Hydrology and Ecology of Freshwater Wetlands in Central Florida—A Primer

By Kim H. Haag and Terrie M. Lee

Prepared in cooperation with the
St. Johns River Water Management District,
the Southwest Florida Water Management District,
and Tampa Bay Water

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Conversion Factors

Multiply	By	To obtain
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
acre	0.4047	hectare
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch per year (in/yr)	2.54	centimeter per year
gallon per day (gal/d)	0.003785	cubic meter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Vertical coordinate information is referenced to National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Terms defined in the Glossary are presented in **boldface type** where first used in the text.

Acronyms and Additional Abbreviations

CAD	Computer Aided Design
DOQ	digital orthophoto quadrangle
DOQQ	digital orthophoto quarter quadrangle
ERP	Environmental Resource Permit
FLUCCS	Florida Land Use and Cover Classifications System
FNAI	Florida Natural Areas Inventory
GIS	Geographic Information System
GPS	geographic positioning system
LIDAR	light detection and ranging
μS/cm	microsiemens per centimeter
μg/L	micrograms per liter
mg/L	milligrams per liter
ppt	parts per thousand
USGS	U.S. Geological Survey

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Introduction

Freshwater **wetlands** are an integral part of central Florida, where thousands are distributed across the landscape. However, their relatively small size and vast numbers challenge efforts to characterize them collectively as a statewide water resource. Wetlands are a dominant landscape feature in Florida; in 1996, an estimated 11.4 million acres of wetlands occupied 29 percent of the area of the State. Wetlands represent a greater percentage of the land surface in Florida than in any other state in the conterminous United States (Dahl, 2000; 2006). Statewide, 90 percent of the total wetland area is freshwater wetlands and 10 percent is coastal wetlands (Dahl, 2005). About 55 percent of the freshwater wetlands in Florida are forested, 25 percent are **marshes** and emergent wetlands, 18 percent are **scrub-shrub** wetlands, and the remaining 2 percent are freshwater ponds.

Freshwater wetlands are distributed differently in central Florida than in other parts of the State. In the panhandle and in northern Florida, there are fewer **isolated wetlands** than in the central and southern parts of the State, and few of those wetlands are affected by activities such as **groundwater** withdrawals. In southern Florida, the vast wetlands of the Everglades and the Big Cypress **Swamp** blanket the landscape and form contiguous shallow expanses of water, which often exhibit slow but continuous flow toward the southwestern coast. In contrast, the wetlands of central Florida are relatively small, numerous, mostly isolated, and widely distributed (fig. 1). In many places, wetlands are flanked by uplands, generating a mosaic of contrasting environments—unique wildlife habitat often adjacent to dense human development. As the population of central Florida increases, the number of residents living near wetlands also increases. Living in close proximity to wetlands provides many Floridians with an increased awareness of nature and an opportunity to examine the relationship between people and wetlands. Specifically, these residents can observe how wetlands are affected by human activities.

Primer Facts

The U.S. Geological Survey reports on the state of the Nation's terrestrial, freshwater, and coastal/marine ecosystems, including wetlands, and studies the causes and consequences of ecological change, monitors and provides methods for protecting and managing the biological and physical components and processes of ecosystems, and interprets for policymakers how current and future rates of change will affect natural resources and society.

Freshwater wetlands are unique and complex ecosystems defined by characteristic properties. Wetlands usually have standing water during at least part of the year, although water depths can vary from a few inches to as much as several feet from one wetland to another. The hydrologic behavior of wetlands is influenced by **drainage basin** characteristics, as well as by natural variations in climate. Wetlands in central Florida (especially forested wetlands) often have **acidic** waters that are darkly stained from organic substances released by decomposing leaves and other plant material. Wetlands are characterized by biogeochemical cycles in which vital elements such as carbon, nitrogen, phosphorus, and others are transformed as they move between wetland soils and sediments, the open water, and the atmosphere. Wetlands are populated with plants that can thrive under conditions of saturated soils and low dissolved-oxygen concentrations. The bottoms of many wetlands, especially marshes, are covered with decayed plant material that can accumulate over time to form brown peat or black muck soils. Wetlands are inhabited by animals that need standing water to complete some or all of their life cycles, and they also provide periodic food, water, and shelter for many other animals that spend most of their lives on dry land. The complex and interrelated components of wetlands directly affect one another and there are numerous feedback mechanisms (fig. 2).

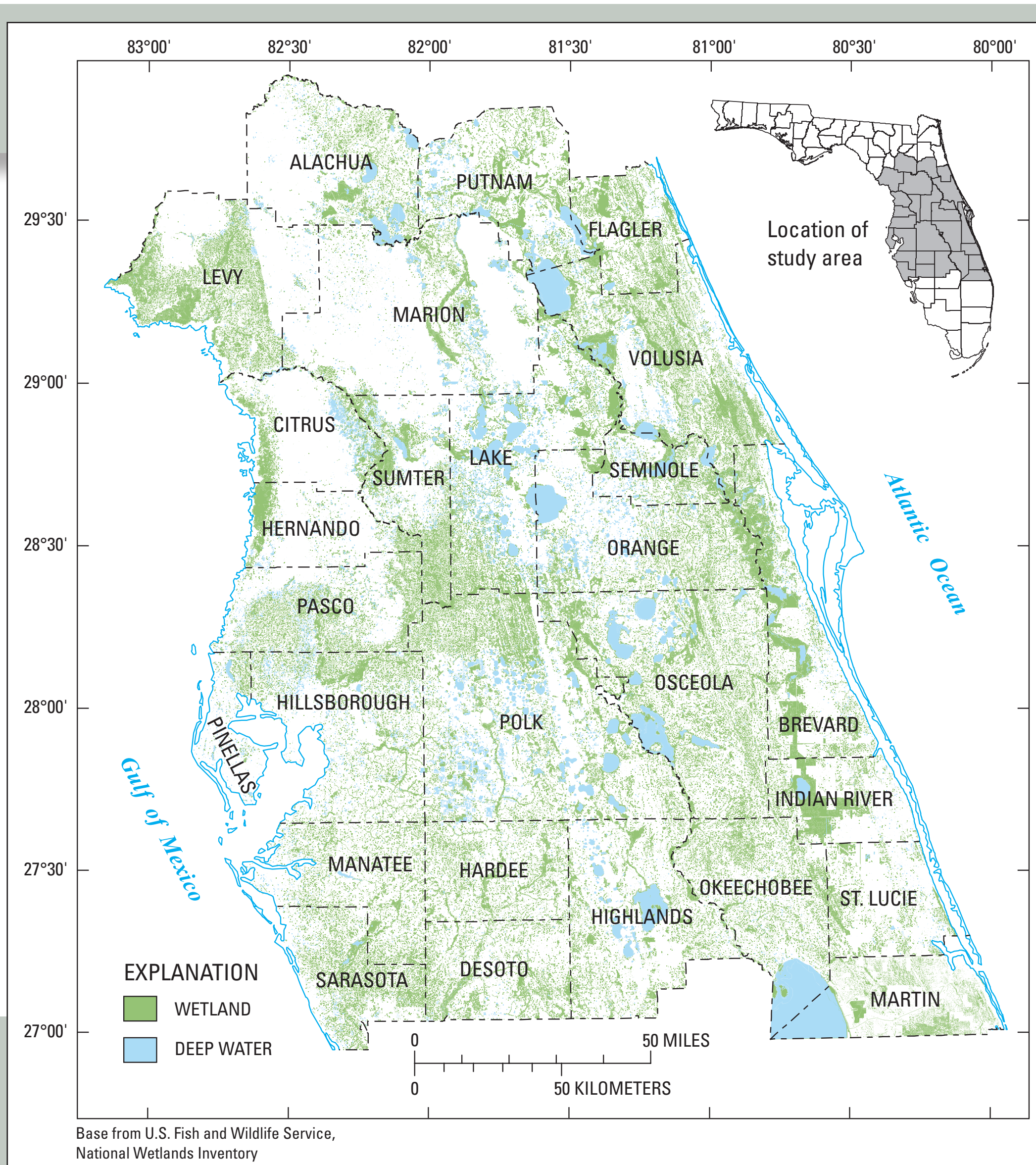


Figure 1. Wetlands in the counties of central Florida.

Wetland **ecology** is directly linked to the extent and duration of wetland flooding and the quality of the water. The vegetation and wildlife associated with wetlands are largely adapted to the changes in water availability associated with seasonal fluctuations between wet and dry conditions, and seasonal patterns are evident to residents living nearby. For example, isolated wetlands are most lush and most densely vegetated during the wet season from summer to early fall. Frog eggs may hatch in abundance during an early wet summer, and frogs adapted to moving from wetlands into upland trees can instead appear on the windows of nearby homes. Colorful dragonflies and damselflies are important predators that feed on swarming mosquitoes and other flying aquatic insects. The burnt-orange fall color of cypress trees in November is one of the few conspicuous indicators of the approach of winter and seasonal dry conditions in central Florida. Many shorebirds overwinter in Florida wetlands, and feed on the **aquatic** insects and other invertebrates that are abundant. December and January are the best times for watching waterfowl on marsh wetlands when the grassy vegetation dies back as wetland flooded areas diminish. Extreme wet or dry conditions can cause some patterns in plant and animal communities to change, and often these changes are noticeable to people living and working near wetlands. Heavy rains and flooding in isolated wetlands in central Florida during the winter bird migration can bring herons, ibis, and other waterfowl wandering through nearby suburban yards. During drought years, central Florida residents may encounter alligators or turtles crossing roads as they migrate between wetlands in search of water.

Wetlands covered an estimated 50 percent of the State before land use changes and other human activities began to cause wetland losses in Florida (Dahl, 1990). Historically, wetlands were viewed as inhospitable places, and their

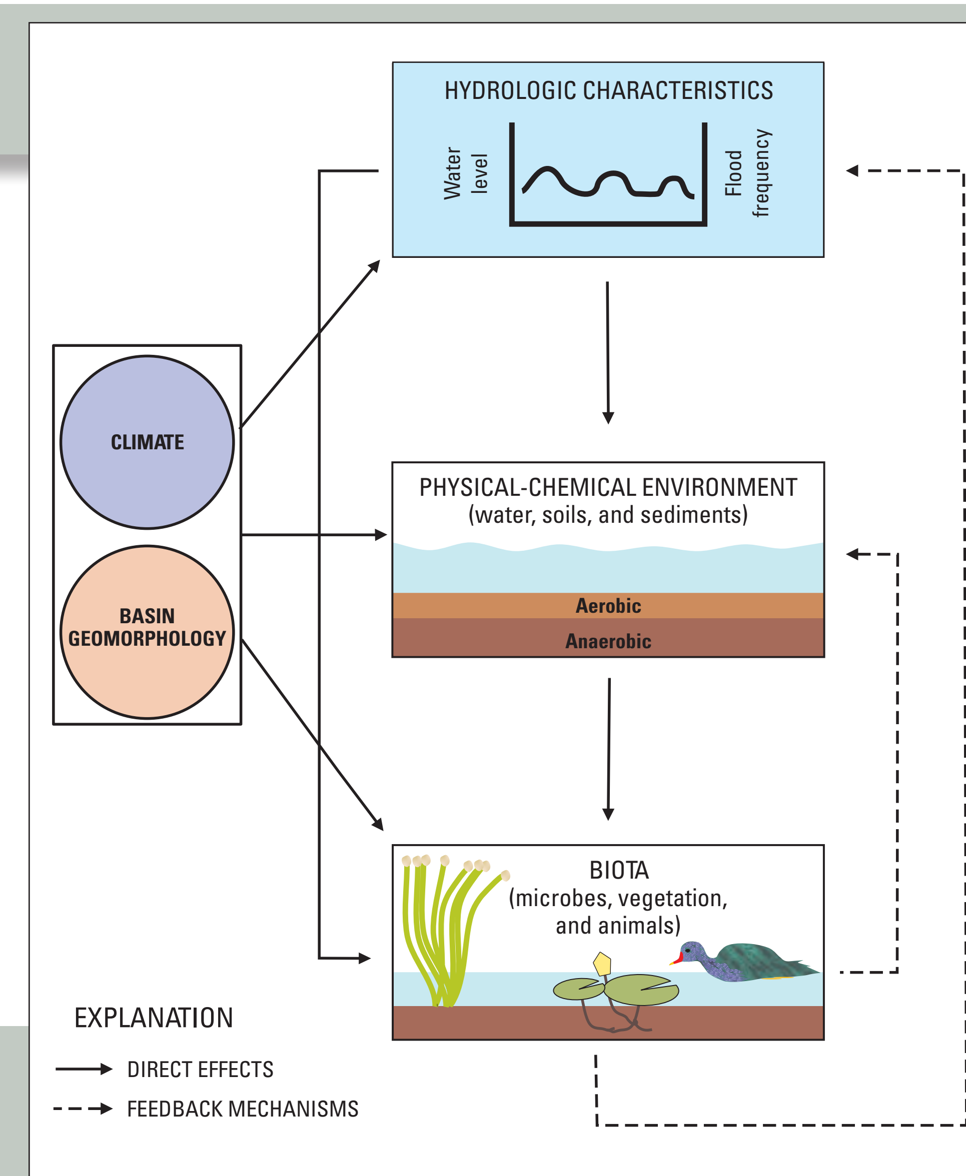


Figure 2. Overview of the direct effects and feedback mechanisms that govern processes in wetlands. (Modified from the National Academy of Sciences, 1995, and published with permission.)

