of supply in Sarasota, Charlotte, and Glades counties.

The Floridan aquifer system underlies the entire state of Florida and portions of Alabama, Georgia, and South Carolina and has been called "Florida's rain barrel" (Parker 1951).The Floridan provides water for many cities including Daytona Beach, Gainesville, Jacksonville, Lakeland, Ocala, Orlando, St. Petersburg, and Tallahassee as well as for hundreds of thousands of people in smaller communities and rural areas. The Floridan is also intensely pumped for industrial and agricultural supply. In several places where the Floridan contains saltwater, such as along the southeast coast, treated sewage and industrial wastes are injected into it. In the Orlando area large quantities of surface runoff are routinely diverted into the Floridan via drainage wells.

The different aquifers in the state have different capabilities of transmitting water. Transmissivity, expressed in feet squared per day, is a measure of the ease with which water moves through an aquifer. It is calculated by multiplying hydraulic conductivity (volume of water that moves in a unit of time under a unit gradient through a unit area) by the saturated thickness of the aquifer. Hydraulic conductivity is highest in aquifers with large conduits such as caves, sinkholes, and solution channels. However, a thick aquifer (hundreds of feet) will have a higher transmissivity than a thinner aquifer (tens of feet) that has the same hydraulic conductivity. In general, aquifers in Florida have high transmissivities. The highest transmissivities are found in the Floridan aquifer system (10,000 to greater than 1,000,000 feet squared per day) and Biscayne aquifer (100,000 to 1,000,000 feet squared per day), followed by the sand and gravel aquifer (10,000 feet squared per day), the surficial aquifer system (1,000 to 10,000 feet squared per day), and the intermediate aquifer system (200 to 13,000 feet squared per day).

Sequence of Aquifers



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McGuinness, C.L. 1963. The Role of Groundwater in the National Water Situation. U.S. Geological Survey Water-Supply Paper 1800. Reston, Virginia.

Conover, C.S. 1973. Florida's Water Resources. Institute of Food and Agricultural Sciences, University of Florida. The Dare Report-1973, Pub 11. Gainesville.

Parker, G.G. 1951. "Geologic and Hydrologic Factors in the Perennial Yield of the Biscayne Aquifer." American Water Works Association Journal 43:810-843.

Study Questions

1. What is meant by the term "potable water?"
2. If 93% of Floridians depend on groundwater for drinking water, where do the other 7% get their drinking water?
3. What is dolomite? How was it formed?
4. What is a hydrologist?
5. Where does Florida get most of its groundwater?
6. What is meant by "recharging the groundwater?"
7. What is an aquifer?
8. What is the difference between an aquifer and an aquifer-system?
9. Florida has three aquifer-system. Name them in order from shallow to deep.
10. In order to understand the explanation in the reading of how an aquifer works, requires that you understand the terms that are used in the text. Define the following words or phrases.
    A. Sedimentary Rock
    B. Depositional History
    C. Sediment Heterogeneity
    D. Stratographic
    E. Lithostratographic
    F. Petrographic
    G. Unconsolidated Sediments
    H. Transmissivity
11. What aquifer-system has the highest transmissivity? Which one has the lowest?

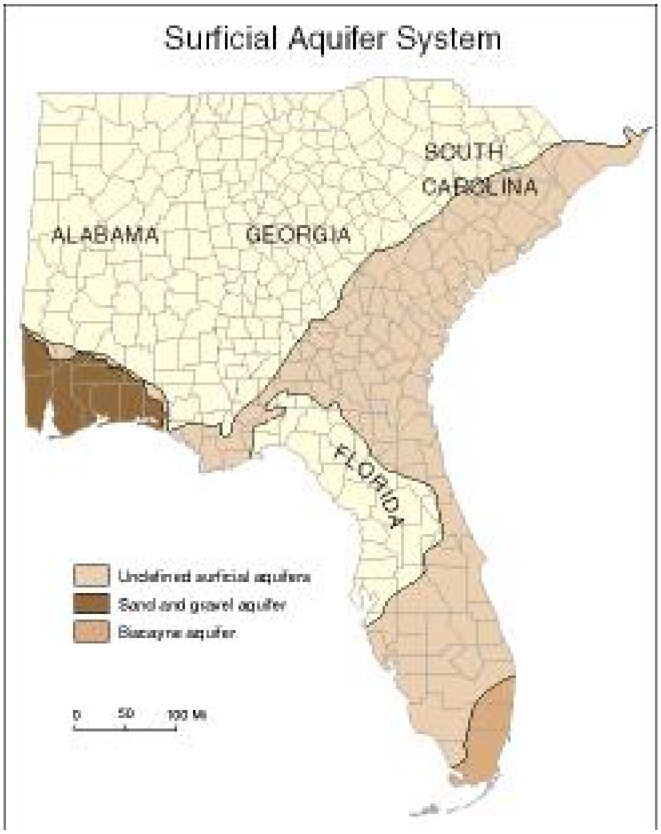
SURFICIAL AQUIFER SYSTEM

The surficial aquifer system in Florida includes aquifers present at the land surface. Even though the sand and gravel aquifer and the Biscayne aquifer are present at the land surface and are hydraulically connected to other surficial aquifers in the surficial aquifer system, they are discussed here as separate and distinct aquifers because of their importance as local water sources. Other parts of the surficial aquifer system occur throughout large portions of Florida and adjacent states and are important sources of water in some small municipalities and in rural areas. The surficial aquifer system is primarily used for individual household wells where the Floridan aquifer system is too deep or contains nonpotable water.

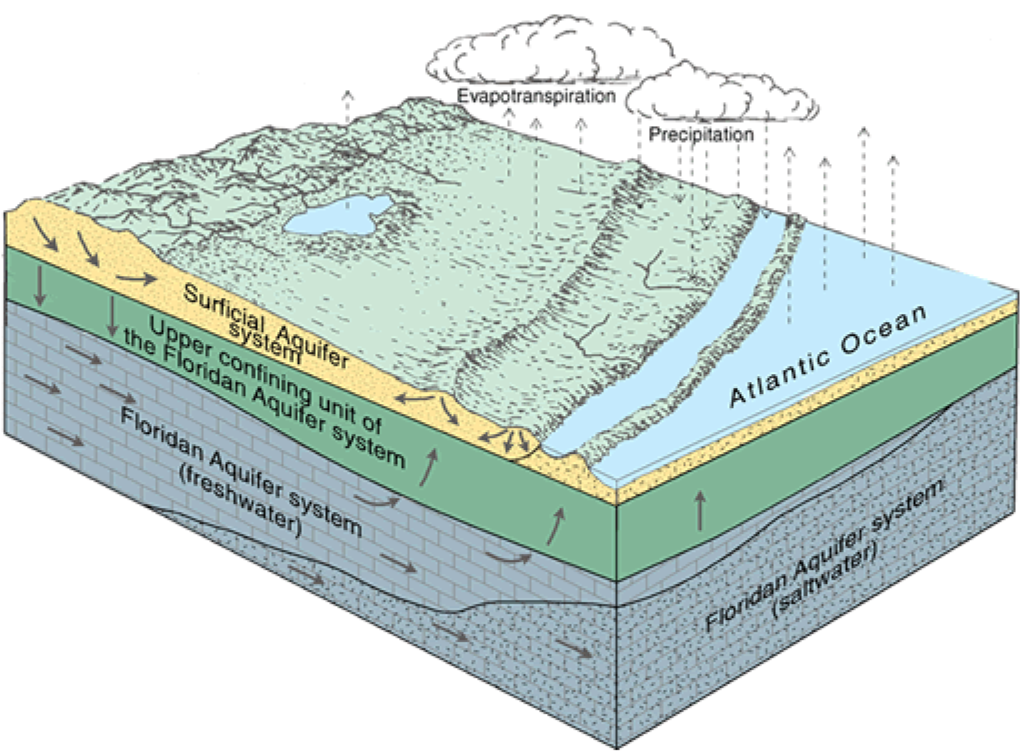
The surficial aquifer system consists mostly of sand, sandy clay, silt, clay, sandstone, limestone, and shell beds. Sandstone and limestone units occur primarily in southwestern Florida. In some places the clays are thick enough and continuous enough to divide the surficial aquifer into two or three separate layers, but generally the aquifer is undivided. Thicknesses of the surficial aquifer system vary across the state and range from tens of feet to several hundred feet in Indian River and St. Lucie counties. The surficial aquifer system is as much as 200 feet thick in Martin and Palm Beach counties and 150 feet thick in eastern St. Johns County. Elsewhere in Florida, the surficial aquifer system is generally less than 100 feet thick.

Groundwater in the surficial aquifer system is unconfined by overlying deposits. Water that enters the aquifer is from precipitation. A large amount of precipitation is returned directly to the atmosphere as evapotranspiration and does not enter the aquifer. Some of the water that enters the aquifer moves quickly along short flowpaths and discharges to lakes and streams. In some places, especially near the coast, water leaks upward from the underlying Floridan aquifer system through the clayey confining unit separating the surficial aquifer and the Floridan aquifer system. In other places, leakage occurs downward from the surficial aquifer to the Floridan aquifer system. The general movement of water in the surficial aquifer is illustrated in the idealized diagram representing the aquifers in south central and coastal Florida.

The altitude of the water table in the surficial aquifer system is generally a subdued replica of the land surface. Relatively steep gradients occur from ridges or hills to streams, and low gradients occur in the low, flat areas between streams and under large topographic highs. Arrows on the map show that the general direction of groundwater flow in the surficial aquifer is toward the Atlantic Ocean, the Gulf of Mexico, or toward major rivers. The directions of groundwater movement can change markedly within short distances.

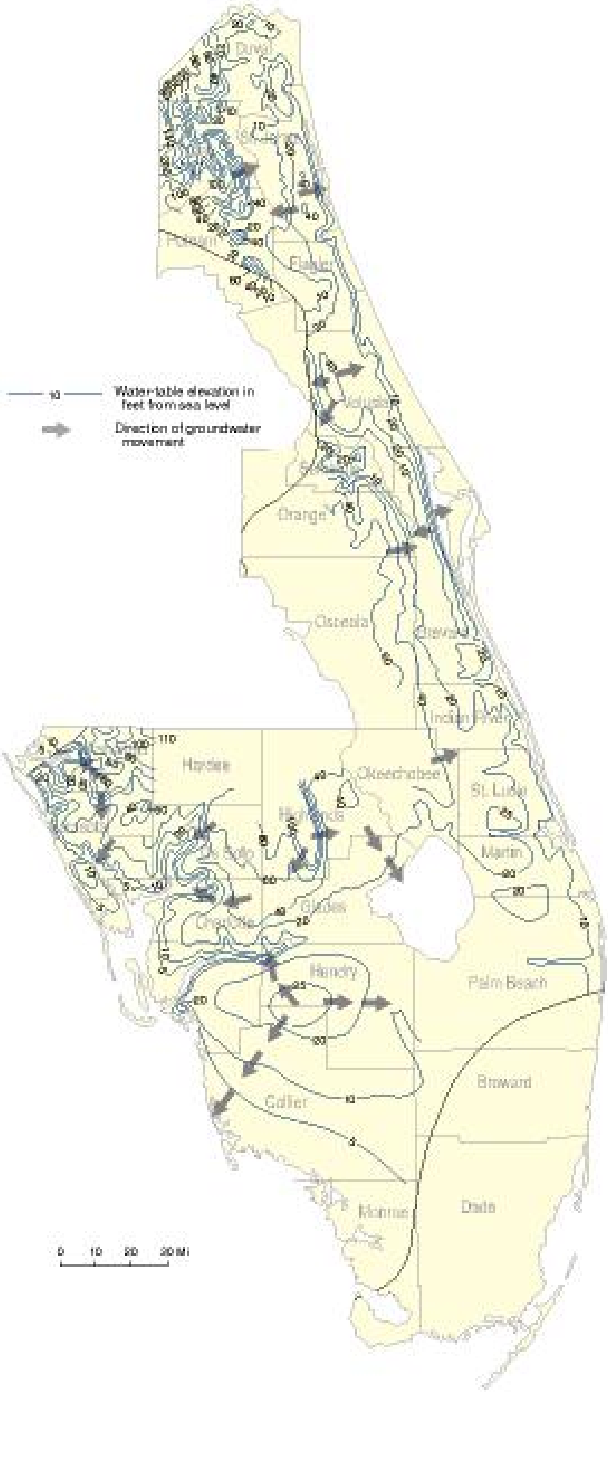


Groundwater Flow



Water-Table Level and Flow

Surficial Aquifer System



Study Questions

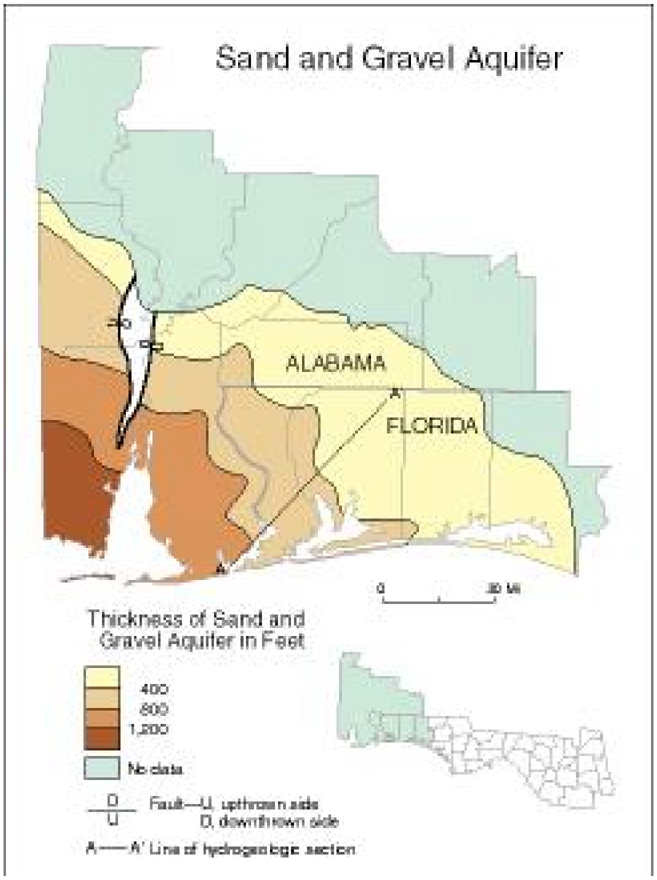
1. What is an unconfined aquifer?
2. Where is the Surficial Aquifer-System most prevalent in Florida?
3. What is the main human use of this aquifer?
4. Because the Surficial Aquifer-System is very shallow it usually takes the shape of the terrain. Look at the map "Water Table Level and Flow." What do the lines with the numbers attached to them signify?
5. What are these lines called?
6. What is the relationship between these lines and the arrows?

SAND AND GRAVEL AQUIFER

The sand and gravel aquifer underlies more than 6,000 square miles of land surface in southwestern Alabama and the western Florida panhandle. It is the major source of groundwater in Escambia and Santa Rosa counties and is a secondary source in Okaloosa and Walton counties. As its name implies, it consists largely of interbedded layers of quartz-rich sand and gravel. Clay beds and lenses are common throughout the aquifer and form local confining beds. The aquifer is wedge-shaped. It is thinnest at its northern and eastern limit and thickest (1,400 feet) in southwestern Alabama. The sand and gravel aquifer has been subdivided into three different hydrologic zones: the upper water-table zone, the intermediate zone, and the lower main producing zone. The upper zone consists mostly of unconsolidated sand of the Citronelle Formation, the intermediate zone consists of less permeable sand and clay deposits, and the main producing zone consists of Miocene age coarse sand and gravel beds. The main producing zone is recharged by downward leakage from the upper zone. The intermediate confining unit underlies the main producing zone inhibiting downward movement of groundwater. Wells in the main producing zone commonly yield more than 1,000 gallons per minute, and the transmissivity is as high as 20,000 feet squared per day.

Water in the aquifer is unconfined where overlying clay deposits are thin or absent and is under artesian conditions where clay deposits are thick and confine water movement. Water enters the sand and gravel aquifer as recharge from precipitation and moves generally downward and downgradient, either discharging to streams or moving toward the coast. The regional flow pattern is affected substantially by pumping. In some locations where heavy pumping from several well fields has occurred, water levels were reported to have dropped 20 to 25 feet from 1940 to 1973 (Trapp 1975).

As is typical of other unconfined surficial aquifers, the sand and gravel aquifer is easily contaminated.



References

Trapp, H. 1975. Preliminary report November 1973, Hydrology of the Sand-and-Gravel Aquifer in Central and Southern Escambia County, Florida. U.S. Geological Survey Open-File Report FL-74027. Tallahassee, Florida.

Study Questions

1. What is an artesian well?
2. What is a confined aquifer?
3. What is the relationship between an artesian well and a confined aquifer?
4. Why is an unconfined surficial aquifer easily contaminated?

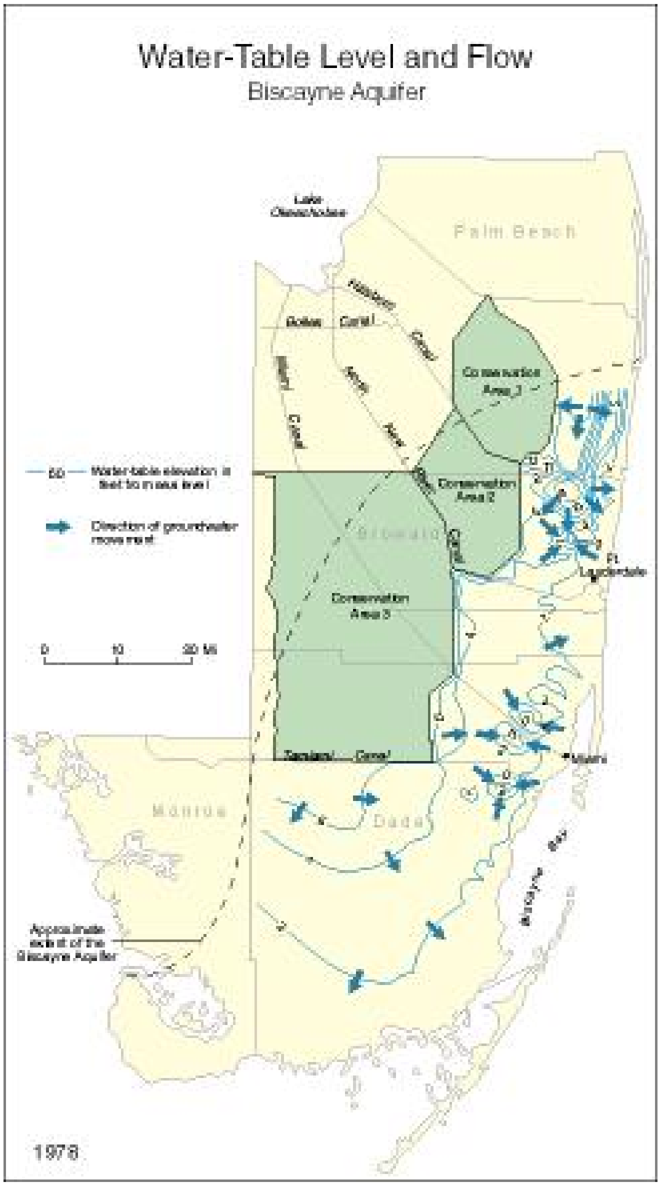
BISCAYNE AQUIFER

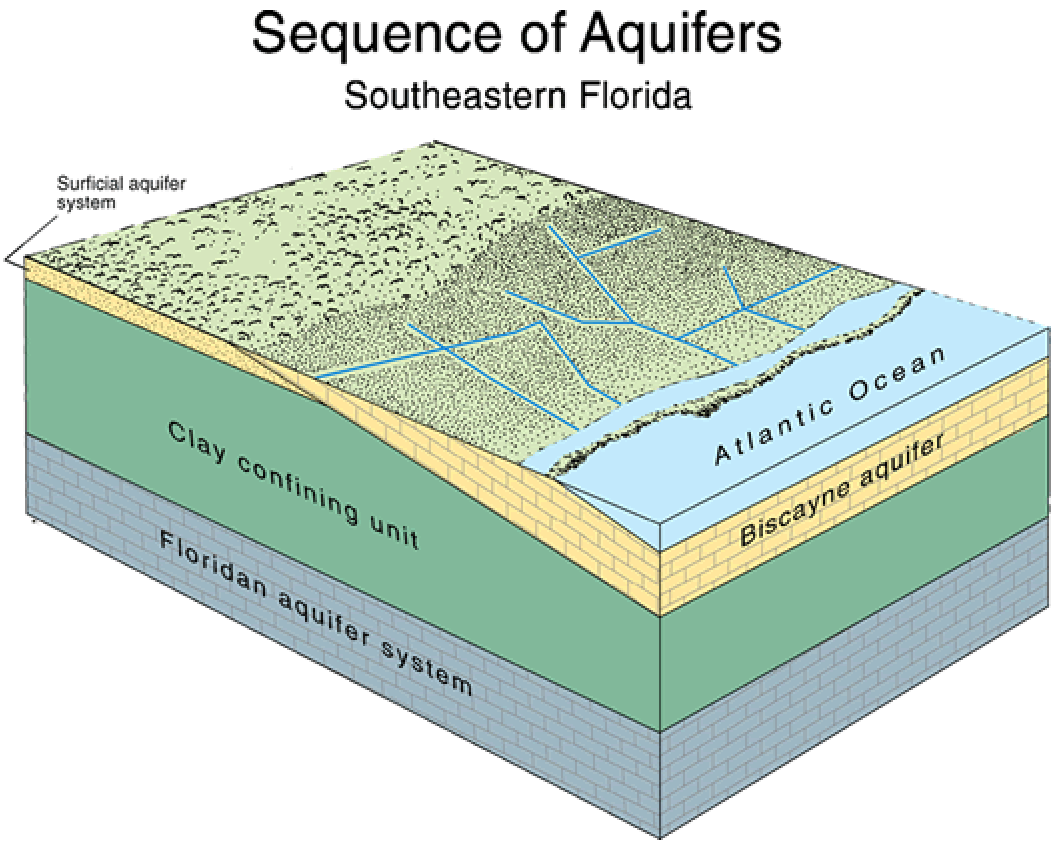
The Biscayne aquifer underlies almost all of Dade and Broward counties and small parts of Palm Beach and Monroe counties. It also extends beneath Biscayne Bay and under the near shore of the Atlantic Ocean, where its highly permeable sediments contain saltwater. The Biscayne aquifer is the sole source of drinking water for over 3 million people in southern Florida. The Biscayne aquifer is wedge-shaped and ranges in thickness from 20 feet on its western edge, to more than 300 feet toward the coast in parts of coastal Broward and Palm Beach counties. The aquifer consists of highly permeable interbedded limestone and sandstone. These highly permeable rocks are covered in most places only by a thin veneer of porous soil. Accordingly, water levels in the aquifer rise rapidly in response to rainfall. The high permeability of the Biscayne aquifer is created largely by extensive dissolution of the carbonate minerals that comprise the limestone units. The thickest and most extensive geologic unit in the Biscayne aquifer is the Fort Thompson Formation. Other units that comprise the aquifer include the Anastasia Formation, Key Largo Limestone, Miami Limestone, and Pamlico Sand.

Before development in southern Florida, a large proportion of the abundant precipitation that fell on the flat, low-lying interior land during the wet season drained southward to the Gulf of Mexico and Florida Bay. Most of this drainage was in the form of wide, shallow sheets of water that moved sluggishly southward. This drainage was a major source of recharge to the Biscayne aquifer. Since the early 1900s, well fields, canals, control structures, levees, and conservation areas have substantially altered natural flow patterns of both surface water and groundwater.

Today, shallow, southward-moving surface water still provides some recharge to the Biscayne aquifer in addition to rain that falls directly on the aquifer. Where the Biscayne aquifer is exposed at the land surface or is covered by only a thin veneer of soil, the slowly moving surface water that passes over the aquifer is able to readily percolate downward into the aquifer. The general movement of water in the Biscayne aquifer is seaward. Water levels are highest near water conservation areas and lowest near the coast. The closed depressions in the water table in eastern Broward and Dade counties are caused by pumpage from major well fields. Withdrawal of large volumes of groundwater has reversed the natural eastward flow pattern of groundwater to westward and has increased the possibility of saltwater intrusion from Biscayne Bay and the Atlantic Ocean.

Canals have been used extensively for drainage and flood control and have lowered groundwater levels and altered groundwater flow patterns in southeast Florida. Levees were also constructed, first to prevent flooding from Lake Okeechobee, and later to impound excess water in three large water conservation areas for later release. A system of canals, levees, control structures, pumping stations and water conservation (storage) areas are used to manage the water resources of southern Florida. The goals of this system are to conserve freshwater, provide flood control, and minimize saltwater encroachment. Saltwater encroachment has long been a concern in southeastern Florida. The installation of canal control structures combined with the impoundment of water in the conservation areas have stabilized the saltwater-freshwater interface near the coast and at the entrances to major canals.