connection to the landscape was not appreciated. Wetlands were often seen as obstacles to agriculture and there was widespread ditching and draining of Florida wetlands as farming expanded, especially cattle grazing and citrus cultivation (Renken and others, 2005). By 1906, when the first systematic inventory of the Nation's wetlands was conducted, there were an estimated 19.8 million acres of wetlands remaining in Florida (Shaw and Fredine, 1956), excluding tidal and coastal wetlands. Wetlands losses continued as human development expanded in Florida, and by the 1950s about 15.3 million acres of wetlands remained (Shaw and Fredine, 1956).

Why have wetlands been eliminated at a rapid rate even though they confer substantial benefits to society? The answer to this paradoxical question is that the majority of wetlands are privately owned and the nature of wetland benefits is such that the owners of wetlands typically cannot capture the benefits for their own use (Florida Department of Environmental Protection, 2008a). For example, flood protection benefits affect people downstream from a given wetland; wildlife species that breed in a wetland often migrate and are enjoyed by other residents; and groundwater recharge provides no immediate commercial benefit to the landowner. Therefore, for a wetland owner to directly benefit from the resource, usually the owner has to alter it, convert it, or develop it (Florida Department of Environmental Protection, 2008a). Fortunately, the public perception of wetlands has changed over time. Substantial losses of wildlife, periodic flooding, widespread water shortages, and pervasive water-quality problems throughout the State have resulted in a new appreciation of wetland values and their benefit to the environment. Today, wetlands are considered important multi-use resources, and are increasingly viewed from a drainage-basin perspective. Wetlands are protected by Federal, State, and local laws designed to preserve their hydrologic and ecological values (Darst and others, 1996).

Increasing the public awareness of wetland **hydrology** is important because wetlands in Florida are at the center of numerous environmental issues related to freshwater quantity and quality. Unlike rivers that carry floodwaters downstream, or a lake basin that collects and accumulates rainfall and **runoff** at a single point, wetlands in central Florida distribute seasonal rainfall into thousands of shallow depressions across the local landscape. The water is temporarily held in these wetlands and then slowly released into the groundwater **aquifer**. Although wetlands retain water in the local landscape, when their capacity for storing water is exceeded, especially during times of heavy rainfall, additional water flows across the adjacent landscape and can cause local flooding. In an undeveloped setting, runoff flows through a network of shallow inconspicuous surface channels that convey flow into and out of a succession of wetlands positioned at progressively lower elevations in the landscape, until the flow exits the drainage basin by way of a stream or river. As the landscape continues to be altered by development, understanding the natural seasonal and annual flooding cycles in the freshwater wetlands of central Florida is increasingly important to residents.

Because wetlands are an important part of the landscape to central Florida residents, and because these ecosystems are complex and change over time, this report was prepared by the U.S. Geological Survey (USGS) to address the need for a broader understanding of the interactions between wetland ecosystems and surface-water and groundwater resources in central Florida. The purpose of this wetland primer is to describe the general hydrology of freshwater wetlands in central Florida, the interactions between wetlands and groundwater/surface-water resources, and how hydrology and water quality are related to the biological communities and ecology of these wetlands. Rather than report the results of new investigations, this primer summarizes existing data and interpretations in a format readily accessible to residents and the water-resources community in central Florida. The report was prepared in cooperation with the St. Johns River Water Management District, the Southwest Florida Water Management District, and Tampa Bay Water.

In collaboration with others, the USGS reports on the state of the Nation's terrestrial, freshwater, and coastal/marine ecosystems, including wetlands, and studies the causes and consequences of ecological change, monitors and provides methods for protecting and managing the biological and physical components and processes of ecosystems, and interprets for policymakers how current and future rates of change will affect natural resources and society (U.S. Geological Survey, 2008a). The USGS has collected hydrologic data in central Florida since the 1920s in response to the requests of those local and regional agencies charged with managing the groundwater and surface-water resources of the region, including wetlands. Beginning in the 1990s, the USGS has undertaken interpretive hydrologic studies of isolated wetlands in the region and published reports and fact sheets about the hydrologic factors that affect wetland water levels and the implications of those factors for wetland ecology.

Above: Wetlands are most lush and densely vegetated during the wet season. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Below: As the landscape is altered, understanding the natural flooding cycles in wetlands like this cypress dome is increasingly important to residents. Photographer credit: Kim Haag, U.S. Geological Survey.

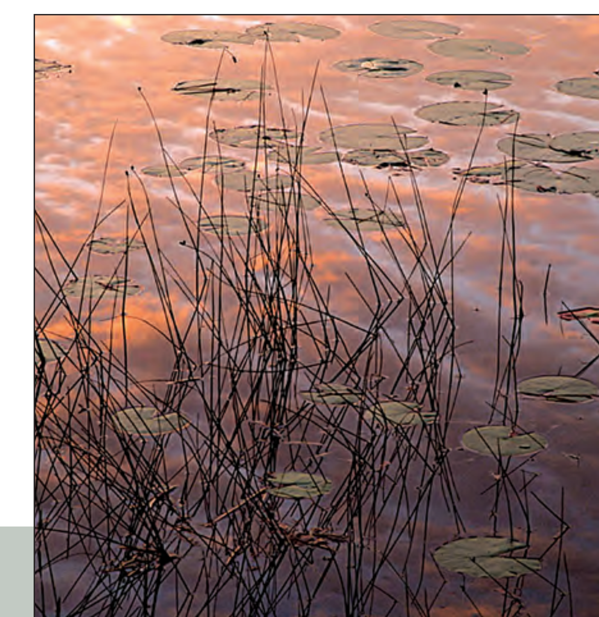
This primer describes the continually changing hydrologic status of isolated freshwater wetlands along a continuum from dry land to flooded water body, including: (1) the seasonal flooding cycle in natural wetlands and in those affected by human activities; (2) how flooding and drying cycles change the percentage of the total wetland area inundated at any given time, and the depth of the water throughout the wetland; (3) annual flooding cycles in wetlands during decade-long time periods that are used to compare the percentages of time that deeper and shallower areas of the wetland bottom remain flooded; and (4) how State and regional agencies monitor the hydrologic condition of central Florida wetlands and assess them as a collective water resource. Viewing the hydrologic condition of wetlands over both short and long time periods allows resource managers to assess current conditions and to predict regional trends in wetland resources.

This primer also describes various aspects of wetland ecology, including (1) an overview of wetland water quality and how water quality and soils affect plant and animal communities in wetlands; (2) a survey of the types of bacteria, algae, and plants that live in central Florida wetlands, how they influence environmental processes in wetlands, and how they change over time with changing hydrologic conditions; (3) a description of the animal communities that populate central Florida wetlands, how they vary seasonally, and how they change in response to changes in the plant community; (4) a discussion of the effects of human activities on the plants and animals that live in central Florida wetlands; and (5) a brief summary of the implications of climate change for wetland ecology.

In addition to describing wetland hydrology and ecology, this primer incorporates 11 features throughout the text that present additional topics of special interest or highlight wetland communities of unique character in central Florida. The appendix at the end of the report contains county maps showing the distribution of wetlands in each county and a pie chart indicating the relative proportions of individual wetland types. Cities, towns, and location names referred to in this report are shown on the county maps as well. Finally, throughout this report the reader is directed to selected wetland publications and websites that can provide further detailed information.

Above: Wetlands can provide food, water, and shelter for wildlife such as these sandhill cranes (*Grus canadensis*). Photographer credit: Dave Slonena, Pinellas County Utilities Department.

Below: Living in close proximity to wetlands provides many Floridians with an increased awareness of nature. Photographer credit: Michael Hancock, Southwest Florida Water Management District.



Classification and Distribution of Wetlands in the Central Florida Landscape

The wetlands in central Florida can be classified according to a number of commonly observed criteria. Some of the earliest classification systems placed wetlands in categories based on their location—near rivers, near lakes, or in uplands (Wright, 1907). Later wetland classification schemes were based on the amount of time a wetland was inundated—permanently, seasonally, or temporarily. Other classifications were implemented in response to national planning needs, or for ecological reasons. For example, a 1950s classification framework was developed for a national inventory to assess waterfowl habitat (Martin and others, 1953). Eventually, more than 50 wetland classification schemes were in use across the United States. Despite the proliferation of classification schemes, most were based upon only a few prominent wetland characteristics related to hydrology, vegetation, and soils. In 1974, the U.S. Fish and Wildlife Service convened a group of wetland scientists to develop a new wetland classification system that (1) was based on the concept of the ecosystem; (2) would facilitate resource management decisions; and (3) would provide uniformity in terminology throughout the Nation so that wetlands could be compared from one region to another and be better understood as a collective national resource. This classification of wetlands and deepwater habitats has become a recognized national standard for identifying and classifying wetlands (Cowardin and others, 1979). The Cowardin classification has five major systems: marine, estuarine, palustrine, lacustrine, and riverine. Within each system are other categories including classes, subclasses, and dominance types. The other categories may or may not be present in all systems.

Freshwater wetlands in central Florida described herein are classified in the Palustrine, Lacustrine, and Riverine Systems (Cowardin and others, 1979). The majority of wetlands in central Florida are in the Palustrine System. The Palustrine System includes all non-tidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, farmed wetlands, and all such wetlands that occur in tidal areas with salinity less than 0.5 ppt. It also includes wetlands lacking such vegetation, but with all the following characteristics: area less than about 20 acres; water depth in the deepest part less than about 6.6 ft; salinity less than 0.5 ppt; and active wave formed or bedrock shoreline features lacking.

Wetlands associated with deepwater habitats include lacustrine and riverine wetlands. Wetlands in the Lacustrine System are situated in a topographic basin; lack trees, shrubs, and persistent emergent vegetation with more than 30 percent areal coverage; exceed 6.6 ft in depth in the deepest part of the basin; and have salinity less than 0.5 parts per thousand. In central Florida, lacustrine wetlands frequently form fringes around lakes. The fringing wetlands often obscure the lake shoreline and provide rich habitat for waterfowl and other wildlife. Wetlands in the Riverine System are contained within a channel of periodically or continually moving water, are bounded by the upland and by the channel bank, and have salinity less than 0.5 ppt. Wetlands in the **flood plains** adjacent to rivers that are inundated by seasonal over-bank flow are not considered part of the Riverine System. The water in flood-plain wetlands may pond in low areas and also may move very slowly in a downstream direction in shallow channels called sloughs. Lacustrine and riverine wetlands are not as abundant as palustrine wetlands in central Florida.