Water-Table Level and Flow
Biscayne Aquifer
Palm Beach
Conservation Area 1
Conservation Area 2
Conservation Area 3
Broward
Dade
Monroe
Tamiami Canal
Miami
Ft. Lauderdale
Direction of groundwater movement
0
10
20 MI
Approximate extent of the Biscayne Aquifer
1978



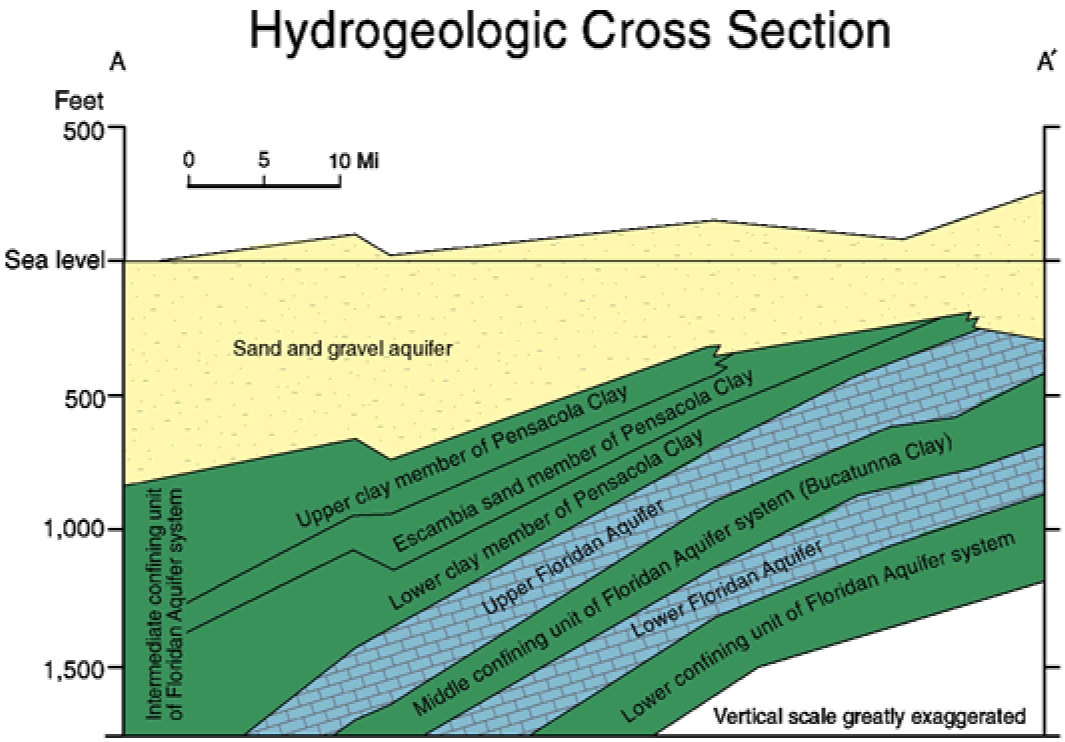
Study Questions

1. Why is the Biscayne Aquifer so very important to certain people of Florida?
2. Define permeable.
3. The Biscayne Aquifer is highly permeable and has historically been subject to rising water levels from rainfall. Since 1900 the water level of the aquifer has fallen. Why has this happened and what has happened to aquifer flow?
4. Why have canal control structures been built in southeastern Florida?
5. Why do you think Dade County (Miami) is interested in some of the larger springs way up in the western panhandle of Florida?

INTERMEDIATE AQUIFER SYSTEM

The intermediate aquifer system consists of those water-bearing units located between the Floridan aquifer system and the overlying surficial aquifers, and consists of one or more water-bearing units separated by confining units. Because of the lower permeability and transmissivity of the intermediate aquifer system compared to the Floridan aquifer system, the intermediate aquifer system acts as a confining unit for the underlying Floridan aquifer system in some places. Because the intermediate aquifer system does not yield as much water as other aquifers, it is used only in places where water from surficial aquifers or the Floridan aquifer system is not adequate in amount or quality. In southwestern Florida, for example, the underlying Floridan aquifer system contains nonpotable water, thus the intermediate aquifer system is the main source of water supply for Charlotte, Lee, and Sarasota counties. The intermediate aquifer system consists predominantly of sand beds and limestone of the Hawthorn Group; and sand, limestone, and shell beds of the Tamiami Formation. The aquifer also contains some sandy limestone, sandstone, and clay beds.

Water in the intermediate aquifer system is under confined conditions, except locally where an upper clay confining unit is absent. In most places, water moves downward through the upper confining unit of the intermediate aquifer system. Most of the water then follows short flowpaths and discharges to surface drainage. Some water percolates downward through the lower confining unit of the intermediate aquifer to rechargeand Lee counties, some water leaks upward from the Floridan aquifer system to the intermediate aquifer system. In Polk County, where the potentiometric surface is more than 120 feet above sea level, the intermediate aquifer system water moves outward from two major recharge areas. From these areas, the lateral flow is toward major surface streams and the Gulf of Mexico. The two depressions in the potentiometric surface in western Sarasota County are caused by pumpage from local pumping stations.



Study Questions

1. Define the term "potentiometric."
2. Where is the Intermediate Aquifer-System located and is it confined or unconfined?
3. Why is the Intermediate Aquifer-System used as a water source in southeastern Florida?
4. Does the Intermediate Aquifer get thicker from north to south or from south to north? How do you know?

FLORIDAN AQUIFER SYSTEM

One of the most productive aquifers in the world, the Floridan aquifer system underlies a total area of about 100,000 square miles in southern Alabama, southeastern Georgia, southern South Carolina, and all of Florida. The Floridan aquifer system is defined on the basis of permeability: it is at least 10 times more permeable than its upper and lower confining units. It is composed of a thick sequence of carbonate rocks (limestone and dolomite) of Tertiary age that range in age from late Paleocene to early Miocene. The aquifer system generally consists of the following geologic units, from oldest to youngest: Oldsmar Formation (lower Eocene age), Avon Park Formation (middle Eocene), Ocala Limestone (upper Eocene), Suwannee Limestone (Oligocene), Hawthorn Group (Miocene), and St. Marks Formation in northern Florida. The Hawthorn Group is part of the Floridan aquifer system where it contains permeable limestone units that are hydraulically connected to the underlying, older rocks. The thickest and most productive units are the Eocene age Avon Park Formation and Ocala Limestone. The Suwannee Limestone of Oligocene age is also a principal source of water, but it is thinner and much less areally extensive than the Eocene units.

The Floridan aquifer system generally thickens toward the south from a thin edge near its northern limit. In most places, the Floridan aquifer system can be divided into three units: the Upper Floridan aquifer, the middle confining unit, and the Lower Floridan aquifer. The middle confining unit restricts the movement of groundwater between the Upper and Lower Floridan aquifers and consists of several separate units. At some locations the confining unit is clay; at others it is a very fine-grained limestone; at still other places it is a dolomite with the pore spaces filled with anhydrite. In some places the middle confining unit yields several hundred gallons per minute to wells and thus may be considered an aquifer. Few supply wells penetrateand because much of the Lower Floridan aquifer contains mineralized or even saline water. South of Lake Okeechobee the entire aquifer system contains saltwater. In places, no middle confining unit exists and the aquifer system is highly permeable throughout its vertical extent.

Two highly permeable zones exist within the Lower Floridan aquifer: the Fernandina permeable zone in northeast Florida and southeast Georgia, and the Boulder Zone in southeast Florida. The Fernandina permeable zone contains large amounts of fresh to brackish water. The Boulder Zone, named not because it contains boulders but because it is difficult to drill into, contains saltwater and is used in the Miami-Ft. Lauderdale area to dispose of sewage and some industrial effluents through injection wells.

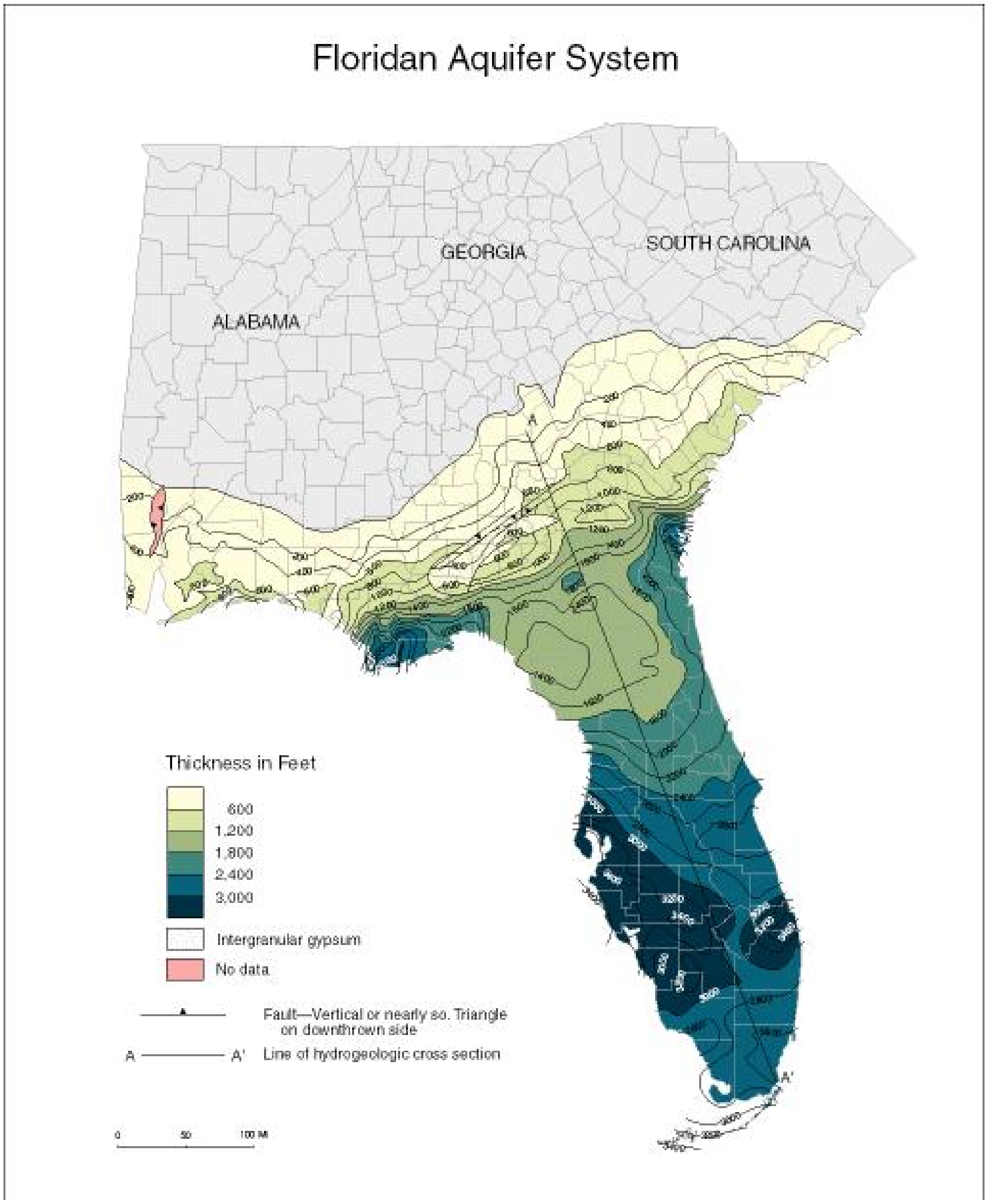
The degree of confinement of the Upper Floridan aquifer is the major hydrogeologic control on the distribution of recharge, discharge, and groundwater flow. Over most of Florida, the Upper Floridan aquifer is overlain by a sequence of sand, clay, limestone, and dolomite that ranges in thickness from a few feet in parts of west central and north central Florida to hundreds of feet in southeastern Georgia, northeastern Florida, southeastern Florida, and the westernmost part of the panhandle of Florida. The overlying sand generally comprises the surficial aquifer system, and the clay and limestone generally comprise the intermediate aquifer system. Both of these aquifers act as confining units to the Upper Floridan aquifer because they are less permeable than the Upper Floridan. Unconfined portions of the Upper Floridan aquifer are located in western parts of north central Florida (north of Pasco County to Wakulla County).

Major (or general) features of the groundwater flow system in the Upper Floridan aquifer are illustrated by a map of its potentiometric surface. The altitude and configuration of the potentiometric surface in 1995 are shown on the map. The arrows show the direction of groundwater movement, which generally is perpendicular to the contours. In the past several decades groundwater withdrawals have had a pronounced effect on the potentiometric surface of the Upper Floridan aquifer in panhandle Florida, northeastern Florida, southwestern Florida, and in southeastern, coastal Georgia.

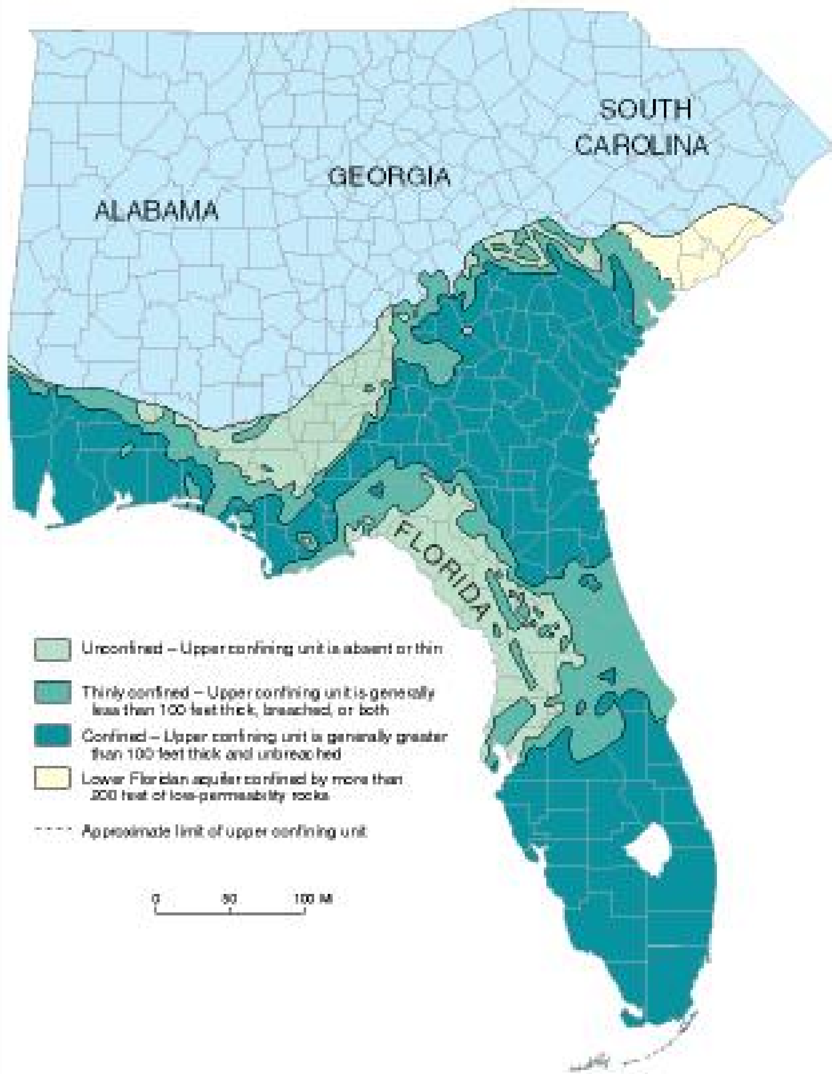
Water in the Upper Floridan aquifer moves from areas of high to low altitude on the potentiometric surface. The highest areas on the Upper Floridan aquifer's potentiometric surface are located where the aquifer is exposed at the land surface near its updip limit and in an area in central peninsular Florida. Water moves coastward from the outcrop area of the aquifer and outward in all directions from the potentiometric surface high in central Florida.

Recharge to the Upper Floridan aquifer (and other confined aquifers) does not occur everywhere but is restricted to places where the altitude of the water table is higher than the altitude of the potentiometric surface of the confined aquifers. Areas with little or no recharge under natural conditions typically occur where the potentiometric surface of the aquifer is above the land surface most of the time, that is, in areas of artesian flow. About 45 percent of the state falls within this classification, mostly in coastal areas and areas south of Lake Okeechobee. Areas of very low recharge occur where the Floridan is overlain by relatively impermeable confining beds that are generally more than 25 feet thick. In these areas recharge rates are estimated to be less than 2 inches per year. Areas of very low to moderate recharge (estimated to rangebetween 2 inches and 10 inches per year) occur where the confining beds are generally less than 25 feet thick or are breached. Where the confining bed is breached or absent, but where the water table and the potentiometric surface of the Floridan aquifer are both close to the land surface, little recharge occurs. Areas of high recharge, which are primarily well-drained upland areas characterized by poorly developed stream drainage and many closed depressions, constitute about 15 percent of the state. Some examples of high recharge areas are the well-drained porous sand ridges of central and west central Florida, including parts of Orange, Lake, Polk, Pasco, and Hernando counties. Many areas where internal drainage through sinkholes connects the land surface to the Floridan aquifer also have high recharge rates, such as in central Polk, north central Pasco, south central Hernando, southwestern Clay, Marion, Sumter, Suwannee, and northwestern Putnam counties. Recharge rates in these areas are estimated to range from 10 to 20 inches per year (Stewart 1980).

These natural recharge conditions in some of these areas have been significantly modified recently by pumping wells. In fact, recharge to the Floridan and other confined aquifers now occurs in some places that were formerly discharge areas.

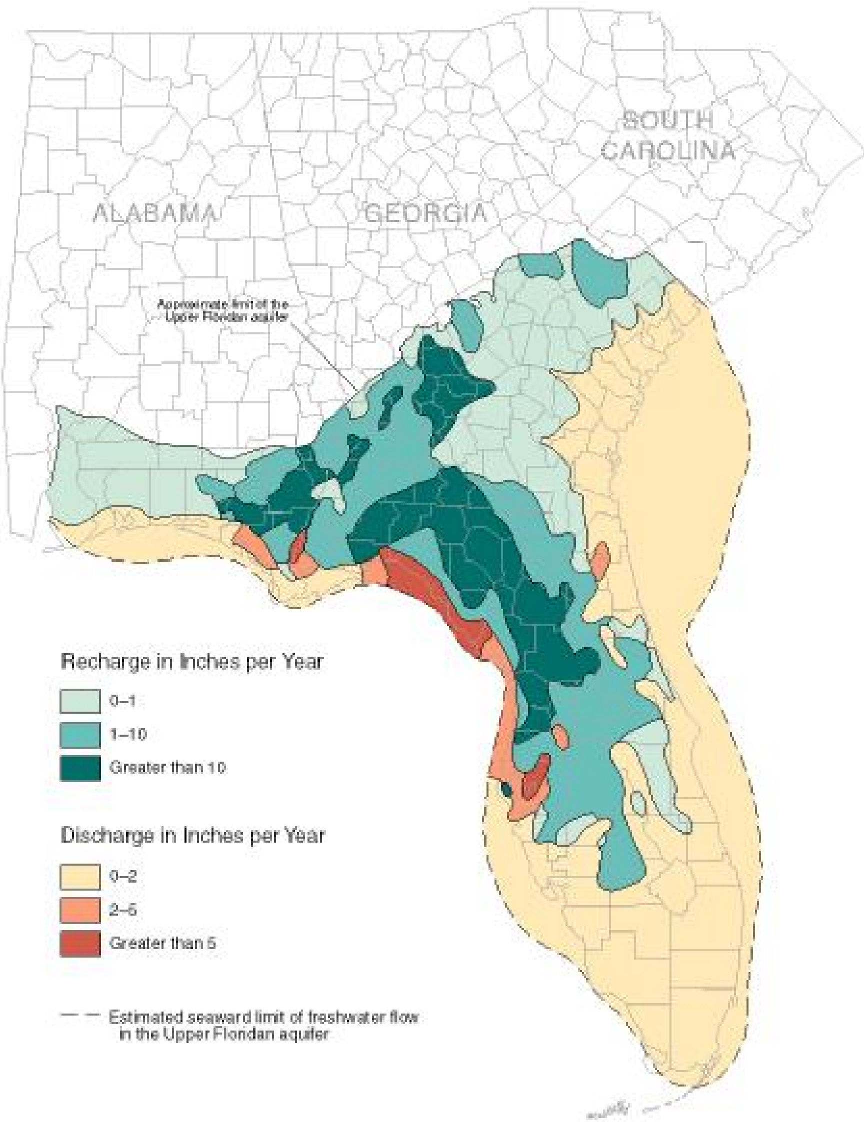

Floridan Aquifer System
GEORGIA
SOUTH CAROLINA
ALABAMA
A
A'
Thickness in Feet
600
1,200
1,800
2,400
3,000
Intergranular gypsum
No data
Fault—Vertical or nearly so. Triangle on downthrown side
A —— A' Line of hydrogeologic cross section
0
50
100 MI

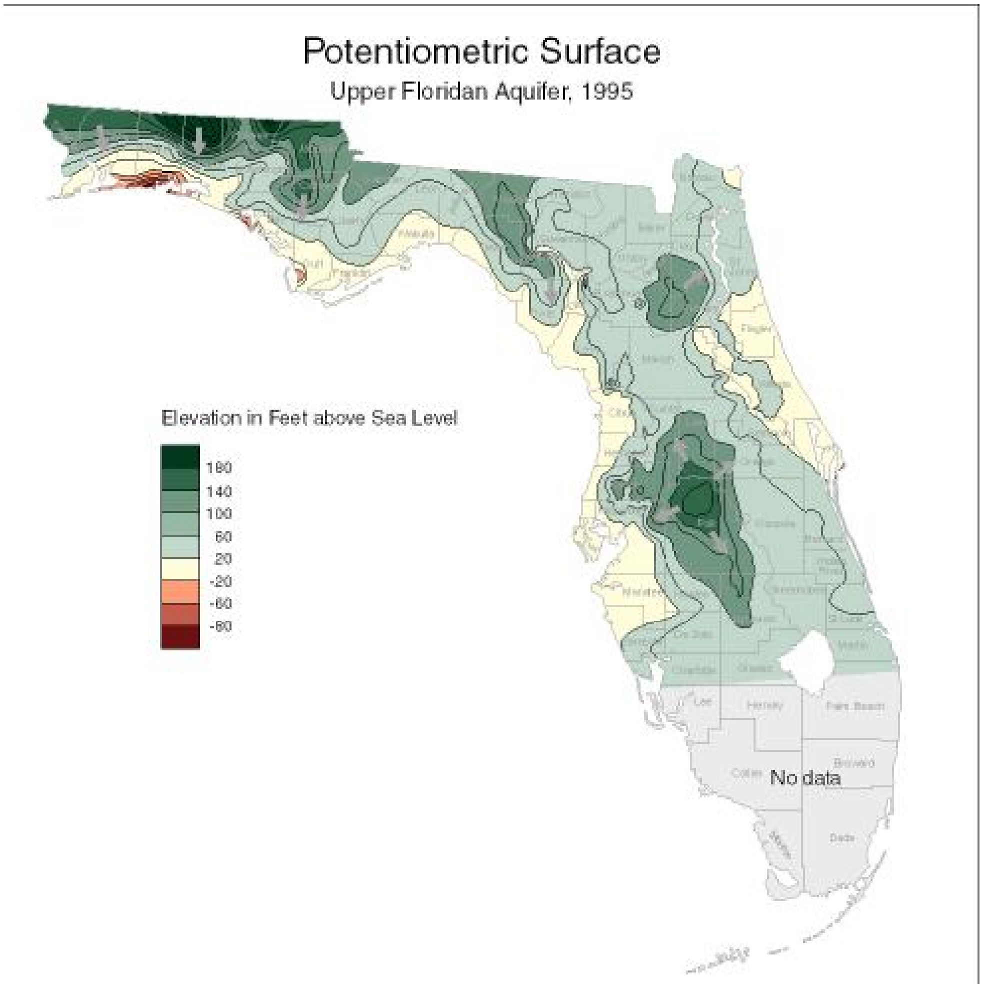
Confinement of the Floridan Aquifer System



Recharge and Discharge

Upper Floridan Aquifer





References

Stewart, J.W. 1980. Areas of natural recharge to the Florida Aquifer in Florida. Prepared by the U.S. Geological Survey in cooperation with the Florida Department of Environmental Regulation. Florida Geological Survey Map Series 98. Tallahassee, Florida.

Study Questions

1. The Floridan Aquifer-System has three divisions, the Upper Floridan Aquifer, the middle confining unit, and the Lower Floridan Aquifer. What does the middle confining unit prevent?
2. Name the three different types of materials that are found in the middle confining unit.
3. What is meant by the term "anhydrite?"
4. Do you think dolomite that contains anhydrite is permeable?
5. Why do you think the way you do?
6. Why don't we sink wells into the Lower Floridan Aquifer, especially south of Lake Okeechobee?
7. What is an injection well?
8. What are the pros and cons of using an injection well?