Central Florida wetlands in the Palustrine, Lacustrine, and Riverine Systems can be grouped into classes based on the nature of the wetland bottom (substrate) and the vegetation defining their general appearance. Seven classes of palustrine wetlands are present in central Florida: rock bottom, unconsolidated bottom, aquatic bed, unconsolidated shore, emergent wetland, scrub-shrub wetland, and forested wetland. Lacustrine and riverine wetlands may include the following classes: rock bottom, unconsolidated bottom, aquatic bed, rocky shore, unconsolidated shore, and emergent wetland. Classes can be further divided into subclasses (for example, persistent and nonpersistent emergent wetlands) and dominance types (individual wetland plant species that are predominant) (Cowardin and others, 1979). In central Florida, for example, the pond cypress (*Taxodium ascendens*) is dominant in some forested wetlands, the buttonbush (*Cephalanthus occidentalis*) is common in scrub-shrub wetlands, maidencane (*Panicum hemitomon*) is widespread in many emergent marsh wetlands, and water lilies (*Nymphaea odorata*) are present in many pond and aquatic bed wetlands. In contrast, slash pine (*Pinus elliottii*) and longleaf pine (*Pinus palustris*) are common upland trees that are often found in the pine flatwoods that surround or separate many of the wetlands.

Freshwater wetlands are present in every county throughout central Florida (fig. 1). The distribution of wetlands in each of the counties of central Florida is shown in detail in the appendix, along with associated pie diagrams that show the relative proportions of each wetland class. The distribution of wetlands is not uniform across the region. Polk, Osceola, Volusia, and Lake Counties have the greatest total acreages of wetlands in the region. Wetlands in these counties account for 30 to 35 percent of the total land area of each county. The lowest acreages of wetlands are found in Pinellas, St. Lucie, Hernando, and Citrus Counties, where wetlands do not exceed 10 to 15 percent of the total county area. The uneven distribution of wetlands in central Florida reflects the influence of regional physiography, hydrogeology, historical wetland destruction, and other factors.

Wetlands distributed across the central Florida landscape form a mosaic of communities, and it is notable that the patterns of wetland distribution change over different timescales. Over long time periods, changes in climate, erosion of rivers, and sea level changes can each bring about wetland change (van der Valk, 2006). During relatively short periods of time (decades), the acreage of wetland classes fluctuates in response to cyclical changes in **precipitation**, from drought to above-average rainfall, and to disturbances such as fire. A wide variety of human activities also cause changes in wetland distribution and vegetation. Trends and changes in wetlands within Florida (and across the United States) are documented by the U.S. Fish and Wildlife Service over short timescales (10 years). Wetland areas are categorized by distinguishing features, typically the nature of the wetland bottom (substrate) and the dominant vegetation type defining their general appearance (Cowardin and others, 1979). Wetland areas are then mapped and numbered in the National Wetlands Inventory (Feature A—Wetland Mapping and the National Wetlands Inventory). The county maps included in the appendix herein are based on the National Wetlands Inventory (U.S. Fish and Wildlife Service, 2009a).

Left: Rainfall beneath the tree canopy in a pond cypress (*Taxodium ascendens*) wetland can be 5-15 percent less than outside the canopy. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Above: White water lily (*Nymphaea ordorata*). Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Below: Meadow beauty (*Rhexia salicifolia*) growing in flooded pine flatwoods. Photographer credit: Dan Duerr, U.S. Geological Survey.

Wetland Mapping and the National Wetlands Inventory

Mapping is necessary for virtually all activities involving wetlands. For example, wetland maps are essential tools for wetland management, protection, and restoration; land-use planning as it relates to wetlands; and regional analysis of wetland status and trends. Wetland maps are used by local, State, and Federal agencies as well as by nongovernmental organizations, businesses, and private residents. Consistent and reproducible methods for mapping are vital for comparison purposes and indispensible for aggregation of regional maps into a national framework.

Background

The U.S. Fish and Wildlife Service within the U.S. Department of the Interior has primary responsibility for mapping all wetlands in the United States. As part of the National Wetlands Inventory, the U.S. Fish and Wildlife Service has developed a series of maps to show wetlands and deepwater habitats. The goal of the National Wetlands Inventory is to provide current geospatially referenced information on the status, extent, characteristics, and functions of wetland, riparian, deepwater, and related aquatic habitats in priority areas to promote the understanding and conservation of these resources.

Although several other Federal agencies have historically mapped wetlands and continue to do so for various purposes related to their missions (U.S. Department of Agriculture; Natural Resources Conservation Service; U.S. Department of Commerce, National Oceanic and Atmospheric Administration), they typically collaborate with the U.S. Fish and Wildlife Service in their efforts. In addition to State and local agencies, many nongovernmental organizations have become interested in mapping wetlands specific to localized areas of the country or to individual projects, often at more refined scales than are available from the National Wetlands Inventory. Clearly, it is desirable to have a wetland mapping standard that everyone can use to map wetlands, and that would facilitate sharing wetland data in digital format. To that end, in 2007–08 the Federal Geographic Data Committee developed a standard to support a consistent and seamless transition from paper-based map products to technology-based map products. The Federal Geographic Data Committee standard also serves as the national standard for wetland mapping inventories for inclusion in the National Spatial Data Infrastructure. The mapping standard will (1) streamline mapping efforts for greater consistency and efficiency; (2) enable any entity to map wetlands using the standard and submit data to construct or update the National Wetlands Inventory geodatabase and the National Map; and (3) facilitate consistent mapping layers that can be used across geopolitical and watershed boundaries.

National Wetlands Inventory Mapping

The National Wetlands Inventory maps are prepared from conventional photointerpretation and analysis of mid- to high-altitude (20,000 ft) stereoscopic color-infrared aerial photographs. The source imagery is collected and archived by the Federal Government's National Aerial Photography Program at a 1:40,000 scale. Flight lines for the National Aerial Photography Program are flown in a north-to-south direction through the east and west halves of 7.5-minute quadrangles. All photography is cloud-free, with strict specifications regarding sun angle and minimal haze. Because they are centered on the quarters of the quadrangles, these photographs are sometimes referred to as "quarter quads." Each 9 × 9-in. photo covers an area of about 5 mi on a side (3.75 minutes), and the photographs are indexed on 1:100,000-scale U.S. Geological Survey maps. National Aerial Photography Program images have a 1-m resolution.

Wetland mapping is most accurate when based on color infrared photography, because the color, texture, and pattern of wetland vegetation, water, and soils in this type of photograph facilitate precise interpretation. For example, wetland vegetation is typically denser and more lush than upland vegetation. Areas covered with water or even saturated soils appear darker than dry soils because of the lack of infrared reflectance. Vegetation factors critical to accurate photo interpretation and wetland mapping include leaf size, shape, structure, and arrangement; branching patterns; height; and growth habit.

Primer Facts

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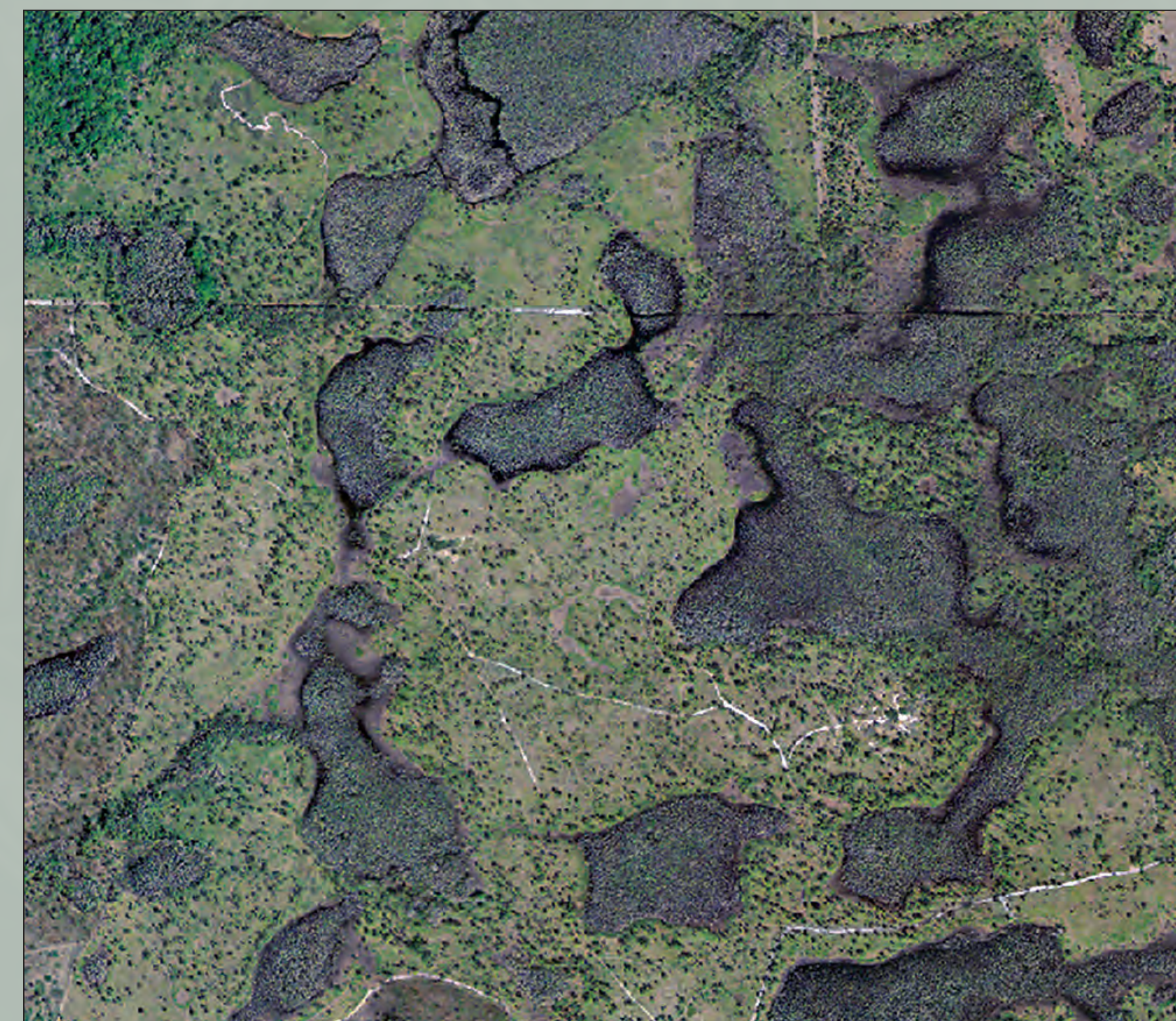

Above: Aerial photograph of forested wetlands in Pasco County. Photograph credit: Southwest Florida Water Management District.

A Continued

The production of National Wetlands Inventory maps involves many steps, including stereoscopic photo interpretation of spatially referenced photographs of the study area, delineation of wetland boundaries, detailed on-the-ground inspection of wetland plants and soils, quality-control checks of photo interpretation, including consultation of collateral information, and extensive review. The final product consists of wetland boundaries (polygons) added to a black-and-white 1:24,000-scale U.S. Geological Survey topographic base map. The wetland polygons are classified using the categories published by Cowardin and others (1979), and identified using an alphanumeric code identified in the map explanation. After the maps are finalized, they are digitized and made available to the public. National Wetlands Inventory maps in digital format can be readily used in Computer Aided Design (CAD) and Geographic Information System (GIS) software applications. Important metadata for the National Wetlands Inventory maps include (1) the year the aerial photographs used for map creation were taken, which is necessary for subsequent analyses of change in wetland area over time; (2) the season, which affects wetland plant development and ease of identification; and (3) the size of the target mapping unit (the smallest area consistently mapped), which ranges from 0.5 to 1.0 acre in many areas of the country.

Other Photography Useful in Wetland Mapping

Digital orthophoto quadrangles (DOQs) are computer-generated images of aerial photographs in which the image displacement caused by uneven terrain and camera tilt have been removed (fig. A–1). The value of a DOQ is that it combines the image characteristics of the original photograph with the geometric qualities of a map. The DOQs can be either black and white, natural color, or color-infrared images. A standard DOQ covers an area of 3.75 minutes latitude by 3.75 minutes longitude (a quarter "quad"), and the image also is commonly called a "DOQQ" (for digital orthophoto quarter quadrangle). All DOQs are referenced to the North American Datum of 1983 and are positioned on the Universal Transverse Mercator map projection. All DOQs have a 1-m ground resolution, and typically have 50 to 300 m of over-edge image beyond the latitude and longitude corner crosses that are imbedded in the image (Wilen and others, 1996). This margin facilitates "edge matching" of multiple adjacent images to create a much larger image. Each image is accompanied with data for identifying, displaying, and georeferencing the image. The users can spatially reference other digital data with the DOQ, and a DOQ can be incorporated into any GIS that can manipulate raster images. There are many uses for these DOQs relating to wetlands, including vegetation assessment, analysis of changes in land use, and groundwater and watershed analysis.