GROUNDWATER AND SURFACE-WATER INTERACTION

Virtually every surface-water feature in the state, including rivers, lakes, wetlands, and estuaries, interacts with adjacent groundwater. This interaction affects the water quality and quantity in both surface water and groundwater. Groundwater and surface-water interaction affects water chemistry, especially acidity, temperature, dissolved solids, dissolved oxygen, and reduction-oxidation potential. As land and water resource development increases in the state, it is becoming readily apparent that groundwater and surface-water interaction must be considered in establishing water management policies. This interaction can take many forms but the most common interactions are between aquifers and stream water, lakes, and wetlands. In coastal areas, interactions between aquifers and seawater occur. All of these interactions occur in Florida.

Streams interact with aquifers in two ways: either they receive water from groundwater inflow or they lose water to aquifers by seepage through the streambed. For many streams in Florida, the flow direction between the stream and aquifer can vary a great deal, sometimes over very short timeframes or distances in response to rapid rises in stream stage or stream flow, commonly from storm runoff. If the rise in stream stage is great enough to overtop the banks and flood large areas of land surface, widespread recharge to groundwater may occur throughout the flooded areas.

The presence of karst features sometimes makes streams and aquifer interaction even more obvious. Karst is a type of topography that is characterized by caves, sinkholes, springs, and other types of openings caused by dissolution of limestone. One of the largest karst environments in the country occurs from the central portion of the Florida peninsula to the big bend portion of the panhandle. In this area the Santa Fe River, a major tributary to the Suwannee River, completely goes underground, becoming part of the groundwater flow system before reemerging as a river three miles downgradient. Interaction between surface water and groundwater in this highly porous karst aquifer system is quite rapid and can significantly impact water quality. The water quality of streams flowing over this karst terrain can be improved or degraded by the addition of groundwater from large springs such as in the lower Suwannee River basin, depending upon the composition of the groundwater. In the Suwannee River a significant portion of the nitrogen load is being contributed from groundwater discharging to the river. During low flow periods in the river, groundwater is the predominant if not sole contributor of water to the river, introducing low dissolved oxygen concentrations which change the river's chemical conditions enough to significantly influence the movement of fish populations in portions of the river. In the St. Johns River basin, over half of the flow in the Ocklawaha River, a major tributary to the St. Johns, is groundwater from Silver Springs.

Aquifer and lake interaction frequently occurs when lakes receive groundwater inflow through part of their bed and have seepage to groundwater through other parts of their bed. Some lakes receive substantial amounts of their water from groundwater. The water levels in lakes generally do not change as rapidly as water levels in streams. Evaporation has a greater effect on lake levels than on stream levels because the surface area of lakes is greater and lake water is not replenished as readily as stream water.

Lake levels can be reduced by groundwater withdrawals and can be increased by groundwater return flows from irrigation and other applications of water to the land surface. The accounting of the groundwater components can be difficult and controversial. In the west central portion of the state, the drying of lakes has been attributed to excessive groundwater pumpage to meet the public water supply needs. As these needs increase in west central Florida, the possibility of transporting water from nearby watersheds is being considered, namely from the lower Suwannee River watershed. Concern for the Suwannee River and its direct connection with the Upper Floridan aquifer is driving recent research to determine potential groundwater pumpage effects on stream flow in the Suwannee River.

Similar to streams, wetlands can receive groundwater inflow, recharge to groundwater, or do both. In Florida, wetlands have interactions with groundwater similar to streams and lakes. Many wetlands are present along streams, especially slow-moving streams. Wetlands along streams and in coastal areas have complex hydrological interactions because they are subject to periodic water level changes. Some wetlands in coastal areas are affected by predictable tidal cycles. Other coastal wetlands are more affected by predictable tidal cycles. Other coastal wetlands are more affected by seasonal water level changes and by flooding. A major difference between lakes and wetlands is that lakes commonly have a shallow zone around their perimeter, permitting waves to remove fine-grained sediments. In wetlands, fine-grained and organic sediments commonly extend to their shoreline (border), resulting in reduced transfer of water between groundwater and surface water in the wetlands.

In coastal areas in south Florida, rapid population growth has greatly increased the demand for water. If too much fresh water is pumped out of the Biscayne aquifer to meet this demand, sea water intrudes to replace the freshwater, contaminating the water supply. Canals constructed to prevent flooding in southern Florida rapidly remove excess surface water and groundwater from inland parts of the aquifer to coastal areas. Control structures near the mouths of canals allow groundwater levels near the canals in coastal areas to remain high enough to retard saltwater encroachment during periods of less than normal rainfall. However, this connection also means that pollutants in canal water from inland areas and saltwater from coastal areas can move through the canals and into the aquifer. The extensive canal system has also altered inland biologic communities dependent on shallow groundwater in the Everglades and wetland areas. Efforts are underway to better understand the interaction between groundwater and sea water in south Florida, so that further contamination can be prevented. This improved understanding can be applied to the management of the system of canals, levees, control structures, pumping stations, and water conservation (storage) areas to preserve the freshwater resources of southern Florida.

Study Questions

1. What are the two ways that streams interact with aquifers?
2. What is karst topography?
3. Geographically, where is the major karst area located in Florida?

SPRINGS

Springs have long been one of Florida's most valued natural and scenic resources. In 1513 the Spanish explorer Ponce de León came to Florida seeking a spring called the Fountain of Youth. Native Floridians used springs for water supply and fished in the streams formed by the springs. Many of Florida's springs are now tourist attractions. Several springs have been developed commercially, including Silver and Rainbow, while others have been incorporated into state parks, including Manatee, Homosassa, Wakulla, and Ichetucknee.

Numerous springs probably occur off the coast of Florida, but most are difficult to detect. Submarine springs sometimes can be detected by the appearance of a "boil" at the water surface. Many of these submarine springs are located near the coast, but a few are up to 20 miles offshore.

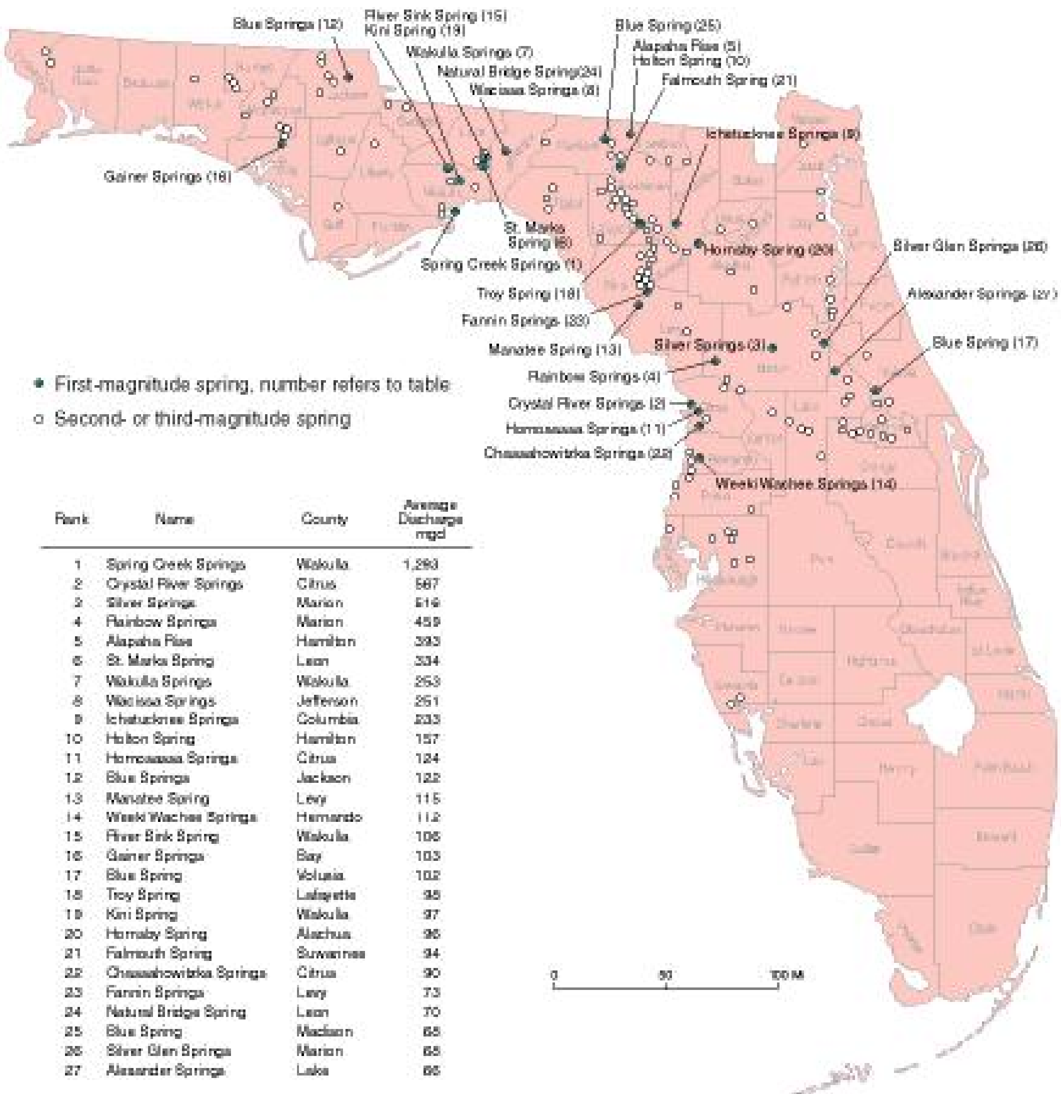
Springs are common in karst areas and are places where groundwater discharges through natural openings in the ground. Florida has about 320 known springs. The outflows from the springs range from less than 1 gallon per minute to 1.3 billion gallons per day at Spring Creek Springs, a group of submarine spring vents off the coast of Wakulla County. The known springs have a combined outflow of nearly 8 billion gallons of water per day. Florida has 27 first-magnitude springs or groups of springs (with flow greater than 64.6 million gallons per day) out of a total of 78 in the nation. All of the springs issue from the Upper Floridan aquifer, and nearly all of them are located in areas where the confining unit above the Upper Floridan aquifer is absent or is less than 100 feet thick. The distribution of large springs discharging from the Upper Floridan aquifer is the direct result of dissolution of carbonate rocks, which results in the development of large conduits and caves. Many of these conduits channel the groundwater to the land surface where they become the orifices of major springs.

The natural flow, water quality, and water temperature of large artesian springs remain relatively stable over long periods. Springs can serve as indicators of trends in hydrologic conditions. Records of spring flow are generally more representative of the character of a large part of an aquifer than are records of well flow. Although spring flow is relatively stable over a long period, it does reflect long- and short-term variations in recharge from rainfall as well as changes in water quantity and quality brought about by human activities. Silver Springs, about 5 miles northeast of Ocala and the largest noncoastal spring in Florida, shows a remarkable long-term consistency in flow with short-term variations. The average flow since 1906 has been 530 million gallons per day (mgd), essentially the same as the earliest recorded flow of 531 mgd in 1898. Flow, however, has ranged from 348 to 833 mgd, reflecting variations in amount of rainfall (Heath and Conover 1981).

Large withdrawals of water from wells near a spring can reduce pressure in the aquifer to a level below the spring orifice and thus stop the flow. The only large spring in Florida known to have ceased flowing is Kissengen Spring, about 4 miles southeast of Bartow. The average discharge of the spring, was about 19 mgd. As withdrawals from wells in the area increased, the decline in artesian pressure caused the spring to cease flowing in February 1950 (Peek 1951).

Water quality of Florida's freshwater springs is relatively constant. For example, the water quality of Wakulla Springs remains essentially the same as it was half a century ago. Although groundwater issuing from springs is usually clear, under certain conditions spring water can be turbid or contain brown organic matter, which is typical of many surface waters in Florida. Where turbid water recharges an aquifer near a spring, the water can move quickly, and minimally altered in quality, through solution channels and emerge at the spring. This is common for some springs in Florida, especially following heavy rainfall. The temperature of springs varies only about 4°C (7.2°F) and averages about 29°C (84°F) in southern Florida and 21°C (70°F) in northern Florida.

Springs



Rank	Name	County	Average Discharge mgd
1	Spring Creek Springs	Wakulla	1,293
2	Crystal River Springs	Citrus	567
3	Silver Springs	Marion	519
4	Rainbow Springs	Marion	459
5	Alapaha Rise	Hamilton	393
6	St. Marks Spring	Leon	334
7	Wakulla Springs	Wakulla	253
8	Wacissa Springs	Jefferson	251
9	Ichetucknee Springs	Columbia	233
10	Holton Spring	Hamilton	157
11	Homosassa Springs	Citrus	124
12	Blue Springs	Jackson	122
13	Manatee Spring	Levy	115
14	Weeki Wachee Springs	Hernando	112
15	River Sink Spring	Wakulla	106
16	Gainer Springs	Bay	103
17	Blue Spring	Volusia	102
18	Troy Spring	Lafayette	95
19	Kini Spring	Wakulla	97
20	Hornsby Spring	Alachua	96
21	Falmouth Spring	Suwannee	94
22	Chassahowitzka Springs	Citrus	90
23	Fannin Springs	Levy	73
24	Natural Bridge Spring	Leon	70
25	Blue Spring	Madison	65
26	Silver Glen Springs	Marion	65
27	Alexander Springs	Lake	66

References

Health, R.C., and C.S. Conover. 1981. Hydrologic Almanac of Florida. U.S. Geological Survey Open-File Report 81-1107. Tallahassee, Florida.

Peek, H.M. 1951. Cessation of Flow of Kissengen Spring in Polk County. Florida Bureau of Geology Report of Investigations 7, Part 3. Tallahassee, Florida.

Study Questions

1. Define a "spring."
2. What is a first-magnitude spring? How many does Florida have?
3. Where are most of the springs located in Florida?
4. How does the location of the springs compare to the location of the karst areas? Why is this true?

SINKHOLES

Sinkholes are closed depressions in the land surface formed by the dissolution of near-surface rocks or by the collapse of the roofs of underground channels and caverns. Sinkholes are a natural, common geologic feature of limestone erosion (dissolution) in karst areas of Florida. Dissolution of rocks is enhanced where groundwater flow is concentrated and most vigorous. In the Floridan aquifer system, the greatest dissolution occurs where the confining unit above the system is thin or absent. Under natural conditions, sinkholes form slowly and expand gradually. Activities such as dredging, constructing reservoirs, diverting surface water, and pumping large amounts of groundwater can accelerate the rate of sinkhole expansion, resulting in the abrupt and dramatic formation of collapse-type sinkholes.

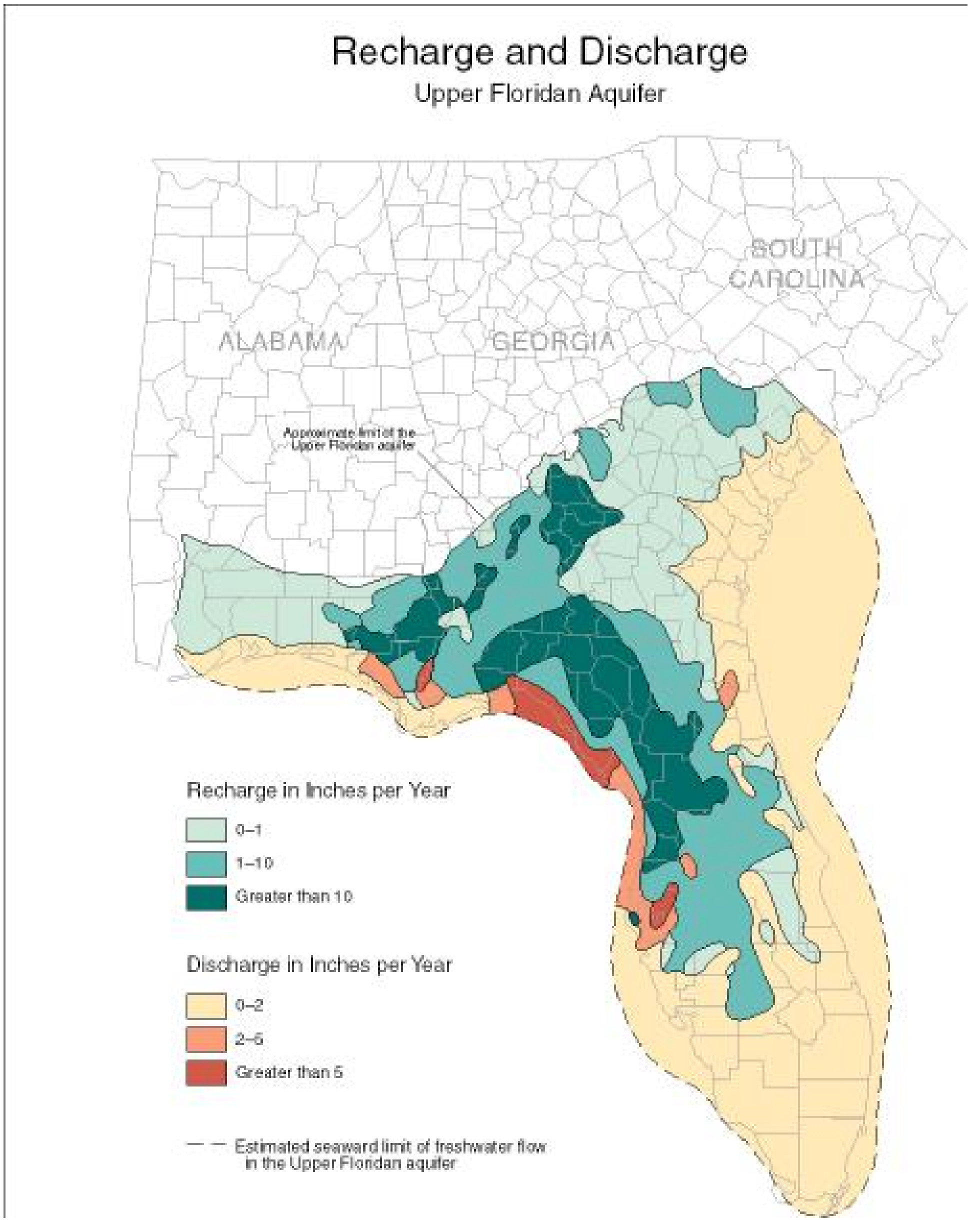
Vertical or near-vertical cracks or fractures in the limestone concentrate or control downward flow of groundwater. These fractures, called joints, commonly occur in intersecting sets. Some sinkholes occur randomly, but others are aligned along joints and at joint intersections. Groundwater can enlarge the pre-existing joints in the limestone and can eventually form caves, pipes, and other types of cavities and conduits, all of which collect and channel large volumes of water.

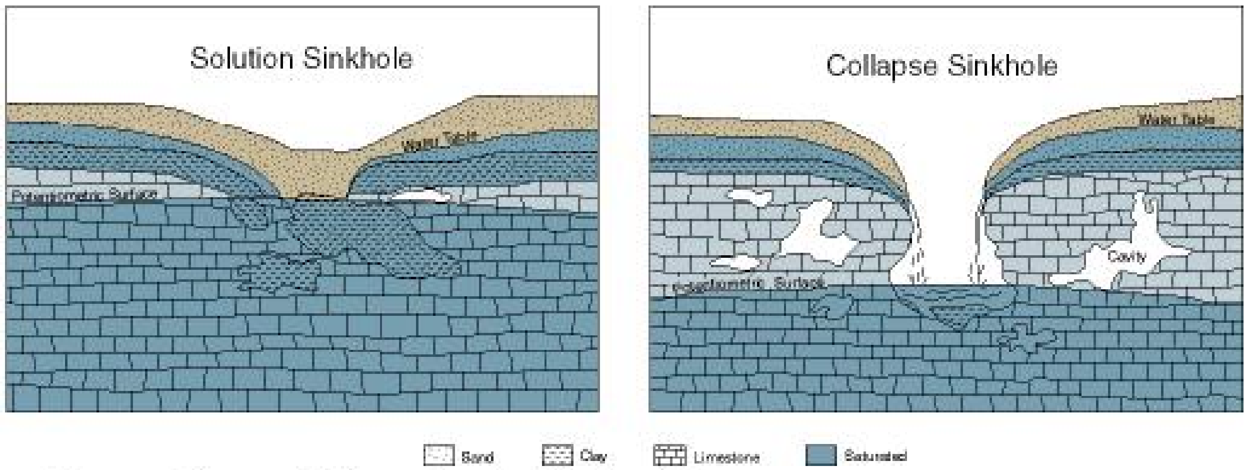
Sinkholes in Florida can be classified into three types, based on the manner in which they form: solution sinkholes, gradually subsiding sinkholes, and collapse sinkholes.

Solution sinkholes occur where the limestone surface is bare or thinly covered by soil or permeable sand. Solution is most active at the contact between the limestone surface and the overlying soil, and is usually concentrated at the intersection of a set of joints where fracturing of the limestone permits water to move easily to the subsurface. The most common type of sinkhole usually results from subsidence at the land surface at approximately the same rate as dissolution of the underlying limestone. The result is a gradual downward movement of the land surface, which develops into a depression that collects increasing amounts of surface runoff as its perimeter expands. This type of sinkhole usually forms as a bowl-shaped depression with the slope of its sides determined by the rate of subsidence relative to the rate of surface eroding into the depression. Surface runoff commonly carries sand, silt, and clay particles into the depression and thus forms a less permeable seal in the center of the depression where a marsh or intermittent lake may form.

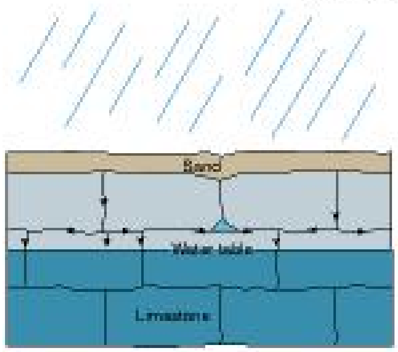
Gradually subsiding sinkholes occur where the limestone is covered by 50 to 100 feet of permeable sand. Under these conditions, individual grains of sand move downward in sequence replacing grains that have themselves moved downward to occupy space formerly held by the dissolved limestone. Spalling of incohesive sand into solution cavities along joints in the limestone can cause subsidence due to upward growth or migration of the cavities, and form holes at the land surface. Gradually subsiding sinkholes may be only a few feet in diameter and depth. Their small size is because cavities in the limestone cannot develop to appreciable size before they are filled with sand.

Collapse sinkholes occur where the limestone is covered by permeable sand and relatively cohesive clay. They occur where a cavity grows in size until its roof of sand and clay no longer supports its own weight. When this occurs, collapse is generally abrupt and sometimes catastrophic. Collapse sinkholes commonly occur where limestone is near the land surface but can also occur where the limestone is hundreds of feet below the surface. Locations of sinkholes are usually controlled by joints in the limestone that have influenced development of solution cavities. Collapse sinkholes commonly have vertical or overhanging walls and may be angular rather than round because of the positioning of joints. The large sinkhole that developed May 8, 1981, in Winter Park, Florida, illustrates the magnitude of a large cover-collapse sinkhole.

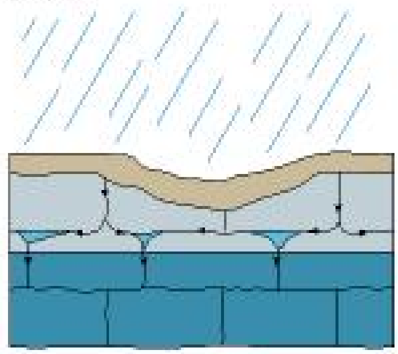




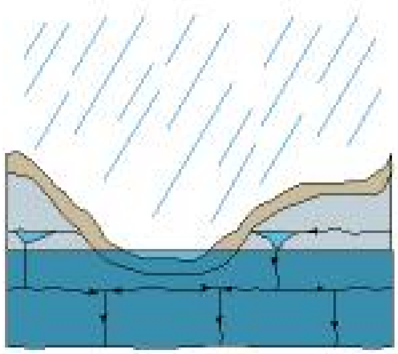
Formation of Gradually Subsiding Sinkholes



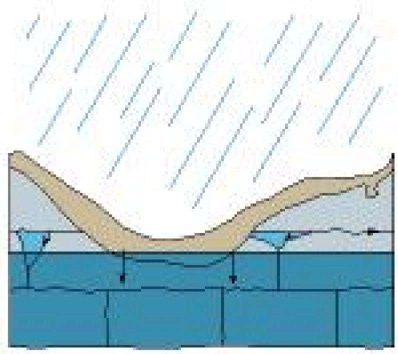
Water percolates through joints in limestone to the water table. The rock adjacent to the joints dissolves faster than elsewhere.



Differential solution of limestone is expressed by a depression at land surface that funnels water to the enlarged joints.



Sinkhole intersects the water table. Rate of dissolution is greatly reduced and may be less than that in surrounding area.



Sinkhole is expressed as a shallow, sand-filled depression because of clay and clayey sand filling, and subsidence of surrounding limestone.

Study Questions

1. Define a sinkhole.
2. Name the three types of sinkholes found in Florida and describe how each is formed?

GROUNDWATER USE AND EFFECTS ON WATER LEVELS

Groundwater has long been a valuable source of plentiful, good-quality drinking water in Florida. About 93 percent of the state's population (14 million residents) relied on groundwater for their drinking water supply in 1995. Most of those people rely on the Upper Floridan aquifer, the Biscayne aquifer, and the surficial aquifer system for their water supplies. The sand and gravel aquifer and intermediate aquifer system are used much less, and only locally in northwestern and southwestern coastal parts of the state. The abundant supply of groundwater is vital to the state's important tourism and agricultural industries in addition to residential usage.

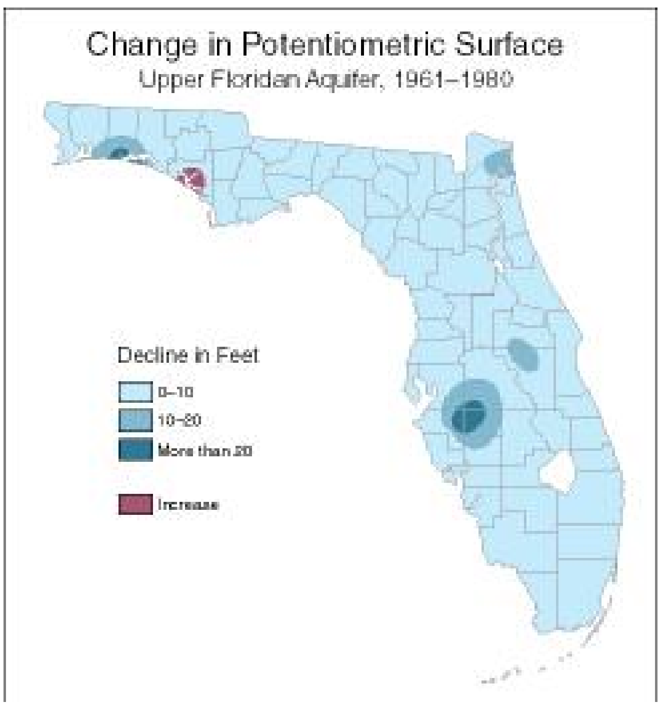
Because of differences in the distribution of population and agriculture, water use varies greatly around the state. The largest amounts of groundwater used were in southeastern and central areas: Dade, Polk, Broward, Orange, and Palm Beach counties. Dade and Broward withdrawals are from the Biscayne aquifer, Polk and Orange from the Upper Floridan aquifer, and Palm Beach from the Biscayne and other surficial aquifers. Most of the water used in these counties is for agriculture and public supply, although Polk County withdrawals also include large amounts of water for phosphate mining.

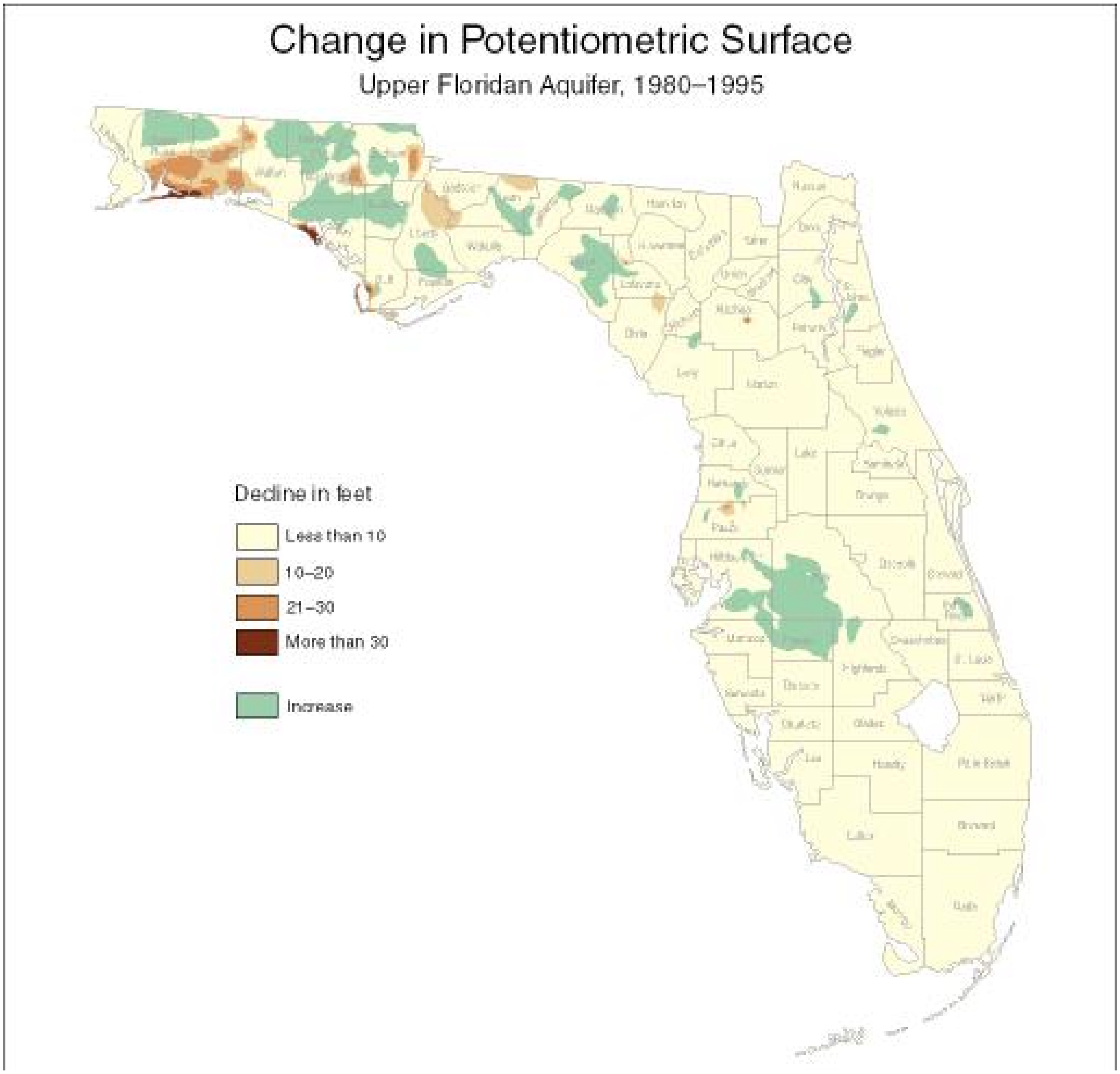
To assess the impact of groundwater withdrawals and pumping on the water supply in an aquifer, periodic measurements are made of water levels in wells. These water levels are measured at various intervals, but measurements are made at least once every five years in a large group of wells in the Upper Floridan aquifer to assess current water levels and to monitor changes over time. In some wells, water levels are measured over long time periods, and graphs can be prepared showing long-term changes in water levels. Groundwater levels decline when wells are pumped and rise when pumping is reduced. Water levels also respond to recharge from rainfall, droughts, and seasonal changes in water demands for drainage, irrigation, public supply, and industry. Irrigation is the largest user of groundwater in Florida and usage varies seasonally and annually in relation to the amount of rainfall. In areas with increased groundwater pumping, water levels have declined over time. When pumping ceases or is reduced substantially, water levels can recover to former levels.

Groundwater levels can fluctuate in response to groundwater management activities, such as control of the discharge in canals in southeastern Florida. The water levels in the Biscayne aquifer in Dade County near Homestead show seasonal changes of as much as eight feet in the early years before water-management control was fully effective, whereas in recent years seasonal changes have been about 4 feet. In general, construction and control of drainage canals have lowered the high seasonal groundwater levels and raised the low seasonal groundwater levels near the coast. Also, despite experiencing large withdrawals in a concentrated area, the Biscayne aquifer in Dade County has not exhibited noticeable declines in water levels. Management of water withdrawals and the extremely high permeability and high recharge rate for the Biscayne aquifer are probably responsible for the lack of decline in water levels.

Saltwater encroachment into groundwater supplies caused by large groundwater withdrawals is a concern in Florida, and of most concern in coastal areas. Saltwater encroachment into freshwater aquifers has several possible mechanisms, including the presence of pockets of relict seawater in the aquifers; lateral movement of saltwater in coastal areas; upconing of saltwater from deeper zones below the pumping zone; upward leakage of saltwater from deeper zones through uncased or improperly constructed wells; upward leakage of saltwater from deeper zones through breached confining units or through joints, faults, or collapse features; and through abandoned or improperly plugged exploratory holes drilled for testing for the presence of petroleum and other minerals and aggregates. These mechanisms are exacerbated by the pumping of large amounts of groundwater. Studies have been done to determine the extent of saltwater encroachment in northeastern, southeastern, southwestern, and west central parts of Florida. Construction of canals and control structures has helped control saltwater encroachment in southeastern Florida. Other parts of the state have not been as strongly impacted by saltwater encroachment.

Despite concerns about groundwater quality and quantity, declining water levels in some areas, and saltwater encroachment, the Upper Floridan aquifer has large areas that contain large quantities of high quality water for public supplies. This includes areas where the aquifer is thick, transmissivities are high, recharge amounts are large, and water quality is unaffected by saltwater encroachment. Because many of these areas include places where the aquifer is unconfined and karst features such as sinkholes and springs occur, these areas can be extremely vulnerable to contamination from surface sources. Potential sources of contamination include waste disposal impoundments, underground storage tanks, drainage wells, septic tanks, landfills, hazardous waste sites, and agricultural chemicals.





Study Questions

1. What aquifers are used by 93% of Florida's population?
2. How do State scientist monitor the supply of groundwater?
3. What is a real danger that can occur by pumping large amounts of groundwater from areas near a coast?
4. What are five sources of contaminants that can pollute an aquifer?
5. What are the characteristics that make an aquifer susceptible to groundwater pollution?

Surface Water

Rivers, lakes, and wetlands are an integral part of the physical and human landscape. They are important for their resources, in addition to their relation to settlement, industry, navigation, and agriculture. Flow and form of rivers and lakes and adjacent wetlands vary spatially and temporally in response to both natural and human factors. Understanding these variations is essential for a variety of concerns, including flood control, engineering structure design, water supply, biotic habitat, navigation, hydroelectric power, and recreation.

Drainage Systems in Florida

A drainage basin is an area on the land surface from which water flows to a stream or lake. Drainage basins are separated from adjacent basins by topographic divides. Portions of drainage basins of several large rivers in Florida are in Alabama and Georgia. Local topography controls the drainage direction and patterns. For management purposes the state has been divided into five surface water regions: the Northwest, Suwannee River, St. Johns River, Southwest, and Kissimmee-Everglades, generally corresponding to directions of surface water flow.

Geology as well as topography influences drainage systems and surface waters. Surficial sediments in Florida are both clastic (derived from weathering of rocks) and carbonate (derived from precipitation of carbonate minerals in solution and biologic processes). Where carbonate sediments are at or near the surface, karst topography typically develops. The landscape is characterized by sinkholes, caves, and underground drainage formed by dissolution of the carbonate sediments. Drainage patterns of karst landscapes are often characterized as disjointed, because rivers and creeks are not always continuous on the land surface and may disappear underground in local sinks or depressions. Karst areas generally have fewer large streams and tributaries than non-karst areas, but better developed underground drainage, such as caves and other underground conduits. Karst areas of Florida have more streams than karst areas elsewhere, partly because of high water tables, low topographic relief, and proximity to sea level. Geology also influences the subsurface drainage, and the groundwater basin contributing to a stream may be quite different from the topographic basin.

Some portions of Florida are poorly drained; that is, there are few or no channels, even though water flows across the surface. Extensive marsh or swamp areas, where the surface is almost flat, have poorly defined drainage. In Florida poorly defined drainage and disjointed drainage are commonly mixed and cannot be separated on a statewide map.

Soil type affects many aspects of drainage. Soil type is strongly influenced by geology, and different materials have differing drainage characteristics. Soils of the Central Ridge and Western Highlands are generally well drained, whereas soils of the Flatwoods and Coastal Lands and those of organic and recent limestone origin are somewhat poorly to very poorly drained, which causes differences in storage potential and the amount of ponding.

Climatic factors, especially inputs of precipitation and losses to evapotranspiration, are the most important influences on spatial and temporal variations in surface hydrology. Precipitation is strongly dominated by rainfall in Florida and contributes to flow in a stream through several pathways. Rainfall can be intercepted by vegetation and buildings, puddle, flow overland as a thin sheet of water, infiltrate the soil, or fall onto the surface of lakes and streams. A substantial proportion of precipitation is evapotranspired in Florida, especially in areas with dense vegetation. Water storage in puddles or depressions is generally temporary, as it ultimately evaporates or infiltrates the soil. Overland flow occurs when the soil is saturated or when the precipitation rate exceeds the infiltration rate. It usually lasts for a brief period during and following rainfall events, unless the ground surface is not very permeable. Soil permeability also influences percolation, or downward movement toward the water table. In permeable parts of the unsaturated zone, water moves downward, but in less permeable parts, infiltrated water will move horizontally, a process known as interflow.

Rainfall is generally abundant in Florida, but varies annually and seasonally. The details of these variations are discussed in the climate chapter. The statewide annual average is approximately 53 inches, and specific locations average from 40 inches in Key West to 69 inches at Wewahitchka in the panhandle. Seasonal distribution also varies, with the northern portion of the state having proportionately more winter precipitation associated with fronts and the southern part having proportionately more summer precipitation associated with thunderstorms.

Two ways in which the flow in streams is measured are discharge and runoff. Discharge is the volume of water pass ally measured in cubic feet or meters per second. Discharge is most often used to distinguish the size of rivers and to characterize temporal variations in flow. The stream flow is comprised of different sources: overland flow, interflow, and groundwater contributions or baseflow. Overland flow tends to produce a fairly rapid influence on stream flow, because water runs across the surface more quickly than though the ground. If the basin is small, rain falling on the basin surface might reach a stream via overland flow in minutes to hours. It could take days in a larger basin. Interflow has an intermediate response time, compared to overland flow and baseflow, because it generally has an intermediate length or pathway, with the response time being dependent upon the basin size, geology, and other factors. The baseflow or groundwater contributions tends to take longer to influence stream flow and is a relatively consistent source of water that allows streams to flow through extended periods of low rainfall. In rivers in karst terrain, groundwater is often contributed to streams via springs of varying sizes. In times of high river flow, springs may become sinks, drawing stream flow into the ground.

Runoff is depth of water uniformly distributed over a drainage basin, computed as the discharge divided by the drainage area. Runoff quantities and rates are influenced by climatic elements, slope, geology, land use, and other factors. Flat, poorly drained lands retain water and allow for more evapotranspiration and infiltration, thus yielding a low runoff per unit area. Permeability, soil moisture content, and the distribution of precipitation and evaporation also affect runoff. Long-term stream flow records show that local average annual runoff varies across the state, ranging from less than 10 to more than 30 inches (Hughes 1978).

Rivers and Their Classification

From a regional perspective, several rivers in Florida are moderate to large in terms of their discharge and drainage area. The largest rivers, as measured by discharge, are the Apalachicola, Suwannee, and St. Johns. Even the largest rivers in Florida have only a fraction of the flow of the continent's and world's largest rivers. Average runoff computations show regional variations throughout the state, with the northwest rivers having the highest discharge per unit of drainage area.

Planners, environmental scientists, and engineers require an understanding of the long-term and annual hydrology to be able to predict the likelihood of floods and droughts and their potential impact on humans and development. Long-term estimates of the seasonal variation in stream flow show considerable variation from the northern to southern part of the state. In the northernmost parts of the state, stream flow is highest in the winter and early spring months. In the southern part of the state, stream flow is highest in the summer and fall.

Several systems, developed primarily by ecologists, have been used for categorizing Florida rivers (Nordlie 1990). The most commonly used classification of Florida waterways, developed by Beck (1965), includes five categories: sand-bottomed streams, calcareous streams, swamp-and-bog streams, large rivers, and canals. Because of problems of mixing criteria, such as materials with size, setting, and human modification, this chapter characterizes Florida natural waterways as predominantly alluvial or predominantly karst. Canals and modified waterways are described separately. Yet this description is also general, as not all rivers in Florida are comprised exclusively of alluvium or carbonate bedrock. Some are transitional and have both materials.

Rivers are three-dimensional, but are typically displayed from various two-dimensional perspectives. Maps show a planform perspective, or comparison of width across the channel with distance along the valley or channel. A cross-section compares elevation (generally bed) with width or distance across the channel. Longitudinal profiles show the elevation of the water or bed surface with distance downstream. From the planform perspective, it is obvious that rivers have differing forms, varying in their sinuosity (ratio of channel length to valley length) and the number of channels.

Alluvial rivers occur in valleys surrounded by their own sedimentary materials and adjust their morphology according to discharges and the sediment sizes and loads present. Alluvial rivers typically develop features, such as meanders, channel bars, and islands, that are uncharacteristic of rivers exclusively in bedrock. Most alluvial rivers in sand and gravel have a series of alternating deeps (pools) and shallows (riffles), with pool-to-pool spacing averaging six times the channel width. They typically are dominated by suspended load transport, especially in low gradient settings as Florida, and experience erosion and deposition along the channel, especially during and following floods. Alluvial rivers are common in the panhandle of Florida, traversing the geologic units comprised of clastic sediments. Some of the larger alluvial rivers in Florida include the Escambia, Choctawhatchee, Apalachicola, and Ochlockonee.

In Florida, alluvial rivers typically have meandering or anastomosing patterns, with multiple channels that are separated by densely vegetated islands. Because elevations in low gradients and thus low energy. Most profiles are concave upward, with steeper headwaters that decrease in gradient approaching the bays or gulf, with local knickpoints associated with changes in geology. Some tributary stream profiles are locally quite pronounced, forming linear valleys with large gradients termed steepheads where some drainage networks have formed by groundwater seeping in highly permeable sands (Schumm et al. 1995).

Overland flow is generally very important in alluvial rivers and the stream hydrographs are relatively flashy (Escambia, Choctawhatchee, and Apalachicola). Even in large rivers, the crest occurs a few days following the precipitation event. Because of the limited delay caused by overland flow contributing much of the discharge during storm events, requests for evacuation in the event of flooding must be heeded immediately.

The stream hydrograph for karst rivers (for example, the Suwannee) is much flatter than those for alluvial rivers. Rivers in karst terrain typically have sinks and springs, and may disappear underground and reemerge for short or long distances. Groundwater input or baseflow contributes appreciably to stream flow, and the material load is dominated by dissolved materials rather than suspended sediments. Surface water-groundwater interactions are often bidirectional, as the river recharges the aquifer during floods, and the aquifer supplies the river during droughts. In rivers in karst terrain, groundwater input or baseflow contributes appreciably to stream flow. Because there is less direct runoff, it may take several weeks and even months for a flood to rise and fall, generally allowing ample time for evacuation. However, the flows are also slow to recede, preventing floodplain residents from returning to their homes for weeks to months during periods of high water. Hydrology and valley evolution are strongly dependent upon subsurface voids and relative sea level changes. The larger karst rivers of the panhandle include the Chipola River and Holmes Creek. In peninsular Florida, karst rivers are best developed in the north and include the Suwannee, Alapaha, Withlacoochee, their tributaries, and a number of smaller rivers.

Sinks and springs of varying sizes, largely associated with the presence of carbonate rocks, are numerous along river corridors. Bed surface irregularities associated with springs and sinks occur on large rivers, such as the Suwannee River (U.S. Army Engineer District-Jacksonville 1974, Mossa and Konwinski 1998). Some rivers, such as the Silver and Ichetucknee, are predominantly spring-fed. Others, such as the the river to disappear underground and springs that cause it to reemerge some distance downstream for all or part of the year. On the Santa Fe the underground channel is connected with wetland lakes between these points (Ellins et al. 1991). Some rivers, including the St. Johns and Kissimmee, have large lakes or large depressions along their courses.

Consequently, the hydrology of such rivers is highly varied along the river course and is sometimes more characteristic of a lake than a river. Channel offsets are a drainage feature which are in part created and maintained by karst processes. The St. Johns River has an offset course where the river initially turns to the west to reach a valley cut in older, higher terrain, then flows northward for a long distance, possibly in an ancestral valley, and then jogs back to the east to traverse a younger, lower surface (Pirkle 1971).

The hydrology of the St. Johns River is highly varied. Upstream at Melrose, the flow is unidirectional and generally not influenced by tides, with notable seasonal variation. Midstream at DeLand, flow is dominantly unidirectional. Since the late 1950s both locations seem to have smaller maxima and means, and DeLand has had more negative flows. Downstream at Jacksonville, flow is bidirectional with a strong daily variation associated with tides.

Lakes

Florida has thousands of large and small lakes. Of the named lakes exceeding one acre in size, the great majority are less than 50 acres. Most of Florida's lakes average between 7 and 20 feet in depth, although a few sinkhole lakes are hundreds of feet deep (Heath and Conover 1981). About 35 percent of the lakes in Florida are concentrated in four counties of central Florida (Osceola, Orange, Lake, and Polk). Schiffer (1998) characterizes the hydrology and issues regarding lakes in these counties. In addition to Lake Okeechobee, one-fourth of all lakes in Florida are in the Kissimmee River drainage.

Most of the lakes are natural in origin, formed by solution processes where groundwater dissolves carbonate sediments to form cavities which collapse to form depressions. Some solution lakes are nearly circular at the surface and conical in cross section, others are somewhat irregular from several coalescing sinkholes, and others are elongated if formed in a valley where the sinkhole becomes plugged. Many of the solution lakes are enclosed by topographic divides, and drainage into them either evaporates or percolates downward to the groundwater system where it may emerge in an adjacent drainage basin. Lakes also originate from relict sea bottom depressions and erosion and sedimentation processes in rivers (Edminston and Myers 1983).

Some Florida lakes have been formed through the emplacement of dams or impoundments to form reservoirs. Other human-made lakes or ponds include rock pits, sand pits, and cooling ponds for large power plants.

Natural lakes vary appreciably in their hydrology, depending on whether they only have subsurface connection, whether streams flow through them, whether streams only flow from the lakes, or whether streams flow into the lake. Lake levels change in response to direct precipitation, runoff, evaporation, and the exchange between the lake and groundwater. In Florida, the more important influences include seepage by groundwater and, secondly, surface drainage. Most Florida lakes are seepage lakes, and some estimates suggest that as many as 70 percent of the lakes lack overland flows (Palmer 1984).

Fluctuations in lakes dominated by seepage correlate with changes in the water table. Fluctuations in lakes that are dominated by drainage, with streams flowing through them, correlate with changes in stream flow. Lakes that are regulated show fairly consistent lake levels except for occasional breakages and stormwater inputs.

Lakes generally show variability annually and seasonally. During periods of below normal rainfall, lake levels begin to drop. They may do so for several years, causing concern for local residents with docks and lakeside businesses. Given time, lake levels generally rebound, and some lakeside residents may complain about too much water. Orange Lake has been through such cycles in recent years. Lake level is not actively regulated, but is influenced by a fixed crest weir on the outlet as there is no outflow, except from evaporation or seepage through the bottom when stages fall below 57.5 feet (Shuman, personal communication). Because slopes are gentle in Florida, vertical changes in water level of a few feet imply horizontal changes in water level of a few hundred feet. The St. Johns River flows through Lake Monroe and several other lakes. Lake levels within the river chain show seasonal fluctuations, related to stream flow variability.

Lakes that are regulated, or impounded for dams, show fairly consistent lake levels, especially in comparison with natural lakes. Variations are mostly associated with occasional breakages, stormwater inputs, and controlled management changes; for example, there was a breakage on Lake Talquin, a reservoir on the Ochlockonee River, in 1959.

<u>Wetlands</u>

Wetlands are the largest component of the state’s surface waters in terms of total area. In wetlands, high water tables determine the nature of soil development and the types of plant and animal communities living in the soil and on the surface. The water table is at, near, or above the land surface for a significant part of most years. These ecosystems are complex transitional systems between aquatic and terrestrial environments. Wetlands are often classified as swamps or marshes, depending on whether the vegetation is dominated by trees (swamps) or by grasses (marshes).