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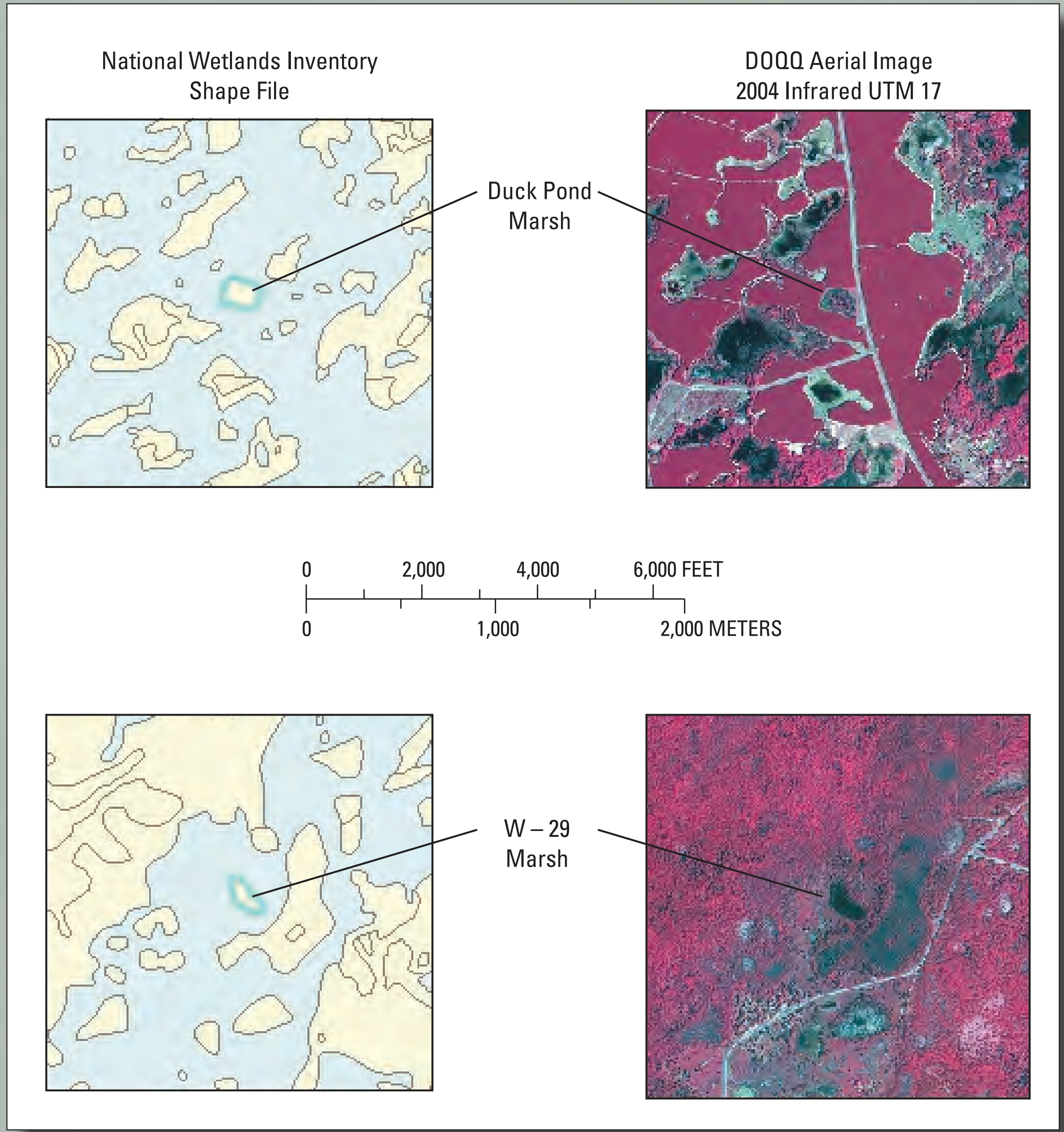


A–1. Digital orthophoto quadrangles (DOQs) are computer-generated images of aerial photographs in which the image displacement caused by uneven terrain and camera tilt have been removed.

Palustrine forested wetlands are the most abundant wetland class in central Florida. For example, the ratio of forested wetlands to emergent marsh wetlands in central Florida is about 3:1 (Dahl, 2005). The most familiar dominant plant communities in this class include mixed hardwood swamps, cypress domes, hydric hammocks, and wet pine flatwoods. The greatest acreages of forested wetlands are located in Volusia, Polk, Levy, Osceola, and Lake Counties. From 1985 to 1996, forested wetlands in Florida increased in total area (Dahl, 2005), reversing a long-term trend of wetland loss since the 1950s. Most of this gain is attributable to the natural maturation of shrub-scrub wetlands to wet forests. Forested wetlands remain vulnerable to loss from rural and urban development, such as expansion of paved roads and related infrastructure.

Palustrine shrub-scrub wetlands are characterized by woody vegetation less than about 20 ft tall. The counties with the greatest acreages of shrub-scrub wetlands are Polk, Indian River, and Brevard. From 1985 to 1996, shrub-scrub wetlands in Florida increased in acreage. Drier conditions throughout much of the State may have contributed to the increase in conversion of marshes to shrub-scrub wetlands as shallow-water lakes experienced shorter **hydroperiods** that are conducive to invasion by shrub-scrub species. Many emergent wetlands subjected to disturbance, nutrient inputs, and lack of fire also tend to develop into shrub-scrub wetlands. Numerous shrub-scrub wetlands have experienced invasions by woody exotic species such as Brazilian pepper (*Schinus terebinthefolius*) and melaleuca (*Melaleuca quinquenerva*), which displace native species and alter habitat for waterfowl and other animals.

Palustrine emergent wetlands include communities such as marshes and wet prairies. Emergent wetlands in central Florida are populated by a wide variety of plant species. Some common emergent species include pickerelweed (*Pontederia cordata*), arrowhead (*Sagittaria latifolia*), and maidencane (*Panicum hemitomon*). The counties having the greatest acreages of emergent wetlands include Brevard, Polk, and Osceola. Emergent wetlands declined in acreage by about 9 percent from 1986 to 1996. This rate of loss was greater than the loss rate during the late 1970s and early 1980s. Some emergent marshes were converted to shrub-scrub wetlands as woody species became established following prolonged periods of drought. Agriculture, urban expansion, and rural development also were responsible for a substantial proportion of the loss (Dahl, 2005).

Palustrine aquatic bed wetlands are characterized by floating and submerged vegetation, whereas palustrine unconsolidated bottom wetlands (open water ponds) have a bottom composed of sand, mud, and/or organic material. Characteristic plants in freshwater ponds that support vegetation include duckweed (*Lemna minor*), bladderworts (*Utricularia* spp.), and water lily (*Nuphar luteum*). Freshwater ponds increased in acreage throughout Florida from 1985 to 1996. The newly created ponds included retention basins in urban areas, ornamental landscape features in office and housing developments, and water traps on golf courses. Retention ponds often are chemically treated to eliminate any aquatic vegetation. Highly urbanized Hillsborough County has a relatively high percentage (13.0 percent) of excavated or impounded wetlands, many of which function as retention ponds in residential developments. The relatively high percentage of excavated wetlands in Polk County (14.4 percent) is a result of widespread phosphate mining. Other counties with a large proportion of excavated or impounded wetlands include Okeechobee and St. Lucie Counties, where freshwater ponds have been created to support agricultural activities.

Right: Aerial view of isolated cypress domes in Sumter County. Photographer credit: Paul Fellers, Lake Region Audubon Society.

Physical Setting of Central Florida Wetlands

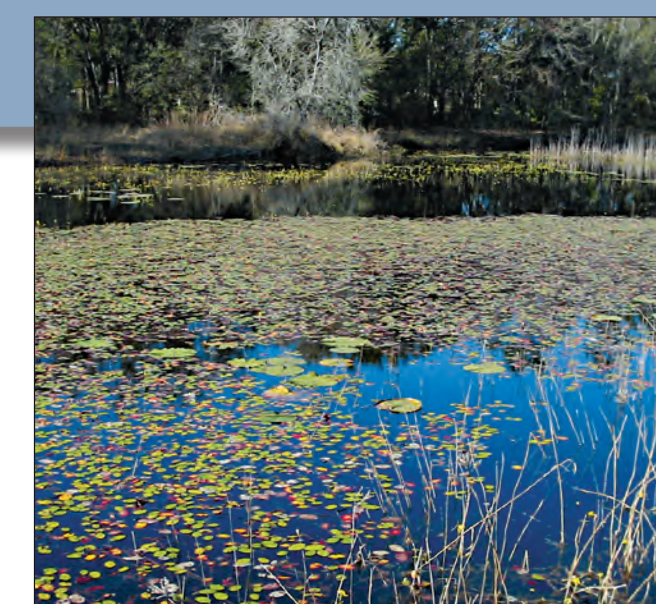
The abundance of freshwater wetlands in central Florida is mostly due to plentiful rainfall and the low, flat terrain. The physiographic features of the landscape, the underlying geology, and the hydrogeology in the region all provide the context for understanding wetland hydrology and the factors that affect wetland water levels in central Florida.

Physiographic Features and Wetland Physical Characteristics

The physiographic features of the landscape in central Florida determine, to a substantial extent, the distribution of wetlands in the counties across the region. Central Florida can be divided into physiographic regions (fig. 3) based on surface features such as ridges, uplands, plains, lowlands, and valleys. Higher areas in the western part of the region include the Brooksville Ridge, Polk Upland, and Sumter Upland. The relatively small number of wetlands in Hernando and Citrus Counties, for example, is due largely to the thick layer of well-drained sands that overlie permeable limestone within the Brooksville Ridge. In contrast, the Gulf Coastal Lowlands and the Western Valley are at lower elevations in the western part of the peninsula, where wetlands are interspersed with pine-palmetto flatwoods. The Western Valley separates the gently rolling Polk Upland from the Brooksville Ridge, creating a broad flat lowland that merges at the Zephryhills Gap with the Gulf Coastal Lowlands.

Landforms underlain by limestone that contains solution cavities are collectively known as **karst**, and are well developed throughout much of central Florida. Karst features are particularly abundant along the northern limit of

Below: Palustrine emergent wetland with maidencane, arrowhead, and pickerelweed. Photographer credit: Kim Haag, U.S. Geological Survey.



Above: Palustrine aquatic bed wetlands support floating aquatic plants including water lilies (*Nymphaea* sp.) and water shield (*Brasenia schreberi*). Photographer credit: Dan Duerr, U.S. Geological Survey.

Above: A sinkhole in Hernando County. Photographer credit: Dan Duerr, U.S. Geological Survey.