Wetlands occur near the ocean and gulf, adjacent to rivers and lakes, in areas of poor soil drainage, and in relict lake valleys or river channels. River and lacustrine (lake) floodplains are periodically inundated and often remain partly wet because of their low topographic position in the proximity of high water tables. In karst areas, the valleys and lakes may become dry because of water-table changes associated with sea level changes, climate, vertical adjustments in the earth’s crust, and cavern development. Specific examples reported include features associated with the Suwannee valley (White 1970) and a dry spring-fed tributary to the Santa Fe near High Springs (Edwards 1948). Paynes Prairie, a 19,000-acre wetland near Gainesville, is a relict lake bed.

Wetlands, like lakes, may be sites of internal drainage, exporting water only by infiltration and evapotranspiration, or they may be connected with streams along the stream corridor, transporting runoff as well. The dense vegetation and flat topography of bottomland wetlands in floodplains attenuates the flood peaks and provides greater detention storage (U.S. Environmental Protection Agency 1983).

Evapotranspiration in wetlands approximates the evaporation from open water bodies (Visher and Hughes 1975). Thus, changes in wetlands, usually a decrease in area from a reduction in hydroperiod, reduce the amount of water lost directly to the atmosphere. Some wetlands play a role in recharge, but most are situated in low-lying areas that are discharge areas of the groundwater system. Recharge results from the vertical movement of water through the soil. However, this vertical movement is often restricted because wetlands are often underlain by virtually impermeable clay and organic layers that severely restrict groundwater recharge.

Wetlands are extensive and are found nearly everywhere in the state. Prior to development, wetlands, including open waters and seasonally flooded areas, covered about half the state's area. Based upon satellite imagery from the early 1970s, wetlands and their associated open-water areas accounted for almost a third of the total land area of the state (Hampson 1984).

Over one-third of the wetlands had been drained for agriculture, flood control, and residential development, but many floodplain wetlands and coastal marshes are still largely undeveloped but are threatened by urban and agricultural land uses.

In southern Florida, extensive areas of wetlands include the Everglades and Big Cypress Swamp, where historically most surface flow moved slowly either as sheet flow through marshes or through broad sloughs. Extensive wetland areas in central Florida include the Green Swamp and parts of the Kissimmee basin. The Okeefenokee is an extensive swamp in the upper Suwannee Basin of northern peninsular Florida.

Human Modifications of Surface Waters

Humans created and modified waterways in Florida for a number of centuries, if not millennia, although the impacts, both indirect and direct, have been particularly severe within this past century. Most indirect changes are associated with human activities and land use changes within the basin, especially close to the channel and floodplain. Deforestation, agriculture, land drainage or flood protection, and urbanization have a number of effects on waterways. These activities typically increase the magnitude of peak flow and decrease the lag time, generally aggravating flooding. To minimize such impacts many communities in Florida have built retention and detention ponds in conjunction with development to increase the local storage and allow flood waters to behave more as they would under predevelopment conditions.

Direct modifications along the channel and floodplain are typically built to manipulate the spatial and temporal variations in surface waters. Structures such as dams and weirs, bridges and pipeline crossings, and activities such as channelization, dredging, and floodplain and in-channel mining are more direct impacts. Direct modifications have a long history, as building canals and modifying waterways dates well before European settlement (Leur 1989). Further changes have occurred in this century, when sections of waterways have been straightened and new artificial channels intertwine with the former natural one, especially along the Kissimmee. Some channels have been deepened or widened locally for navigation by dredging, and others have artificial cutoffs or shortcuts across meander bends. Blount Island on the St. Johns River is one of the larger artificial cutoffs, and several occur on the Caloosahatchee River and Upper St. Johns River as well.

Canals have been constructed in a number of places throughout peninsular Florida, especially the lowlands of south Florida in areas of urban and agricultural development. They have been constructed for a multitude of reasons, including flood control, water supply, navigation, wetlands drainage, and for control of water flow directions and elevations. Canalization results in either the straightening, widening, and/or deepening of an existing waterway or in the construction of a new waterway. Examples of canalization are so numerous that canals are included in Beck's (1965) classification of Florida's waterways. Eight major waterways, including the Caloosahatchee and Kissimmee rivers, and the Tamiami, Miami, North New River, Hillsboro, West Palm Beach, and St. Lucie canals are classified as such. Furthermore, there is an extensive set of numbered rather than named canals. This extensive network of canals built for flood control and water supply has led Palmer (1984) to characterize south Florida as the "quintessence of surface water manipulation."

Two areas of considerable modification in Florida include the partially completed Cross Florida Barge Canal (St. Johns to southern Withlacoochee) and the Kissimmee River basin. The Cross Florida Barge Canal was to have connected the east and west coast via the Withlacoochee, Ocklawaha, and St. Johns rivers, resulting in the modification of a number of Florida waterways. Predecessors to this aborted project were first initiated in 1850. Construction on the canal was first halted in 1862 because of the Civil War, but resumed for a short time in 1935 and 1936. Later, work recommenced in the 1960s with construction of major dams and locks on the Ocklawaha and Withlacoochee rivers (Southeastern Geological Society 1970). More recently, construction was halted in 1971, largely because of environmental opposition. Considerable controversy exists as to whether the modified system should be retained, whether the original conditions should be restored as much as possible, or whether a compromise involving partial restoration should be attempted. The Rodman Dam on the Ocklawaha River represents part of this controversy (Shuman 1995). Both the St. Johns River Water Management District (1994) and the Florida Department of Environmental Protection (1998) have conducted studies documenting problems resulting from the Rodman Dam. The Florida Defenders of the Environment (1998) have called for removal of the dam and restoration of the Ocklawaha, and the U.S. Fish and Wildlife Service (1997) has also issued a Biological Opinion in favor of restoration.

Construction of the project initially resulted in destruction of much bottomland forest. By changing the hydrology, the dam reduces productivity in the St. Johns River. The dam also is harmful to migratory aquatic species, especially manatees, because structures block passage and reduce habitat of these and other species. In warm and nutrient-rich waters of the reservoir, aquatic weeds and algae have flourished, requiring the use of mechanical and chemical treatments to control undesirable water plants. Additionally, maintaining the structure has an annual cost which over a period of years exceeds the one-time cost of destruction. However, many local fishermen, supported by a powerful legislator, want it left in place because it has become a favorite spot for bass, and the fish and bird populations now accustomed to the dam would undergo a period of adjustment. Should the dam be removed, much planning and environmental assessment will be needed to minimize potential problems associated with sediments, channel instability, and ecological changes.

The Kissimmee River is in south-central peninsular Florida. The Lower Kissimmee flows about 100 miles from Lake Kissimmee to Lake Okeechobee. Congress authorized the Kissimmee River Flood Control Project in 1954 to facilitate the passage of floodwater, and it was constructed between 1962 and 1971 at a cost of $32 million. The project diverted flow from the 103 miles of meandering river channel and a 0.9- to 1.9-mile-wide floodplain to an excavated 56-mile-long, 210- to 345-foot-wide, 29.5-foot-deep canal named C-38. Included in the project were six water flow control structures with tieback levees and navigation locks designed to allow passage of small boats. These maintain stable water levels in five stair-step impoundments or “pools” along the canal’s length. Although remnants of the former river channel remain on either side of the canal, the flowing river ecosystem has essentially been replaced by a series of relatively stagnant reservoirs with a central deep canal (Toth et al. 1993).

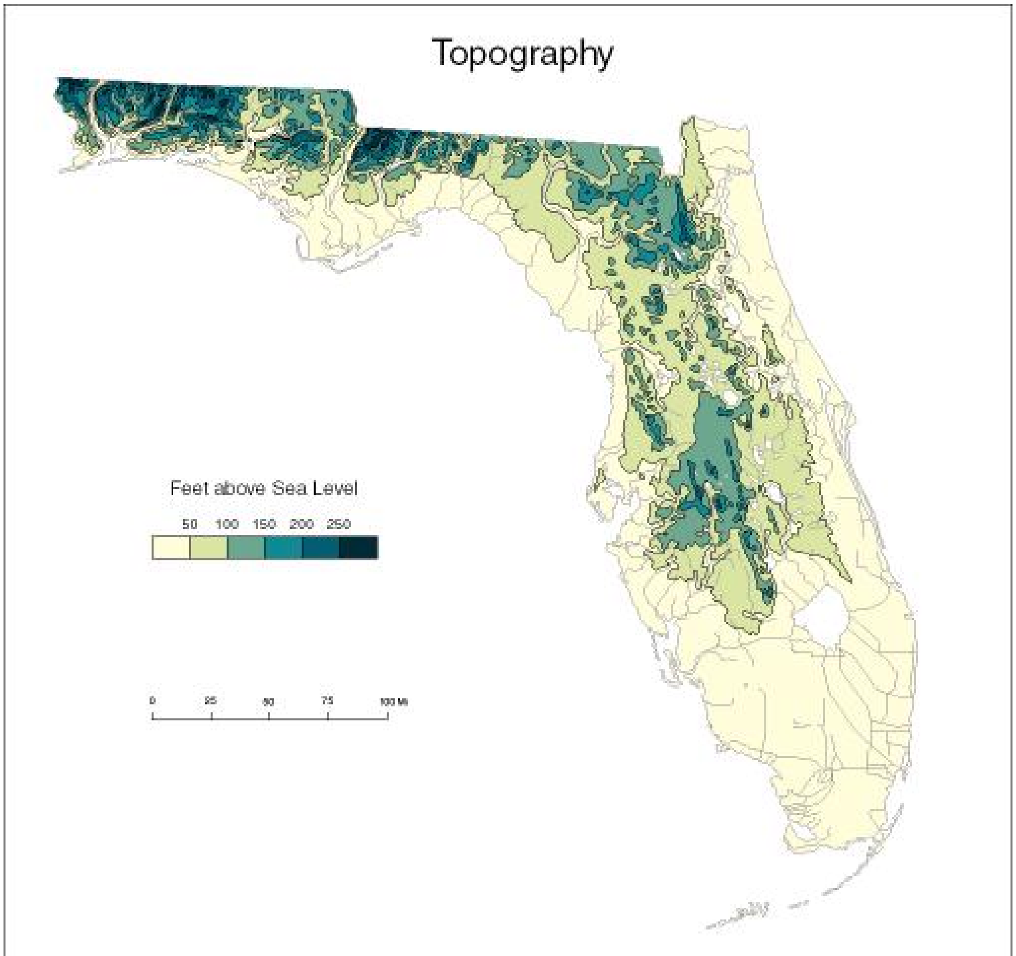
Inflows to C-38 occur through the uppermost structure and are regulated by a flood control operation schedule that was implemented in the Kissimmee’s headwater lakes.

Loss of wetlands and water-quality problems were anticipated, but the project went ahead anyway (Pilkey and Dixon 1996).

The drainage of 200,000 acres of floodplain wetlands caused a decline in water quality, water birds, commercially valuable fish species, and wildlife habitat. In the absence of flow, thick deposits of organic matter accumulated on the bottom of the remaining river channel and reduced depth and substrate diversity within these stagnant, remnant river courses (Toth 1993, Toth et al. 1993).

One year after the canal’s completion, there was much opposition calling for river restoration. In 1991, under a congressional mandate, the corps began restoring about one-third of C-38, which will cost over $400 million, more than ten times the cost of the entire original project (Pilkey and Dixon 1996).

Little is known about appropriate strategies for river restoration since such efforts have only been attempted quite recently, so it is unknown how successful these efforts will be. To avoid repeating such mistakes, an increasing number of individuals are interested in seeking alternatives to river modification, such as land acquisition and other approaches.


Topography
Feet above Sea Level
50 100 150 200 250
0 25 50 75 100 Mi


Wetlands Prior to Development
Wetlands

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Study Questions

1. The State of Florida is a flat land topographically with large amounts of slow-moving surface water. This type of land surface would not normally be conducive to hydroelectric power but there are several places in Florida that have water generators. Do a little research and answer the following questions:

1a. Are there any hydroelectric generating plants in your area of the state?
Where are most of the generators found geographically in Florida?

1b. How much electricity can they generate and do they function as a supplemental or a primary source of power?

2. Define a drainage basin?

3. What is a karst area? What are the characteristics of a karst area in Florida?

4. In Florida, what is the difference between the soils of the Central Ridge or Western Highlands and the soils of the Flatlands and Coastal Lands?

5. What are the two ways in which the flow in streams is measured? Define each type?

6. What are three largest rivers in terms of discharge in the State of Florida?

7. Define the following terms:
   a. alluvial river
   b. anastomosing
   c. sinuosity

8. What is the difference between an alluvial river and a karst river?

9. In a river what is the difference between a unidirectional and a bi-directional flow? What would cause a bi-directional flow?

10. What is a wetland? What is the difference between a swamp and a marsh?

Natural Systems

Hydrological Cycles and Hydroperiods

In simplest terms, the hydrological cycle is the process by which water that rains on the land eventually flows to the sea, and water in the sea evaporates into the atmosphere, is blown over land, and falls on the land as rain, completing the cycle. In Florida, rainfall at times is torrential, leading to flood conditions in rivers, lakes, and wetlands. At other times, scarce rainfall leads to periods of drought when river, lake, and groundwater levels fall, and wetlands dry out. Floods and droughts both create stressful conditions to which the plants, animals, and natural communities of Florida have evolved a variety of adaptations. To a great extent, the locations of plants, animals, and communities are determined not only by seasonal rainfall patterns and geographic location but also by floods and droughts.

Florida is relatively flat with abundant rainfall and a water table that is near the soil surface in many places. As a result, wetlands are a common feature of the landscape. A factor which plays a strong role in determining the locations of wetland-adapted species, and therefore wetland communities in Florida, is hydroperiod (Ewel 1990).

Hydroperiod refers to the depth and duration of standing water in wetlands following rain events. For example, the forested wetlands found in the floodplains of major rivers typically are inundated for 1 to 6 months each year. Hydric hammocks, which are usually found where limestone is very near the earth's surface and groundwater seepage is constant, typically are inundated for 3 to 6 months each year. Most forested wetlands typically are inundated for 5 to 9 months each year. Bay swamps and shrub bogs, both of which occur on sites that have constantly saturated soils that rarely flood, have hydroperiods of 9 to 11 months each year. Herbaceous freshwater wetlands are inundated 7 to 12 months each year to depths of less than 20 inches, and they dry out to depths of less than 12 inches below the ground surface (Kushlan 1990). Hydroperiods are determined in part by wetland location and soil type. For example, river floodplains, obviously, extend landward from the banks of rivers. The species of wetlands plants typical of these areas tolerate frequent, often deep, inundation by flowing waters, but they are intolerant of still-water situations. On the other hand, wetlands found in flatwoods (e.g., cypress ponds, gum ponds, prairie marshes) are in environments where the water does not flow, but rather fluctuates up and down, and inundation may extend for longer periods of time. The species of plants adapted to flatwoods wetlands require adaptations that allow their roots to survive in soils that are low in oxygen for extended periods. Bay swamps often are found at the bases of sandy ridges where rainwater drains through the excessively drained soils, reaches the groundwater table, and then migrates to the base of the ridge where it constantly seeps out. In this situation, the soil remains constantly saturated but rarely floods. The bay swamp at the base of the southeastern end of the Lake Wales Ridge in Highlands County was formed in this manner.

Fire

Naturally occurring wild fires have played a defining role in shaping Florida's natural communities. Florida has one of the highest frequencies of lightning strikes of any region in the United States and more thunderstorm days per year than anywhere in the country (Abrahamson and Hartnett 1990). In response to thousands of years of frequent lightning-set wild fires, many natural communities in Florida actually are maintained in a stable, nonsuccessional state by frequent fires. Pine flatwoods, longleaf pine (*Pinus palustris*)-wiregrass (*Aristida stricta*) sandhills and clayhills, prairies, scrubs, and herbaceous wetlands all are maintained by regularly occurring fires. In the absence of fires, fire intolerant species, particularly hardwoods, invade a site, and over time the vegetation of a site will succeed to a hardwood forest.

Longleaf pine, formerly the dominant tree of sandhills, clayhills, and flatwoods in the northern two-thirds of the state, is well adapted to frequent wildfires. Longleaf pine is even credited with having adaptations that promote frequent fires. The bark of longleaf pines is highly fire-resistant such that the base of a tree will be scorched by a fire, but the entire tree rarely burns. Juvenile longleaf pines go through a "grass" stage in which the delicate growing bud is closely surrounded by densely packed needles that protect it from ground fires. Longleaf pines also drop their needles like a carpet on the forest floor or on any low-growing vegetation beneath them. Highly flammable when dry, the pine needles readily carry a ground fire of low intensity such that flames rarely reach the forest canopy. In a natural state, longleaf pines grow in a fairly open, park-like situation which does not allow a fire to spread through the canopy even if flames manage to reach the canopy of some trees. Ground cover species such as wiregrass and saw palmetto (*Serenoa repens*) also are highly flammable, promoting the spread of fires, but they rapidly send up new shoots from underground stems and roots after a burn.

Specific burn frequencies are necessary to maintain fire-adapted communities. Sandhills and clayhills burn every 2 to 3 years, pine flatwoods and prairies burn every 3 to 7 years, scrubs burn no more often than every 40 to 55 years, deep water marshes burn every 3 to 5 years, shallow water marshes burn on 1- to 3-year cycles (Kushlan1990), shrub bogs burn every 11 to 33 years, dwarf cypress savannas burn every 11 to 12 years, and cypress ponds and strands burn as often as once every 20 to 25 years (Ewel 1990).

Almost all upland and wetland communities are affected by fire at one time or another. Even forested wetlands, such as river swamps, hydric hammocks, mixed hardwood swamps, gum ponds, lake fringe swamps, and bay swamps, are likely to experience fire once a century. Hardwood forests are about the only upland type of community that does not burn regularly. Fires that burn hardwood forests typically are catastrophic, and other types of communities are likely to vegetate a site after a hardwood forest has burned.

Historically, naturally occurring wild fires could burn over large areas, impeded only by water bodies or saturated wetlands. However, Florida is now crisscrossed with roads and fire lanes, urban developments have sprung up next to flatwoods and sandhills, and timber has been cleared. The net result of human intervention has been that naturally occurring wild fires no longer occur with their former frequency, and fire-maintained communities are no longer able to sustain themselves without help. Many forests must now be burned under controlled conditions in order to reduce fuel and eliminate hardwoods. Otherwise, unburned sites will either succeed to hardwood forests or will burn catastrophically due to over-accumulation of fuel. However, even controlled burning of fire-maintained communities is becoming more difficult as Florida continues to develop. Smoke from controlled fires may drift across an increasing number of roads, creating traffic hazards, or it may blow into urban neighborhoods where the residents are likely to have health or safety concerns.

A further issue with burning pertains to season of burn. Most natural wild fires occur in the summer months when thunderstorms and lightning are more likely. Summer is the growing season for most plants as well as the reproductive season for most animals. Plant ecologists, in particular, believe that the growing season is the appropriate time to conduct controlled burns of Florida's fire-maintained communities as many species of plants are stimulated to reproduce by fires. However, most controlled burns have been conducted in the winter when weather is cooler and plant materials are dead or dry and highly flammable. Many ecologists believe that the long history of winter burns has subtly shifted the composition of many plant communities away from that which occurred naturally. Land managers are experimenting with conducting controlled fires during the growing season in an effort to shift fire-maintained communities towards a more natural state.

Nutrient Cycling and Food Webs

The phrase "ashes to ashes, dust to dust" is an age-old acknowledgment of the existence and fundamental necessity of nutrient cycling. All plants and animals require nutrients in order to live and grow. Whereas plants require nutrients in elemental or ionic form, animals are more dependent on nutrients in organic form. The principal nutrients affecting life on earth are nitrogen, phosphorus, potassium, sulphur, oxygen, and carbon. Since the earth contains a finite quantity of the nutrients needed for life, plants, animals, and communities have evolved complex mechanisms for recycling nutrients for repeated use.

Plants obtain nitrogen, phosphorus, potassium, and sulphur from the soil, and they obtain carbon and oxygen from the air around them. These raw ingredients are used to capture sunlight energy and build plant tissues. The process of growing depletes nutrient reserves in the soil, and, in order for life to continue, mechanisms are needed to return nutrients to the soil. This is accomplished in several ways. Plants may die and fall to the ground where decomposing organisms, such as fungi and bacteria, slowly break organic materials down into inorganic form for reuse by plants. Fire is a more rapid way of recycling nutrients. Wild fires or prescribed burns quickly turn organic plant (and animal) materials into inorganic form, bypassing the decomposer organisms and making nutrients available to plants.

Another way that nutrients are recycled is through the food web. Most plants and plant parts are eaten by some type of animal. Animal species have evolved a tremendous variety of adaptations to take advantage of specific species of plant or particular parts of plants. For example, butterfly larvae eat leaves, aphids suck plant juices, sandhill cranes feed in part on plant roots, cedar waxwings prefer berries, and gopher tortoises eat grass. In turn, animals are eaten by other animals, which are eaten by still other animals. All along the way, all animals excrete dung, which usually ends up on the ground where it is reduced to inorganic form by decomposer organisms. Animals may also simply die of illness or old age and be recycled to the soil, again by decomposer organsims.

Nutrients often are exported from one ecosystem to another by water. Falling rain carries with it dilute quantities of dissolved nutrients which are readily available to plant life. As water from rainfall seeps into the soil or flows off the land, nutrients are leached from the soil and carried downstream, ultimately fueling life in rivers, lakes, estuaries, and the ocean.

A very special form of nutrient recycling without which life could not exist is anaerobic decomposition, the break down of organic materials in environments where oxygen is lacking. Such environments typically occur in sediments at the bottoms of lakes, wetlands, estuaries, or marine ecosystems. In these environments, specially adapted bacteria are capable of using the energy available in organic compounds to break organic materials into inorganic nutrients. In the process, these special decomposers release elemental nitrogen and hydrogen sulfide gases which bubble to the surface and are released into the atmosphere. Anaerobic decomposition is the only way that nitrogen and sulphur are recycled for reuse by plants and animals. In the absence of anaerobic decomposition, all dead organic materials would eventually end up in an anaerobic environment at the bottom of a water body, and life would cease to exist. Famed Florida limnologist Edward Deevy once wrote a brilliant essay entitled, “In Defense of Mud,” in which he extolled the importance of mud, wetlands, and smelly estuarine sediments for their role in recycling nutrients essential to the very existence of life.

Natural Ecosystems Management Issues

Atmospheric Deposition

Air pollution not only affects human health, but can also affect the quality of water in rivers, lakes, and estuaries. Air pollutants may fall as dry particles on land or water or may be deposited with rainfall. The process of deposition entails emissions of particulates and gases from air pollution sources, transport of these emissions by wind, potential chemical or physical transformations, and depositions to land and water surfaces. Deposition may be direct to the water body or indirect from runoff from the land surface.

Sources of pollutants reaching Florida may be global as well as regional and local. In Florida most air pollutants come from fossil fuel combustion, mostly from power plants and motor vehicles. Waste incineration, sulfuric acid production, cement manufacturing, pulp and paper production, and combustion of plant and animal biomass are also significant sources of air pollutants. Natural processes such as volcanic eruptions, forest fires, and suspension of eroded soil particles may contribute to air pollution.

The U.S. Environmental Protection Agency conducted a national surface water survey between 1984 and 1986 to identify the extent of acidification of lakes and streams in the United States. Of water bodies sampled in Florida, 23 percent of the lakes and 39 percent of the streams were found to be acidic. Further studies indicated that some lakes in the north central peninsula do have increased acidity due to atmospheric deposition. In most cases, however, naturally occurring organic acids are the dominant factor controlling the acidity in acidic streams. No widespread fish population losses or decreases in fish biomass have been documented because of acidic deposition in Florida.

The U.S. Environmental Protection Agency has identified eutrophication (nutrient enrichment) as one of the most serious pollution problems facing estuarine waters in the United States. Nitrogen compounds from atmospheric deposition exacerbate this problem. Eutrophication may result in oxygen depletion or reduced oxygen in the water, nuisance or toxic algae blooms, dieback of underwater plants due to reduced light penetration, and reduced populations of fish and shellfish.

In Florida coastal waters seagrasses provide shelter, and nursery and feeding habitat for many popular fish and shellfish. The quantity of seagrass is an important indicator of estuary health. In the Tampa Bay estuary, for example, seagrass losses have been attributed, in part, to reduced penetration of sunlight due to excess concentrations of phytoplankton and suspended solids in the water column. These excess concentrations are related to the increased nutrient loadings that have occurred in the past in the Tampa Bay estuary. Over the past 10 to 15 years, however, seagrass has increased by about 4,000 acres, largely as a result of improvements in sewage treatment and stormwater management. The current nitrogen loading to Tampa Bay is largely due to atmospheric deposition, either directly to the bay’s surface or transported by stormwater from the bay’s watershed. The Tampa Bay National Estuary Program has estimated that 27 percent of the bay’s nitrogen loading is due to direct deposition to the bay. Atmospherically derived nitrogen from watershed runoff could increase the total to 50 to 60 percent.

In 1989 a joint monitoring project by the Florida Game and Fresh Water Fish Commission, Florida Department of Health and Rehabilitative Services, and the Florida Department of Environmental Protection found high levels of mercury in fish from the Everglades. Mercury is known to be neurotoxic to humans, and its consumption through contaminated food has caused substantial illness and mortality in several episodes elsewhere in the world. These and subsequent findings of high mercury levels in fish led the State Health Officer to issue a series of health advisories urging fishermen not to eat some species of fish caught in the Everglades, and to sharply limit consumption of largemouth bass taken from other fresh waters in Florida.

At the time of this writing, seven years after the initial findings, we know that approximately 1 million acres of the Everglades drainage system contain fish with markedly elevated mercury burdens. Largemouth bass (*Micropterus salmoides*) average over 1.5 parts per million mercury, which exceeds all health-based standards. More than another million acres of fresh waters of Florida contain largemouth bass with elevated, but lesser, levels of mercury. When sampling is complete, mercury problems in bass are expected to be found in one-half to two-thirds of Florida's lakes and streams. Excessive mercury levels are also found in some marine fish, particularly large, long-lived predators such as shark and king mackerel (*Scomberomerus cavalla*), and certain fish from limited areas of near-shore waters.

Excessive levels of mercury found in fish today is not limited to Florida. Thirty--seven states have issued health advisories restricting consumption of fish, and similar problems arefound widely in North America, Europe, and Asia. Many lakes in Canada and Scandinavia, for example, are affected.

It is generally accepted that the widespread mercury problem is caused by air pollution. Both long distance transport and localized deposition around certain types of sources may be important. Major sources to the atmosphere are metals mining and smelting, coal-fired utilities and industry, and the use and disposal of mercury in commercial products. The unusually severe problem in the Everglades has many unique features, and may be the result of a combination of other factors. Initial studies focused on the local effects of municipal incinerators and other emissions sources on the southeast coast of Florida, increased release of mercury from the soils of the Everglades Agricultural Area promoted by drainage and soil disturbance, or increased mercury mobilization from Everglades soils stemming from hydrological changes caused by the Central and South Florida Flood Control Project.

A four-year study by researchers at Florida State University and Texas A & M University funded by the U.S. Environmental Protection Agency, Florida Department of Environmental Protection, the Florida Electric Power Coordinating Group, Florida Power and Light, the Electric Power Research Institute, and the South Florida Water Management District found that mercury concentrations in rainfall increase in the summertime when rainfall is highest, whereas concentrations of other pollutants decrease. Researchers theorized that most of the air-borne mercury falling on the Everglades originates from heavy industry to the north both in the United States and abroad. Elemental mercury travels along with air currents from the U.S. east across the Atlantic until it reaches and mixes with air currents from the coast of Europe, which contain mercury not only from Europe but perhaps from Russia and China as well. The air mass now travels south where the trade winds carry it back across the Atlantic to Florida. Summer thunderstorms, with thunderheads up to 12 miles high, scour the mercury out of the upper atmosphere (Stephenson 1997).

Once mercury is in the surface water rapid geochemical transformations can occur beginning the process of bioaccumulation. Precise mechanisms are unknown, but mercury probably enters the food chain when plankton consume mercury containing bacteria. Understanding this initial step is critical because concentrations of mercury in plankton increase 10,000-fold over water concentrations (Krabbenhoft 1996). At each other trophic level the increase in concentration is 10-fold or less. The U.S. Geological Survey, the South Florida Water Management District, and the U.S. Environmental Protection Agency are co-funding a group of scientists to study mercury bioaccumulation in the Everglades. The overall objective of the study is to provide resource managers with information on the hydrologic, biologic, and geochemical processes controlling mercury cycling in the Everglades. Results of this study are expected to be available in the fall of 1999.

Loss and Degradation of Upland and Wetland Habitats

The land area of Florida supporting natural vegetation types has declined dramatically since European settlement. Florida's rapid population growth, particularly over the last 100 years, has resulted in the conversion of vast areas of the natural landscape to human uses. Today, agricultural, urban, and other uses account for 43 percent of the Florida landscape, and forests and herbaceous wetlands comprise the other 57 percent (Kautz, in press).

Most of the remaining 57 percent that is in some type of natural vegetative cover has been affected by human use to some extent. For example, nearly all forest lands in Florida have been logged at some time in the past. In 1995, 24 percent of all forest land was in densely stocked, single-species pine plantations (Kautz, in press), and wetland and upland hardwood forests increasingly are being logged for wood products. Many remaining natural areas are subject to intensive recreational uses including off-road vehicle and airboat operation. In addition, exotic species, such as melaleuca (*Melaleuca quinquenervia*) and Brazilian pepper *(Schinus terebinthefolius*), have invaded many natural areas, radically altering habitat values for native species of plants and animals.

In the course of conversion of the Florida landscape to human uses, some natural community types have been impacted more severely than others. Overall, forested lands have suffered the most with over 4.63 million acres having been cleared in the last 59 years (Kautz, in press). Of particular interest, south Florida pine rocklands have all but disappeared. Of the 375,000 acres of south Florida pine rockland habitats mapped by Davis (1967), only 6,000 acres remained (a 98 percent loss) in 1988. Large areas of herbaceous wetlands have been drained and converted to human uses. For example, herbaceous wetlands declined 51 percent between 1936 and 1995 (Kautz, in press) with over 700,000 acres having been lost in the Everglades ecosystem alone. Forested wetlands declined 17 percent between 1970 and 1987 despite aggressive wetlands protection programs (Kautz 1993).

Loss and Degradation of Riverine Habitats

The rivers throughout Florida are under stress from a number of factors. Many of the rivers have been channelized for navigation; flows have been stabilized by dams and reservoirs; floodplains have been converted to agricultural, development-related, or mining-related uses or have been destroyed by dams; and flows have been reduced due to water withdrawal for human use. These man-made alterations have resulted in loss of physical habitat and of aquatic species. For example, many species of mussels are in serious decline due to alterations of riverine habitats, siltation, deteriorating water quality, and flow stabilization throughout the United States.

The Apalachicola River system is an example of a river system that has been altered by navigation, reservoir management, and potential minimum flow level requirements. The river has a congressionally authorized 106-mile navigation channel, upstream dams, and a reservoir/dam located at the Florida state line. Navigation channel maintenance has led to substantial changes in shoreline and floodplain habitats (Ager et al. 1987). The shoreline has been converted from snag and natural bank habitat to unproductive sand piles due to spoil disposal practices. The Jim Woodruff Dam at the Florida state line impedes the migration and spawning of anadromous fish species, like the threatened Gulf sturgeon and striped bass. Striped bass eggs naturally float or bounce down the river prior to hatching into fry. Prior to the dam, striped bass could swim upstream far enough that, when spawning was complete, the eggs were in no danger of reaching the injurious brackish waters of Apalachicola Bay before hatching. However, now, with the dam in place, striped bass eggs float downstream into the estuary before they can hatch, effectively precluding striped bass reproduction from the Apalachicola River. During low flow periods, the management of the upstream reservoirs and dams is altered to create short-term flow pulses for navigation. These pulses have been observed to affect the spawning behavior of fish (Charles Mesing, personal communication) and may affect the ecology of the river and bay. Upstream users also are interested in the identification of minimum flow levels for the Apalachicola River such that in-stream biological resources are protected while water use needs of Georgia residents are met (U.S. Army Corps of Engineers 1992).

If a single minimum flow level is established, the entire river and bay system ecology will change without the naturally occurring high and low flow conditions.

The introduction of non-native species has also placed riverine ecosystems under extreme stress. These species compete with the native species for habitat and food. Non-native species often will eliminate native species from their natural habitats. These introductions have occurred over the years due to intentional release by individuals, escapes from fish hatcheries, migration from upstream sources, inadvertent transport by shipping and boating interests, and escapes of ornamentals from landscaping projects. Several aquatic plants that were released into Florida's rivers, lakes, and streams, such as hydrilla, Eurasian water milfoil (Myriophyllum spicatum), and water hyacinth, require extensive control measures in order to keep the water bodies open and not completely covered by the vegetation. Non-native fish that have escaped from fish hatcheries ortral and south Florida streams and canals. Many of these fish have established breeding populations and are eliminating native fish populations. The National Biological Survey has documented over 100 non-indigenous species and over 750 specific location occurrences in Florida water bodies. The flathead catfish (Pylodictis olivaris) and several mussel species have migrated into Florida rivers from upstream sources. The appearance of the flathead catfish in several north Florida rivers corresponds to a decline in redbreast sunfish (Lepomis auritus) populations, which are a food source for the flathead catfish (Charles Mesing, personal communication).

Loss and Degradation of Lake Habitats

The principal problems experienced by Florida lakes are: lake level stabilization, dredge and fill, eutrophication, lowered lake levels from groundwater withdrawals, and invasion by non-native aquatic plants.

In their natural condition, water levels of Florida lakes fluctuated in response to rainfall. In many areas, the very flat landscape allowed lake margins to expand or contract over a large floodplain depending on whether flood or drought conditions prevailed. As a result, many lakes were characterized by broad, productive floodplains usually supporting herbaceous wetland vegetation. Fluctuating lake levels allowed fish populations to expand and contract, and permitted shallow margins to dry out and accumulated organic sediments to decompose. However, throughout central and south Florida, lakes have been connected by canals, and water levels have been stabilized by water control structures as a flood control measure. The consequences of lake level stabilization have been that large areas of floodplain habitat are no longer available to aquatic life in many lakes, and no opportunity exists for organic sediments that accumulate on the lake bottom to decompose. Under these conditions, habitat conditions for aquatic life have deteriorated. In an effort to rejuvenate conditions for aquatic life, many lakes are drawn down and dried out on 7- to 10-year cycles to allow organic accumulations to decompose. However, lakes never have the chance to flood their natural floodplain because those areas have been converted to housing developments that would flood if lake levels were raised.

The dredging of lake bottoms to create navigation canals, the filling of lake bottoms for building construction, or the removal of shoreline vegetation for beach development have all led to loss or degradation of lake habitats. Dredging of lake bottoms typically creates a zone that is too deep for light penetration. Moreover, deep areas of lake tend to accumulate organic sediments that rob the water column of oxygen as they decompose and render those areas of the lake bottom uninhabitable to most aquatic life, including sport fishes. Filling of lake bottoms for building construction eliminates wetland and aquatic plants. Similarly, the clearing of wetlands and aquatic vegetation from the shoreline for aesthetic purposes or to create a beach destroys plants and animals.

Eutrophication is the natural process of aging of lakes (and even estuaries). All lakes receive a steady supply of nutrients, particularly nitrogen and phosphorus, from rainfall and runoff. Nutrients stimulate the growth of algae and aquatic plants, which ultimately die, fall to the bottom, and decompose. Because decomposition is usually incomplete, lakes gradually fill in over long periods of time, eventually becoming wetlands. Today most Florida lakes receive excessive nutrients in stormwater runoff draining from agricultural fields, fertilized lawns, and other sources. Increased nutrient inputs have dramatically increased algal production in many Florida lakes. The higher numbers of algae not only reduce light penetration, rendering shallow habitats less suitable to submerged aquatic plants, but they also accumulate on the bottom. As a result, bottom habitats are deprived of oxygen by oxygen-demanding decomposer organisms and are rendered unsuitable for many forms of aquatic life. Although the early stages of lake eutrophication result in increased populations of sport fishes, continued inputs of nutrients accelerate the aging process, leading to poor habitat conditions and low fish populations. Examples of highly eutrophic lakes are Lake Apopka, Lake Jessup, Lake Hancock, and Lake Munson. Lake drawdowns also are used to rejuvenate eutrophic lakes, at least for 7 to 10 years, depending on nutrient input levels.

In some areas, such as the DeLand Ridge, excessive withdrawals of groundwater for human uses have dramatically lowered the level of the surficial aquifer. Since lakes typically occur where groundwater levels intersect the land surface, lowered groundwater levels have led to lowered lake levels. In some cases, lakes have dried up completely due to excessive groundwater pumping. Lakes that occur in regions of deep, sandy, excessively drained soils are especially susceptible to lowered levels in response to lowered groundwater levels.

Many Florida lakes are infested with non-native aquatic plants, the most familiar being hydrilla (*Hydrilla verticillata*) and water hyacinth (*Eichhornia crassipes*). Hydrilla, a rooted, submersed aquatic weed, is the most troublesome nuisance aquatic plant in Florida lakes (Nordlie 1990).

Hydrilla, which spreads rapidly from both underground rhizomes as well as seeds, can quickly fill the water column and form dense mats at the surface. Dense growths of hydrilla reduce fish habitat, impede navigation, and accelerate eutrophication by overloading a lake with huge quantities of dead plant materials. Water hyacinth, a free-floating aquatic plant from Brazil, can double its biomass in two weeks in nutrient rich waters. Water hyacinths can completely cover the surface of small lakes or of embayments of larger lakes. Water hyacinths prevent sunlight from penetrating the water column and reaching submersed aquatic plants. They continually rain dead plant materials on the lake bottom, overloading the decompositional capabilities of lake sediments, depleting oxygen from the water column, and rendering the water column beneath water hyacinth mats uninhabitable to most fishes and other forms of aquatic life.

Loss and Degradation of Estuarine and Marine Habitats

Loss and degradation of estuarine and marine habitat from human impact has been prevalent ever since coastal development began in Florida. Habitat loss and degradation can be categorized into five broad categories: dredge and fill, mosquito control impoundments, water quality degradation, propeller scarring, and alteration of freshwater inflows.

In Florida dredging and filling typically refers to the practice of digging or filling areas classified as wetland or submerged lands. Historically, this has been the most prevalent type of direct impact on mangrove, salt marsh, seagrasses, and tidal river habitats. Major dredge and fill impacts have been from waterfront development and navigation channel construction and maintenance. In three case studies Durako et al. (1988) found that dredge and fill accounted for salt marsh losses of 36 percent, 20 percent, and 19 percent, respectively, in the Jacksonville, St. Augustine, and Daytona Beach regions since the 1940s. Boca Ciega Bay near Tampa is an example of extreme loss (over 90 percent) of estuarine habitat. Shallow seagrass beds were dredged into massive fill areas for residential and commercial development (Haddad 1989).

Since the 1970s, loss of estuarine and marine habitat due to dredge and fill has been significantly reduced through regulation.

Mosquito control has been responsible for much of the impact to salt marshes and mangrove swamps in Florida. The salt marsh mosquito (Aedes taeniorhynchus) lays its eggs on tidally moist sediments, and small tidal pools and puddles within a marsh are necessary for successful larval hatching. One technique to control mosquitoes has been to build a dike around a marsh, cutting it off from the estuary. Salt water is then pumped into the impounded area to flood the marsh so that tidally moist sediments are not available for egg laying. In the Indian River Lagoon, over 85 percent of the salt marsh and mangrove swamp habitats have been impounded, effectively removing these habitats as functional components of the estuary. Salt marsh impoundments are no longer permitted, and active impoundment management and reconnection of the marshes to the estuary is taking place to try to reduce the extent of previous impacts.

Ditching has been the most widespread method of salt marsh mosquito habitat control. Ditches are dug to drain or to allow predatory fishes access to the small intramarsh tidal pools and puddles required for the five-day, aquatic larval stage of the salt water mosquito. Thousands of miles of ditches have been dug, crisscrossing virtually every major tidal marsh and wetland in Florida. Not only were ditches created, but also the spoil taken out of the ditch often became a dike that impeded sheet flow, altering the drainage patterns responsible for creating the marsh in the first place.

Degradation of water quality has been determined to be a significant factor in the loss of seagrass habitat and is potentially detrimental to the health of Florida’s coral reefs. Seagrass health and distribution are primarily controlled by the amount of light available for photosynthesis. By changing upland and riverine drainage and land-use patterns, increased quantities of nutrients and silts have been introduced into estuaries, the result of which has been reduced water clarity. Coupled with discharges of treated sewage and industrial effluents, reductions in water quality have significantly impacted seagrass populations. For example, it has been estimated that Tampa Bay has lost 81 percent of its seagrass beds since the 1940s, Charlotte Harbor has lost 29 percent of its seagrass beds, and Indian River Lagoon has lost 30 percent due to degraded water quality (Lewis et al. 1985, Haddad and Harris, 1985)

Water quality degradation remains the most significant threat to seagrasses statewide. A costly and successful effort to ameliorate water quality problems in Tampa Bay has resulted in an increase in water clarity and a concurrent 10 percent increase in seagrass (Lewis et al. 1991). This demonstrates that many areas that have historically lost seagrasses can recover if water quality is improved.

There is considerable concern that degradation of water quality in the Everglades has led to deteriorating habitat conditions in Florida Bay and that degraded waters from the Florida Keys are impacting Florida's precious coral reefs. Smith-Vaniz et al. (1995)
have suggested that Florida coral reefs are undergoing change due to water quality.

A phenomenon associated with the tremendous increase in the number of power boats coursing Florida's coastal waters is propeller scarring of seagrass beds. In many areas, seagrass beds are in estuarine and marine waters at depths less than 3.5 feet. When power boats move through such areas, their propellers often hit bottom, uprooting and killing seagrasses. In shallow waters that experience heavy boat traffic, seagrass beds can be badly damaged, seagrass productivity can be lowered, and the value of these waters as habitats for estuarine and marine life can be severely damaged.

Estuarine ecosystems have evolved into one of the most productive ecosystems in the world in response to naturally fluctuating, seasonal drainage patterns of freshwaters flowing to the sea. Freshwater delivers the needed nutrients and environmental conditions for sustaining habitat, and the life cycles of many of the marine species of recreational and economic importance are closely tied to natural freshwater inputs.

The flow of too much freshwater into an estuary can be catastrophic. In many areas of Florida, the practice of flood control has resulted in huge volumes of water being released into the estuarine environment over short periods of time. For example, water management practices in the upper Everglades result in excessive flood water releases into the St. Lucie estuary. The flood waters carry heavy loads of silt that have smothered some of the offshore hard bottom and reef communities in the area. Further south at the terminus of the Everglades, large volume releases of fresh water through the C-111 canal system into Barnes Sound have resulted in massive fish kills and loss of seagrass bed and other bottom habitats. Similarly, a flood control canal connecting the upper St. Johns River to the Indian River Lagoon occasionally releases huge quantities of freshwater through the Sebastian River, periodically devastating commercially cultured clams in the lagoon.

Too little freshwater can also be detrimental to estuaries. Perhaps Florida Bay at the southern tip of Florida represents the extreme results of reductions in water delivery. Since the late 1800s, the Everglades ecosystem, stretching from the Kissimmee River to Florida Bay, has been ditched and drained for farming and flood control. Now, about 80 percent of the water that formerly moved slowly through the Everglades and into southern estuaries, such as Florida Bay, today is discharged to east and west coast estuaries. As a result, conditions in the Everglades have changed in response to changes in water delivery and water quality, and reductions in freshwater inflows are believed to be a major reason for the ongoing problems with the biological systems of Florida Bay. It has been estimated that many thousands of acres of seagrass beds have been dying due to poorly understood changes in the Florida Bayas well as mangrove and sponge die-offs, have been occurring in the bay. These changes appear to be linked to the overall problems in the Everglades. Reduced freshwater inflows also allow higher salinities to extend further upstream in tidal rivers, often killing plants and animals adapted to tidal freshwater environments.

With the exception of the Caloosahatchee River, the estuaries of the Florida Gulf coast have experienced decreasing inflows of freshwater, in part for climatological and in part for cultural reasons. In order to meet the demands of a growing population for water supply, flood control, and irrigation, further declines in freshwater inflows to Gulf coast estuaries are very likely in coming decades. Some river supplies already are tapped to the maximum, as is the case with the Manatee River near Bradenton, where impoundment and diversion of water for municipal supply reduces river flow by 90 percent for 80 percent of the time. In other streams, such as the Peace River, water use permits allowing for gradual, albeit monitored, increases in flow diversions to support a regional water supply system have been issued. Like their counterparts in the Apalachicola, estuarine scientists and resource managers working in the Suwannee River are bracing for claims from south Florida residents on that river's abundant supply of fresh water.

Ecological effects of reduced freshwater inflows are numerous and diverse, and depend on the nature of the changes. Inflow reductions promote higher salinities in estuaries. In some cases, flow reductions also can accelerate eutrophication by increasing retention times of nutrients in estuaries. In the Tampa bypass canal (formerly the Palm River), reduced flows create hypoxic (low-oxygen) zones harmful to larval and juvenile fishes. Sub-lethal harm to fisheries may result when changed inflows dislocate physiologically favorable salinity zones in rivers or estuaries from the preferred marsh, seagrass, oyster-reef, or other structural habitats preferred by particular life stages of individual species.

Some estuarine ecosystems have been or may be affected by multiple changes. In southwest Florida, for example, the connected estuaries of Faka Union, Fakahatchee, and Pumpkin bays have experienced freshwater inflow increases, decreases, changes in timing, and relocations of points of delivery, owing largely to drainage impacts caused by the Golden Gate Estates canal.

Slow progress is being made in methods for detecting ecological responses caused by inflow changes. It is clear from studies of panhandle oysters or south Florida shrimps that inflows at certain times of the year are more critical than other times. The same studies have shown that statistical relationships between flows and landings or catch-per-unit-effort must consider the maturation rate of particular species. Recent studies around the margin of Tampa Bay have shown that small changes in the riverine position of salinity zones can translate into large gains or losses of oligohaline (i.e., low salinity) habitat.

Impacts of flow alterations are worsened by the presence of instream barriers. Many Florida streams have dams, flood-control gates, salinity barriers, or other structures near, if not actually in, tidal waters. Numerous estuarine fishes historically moved far up into Florida’s freshwater rivers due, in part, to the state’s abundance of mineralized springs. Instream barriers prevent such movements. A single flood control structure in the tidal Sebastian River, for example, has reduced fish species diversity by 60 percent upstream of the barrier. Many valued species, such as the snook (*Centropomus undecimalis*), naturally extend into rivers. For example, some 3.4 percent of fishes at Fort Meade, 109 miles upstream of the mouth of the Peace River, are snook. However, snook no longer occur upstream of large barriers on other coastal rivers. Instream barriers that no longer serve their purpose need to be identified and either replaced by other structures or removed.

Loss of Biological Diversity

Extinction refers to the decline and eventual complete disappearance of all individuals of a species or subspecies. Extirpation refers to disappearance of all individuals of a species or subspecies from a particular region, even though the species or subspecies may persist elsewhere. Whereas extinction is forever, extirpation holds out the hope that a species or subspecies may be reintroduced into and persist in its former range.

Since the time of settlement, 12 vertebrates and 14 plants have either become extinct or have been extirpated from Florida. These species were lost as the result of wanton slaughter, over-collection, or conversion of Florida’s natural ecosystems to human uses.

Another measure of the status of biological diversity in Florida is the number of species listed as endangered, threatened, and species of special concern. Species listed as endangered have population sizes so low that they are in imminent danger of extinction. Species listed as threatened have declining populations and are in jeopardy of being listed as endangered if population trends are not reversed in the near future. The species of special concern category serves as an early warning system by recognizing species that are declining.

In part due to the rich variety of life in Florida and in part due to extent of development in the state, Florida is second only to California in the number of species listed by the federal government as endangered and threatened. Florida lists 110 vertebrates, 7 invertebrates, and 413 plants as endangered, threatened, and species of special concern (Logan 1997). These endangered and imperiled species include 13 percent of freshwater fishes, 9 percent of the amphibians, 19 percent of the reptiles, 12 percent of the birds, 33 percent of the mammals, and 12 percent of the vascular plants in the state. Overall, a relatively high percentage of the state’s plants and animals are in sufficient jeopardy of extinction or extirpation that they are legally recognized as in need of conservation attention.

The populations of Florida’s most endangered species are perilously low. The Florida panther (Puma concolor coryi) numbers 30 to 50 adults. The key deer (Odocoileus virginiana clavium) population is estimated to include only 250 individuals. The American crocodile (Crocodylus acutus) population includes no more than 500 juveniles and adults, of which only 30 are breeding females.

Although a few Florida species are already extinct or extirpated, and although many have already been listed as endangered or potentially endangered, many more are known or suspected to have declining populations. In a survey of experts in vertebrate biology in Florida**,** Millsap et al. (1990) found that 31 fishes, 12 amphibians, 59 reptiles, 151 birds, and 43 mammals have declining populations. Overall, this survey showed that 44 percent of all Florida vertebrates are known to have, or are suspected of having, declining populations. Loss of habitat to development is usually cited as the reason for the observed declines in the populations of most of these vertebrates.

Habitat Fragmentation

One consequence of the conversion of the natural Florida landscape to agricultural, silvicultural, mining, and urban uses has the been the fragmentation of remaining habitats. As development progresses, remaining habitat patches become smaller in size and increasingly isolated from one another (Wilcove et al. 1986)**.** The inevitable consequence of habitat fragmentation is the loss of biological diversity from a region. Remaining patches of habitat grow too small to support individual plants or animals of a given species, and those species are eliminated from the patch. When many habitat patches in a region become too small to support individuals, entire populations may disappear from a region even though remaining patches appear to contain suitable habitat in all other respects.