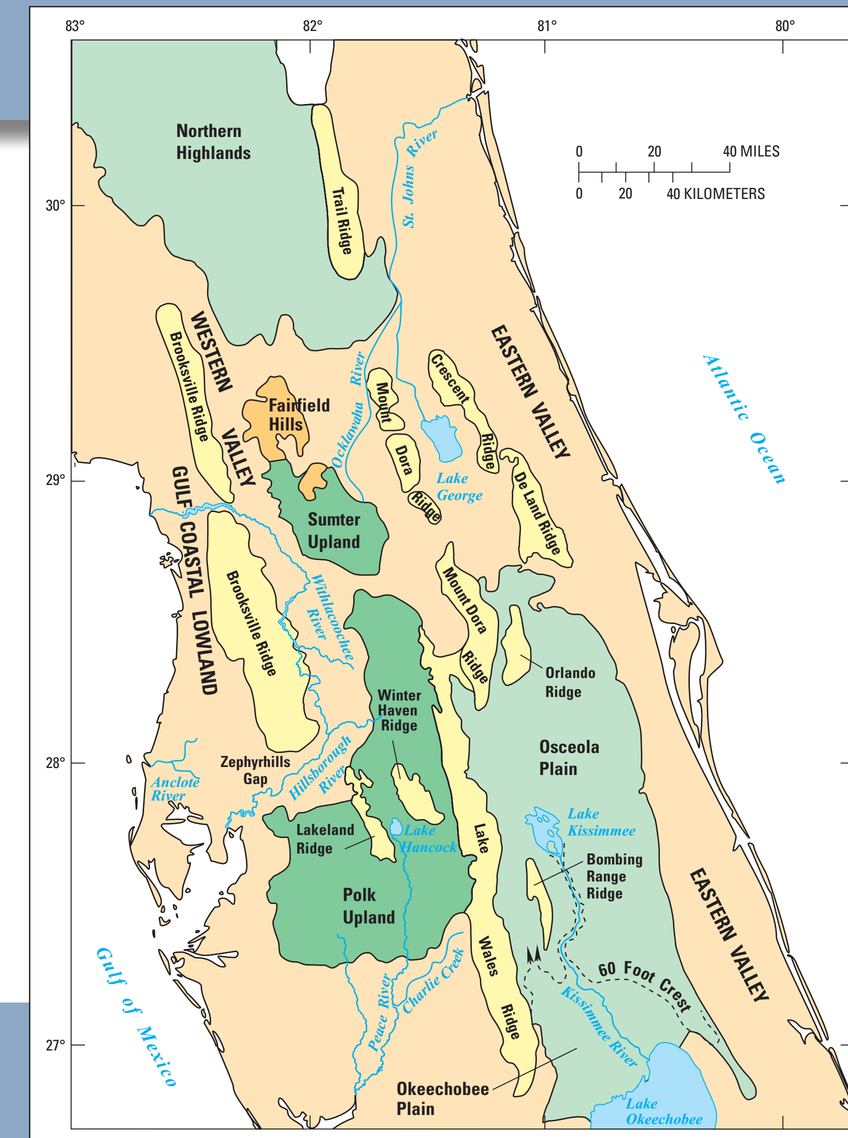


Figure 3. Physiographic regions of central Florida (modified from White, 1970).

the Polk Upland within the Gulf Coastal Lowlands, and within the Brooksville and Lake Wales Ridges. **Sinkholes** develop in the porous limestone and result in shallow depressions that often fill with water to become isolated wetlands. The Lake Wales Ridge lies in the approximate geographic center of the peninsula, and has a maximum elevation of about 290 ft above NGVD 29. To its north are the Mount Dora Ridge, Trail Ridge, and Northern Highlands. To the east of the Lake Wales Ridge, the relatively flat Osceola Plain contains the Kissimmee River and associated lakes and wetlands. Farther east, the Eastern Valley is a broad expanse of lowland along the Atlantic coast that includes the St. Johns River and numerous wetlands. Landforms such as sinkholes and shallow basins are common in the Eastern Valley and they often contain isolated wetlands.

Regional physiographic features also help determine wetland physical characteristics such as shape, size, depth, and total volume. The typically round to oval shapes of many wetlands in central Florida that occupy depressions, as seen in aerial infrared photography of the central Florida landscape (Feature A—Wetland Mapping and the National Wetlands Inventory), are similar to the shapes of many lakes in the area, and are indicative of their similar sinkhole origins. The small depressional features in the bottoms of many wetlands, which are revealed by detailed bathymetric measurements (Haag and others, 2005), provide further evidence of karst subsidence. The deepest areas in wetlands may overlie sand columns or "piping features" created by localized karst subsidence activity under the wetlands. The extent of localized subsidence, both recent and relict, has contributed to the drying out of some wetlands in west-central Florida when sinkholes breach the underlying clay layer. Breaches create a more direct connection between surface-water and groundwater systems that make some wetlands more susceptible to lower groundwater levels. In these areas, the potential for downward drainage may increase, especially when subsurface cavities are filled with coarser sediments that have high hydraulic conductivity.

Most wetlands in shallow depressions are relatively small. Although central Florida wetlands range in size from less than an acre to more than 100 acres, many are at the lower end of this size range. Throughout Florida, forested wetlands generally are larger than shrub or emergent wetlands, with the exception of the Everglades. For example, forested wetlands average about 20 acres in area, emergent wetlands about 10 acres, shrub wetlands about 7 acres, and freshwater ponds less than 2 acres (Dahl, 2005). Many central Florida wetlands are only 1 to 2 ft deep (Michael Hancock, Southwest Florida Water Management District, written commun., 2009).

Wetlands that do not occupy depressions in the landscape, and that are present on slopes, near lakes, and in river channels, have different shapes than depressional wetlands and are less numerous in central Florida. **Seepage wetlands**, which are often found on slopes, tend to be small (Feature B—Seepage Wetlands). Other types of nondepressional wetlands can cover large areas. Fringing wetlands, which exist around impoundments, natural lakes, and ponds, can be extensive, depending on the lake size and the slope of the shoreline. Flood-plain wetlands can be very wide if they are associated with the extensive flood-plain valleys of major rivers, whereas riverine wetlands in stream channels typically exist only as narrow strips.

B Seepage Wetlands

Seepage wetlands differ from other types of forested palustrine wetlands in that they seldom or never experience inundation or flooding, although their soils remain saturated for extended periods. Anywhere that the water table intersects the land surface, shallow groundwater can discharge or seep out to the surface and maintain wet soils, but lateral drainage prevents water from ponding.

Many seepage wetlands form at the base of hillsides (fig. B–1). Rainwater percolates through sand, and when it encounters a less permeable layer such as clayey sand, clay, or rock, the water flows laterally until it encounters the land surface and collects in a topographic depression. Seepage wetlands also may form in shallow depressions on flat sites where the bottom of the wetland is lower than the elevation of the adjacent water table. Other seepage wetlands are present within the flood plains of large rivers. Although seepage wetlands are defined by their hydrology, they are sometimes also named by the dominant vegetation type. In central Florida, the most common types of seepage wetlands are bay heads or bay swamps, hydric hammocks, and flood-plain seepage swamps. Cutthroat seeps, named after the dominant cutthroat grass (*Panicum abscissum*), are a less common and threatened type of seepage wetland in central Florida.

Bay Heads

Bay heads (also called bay galls, bay swamps, or seepage swamps) are densely forested, peat-filled depressions. These features may be found at the base of slopes where ground-water **seepage** keeps the soils moist. Bay heads also are found in shallow depressions in areas with abundant cypress wet-lands, such as the Green Swamp. In these areas, bay heads represent an advanced stage of wetland succession in which the acidic (pH 3.5–4.5) peat soils accumulate in the absence of severe fire (Florida Natural Areas Inventory, 2006). The hydrologic regime is maintained by the capillary action of the peat soils that draw groundwater up from a shallow water table below the wetland. Substantial surface flooding is rare, and these systems are more hydrologically stable than many other types of wetlands. Fire frequency is highly variable in these systems; shrub-dominated bay heads may burn every 3 to 8 years, whereas a woody bay may burn every 50 to 150 years. After a typical fire, the bay trees usually germinate from seeds and replace those lost (Florida Department of Natural Resources, 1990).

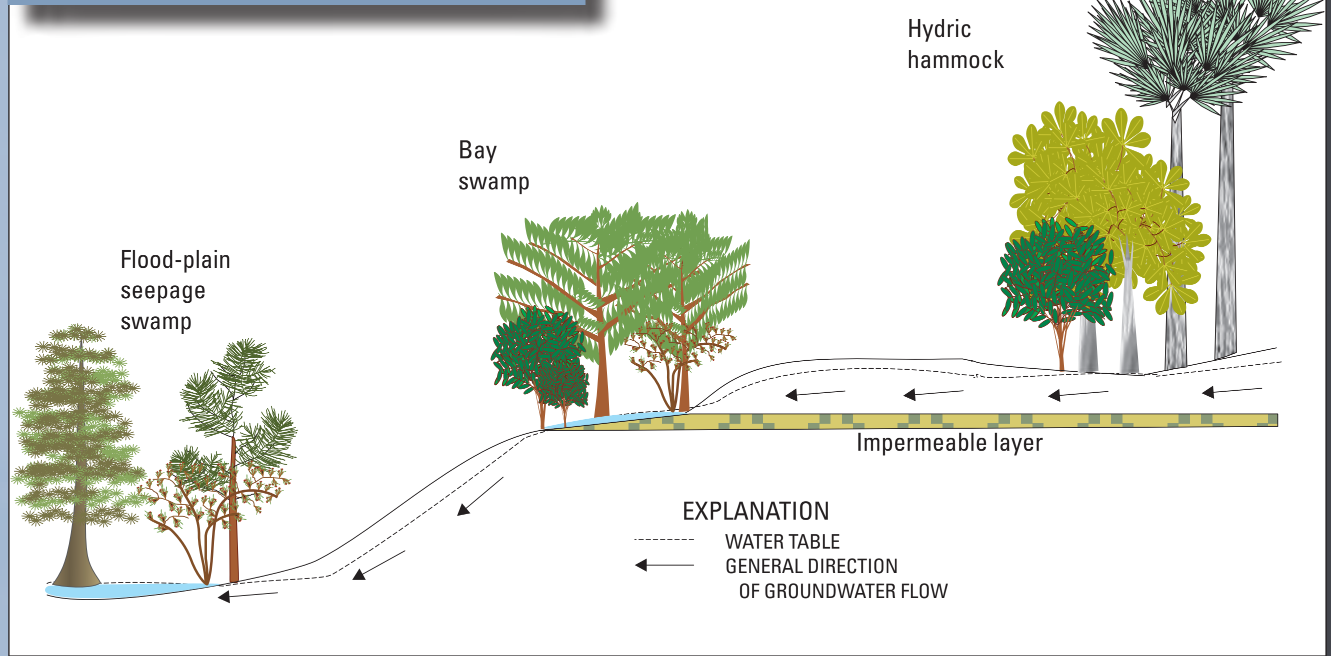
Bay heads are dense evergreen forests or shrub thickets with an understory of moss and ferns. The canopy is composed of densely-packed stands of fragrant sweetbay (*Magnolia virginiana*), swamp bay (*Persea palustris*), red bay (*Persea borbonia*), and loblolly bay (*Gordonia lasianthus*).

Above: Bay seepage swamp in Putnam County. Photographer credit: Mark Minno, St. Johns Water Management District.

Primer Facts

In central Florida, the most common types of seepage wetlands are bay heads or bay swamps, hydric hammocks, and flood-plain seepage swamps.

Figure B–1. Representative seepage wetlands (below).



Left: Moss growing in the understory of a seepage wetland. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

B Continued

The understory is mostly open with shrubs and ferns predominating. Other plants typically found include dahoon holly (*Ilex cassine*), fetter bush (*Lyonia lucida*), wax myrtle (*Myrica cerifera*), cinnamon fern (*Osmunda cinnamomea*), chain fern (*Woodwardia* spp.), and lizard's tail (*Saururus cernuus*).

Hydric Hammocks

Hydric hammocks most often develop as patches on low, flat sites where limestone is at or near the surface and shallow groundwater seepage is present. Soils are usually sandy and contain considerable amounts of organic material. Hydric hammocks have soils that are generally saturated, and these wetlands are inundated only for short periods (seldom more than 60 days per year) following very heavy rainfall. If the water table is lowered by drought or human activities, hydric hammocks gradually change to mesic (drier) forests. If flooding is more frequent, the trees are replaced with species that are more tolerant of standing water.

Hydric hammocks are typically open forests. Cabbage palms (*Sabal palmetto*) and laurel oaks (*Quercus laurifolia*) are mixed with hardwoods such as red maple (*Acer rubrum*), water oak (*Quercus nigra*), dahoon (*Ilex cassine*), gallberry (*Ilex coriacea*), and wax myrtle (*Myrica cerifera*). There is usually minimal understory and little herbaceous vegetation on the forest floor.