Small patches of habitat, particularly forests, also experience edge effects. Edge refers to a zone extending from the forest edge some distance into the interior where influencesreceive more sunlight and are more subject to winds. As a result, microclimate conditions in forest edges are hotter and drier than they are in the interior of the forest. Edge habitats are dominated by common, weedy, early successional stage species of plants, whereas forest interiors are dominated by shade-tolerant climax species. As a general rule, forest interiors also support more rare species. The animals that inhabit edge habitats are subject to increased predation and nest parasitism. Moreover, small patches of forest habitat are comprised of entirely edge species and have no species typically found in forest interiors.

Another consequence of conversion of the landscape to human uses is the loss of natural connections among remaining patches of habitat. Linkages between habitat patches benefit many species by allowing for dispersal of juveniles away from their places of birth, for movement of animals within their home ranges, and for long distance range shifts (Noss and Cooperrider 1994). Landscape linkages, such as riparian forests, may also provide habitat directly for many species. Loss of connections among habitat patches can be particularly severe in the case of wide-ranging species. The Florida black bear and Florida panther have become increasingly susceptible to collisions with automobiles as they cross busy highways trying to reach other patches of suitable habitat.

Many conservation biologists agree that the greatest hope for conserving Florida's biological heritage rests in the state's system of public lands. Lands in public ownership are less subject to development than privately owned lands, and many parcels of public land are managed specifically for the maintenance of biodiversity.

As of 1996, the system of public lands in Florida consisted of 3,020 parcels of land covering approximately 21 percent of the state. Biologists often are tempted to view public lands as islands of natural habitat surrounded by a sea of human land uses. Over two-thirds of public lands are smaller than 100 acres in size, and approximately 90 percent are smaller than 1,000 acres. The largest parcel of public land in Florida is Everglades National Park, which is 1.5 million acres in size. This large-scale picture of the system of public lands in Florida is one of many very small, poorly connected patches of habitat with all of the problems associated with small patch sizes.

Priority Conservation Lands

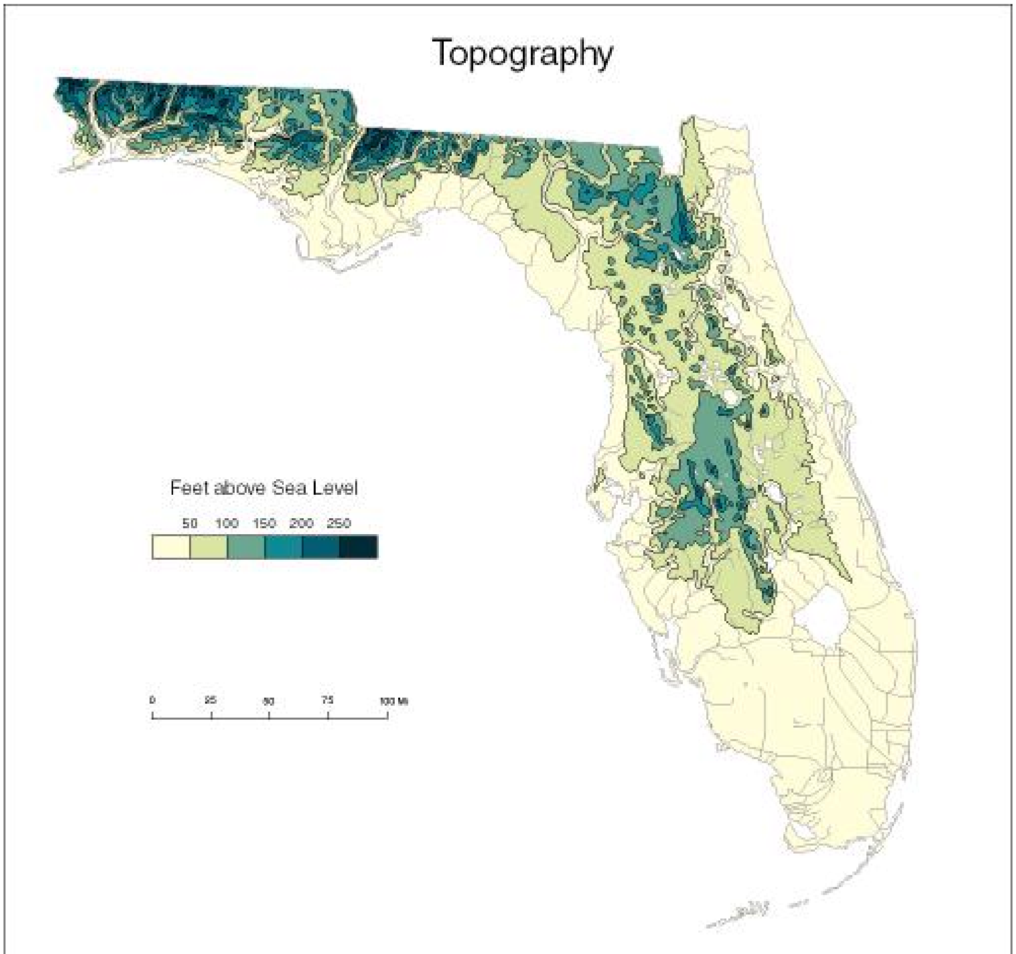
In 1994, the Florida Game and Fresh Water Fish Commission published a technical report (Cox et al. 1994) which identified a set of lands referred to as Strategic Habitat Conservation Areas (SHCA). SHCAs are 4.82 million acres of privately owned lands that should be protected from development in order to ensure the long-term persistence of most elements of Florida's biological diversity. SHCAs are built around and intended to complement biodiversity conservation efforts on the existing system of public lands.

The lands identified as SHCAs include (1) the minimum area of habitat needed to maintain viable populations of 30vertebrates inadequately protected by the current system of public lands, (2) known high quality examples of four rare community types including pine rocklands, tropical hardwood hammocks, sandhills, and scrubs, (3) wetlands important to the continued nesting success of wading birds, (4) lands needed to protect significant bat caves, and (5) lands important to the conservation of 105 globally rare species of plants. The SHCA maps were developed as a guide to decision makers involved in public land acquisition, land use planning, development regulation, and private landowner conservation initiatives.

As a part of the Florida Game and Fresh Water Fish Commission project to map Strategic Habitat Conservation Areas, Cox et al. (1994) also mapped lands they referred to as Biodiversity Hot Spots. This map depicts patterns of species richness for 54 focal species of vertebrates selected as indicators of biological diversity in Florida. The criteria used to select the 54 focal species were: species listed by the state of Florida as endangered, threatened, or species of special concern that are jeopardized by habitat loss; wide-ranging species whose protection would also protect habitats for many species with smaller area requirements; species that are indicators of rare community types; and keystone species whose activities allow other species also to be present. Separate habitat distribution maps were created for each of the 54 focal species using a map of Florida vegetation derived from Landsat satellite imagery, records of known occurrences for each species, and information on the habitat requirements of each species. Then, the 54 individual species maps were overlaid and ranked to produce the Biodiversity Hot Spots map. The importance of large public land holdings to many focal species is clearly apparent from the map. Areas appearing in gray on the map generally indicate relatively large tracts of forested lands utilized by bobcat and wild turkey (*Melagris gallopavo*). Although these two focal species are not currently in jeopardy in Florida, their presence usually indicates habitat conditions suitable for a variety of native species.

Among the vertebrates listed by the state of Florida as endangered, threatened, or species of special concern, 33 are wetland-dependent. That is, these species inhabit only wetlands, or they require wetlands during some time in their lives to survive (e.g., breeding, feeding, roosting).

Kautz et al. (1994) mapped and ranked Florida wetlands based on the number of wetland-dependent listed species likely to use each wetlands. The map was created by first developing a distribution map for each species using habitat maps and known occurrence information, and then overlaying the 33 separate species maps and ranking wetlands based on species use. The extensive wetlands ecosystems of south Florida, particularly in the regions of the Everglades and Big Cypress Swamp, provide habitat to the largest number of wetland-dependent listed species. Other notable wetlands include the marshes of Lake Okeechobee, the marshes of the upper St. Johns River, coastal wetlands around Pine Island in Charlotte Harbor, the wet prairies south of Gainesville, forested and shrub swamp wetlands in Dixie and Lafayette counties, and forested wetlands around Osceola National Forest. Also mapped by Kautz et al. (1994) were upland habitats used by some of the wetland-dependent listed species. The most extensive areas of upland use are the pine flatwoods ecosystems of north Florida lands that provide habitat for the Florida black bear.


Topography
Feet above Sea Level
50 100 150 200 250
0 25 50 75 100 Mi


Wetlands Prior to Development
Wetlands

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Study Questions

1. What is a hydrological cycle?

2. What is a hydroperiod?

3. What is a controlled burn? Scientifically, what time of year should it be done in Florida?

4. Define eutrophication? What are the problems associated with this phenomenon?

5. Look up Melaleuca quinquenervia and Brazilian pepper (Schinus terebinthefolius) on the internet? What are the problems each of these species present to the ecosyustems of Florida?

6. Write a short paragraph about Hydrilla verticillata and water hyacinth (Eichhomia crassipes). Include their origin, introduction, and problems they create in Florida lakes.

7. What effect does freshwater have on an esturine ecosystem?

8. What is biodiversity? Why is it important? What is happening to biodiversity in Florida?

9. What are Strategic Habitat Conservation Areas (SHCA)? What are they for? What types of lands are involved?

Northwest Florida Water Management District

The Northwest Florida Water Management District (NWFWMD) stretches from the St. Marks River basin in Jefferson County to the Perdido River in Escambia County. The district encompasses all of 15 counties as well as the portion of Jefferson County within the St. Marks River basin. Within its 11,305 square miles of land are parts of five major drainage basins: the Perdido-Escambia, the Blackwater-Yellow, the Choctawhatchee, the Apalachicola-Chipola, and the Ochlockonee-St. Marks. When areas of water are combined with land areas, the square miles within the district total 13,264. Tallahassee, the state capital, with an estimated 1990 population of 124,773, is the largest city. All of the other major urbanized areas—Pensacola, Destin, Ft. Walton Beach, Panama City—are on the coast. Small towns dot the interior of the region where most of the land is in agriculture or forestry. Within Northwest Florida are several large government land holdings including Eglin Air Force Base, the Apalachicola National Forest, the Blackwater River State Forest, and the St. Marks National Wildlife Refuge.

Northwest Florida has more rivers and streams than any other region in the state. Seven major rivers (Escambia, Blackwater, Yellow, Choctawhatchee, Chipola, Apalachicola, Ochlockonee) cross the district on their way to the coast. By volume of flow Northwest Florida has three of the five largest rivers in the state: the Apalachicola, Choctawhatchee, and Escambia. The Apalachicola, the largest river in the state, derives its flow from the extensive basins of the Flint and the Chattahoochee in Georgia, which converge at Lake Seminole, an impoundment created by the Jim Woodruff Dam.

Northwest Florida Water Management District is participating in a multiyear comprehensive study of the Apalachicola-Chattahoochee-Flint river system with the states of Alabama and Georgia and the U.S. Army Corps of Engineers. This study includes a freshwater needs assessment of the Apalachicola River and Bay to identify minimum flows of freshwater needed to sustain the current productivity of the river and bay. In 1997 the legislatures of Florida, Georgia, and Alabama adopted the Apalachicola-Chattahoochee-Flint River Basin Compact creating the Apalachicola-Chattahoochee-Flint River Basin Commission. The U.S. Congress ratified the compact in November 1997 and President Clinton signed the compact into law on November 20, 1997.

Most of the region’s rivers are in their natural state and have few man-made structures that alter their floodplains and channels or control their flow rates. Rainfall, runoff, and groundwater discharge into the streams determine variations in flow. In the western portion of the region the rivers are generally highly colored with little sediment and few nutrients. Those in the eastern portion of the district are generally alluvial and nutrient rich.

Flooding can and does occur along major rivers, although damages are not usually widespread because of relatively sparse development and public ownership within floodplains. Caryville on the Choctawhatchee River, however, has experienced several disastrous floods during this century. Blountstown and a few other communities on the Apalachicola River flooded during the summer of

1994 from tropical storms Alberto and Beryl. Local flooding also occurs in some urban areas as a result of inadequate stormwater drainage.

Although surface water is plentiful, the Floridan and sand and gravel aquifers supply about 77 percent of the potable water needs in the region. For the most part the Floridan yields water of excellent quality that requires little or no treatment. In Escambia, Santa Rosa, and parts of Okaloosa counties, however, water from the Floridan is saline, and potable supplies are obtained from the sand and gravel aquifer overlying the Floridan. Only Bay County (Panama City metropolitan area) and Quincy (Gadsden County) use surface water for public supply. In Bay County, Deer Point Lake, a reservoir created in 1961, supplies about 19 million gallons of potable water per day. The city of Quincy depends on Quincy Creek for its potable water supply.

Both surface-water and groundwater quality are generally good in Northwest Florida, although localized problems do exist. Several rivers originate in Alabama and Georgia making them vulnerable to water quality degradation caused by actions in those states. The sand and gravel aquifer, like other surficial aquifers, is very susceptible to contamination. Investigations have found instances of groundwater contamination in southern Escambia County. In Jackson County, domestic wells in the Floridan aquifer were found to be contaminated with the agricultural pesticide ethylene dibromide (EDB). Several public water supply wells in Leon and Escambia counties were shut down because of contamination with dry-cleaning solvent. Continuing large withdrawals of groundwater in coastal areas have the potential to degrade groundwater quality by inducing saltwater intrusion. Abandoned wells pose an additional groundwater contamination threat. Between 1990 and 1995, over 4,700 abandoned wells were identified and plugged in the district.

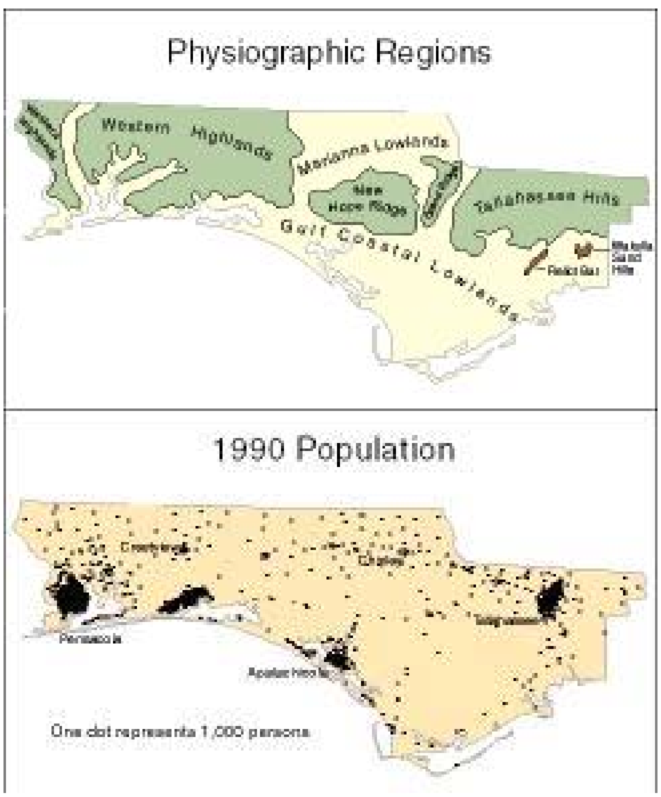
Wellhead protection is an area of increasing concern and activity in the district, especially in the westernmost portions such as Escambia and Santa Rosa counties, which rely on the sand and gravel aquifer. Other places where wellhead protection is critical include recharge areas where the Floridan aquifer is at or near the surface such as in Leon, Wakulla, Jefferson, Jackson, Holmes, and Washington counties.

Pollution of bays, rivers, and lakes from stormwater runoff is a serious problem in the region and throughout Florida. For example, Lake Jackson in Leon County, once a pristine lake famous for its trophy-size largemouth bass, has been adversely affected since the early 1970s by stormwater runoff. The Pensacola Bay system has also been affected by stormwater runoff as well as by point-source pollution. By the late 1960s and early 1970s the system experienced decreased fish landings, fish kills, and severe reductions in seagrass beds. The water management district is working with local governments to monitor stormwater and to develop stormwater management plans.

Before human alteration, most of Northwest Florida was open pine woods on rolling hills and flat lands. In the valley bottoms and along creeks were hardwood forests. Since 1984, the district has acquired approximately 150,000 acres through Save Our Rivers and Preservation 2000 for preservation and, in many cases, for restoration to more natural conditions. Included are river floodplains, headwater wetlands, coastal marshes, first-magnitude springs, and bottomland hardwood and associated upland forests. Within the region are eight first-magnitude springs, most of which are popular recreation spots. Wakulla Springs, the most notable, has an annual average discharge of 250 million gallons per day. More than 85 percent of the floodplains along the Choctawhatchee and Escambia rivers have been acquired by the district.

Although an adequate supply of water is, for the most part, available for existing and future demands throughout most of the region, the district's governing board has designated two Water Resource Caution Areas: the coastal portion of Santa Rosa, Okaloosa, and Walton counties and the Upper Telogia Creek drainage basin in Gadsden County. By 1980, Floridan aquifer water levels in the Ft. Walton Beach area in southern Okaloosa County had declined as much as 100 feet below sea level. Large amounts of water are withdrawn from the upper Telogia Creek basin for irrigation.

Water management activities in Northwest Florida are limited by the current taxing structure. All of the state's five water management districts have the authority to levy ad valorem (property) taxes. Four of the five districts are allowed by the Florida Constitution to levy up to one mill. NWFWMD is limited to 1/20th (.05) of a mill, which is 5 cents for every $1,000 of taxable property value. Most of the district's funding comes from cooperative projects, grants, and legislatively funded programs such as Save Our Rivers and Preservation 2000.



SUWANNEE RIVER WATER MANAGEMENT DISTRICT

The Suwannee River Water Management District (SRWMD) covers 7,640 square miles in north central Florida including all or part of 15 counties. The area is one of the least populated in the state, with a 1995 population of about 280,000. Florida's rapid population growth during the last several decades bypassed north central Florida, indirectly helping keep the region's natural resources healthy. The region's water-related problems are of a smaller scale and more localized than those in more urbanized and developed parts of the state and nation. The region has become increasingly attractive to retirees and second-home developers from other parts of the state and nation. This presents a challenge for the region: providing for continued growth and development while protecting water and related resources.

The defining natural feature of the region is the Suwannee River. From its source in the Okefenokee Swamp in southeastern Georgia, the Suwannee winds its way to the Gulf of Mexico 12 miles above Cedar Key. Two major tributaries also originate in Georgia. The Alapaha River joins the Suwannee southwest of Jasper, and the Withlacoochee flows into the Suwannee a few miles downstream at Ellaville. The Santa Fe River flows west from its headwaters in the Santa Fe Lakes area to join the Suwannee near Branford.

The Suwannee begins as a narrow stream and then broadens and flows through extensive swamps and marshes. The Suwannee River estuary is a complex of diverse natural communities and a major nursery for commercially important fish and invertebrates. Other major stream systems within the district include the Waccasassa, Steinhatchee, Fenholloway, Econfina, and Aucilla. The region's surface waters—lakes and springs as well as rivers—are a major recreational resource for residents and tourists. Groundwater is the major source of water for public supply, agriculture, industry, and domestic use.

Population distribution within the region is influenced by topography and patterns of land tenure. Most of the population is in the higher, drier counties east of the Suwannee River, concentrated around Lake City and Live Oak and along the northern and western edge of Gainesville. Other population centers are Starke, Alachua, and Chiefland east of the river, and Madison and Perry west of the river. Along the Suwannee River the largest incorporated towns are White Springs and Branford, each with a population of about 700. To the west of the Suwannee River are extensive low, wet areas and large tracts of land owned by timber companies. In portions of this western region, mile upon mile of back roads can be traveled without sign of permanent human habitation.

The district's rural character and low population density often lead to the conclusion that the economy of the region is based primarily on agriculture. In reality, agricultural wages and employment rank far behind those for other employment categories. Only about three percent of all employed persons in 1994 worked in farm-related jobs. The two largest industries that have long provided an important economic base for the region are forest products and phosphate mining. One of the larger employment sectors is government—about

52 percent of the 14-county workforce is employed by federal, state, regional, and local government agencies. Most of this employment is with local school boards, the University of Florida, and correctional facilities. The region's increasing number of retirees has given rise to a trend toward a service-oriented economy that is expected to continue.

The district's nine-member governing board, appointed by the governor and confirmed by the senate, has the authority to levy ad valorem taxes and to implement rules and regulations for the management of groundwater and surface water within the district. One board member must reside in the Aucilla River basin; the coastal area between the Suwannee and Aucilla rivers; the Withlacoochee (north) and Alapaha river basin and the Suwannee River basin north of the Withlacoochee River; the Suwannee River basin south of the Withlacoochee River (excluding the Santa Fe River basin); and the Santa Fe River basin, Waccasassa River basin, and coastal area between the Withlacoochee (south) and Suwannee rivers. The other four members are appointed at large.

Topography, Physiographic Features, and Climate

The topography in the region overall is subdued, although some dramatic effects have been produced by solution activity and ancient marine processes. Elevations range from at or near sea level in the coastal swamps, lowlands, and river valleys to over 200 feet above mean sea level (msl) in the Northern Highlands and Tallahassee Hills.

The Northern Highlands, considered to be the most distinct physiographic feature in north central Florida, include several subdivisions, one of which is the Tallahassee Hills. All the highlands appear to be disconnected remnants of a once-continuous residual highland (Yon 1966). The line of demarcation separating the Northern Highlands from the Gulf Coastal Lowlands is the Cody Scarp, termed the "most persistent topographic break in the state" by Puri and Vernon (1964). The Suwannee River is the only major stream that does not go underground crossing this transition zone. The Santa Fe and Alapaha re-emerge miles downstream, while smaller streams such as Rose Creek and Pareners Branch disappear into the Floridan aquifer system.

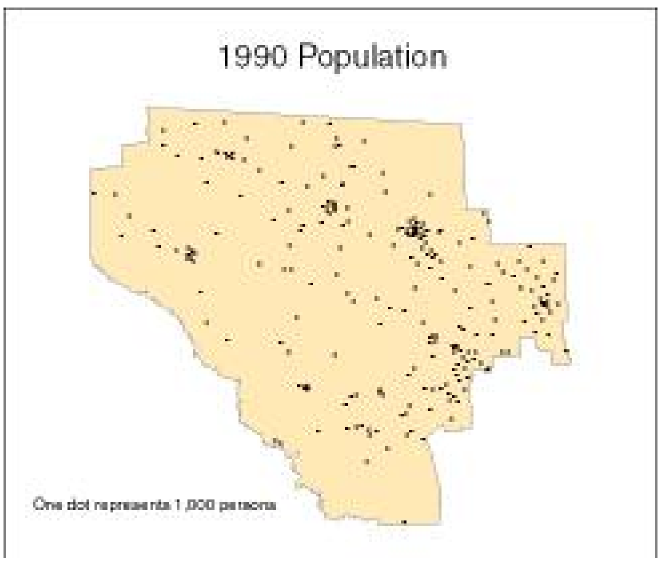
The Gulf Coastal Lowlands consist of a series of Pleistocene surfaces and shorelines with limestone at or near the land surface. Karstic topography produced by intense solution activity is prominent. Important remnant features in the Gulf Coastal Lowlands are the Bell and Brooksville ridges. Towards the east the Brooksville Ridge becomes a rolling plain with sinkholes. The western edge is probably bounded by a marine terrace scarp (White 1970). Bell Ridge, an outlier of the Brooksville Ridge, consists of two irregularly shaped ridges approximately 20 miles long with crests ranging from 80 to 100 feet above msl.

The Coastal Swamp consists of mud and silt over limestone and supports both freshwater swamp and salt marsh. The relative absence of sand barriers and beaches along the coastline is the result of a shallow, sloping sub-marine surface, lack of wave activity, and inadequate sand supply (Tanner 1960).

Remnant dunes, of either aeolian (wind-deposited) or marine origin, can be found inland from Cedar Key to Steinhatchee.

The climate of the region is humid subtropical. Average annual temperatures range from 68½F in Madison County to 72½F at Cedar Key in Levy County. During the winter, temperatures in the 40–50½F range are typical, although freezing temperatures associated with cold fronts are common. Precipitation throughout the district varies from 58 inches annually at Perry to 52 inches annually at Madison, with 50 percent of this amount falling during the summer months (June through September). Summer rainfall is associated with localized thunderstorm activity. In winter, fronts bring sweeping bands of rain and cooler temperatures. Frontal rains are usually more evenly distributed areally and are of longer duration than summer rainfall. Since evaporation and plant transpiration are significantly lower during the winter, these frontal rains are important for recharging groundwater.

Rainfall during spring and summer, although unevenly distributed, is normally sufficient for plant growth. However, spring and summer droughts of varying severity occur, but not in any predictable patterns. Dry conditions in the late 1970s and early 1980s, combined with improvements in irrigation technology, led to an increase in the use of center-pivot and other irrigation systems. Although demands on the Floridan aquifer system are greatest during drought, a period of record-low groundwater levels in 1990–1991 throughout most of the region did not cause any significant water shortages.



ST. JOHNS WATER MANAGEMENT DISTRICT

St. Johns River Water Management District is located in northeastern and east central Florida, extending south from the Georgia border to cover 12,400 square miles, almost 21 percent of the state's total area. Within its boundaries are the entire St. Johns and Nassau River basins, the Indian River Lagoon and Northern Coastal basins, and the Florida portion of the St. Marys basin. The district includes all or part of 19 counties and has a population of approximately 3.7 million, or 25 percent of the state's total.

It is a diverse region, with rural counties dominated by pine plantations in the Nassau and St. Marys river basins, major urban areas including Jacksonville and large portions of the Gainesville and Orlando metropolitan areas, and world-famous Atlantic coast beaches. It has the oldest continuously occupied European settlement in the U.S. and the first National Audubon Sanctuary; a major citrus-producing region and one of the largest cattle-producing areas in the nation; the largest stand of sand pine and the most biologically diverse estuary in North America (shared with the South Florida Water Management District).

This district contains the longest river in the state, over one-third of the state's lakes including the second largest, and 12 of the 20 exceeding 10 square miles, one of four National Estuary Programs, and numerous springs and spring runs, most notably Silver Springs with outflow among the largest in the world. Florida's most popular tourist attraction in the late 1800s was a steamship tour up the St. Johns and Ocklawaha rivers to Silver Springs.

In the 1960s, as part of construction of the Cross-Florida Barge Canal, the lower Ocklawaha was dammed and about 20 miles of the river were flooded, creating Rodman Reservoir. Upstream portions of the Ocklawaha had been channelized earlier in the century, and marshlands along the river and lakes in the Ocklawaha chain had been drained for farming. The district has purchased large tracts of these drained marshes, stopped the pumping of polluted water from farms and reflooded the fields. The marshes are returning and with them wintering waterfowl, wading birds, and other wildlife.

Major efforts are underway to restore Lake Apopka, one of the most polluted lakes in the state and the main headwater for the Ocklawaha river and chain of lakes. Removal of excess nutrients presently in the lake is being addressed through harvest of gizzard shad and construction of a marsh filtration system on former muck farmland. Direct discharges from sewage treatment plants and citrus processing plants have stopped.

For further reduction of nutrient inputs to Lake Apopka and restoration of its wetlands, funding has been provided by the Florida legislature and the federal Wetland Reserve Program for acquisition of the remaining muck farms. To encourage the return of game fish populations, native aquatic vegetation species that were originally in the lake are being planted in the shallow water near the shoreline. The plants provide food, protection from predators, and spawning sites for fish and other wildlife, and their root systems help stabilize the loose sediments on the lake bottom, improving water clarity.

As in the Ocklawaha basin, the upper St. Johns River floodplain was diked and drained. One of the largest wetland restoration projects in the world is repairing the resulting environmental damage. The Upper St. Johns River Basin (USJRB) Project is a cooperative effort with U.S. Army Corps of Engineers that encompasses 235 square miles and incorporates flood control, habitat, and water quality components, restoring 150,000 acres of floodplain wetlands.

The USJRB project also benefits the Indian River Lagoon (IRL) by reducing the amount of upper basin runoff diverted there. That runoff carries excess freshwater that changes the salinity of the lagoon, affecting animals such as oysters and clams, and delivers nutrients (nitrogen and phosphorus) that can cause the overgrowth of algae, resulting in the death of seagrasses. Protection and restoration of seagrass beds and reconnection of mangroves and marshes diked off from the lagoon for mosquito control are major IRL issues being addressed by the district.

Many restoration projects are made possible by the district's land acquisition program. Highest priority in the 1980s was given to purchase of the land needed for the upper basin project, where the most severe loss of floodplain had occurred. SJRWMD now owns property in all its major basins except Florida Ridge, most of which is in the Southwest Florida Water Management District. These lands are acquired for flood protection, water supply protection, water body preservation, restoration, and habitat protection. They provide the added benefit of public recreation, with 98 percent open to the public.

Joint purchases and management agreements with local governments and other agencies supplement funds available to the district. Less-than-fee acquisitions, or purchase of conservation easements, have been used to stretch those funds where the cost of the development rights is significantly less than the total purchase price of the land.

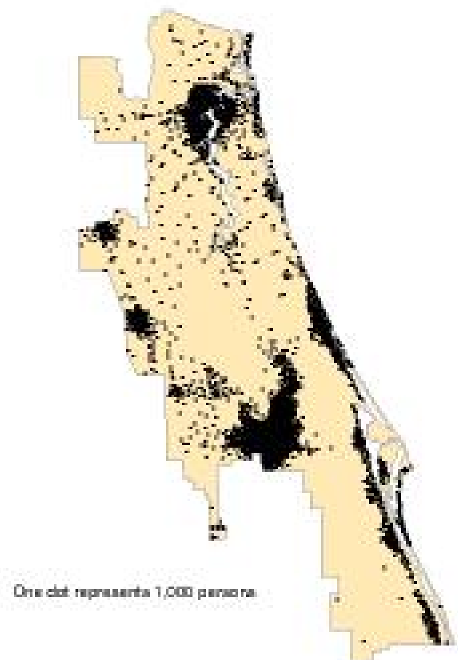
Passage of the Bluebelt Act by the 1996 Legislature recognized the importance of land owner agreements to refrain from developing significant recharge areas. The Floridan aquifer isSJRWMD's main source for public supply, and the district will delineate significant recharge areas for any of its counties willing to offer reduced tax assessments in exchange for their protection, as authorized by the act. Orange County was the first county in Florida to offer this opportunity to its residents.

In some parts of the district, use of the Floridan aquifer is limited because of poor quality. High chloride content generally occurs east of the St. Johns River where intensive agricultural, industrial, and urban uses as well as abandoned free-flowing wells have reduced groundwater supplies and contributed to saltwater contamination. In those areas the surficial aquifer is tapped as a potable water source, and in some cases blended with water from the Floridan. In addition, reverse osmosis is increasingly being used to provide drinking water.

Physiographic Regions

Topography

1990 Population



SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT

The Florida legislature created the Southwest Florida Water Management District (SWFWMD) in 1961 to be the local sponsor of the Four River Basins, Florida Project. The U.S. Army Corps of Engineers initiated this major flood control project after Hurricane Donna severely damaged southwest Florida in 1960. The project includes flood control structures and 6,000 square miles of water detention areas. SWFWMD continues to cooperate with the corps in maintaining and operating portions of this flood control system.

The district's responsibilities expanded in the mid to late 1960s when regulatory programs for regional wellfields serving the Tampa Bay metropolitan area were initiated, and again in 1972 when the Florida legislature passed the Water Resources Act. This act significantly furthered the transition from strictly flood control to a more broad-based policy of resource management and service to the public.

SWFWMD is governed by an 11-member board appointed by the governor and confirmed by the senate. Board members, who must live in the district, serve staggered four-year terms. The district's primary funding source is ad valorem taxes, although revenues are also derived from state and federal appropriations, permit fees, interest earnings, and other sources. The taxing capabilities of the district are established by the legislature within the limits set by the Florida Constitution. The limit for SWFWMD is one mill, or one dollar per thousand dollars of assessed value.

SWFWMD is further divided into nine hydrologic subdistricts, or basins, eight of which have separate basin boards. Activities within the Green Swamp Basin are the responsibility of the governing board. Members of the basin boards are also appointed by the governor, confirmed by the senate, and serve three-year terms. These boards identify water-related issues and problems in their basins, and provide programs and budgets to address these concerns. At present, SWFWMD is the only water management district with this form of basin system.

The one-mill taxing capability of the district is divided evenly between the governing board (0.5 mill) and the district's eight basin boards (0.5 mill).

SWFWMD includes all or part of 16 counties on the west-central coast of Florida, from Charlotte County on the south to Levy County on the north. It extends from the Gulf of Mexico east to Polk and Highlands counties. Several major and rapidly growing urban areas lie within this area, as does much of Florida's most productive agricultural lands (especially for citrus) and major phosphate areas. The region also contains the Green Swamp, headwaters for the Peace, Hillsborough, Withlacoochee, and Ocklawaha rivers, and many lakes, springs, and streams.

The significance of Tampa Bay, Sarasota Bay, and Charlotte Harbor estuaries has been recognized through the National Estuary Programs. These vital estuarine systems have also been designated as state priorities through the Surface Water Improvement and Management Program (SWIM). It is often along, and in, these very sensitive ecosystems that development pressure and population growth have been most demanding and have had adverse environmental impacts.

Physiography and Topography

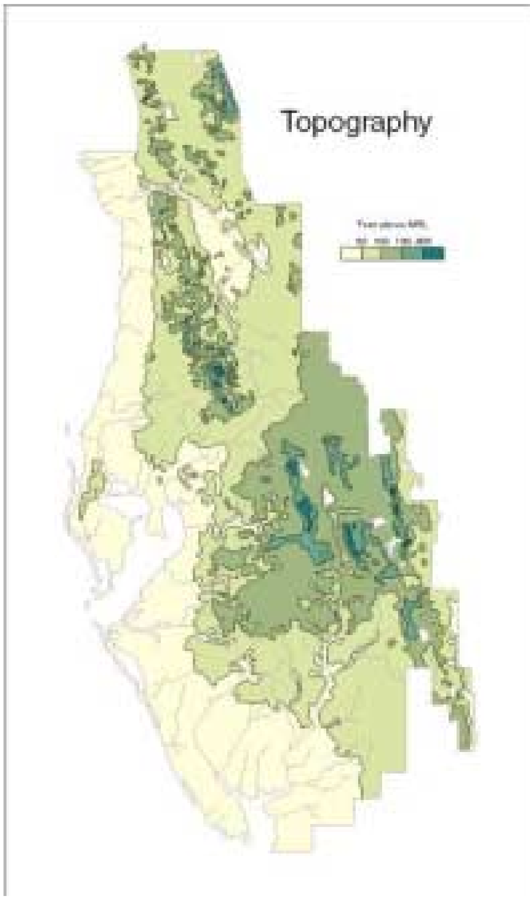
Land in the region ranges in elevation from sea level along the Gulf coast to more than 290 feet above mean sea level at several places along the Lake Wales Ridge. Higher elevations are associated in particular with three ridges, the Brooksville, Lakeland, and Lake Wales ridges, aligned with the Florida peninsula. The Polk Upland region has gently rolling, sometimes hilly, terrain. The Tsala-Apopka Plain is part of the Withlacoochee River valley. The Withlacoochee River originates in the Green Swamp and flows northward before turning west through the Dunnellon Gap.

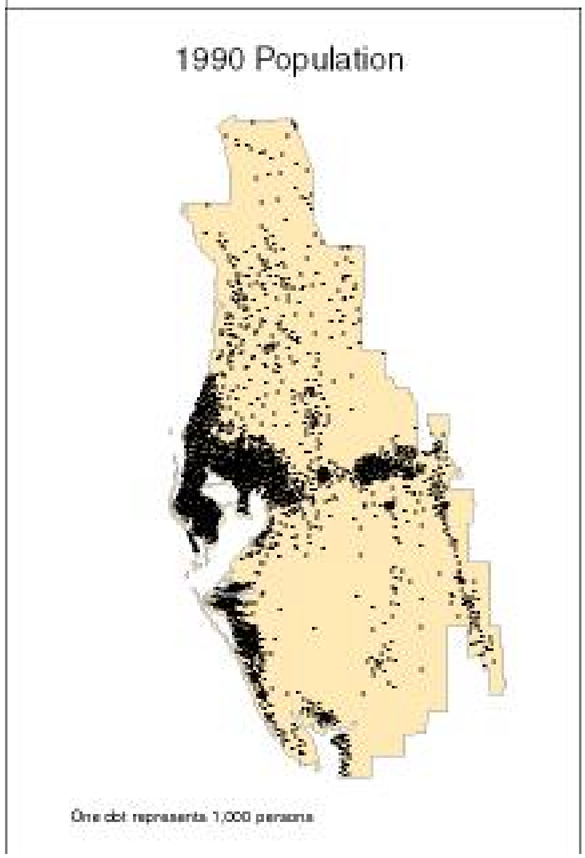
The high sandy ridges are remnants of ancient sand dunes, the only portion of peninsular Florida not inundated in a series of advancing and receding ocean levels. This unique isolation created and supports ecosystems not found anywhere else in the world. The high sandy soils are also a high recharge area for the Floridan aquifer. In the northern part of the region, the Floridan rises close to, and is often exposed at, the surface. This exposed aquifer is the source of the several first-magnitude springs in Hernando and Citrus counties.

The Gulf Coastal Lowlands and the DeSoto Plain are flat areas with wetlands interspersed with pine-palmetto flatwoods. In the southern part of Southwest Florida, soils in these flat areas are typically acidic because of the dominant types of vegetation and the lack of underground drainage. Rivers in this area are characterized as “black water,” so called because the acidic soil causes a high tannic content (tea-colored water) in the surface water runoff.

The northern part of Southwest Florida has karst geology. In karst areas, water-soluble limestone below the earth’s surface may dissolve, causing the land surface to sink or collapse, and often, to fill with water. This condition, most common in the northern and eastern regions of the district, produces sinkholes. They can range from 20 feet in diameter to half a square mile or more.

Under karst conditions, surface water and groundwater are closely interrelated. Lake levels are often a direct reflection of groundwater levels; spring flow and seepage constitute the base flow of many streams; freshwater wetlands slow and store floodwaters and enhance infiltration to groundwater; and stream discharges to estuaries are critical for maintenance of salinity regimes. As development increases on the sandy ridges and karst areas of this region, so to has nutrient loading to the groundwater. This nutrient loading is thought to be a factor in increased algal blooms occurring in the northern coastal springs.


Topography


1990 Population
One dot represents 1,000 persons

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

The 17,000-square-mile South Florida Water Management District encompasses all or portions of 16 counties. Forty percent of the population and 31 percent of the land area of the state are within its boundaries. The district contains two watersheds or drainage basins: the Big Cypress Basin (Collier County and part of Monroe County) and the larger Okeechobee Basin, which begins at the headwaters of the Kissimmee River and ends in Florida Bay.

In its natural state, South Florida can be described in one word—wet. Rainfall occurs at an annual average rate of about 54 inches; 67 percent of that amount, or about 36 inches, occurs between May and September. The combination of concentrated periods of rainfall and flat terrain produces a continually swampy, flooded condition throughout much of the region during the wet season, a subtropical characteristic which, for a long time, made South Florida a less-than-desirable spot for human settlement. Over the last 100 years or so the South Florida environment has been substantially modified to accommodate urban, residential, and agricultural development, often to the detriment of the remaining areas of subtropical wilderness.

The first large-scale regional drainage project in South Florida began in 1881, when Hamilton Disston bought 4 million acres of land from the state for twenty-five cents per acre. In 1882, a Lake Okeechobee outlet to the Gulf coast, via the Caloosahatchee River was completed. In the same year, Southport Canal was cut between Lake Tohopekaliga and Lake Cypress. The St. Cloud Canal, which connects Lake Tohopekaliga to East Lake Tohopekaliga, was completed next. By fall of 1883, Disston's company had drained land and opened navigation channels from the Kissimmee Lakes to the Gulf of Mexico.

Disston's land reclamation project revived the depressed railroad industry in Florida which, in turn, brought new settlement, new industry, and new growth. The region's development, however, proceeded in a very haphazard manner—a reflection of the variety of private interests trying to make a profit from South Florida. Funding to sustain large land reclamation projects became harder to acquire as the nineteenth century drew to a close, and drainage efforts by private business ended as well.

In 1907, the state legislature created the Everglades Drainage District. From 1913 to 1927, six major canals and several smaller waterways, 440 miles of levees, and 16 locks and dams were constructed. Hurricanes in 1926 and 1928 halted construction by the Everglades Drainage District, but gave rise to the Okeechobee Drainage District (1929). The Okeechobee district was created to prevent a recurrence of the flooding produced by wind tides on Lake Okeechobee and constructed floodway channels, control gates, and major levees along the lake's shores.

Droughts occurred between 1931 and 1945, bringing saltwater intrusion along the coasts and causing extensive fires in the muck soils of the Everglades. This period came to a dramatic end with the hurricane of 1947. In 1948, Congress authorized the Central and Southern Flood Control Project to provide flood protection and adequate water supply, prevent saltwater intrusion, encourage agricultural and urban development, and preserve fish and wildlife. The Central and Southern Florida Flood Control District (CSFFCD) was established in 1949 by the Florida legislature to act as local sponsor for the federal project. The CSFFCD acquired lands for, and assumed operation and maintenance of, each section of the project as it was completed.

From 1949 through 1969, the U.S. Army Corps of Engineers and the CSFFCD built and operated the project works. At the same time, South Florida's population surged, and industrial and residential consumption became significant components, in addition to the existing agricultural demands, of water use within South Florida.

The National Environmental Protection Act, passed in 1969, requires the corps and the CSFFCD to consider damage to the environment when making management decisions. Growing concern for preservation of the environment prompted, in 1971, a Governor's conference on Florida's water management issues. The conference produced legislative action, the Water Resources Act of 1972, which broadens the authority and responsibility of the CSFFCD, and requires control and regulation of water supplies and their use. In 1976 the CSFFCD became the South Florida Water Management District (SFWMD), to reflect the changing scope of the district's responsibilities.

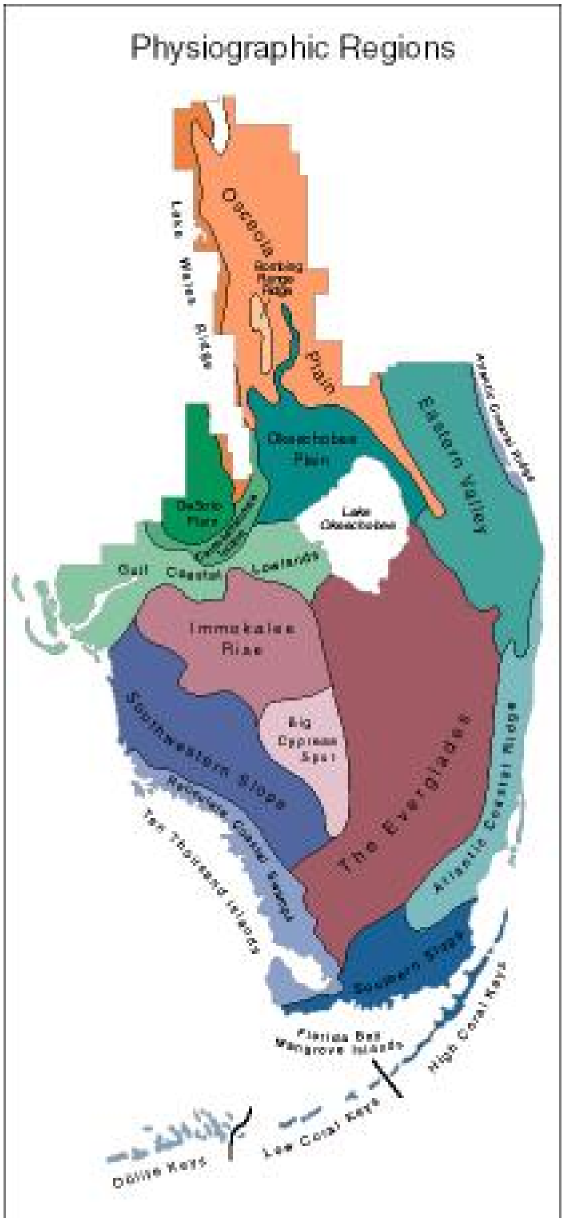
Excavation, construction of barriers, and other mechanical means to channel and retain water have been supplemented by the use of improved planning, operational, and regulatory processes to control human use of water. Recent efforts have focused on developing water management plans for four planning districts within the SFWMD and for Lake Okeechobee to address water supply, water quality, flood control, and enviTopography, Physiographic Features, and

Climate

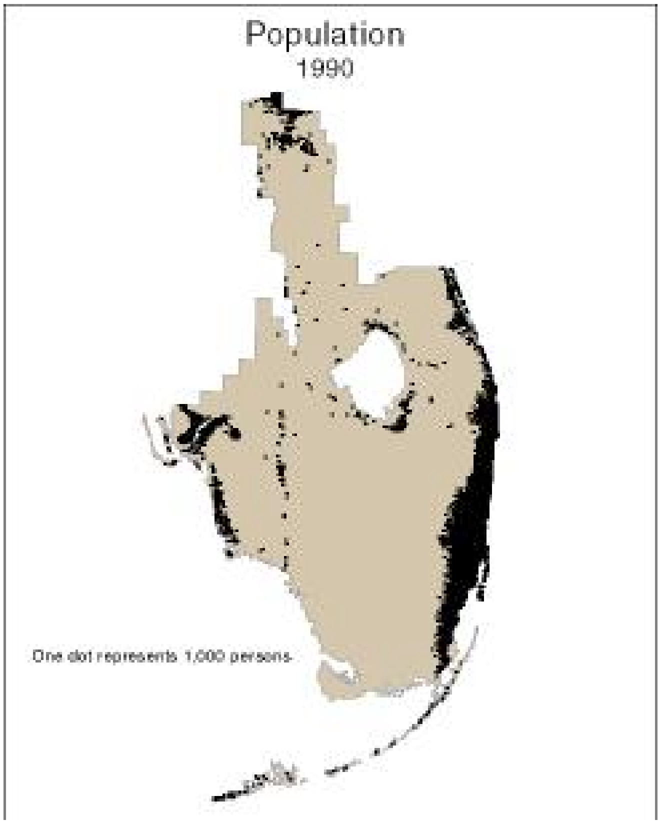
Nearly all the land in South Florida is less than 100 feet above mean sea level (msl). Land surface generally slopes from north to south. The coastal regions and most of the peninsula south of Lake Okeechobee are very flat and lie below 25 feet msl, except near Immokalee and parts of the Atlantic Coastal Ridge. North of Lake Okeechobee, the Lake Wales Ridge juts down the center of the peninsula and is mostly above the 100-foot contour. East of this ridge, the Okeechobee Plain rises from approximately 20 feet at the lake to 30 to 40 feet at the edge of the Osceola Plain, which rises in elevation from 60 feet to 90 feet.

Two major physiographic features, Lake Okeechobee and the Everglades, are discussed separately in this chapter. The Kissimmee River valley (also discussed separately) crosses the Osceola and Okeechobee plains and is a major source of surface water to Lake Okeechobee and the Everglades. Rainfall in the northern portion of the Osceola Plain recharges the Floridan aquifer. The Immokalee Rise provides recharge to the water table and sandstone aquifers in Lee and Collier counties. Water from the Atlantic Coastal Ridge and Everglades recharges the Biscayne aquifer in Dade and Broward counties and provides surface water flows to Florida Bay. The Big Cypress Swamp in eastern Collier and southern Hendry counties contributes primarily to surface-water flow to coastal estuaries along the southwest coast of Collier County and Everglades National Park. The Florida Keys have no major source of freshwater except for rainfall and limited storage in the shallow aquifer of the larger islands. Coastal marshes and mangrove swamps, which are subject to tidal influx of saltwater, border the southern end of the peninsula.

South Florida, with its distinct wet and dry seasons, is the only savanna climate in the continental United States. Within this region, rainfall varies considerably. Average wet season (May 1–October 31) rainfall ranges from 46 inches near the southeast coast to 36 inches in the Kissimmee valley. Average dry season rainfall varies from 17 inches along the southeast coast to 10 inches on the southwest coast. The driest month is December, when average monthly rainfall ranges from less than 1.25 inches near Everglades City to 2.50 inches near West Palm Beach. The wettest month is September, when average rainfall ranges from 9.5 inches at West Palm Beach and Homestead to 6 inches near Okeechobee. The area occasionally experiences extended periods of below average rainfall, such as occurred during the drought of 1988–91. South Florida is also subject to tropical storms and hurricanes, which can produce significant amounts of rain. During such years, rainfall for the year can total over 80 inches.



Physiographic Regions
Osceola Plain
Lake Wales Ridge
Bombing Range Ridge
Okeechobee Plain
Atlantic Coastal Ridge
Eastern Valley
DeSoto Plain
Lake Okeechobee
Gulf Coastal Lowlands
Immokalee Rise
Big Cypress Spur
Southwestern Slope
The Everglades
Reticulate Coastal Swamps
Ten Thousand Islands
Atlantic Coastal Ridge
Southern Slope
Florida Bay Mangrove Islands
High Coral Keys
Low Coral Keys
Oolite Keys


Population
1990
One dot represents 1,000 persons