Hydric hammocks rarely burn, due to their continuously damp soils and sparse herbaceous ground cover. However, in communities with abundant cabbage palms (*Sabal palmetto*), periodic fires of the flammable palm fronds favor survival of this generally fire-resistant species over other herbaceous vegetation and maintain the palm-dominated hammocks in prairie landscapes (Florida Department of Natural Resources, 1990).

Flood-Plain Seepage Swamps

Flood-plain seepage swamps are present on flood plains of larger rivers, where lateral inputs of **surface runoff** and groundwater seepage are more important than riverbank overflow. River overflows, when they do occur, are shallow and gentle, and carry little sediment or leaf litter.

Flood-plain seepage swamps in central Florida are bay swamps with additional tree species. Other common tree species are bald cypress (*Taxodium distichum*) and black gum (*Nyssa sylvatica* var. *biflora*). There may also be sweetbay (*Magnolia virginiana*), loblolly pine (*Pinus taeda*), and slash pine (*Pinus elliottii*). *Ilex ambigua* is a holly that grows more often in flood-plain seepage swamps than in other kinds of bay swamps (Livingston, 1991).

Cutthroat Seeps

Cutthroat seeps are communities where shallow groundwater flows downslope at or near the soil surface for several months each year, maintaining a thick bright green carpet of cutthroat grass (*Panicum abscissum*). These communities also may support a few widely scattered slash pines (*Pinus elliottii*) or longleaf pines (*Pinus palustris*), particularly as they grade into more mesic wet flatwoods. In central Florida, cutthroat seeps are common on side slopes of the Lake Wales Ridge in Highlands and Polk Counties. Cutthroat seeps are dependent on frequent fires to maintain their community integrity. Without fire, shrub species such as fetter bush (*Lyonia lucida*), wax myrtle (*Myrica cerifera*), and gallberry (*Ilex glabra*) begin to invade these communities, and trees such as loblolly bay (*Gordonia lasianthus*) begin to dominate within a 10-year period. Cutthroat seeps have been reduced in number since the 1940s, primarily because of long-term fire suppression (U.S. Fish and Wildlife Service, 1999).

Occurrence and Protection

A number of conservation areas protect seepage wetlands in central Florida (U.S. Fish and Wildlife Service, 1999). For example, the Green Swamp has hydric hammocks that drain into the Withlacoochee River (Feature I—The Green Swamp and Use of Wetland Conservation Partnerships). Natural areas in Highlands County contain seepage slopes and hydric hammocks. Some managed areas including the Avon Park Air Force Range also contain seepage wetlands.

Another area with seepage wetlands is in Putnam County south of Welaka (Laessle, 1942). Much of the land is flat, and lateral water movement is slow. The water table is close to the surface, and as organic material accumulates in a wet environment, a hardpan commonly forms. This hardpan layer of dense soil is largely impervious to water. Along the St. Johns River, there are extensive areas rich in peaty organic material. Seepage wetlands form in these areas along the slope between the flatwoods and river. Water moves laterally under the flatwoods and above the hardpan. The hardpan ends at the crest of the slope, where lateral movement provides a surface seep and supports bay head vegetation. Somewhat steeper topography and extensive sands permit rapid percolation and lateral water movement. At the base of the slope just above the water table, hydric hammocks develop where the soils are nearly saturated with moisture due to seepage of groundwater from upslope areas. Accumulated organic material results in soils that have a low pH and are quite peaty. Characteristic trees in the bay heads of the area are loblolly bay (*Gordonia lasianthus*), sweetbay (*Magnolia virginiana*), and swamp bay (*Persea palustris*). Understory shrubs include gallberry, fetterbush, and wax myrtle. Hydric hammocks are populated with water oak, sweet gum, and American elm. Live oak, loblolly bay, and cabbage palm are also found. Common shrubs are wax myrtle, large gallberry (*Ilex coriacea*), and saw palmetto, and herbaceous vegetation is sparse.

Because seepage wetlands depend on a high water table and seepage flow, they are quickly affected by changes in local or regional hydrology. Development which increases the amount of impermeable surface (roads, parking lots, roofed buildings) can increase the amount of runoff, shifting the hydrologic regime from saturation to inundation, and fostering a change to hardwood swamps. Alternatively, drought and well-field drawdown can lower water tables and reduce or eliminate soil saturation. Under excessively dry conditions, the threat of severe fire is substantial. If the ground surface is lowered from fire damage to the peat, then willows (*Salix caroliniana*) may invade, and a cypress-dominated community can develop. Recurrent fire may result in conversion to a shrub bog. The invasion of exotic species is an increasing problem in seepage swamps, and problematic species include melaleuca (*Melaleuca quinquenervia*), Brazilian pepper (*Schinus terebinthifolius*), Japanese climbing fern (*Lygodium japonicum*), and skunk vine (*Paederia foetida*) (Florida Department of Natural Resources, 1990).

Right: Cutthroat grass (*Panicum abscissum*) communities require frequent fire for maintenance of their community integrity. The greatest threats to cutthroat grass communities are continued fire-suppression and drainage effects. Photographer credit: Steve Morrison, The Nature Conservancy.

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APPROXIMATE NUMBER OF YEARS AGO	SYSTEM	SERIES	GEOLOGIC UNIT	DESCRIPTION	HYDROGEOLOGIC UNIT
Present to 2,000,000	Quaternary	Recent and Pleistocene	Undifferentiated deposits	Unconsolidated materials including sand, clay, marl, shell, and phosphorite	Surficial aquifer system
2,000,000 to 65,000,000	Tertiary	Pliocene	Undifferentiated deposits	Silty to sandy clay, thin shell beds, and basal limestone beds of variable thickness, phosphatic	Intermediate confining unit or intermediate aquifer system
		Miocene	Hawthorn Group	Dolomite, sand, clay, and limestone; silty, phosphatic	
		Oligocene	Suwannee Limestone	Limestone, phosphatic (discontinuous)	Floridan aquifer system — Upper Floridan aquifer
		Eocene — Late	Ocala Limestone	Limestone, chalky, foraminiferal, dolomitic near bottom	
		Eocene — Middle	Avon Park Formation	Limestone and hard brown dolomite	Floridan aquifer system — Middle semiconfining unit
		Eocene — Early	Oldsmar Formation	Dolomite and limestone with intergranular gypsum	Floridan aquifer system — Lower Floridan aquifer
		Paleocene	Cedar Key Formation	Dolomite and limestone with beds of anhydrite	Sub-Floridan confining unit

Figure 4. Generalized geology and hydrogeology of central Florida (modified from Metz and Sacks, 2002).

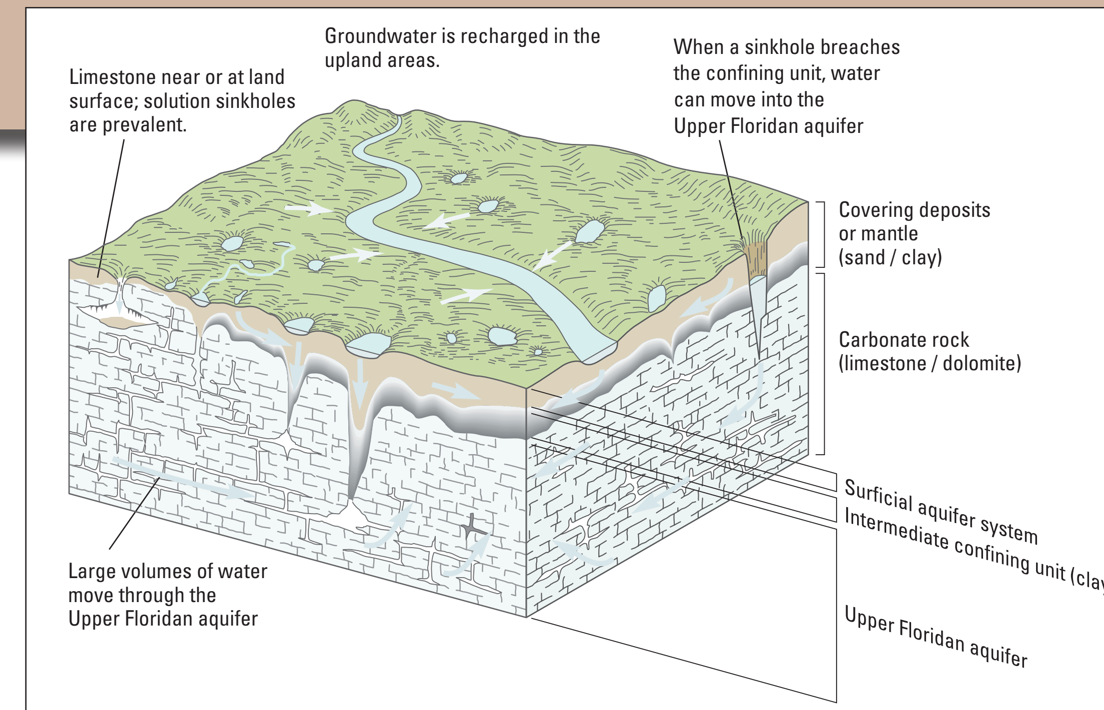


Figure 5. Landscape features, covering deposits, and the hydrogeologic framework of karst terrane that gives rise to wetlands in central Florida (modified from Tihansky, 1999).

Left: Limestone outcrop of the Hawthorn Group along the Peace River in Polk County. Photographer credit: Patricia Metz, U.S. Geological Survey.

Wetlands in central Florida contain a substantial amount of surface water, but this fact has gone largely unappreciated because wetlands have been viewed more as a landscape feature and less as a water resource, and also because more attention has been focused on lakes and rivers as the principal water bodies in the State (Livingston, 1990; Schiffer, 1998). The volume of a particular wetland, also called its storage capacity, can be estimated if the **bathymetry** of the wetland has been determined. In addition to bathymetry, this storage capacity is determined collectively by the geology, soils, groundwater levels, and vegetation.

Some wetlands that are isolated most of the time may have flow to and from other wetlands, lakes, and rivers during wet years, and continue to flow repeatedly during a series of wet years. Flood-plain wetlands experience “flood pulses” during which floodwaters redistribute nutrients and sediment, and for this reason they are more easily colonized by a wider variety of aquatic organisms than isolated wetlands.

Geologic and Hydrogeologic Framework

The geology of the Florida peninsula provides a framework for the hydrogeologic units that hold water beneath the land surface (fig. 4). The movement of water on and below the surface of the central Florida landscape and the erosion of the karst terrane form wetlands and lakes in this region (fig. 5).

The foundation of the Florida peninsula is composed of igneous and metamorphic rocks overlain by successive layers of sedimentary carbonate rock (limestone and dolomite). Most of the **carbonates** were deposited during a 100-million-year period when Florida was below sea level. Deep oceans covered the Florida peninsula during the first part of that period; those oceans were less deep during the last 25 million years, forming a shallow reef across the peninsula. Subsequently, sea level rose and receded cyclically so that carbonates alternately were deposited and eroded. During the last 5 million years, eroded sediments originating from the land surface (quartz sand, clay, and silt) were deposited. These unconsolidated terrestrial deposits were then eroded, transported, and redeposited during successive periods of global warming and cooling.

The thickness and composition of one particular geologic unit, the Hawthorn Group, varies across central Florida and influences the formation of lakes and isolated wetlands and their ability to hold water. The Hawthorn Group has a complex depositional and erosional history occurring in open marine, coastal marine, estuarine, and riverine environments (Gilboy, 1985). The thickness varies in part because the limestone formation over which the Hawthorn Group was deposited was eroded unevenly in geologic time. In parts of Volusia County, the unit was eroded entirely and is absent from the underlying strata. The composition varies because the lower layers of the Hawthorn Group are marine derived and are relatively porous. The upper layers are mostly land derived and contain clay, fine sands, and silt, which tend to restrict the downward movement of groundwater. Where the Hawthorn is thin, vertical water movement is less restricted and **percolation** can dissolve the underlying limestone, allowing depressional features and sinkholes to develop. Where the Hawthorn is thick, sinkholes are less common.

The three major aquifer systems (layers of permeable rock or other porous materials that hold water) in central Florida, from shallowest to deepest, are the surficial aquifer system, intermediate aquifer system, and Floridan aquifer system. The thickness, degree of confinement, and capacity to yield water of these three aquifer systems varies spatially throughout the study area (Gilboy, 1985; St. Johns River Water Management District, 2008; U.S. Geological Survey, 2008b).

The surficial aquifer system, which is composed of unconsolidated materials including sand, clayey sand, clay, marl, and shell, is nearest to the land surface. The sand and shell layers vary in thickness across central Florida. Typically, the clay layers are not sufficiently thick to slow the downward movement of water. The water in the surficial aquifer system is unconfined in most areas and its level is free to rise and fall. The level of the water in the surficial aquifer system is called the **water table**, and below the water table all openings or spaces in the soil or rock are filled with water (saturated). The water table may be as much as 50 to 100 ft below land surface in ridge areas, and at land surface in other places. In lakes and wetlands, the surface of the water is an expression of the adjacent water table.

The surficial aquifer system is recharged principally by rainfall. However, lakes, streams, wetlands, irrigation ditches, stormwater retention ponds, and septic tanks also can recharge the surficial aquifer system. Water leaves the surficial aquifer system by **evaporation** from soil, **transpiration** by plants, seepage to lakes and wetlands, discharge to streams and wetlands, and downward leakage to underlying aquifers. The surficial aquifer system is tapped by private wells for irrigation of lawns and gardens in many areas. In Duval, St. Johns, Brevard, and Indian River Counties in the eastern part of central Florida, the surficial aquifer system also is used for public drinking-water supply.

The intermediate aquifer system lies directly below the surficial aquifer system in the southwestern part of central Florida. It consists of thin discontinuous layers and undifferentiated deposits of Pliocene and phosphatic sands, silts, and clays, as well as limestone and dolomite of the Hawthorn Group of Miocene age. The thickness of the intermediate aquifer system generally decreases from south to north, ranging from more than 400 ft south of DeSoto County to less than 50 ft in Hillsborough County (Southwest Florida Water Management District, 2009a). The aquifer system is absent north of Hillsborough County and in the eastern part of central Florida, where the geologic units that make up the intermediate aquifer system act as **confining layers** to the Upper Floridan aquifer. Water in the intermediate aquifer system is confined in some areas, principally by clays in the overlying Pliocene sediments and the Hawthorn Group. The aquifer system can yield small amounts of water sufficient for private use, particularly in areas where the lower part of the aquifer system consists of highly fractured limestone and dolomite, although in Sarasota County it is tapped for public supply (Fernald and Purdum, 1998). The intermediate aquifer system can be recharged from both the overlying surficial aquifer system and the underlying Floridan aquifer system.

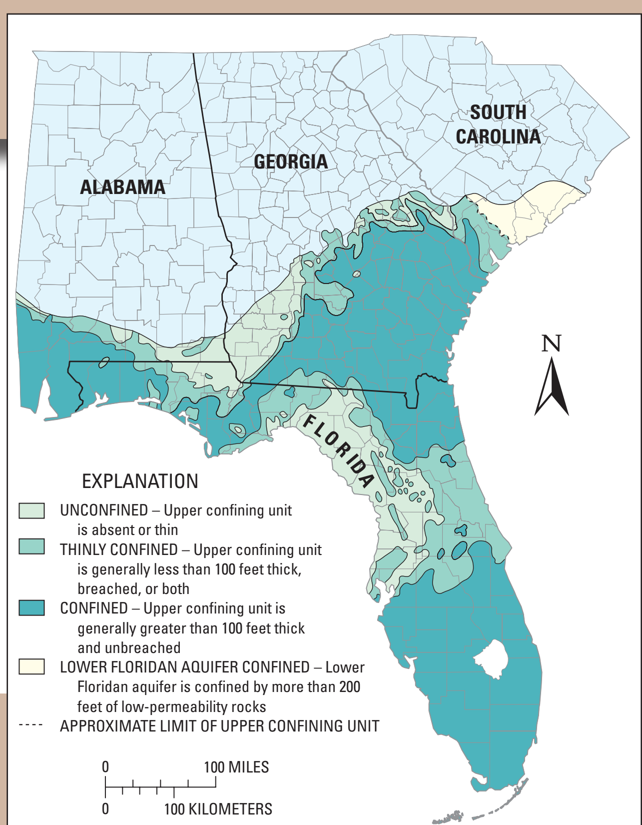


Figure 6. Confinement of the Floridan aquifer system (reprinted from Fernald and Purdum, 1998, and published with permission).

Primer Facts

In central Florida, wetlands overlie areas where the Upper Floridan aquifer is confined, unconfined, and thinly confined.

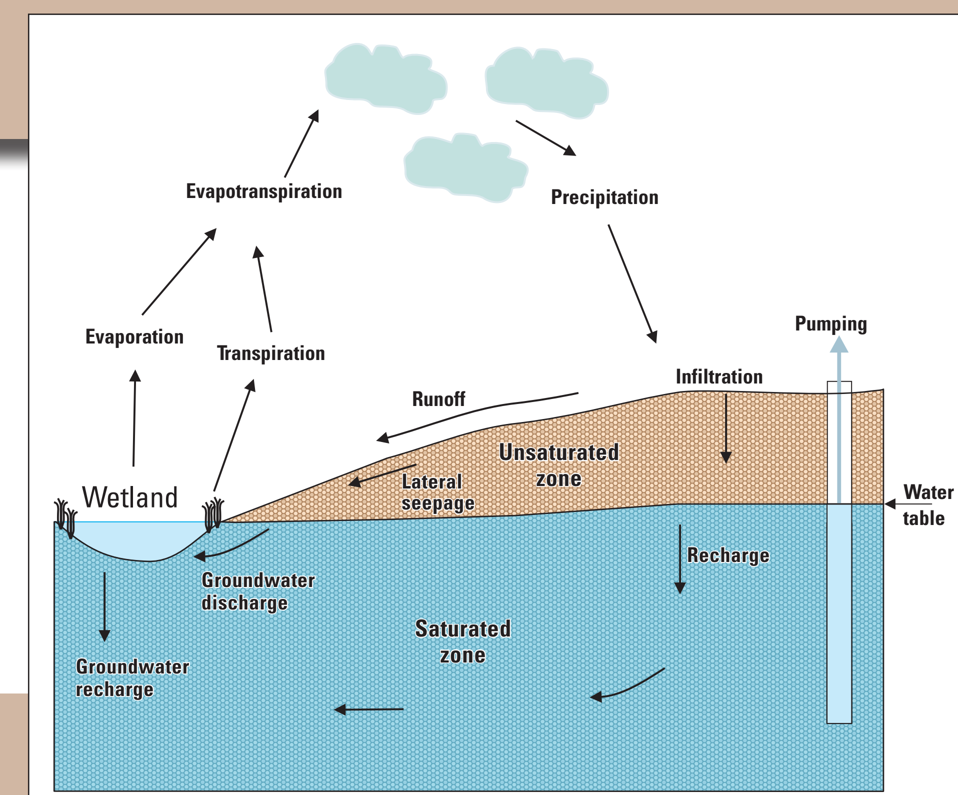
The Floridan aquifer system is composed of a thick sequence of limestone and dolomite. It is effectively divided vertically into three zones based on differences in **permeability**. The lower and upper zones of the Floridan aquifer system are more permeable than the middle unit. The middle (semiconfining) unit is composed of less-permeable dolomitic limestone, and it restricts movement of water between the upper (mostly freshwater) and lower (primarily saline water) zones of the Floridan aquifer system (fig. 4).

The Upper Floridan aquifer provides most of the drinking water for central Florida residents, and its thickness increases from north to south, ranging from several hundred feet to more than 1,400 ft in parts of Manatee and Sarasota Counties (Southwest Florida Water Management District, 2009a). The top of the Upper Floridan aquifer is closest to land surface in the eastern part of central Florida (east Marion, Lake, central Volusia, west Orange, and west Seminole Counties), where it can be at or slightly above sea level. The lower zone of the Floridan aquifer system in some areas of central Florida contains water that is too high in dissolved constituents (magnesium, calcium, and sulfur-containing compounds) to be used for drinking water. The Upper Floridan aquifer is confined in many parts of central Florida (fig. 6) because in these areas it is overlain by layers of clay, silt, and limestone beds of the Hawthorn Group. These clay-containing layers form a confining unit that is not very permeable and restricts water movement across it. The Upper Floridan aquifer is unconfined, however, in the northern part of west-central Florida, including parts of Alachua, Marion, Lake and Sumter Counties. Moreover, the western boundary of the St. Johns River drainage basin is underlain by the Ocala Limestone, part of the Upper Floridan aquifer. Surface waters percolate through the porous deposits and into the limestone. The high permeability of the Ocala Limestone results in extensive lateral movement of groundwater. This groundwater discharges to numerous springs within the drainage basin, many within the riverbed itself (DeMort, 1991).

Hydrology of Central Florida Wetlands

The movement of water from the atmosphere to land and back again in a series of continuous processes collectively is called the **hydrologic cycle**. The processes in the hydrologic cycle that are important to wetland water levels in central Florida are precipitation (rainfall), **evapotranspiration**, runoff, and **infiltration** (fig. 7). Hydrologic processes fundamentally influence the formation, size, persistence, and functioning of freshwater wetlands (Carter, 1996).

Figure 7. Hydrologic processes that affect water levels in wetlands (modified from Fitts, 2002, and published with permission).



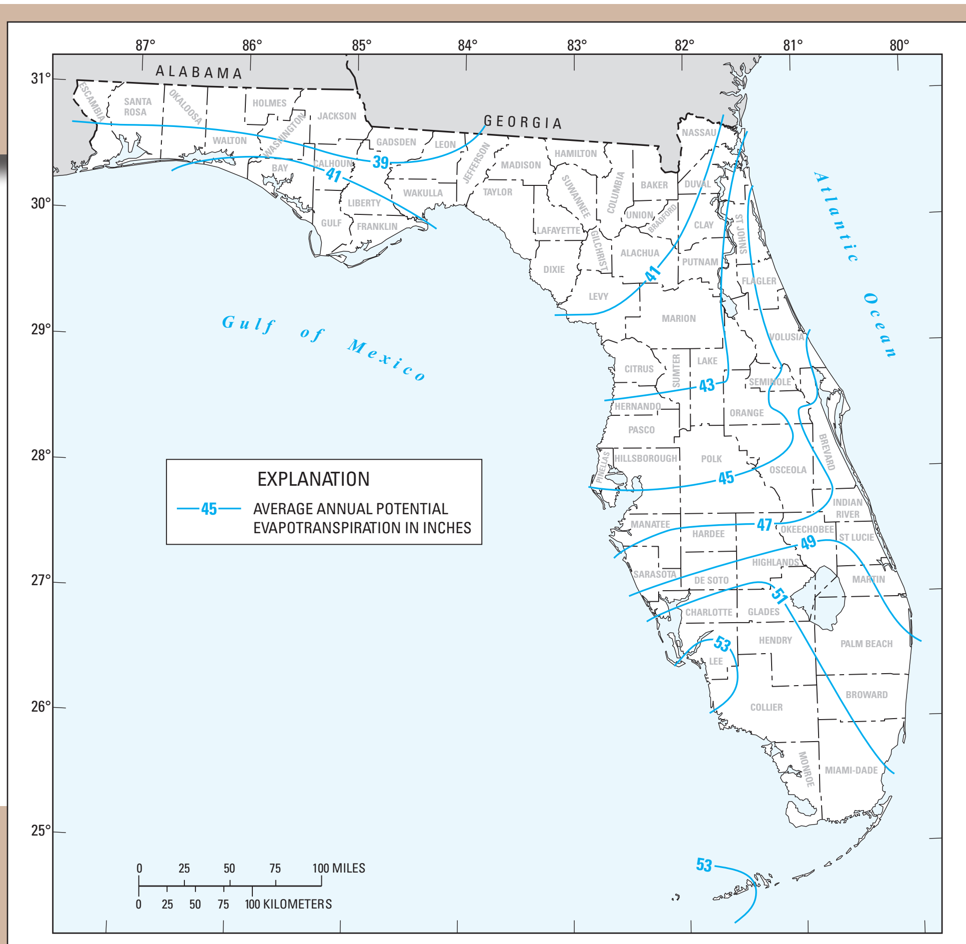


Figure 8. Average annual potential evapotranspiration in Florida (reprinted from Fernald and Purdum, 1998, and published with permission).

These processes can vary substantially over time and they are related to wetland water levels in complex ways. The cycles of above- and below-average rainfall that occur in central Florida directly affect wetland vegetation patterns and the abundance of wetland wildlife. Changes in runoff and surface-water flow patterns in drainage basins may have substantial effects that are not immediately evident to property owners, but become apparent when rainfall patterns change. Infiltration, groundwater movement, and groundwater/surface-water interactions change in intensity under different rainfall conditions, and processes such as sinkhole development may be exacerbated under both wet and dry conditions. Understanding the influence of these hydrologic processes is important for residents and for those involved with wetland resource management.

Cyclical Changes in Rainfall and the Influence of Evapotranspiration

Rainfall is the primary source of water in many central Florida wetlands. The average annual rainfall in the central Florida region is between 48 and 56 in/yr (Fernald and Purdum, 1998). The National Climatic Data Center of the National Oceanic and Atmospheric Administration summarized long-term regional rainfall averages for 1895–2005. The long-term regional average is 52.26 in/yr for north-central Florida and 51.84 in/yr for south-central Florida (National Oceanic and Atmospheric Administration, 2008). These two climatological divisions cover the central Florida study area (Fernald and Purdum, 1998). Most of the rain in central Florida comes from summer storms during June to September that are associated with scattered, short-lived convective thunderstorms and tropical weather systems such as hurricanes. Monthly average rainfall can be above 7 in. during those months, when two-thirds of the annual rainfall typically accumulates, but these convective thunderstorms can be highly localized. Rainfall during November to May affects larger geographic areas, and is associated with frontal systems that originate in the northern latitudes and move south. Monthly average rainfall typically is less than 3 in. during these months. Tropical storms, hurricanes, and El Niño climate conditions can cause the annual rainfall to exceed the average by 10 in. or more (National Oceanic and Atmospheric Administration, 2008). Spatial variability across central Florida can sometimes exceed the temporal variability from year to year (Chen and Gerber, 1990). For example, annual

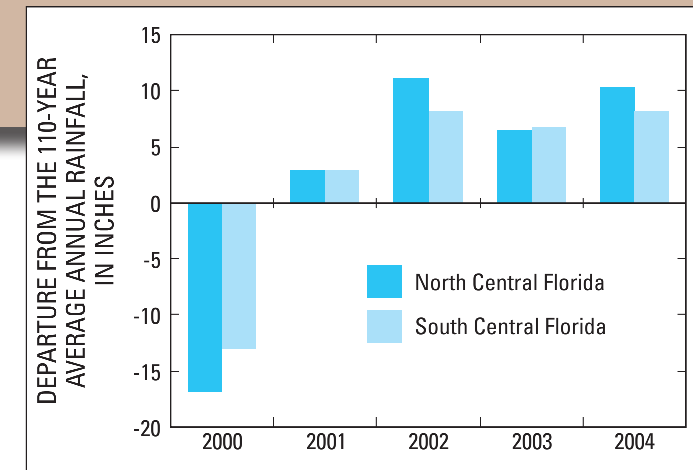


Figure 9. Regional annual rainfall departures from the long-term average for the period 2000–04 (modified from Lee and others, 2009).

Right: A 120-ft tower for the collection of evapotranspiration data in a pine upland. Photograph credit: South Florida Water Management District.

average rainfall is the greatest (above 60 in.) in many areas along the east coast of Florida, but is below 45 in. in many areas near Lake Okeechobee in the center part of the State. Typically, average rainfall is higher near the east coast in the dry season and is higher near the west coast in the wet season (Ali and others, 2000).

Evapotranspiration is an important hydrologic process whereby wetlands lose water to the atmosphere through alternate pathways. Water evaporates into the atmosphere from soil and from the surface of open water in wetlands. Water also is lost to the atmosphere by plants through transpiration as plant roots extract water from the soil and release water vapor into the atmosphere through leaf openings. Evaporation and transpiration losses often are combined and referred to as evapotranspiration. Rates of evapotranspiration vary seasonally and spatially. Seasonal differences occur at a given location because evapotranspiration is much greater in summer than in winter, primarily as a function of solar radiation. Spatially, evapotranspiration increases from north to south across central Florida (fig. 8), again as a function of solar radiation. Moreover, variations in evapotranspiration can be very large depending on the type of ecosystem. For example, the highest evaporation rates occur from the open surfaces of lakes and other water bodies, and can amount to almost 110 percent of annual precipitation (Sumner, 2006). In places where the water table is deep and sandy soil is present, evapotranspiration can be less than 50 percent of annual precipitation. Wetland evapotranspiration is typically within these extremes and depends on the plant type (grasses, shrubs, or trees), density of plant coverage, and availability of water.

Annual variations in rainfall in central Florida (Spechler and Kroening, 2007) occur as a result of multidecadal cycles of warmer and cooler sea-surface temperatures that affect the entire eastern United States (a detailed discussion is provided in Enfield and others, 2001). Annual variations are evident when long- and short-term records are examined. For example, in central Florida annual rainfall was well below average in 2000, close to average in 2001, and 5 to 10 in. above average during 2002–04 (fig. 9). Water levels in isolated, lacustrine, and riverine wetlands fluctuate in response to the annual and seasonal variations in rainfall and evapotranspiration in Florida. However, evapotranspiration losses are more consistent on a monthly and annual basis than rainfall because they are primarily a function of solar radiation and depth to the water table. Therefore, seasonal and annual rainfall patterns are a predominant influence on wetland water levels.

The seasonal patterns of rainfall in central Florida vary spatially across the region. In the southern part of central Florida, convective thunderstorms during the warm summer months contribute more than half of the annual rainfall. Average monthly rainfall rates greatly exceed evapotranspiration rates from June to September (fig. 10), and wetland water levels typically rise. Groundwater levels also rise as the wet season progresses, such that successive storms generate increasing runoff to wetlands, streams, and rivers. Summer rainfall and the additional effect of runoff typically cause wetland water levels to reach a seasonal maximum between July and September (fig. 11). In some years, large individual rainfall events, such as those associated with tropical storms, hurricanes, or El Niño climate patterns, can shift the seasonal maximum wetland water level to fall or, rarely, early winter.

In the northern part of central Florida, a greater proportion of the annual rainfall occurs in the winter months of January, February, and March. This pattern has been observed in long-term data sets (1961–90) (Fernald and Purdum, 1998) and in more recent data (1982–88) (Southwest Florida Water Management District, 2009a,b). Winter rainfall in this region comes from frontal storms—cold continental air masses that push into northern Florida and collide with warmer, wetter maritime air moving up from the south (Chen and Gerber, 1990). In general, winter storm fronts dissipate as they move south, and contribute less rainfall to wetlands in the southern part of central Florida. Winter months have the lowest evapotranspiration rates of the year (Bidlake and others, 1996; Sumner, 2001). Therefore, although winter rainfall is less than summer rainfall, it can generate proportionately greater runoff. For this reason, wetland water levels often reach a secondary maximum between January and March. For example, when peak wetland water levels were ordered by month at a **cypress wetland** (GS–2) in the Green Swamp, July was the most common summer month and March was the most common spring month for peak water levels to occur (Southwest Florida Water Management District, 2008).

Throughout central Florida, evapotranspiration rates begin to rise in February (early spring) as days warm and increase in length. April and May (late spring) are among the months with the lowest average rainfall of the year (fig. 10). The dry conditions in the late spring occur throughout central Florida in response to a recurring climate pattern called the Bermuda high, a region of high atmospheric pressure that persists off the Atlantic coast of Florida (Chen and Gerber, 1990). With decreasing rainfall and increasing evapotranspiration, wetland water levels typically reach an annual minimum sometime between May and June, and many wetlands often become dry (fig. 11). Wetlands usually experience a smaller secondary water-level minimum toward the end of the calendar year, between the summer and spring peaks (fig. 11). The lack of an early spring peak in water levels can result in prolonged dry conditions in wetlands between two consecutive summer peaks (such as in 1984–85; fig. 11).

Water levels in flood-plain wetlands of central Florida have a seasonal response to rainfall and evapotranspiration similar to that of isolated wetlands. The year-to-year variability in water levels in relation to rainfall can be interpreted from long-term monitoring data. Stream discharge and water levels are measured for most of the principal rivers in central Florida by the USGS and by the regional Water Management Districts, and many streams have more than five decades of water-level measurements. These measurements can be used to reconstruct flooding patterns in riverine and flood-plain wetlands if the topography of the river channel and the adjacent flood plain has been mapped (Lewelling, 2003; 2004) (Feature C—Wetland Bathymetry and Flooded Area). The largest rainfall events generate extreme flooding that inundates large expanses of flood-plain wetlands. Rising river levels also cause river water to go into bank storage (water absorbed in the permeable bed and banks of streams). Because flood-plain deposits in bank storage areas tend to be highly permeable, the resulting hydraulic connection with adjacent wetlands raises wetland water levels in flood plains, even without overbank flooding (Winter and Woo, 1990).

Long-term monitoring of water levels in isolated wetlands across central Florida has been far more limited than river monitoring. Several hundred isolated wetlands have been routinely monitored in the northern Tampa Bay area (Hillsborough, Pasco, and Sumter Counties) for about 10 years. This is the largest concentration of monitored wetlands in central Florida (Southwest Florida Water Management District, 1996). However, 10 years of water-level data are typically not sufficient to describe the long-term effects of rainfall on wetland water levels. For this reason, the water-level condition of the tens of thousands of isolated wetlands in central Florida must be inferred from the relatively small number of sites that have been monitored for periods longer than 10 years.

Some of the longest wetland water-level records available are for six natural cypress wetlands in the Green Swamp of Sumter and Lake Counties that have been continuously monitored for almost 30 years. The wetlands are located in the middle part of the central Florida region. The Green Swamp wetlands are reliable indicators of climate effects on water levels because they have not been substantially affected by land-use changes or groundwater pumping, Historical water-level data for the six isolated cypress wetlands in the Green Swamp indicate the relation between annual rainfall and the amount of time a wetland is dry. It is useful to compare the timing and duration of dry conditions instead of wet conditions because surface-water levels are unambiguous when a wetland is dry. In contrast, comparing wet conditions in wetlands may be misleading because wet conditions reflect a continuum from a puddle of water in the deepest location of one wetland to widespread flooding in another.

Primer Facts

Annually, water levels in many central Florida wetlands have two highs and two lows. Highest water levels typically occur in March and July; lowest in December and May through June.

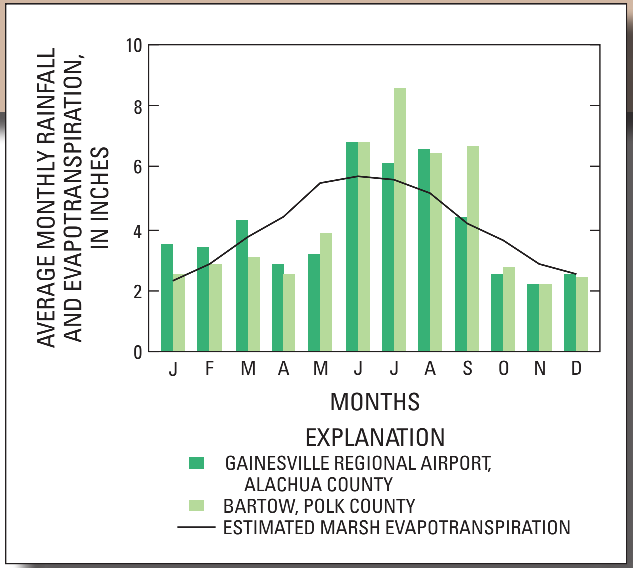


Figure 10. Average monthly rainfall in northern and southern areas of central Florida (data from National Oceanic and Atmospheric Administration, 2008) and estimated marsh evapotranspiration (Lee and others, 2009).

Right: Cardinal flowers (*Lobelia cardinalis*) add brilliant color to Florida marshes and wet meadows during the wet season from July to October. Photographer credit: Paul Fellers, Lake Region Audubon Society.

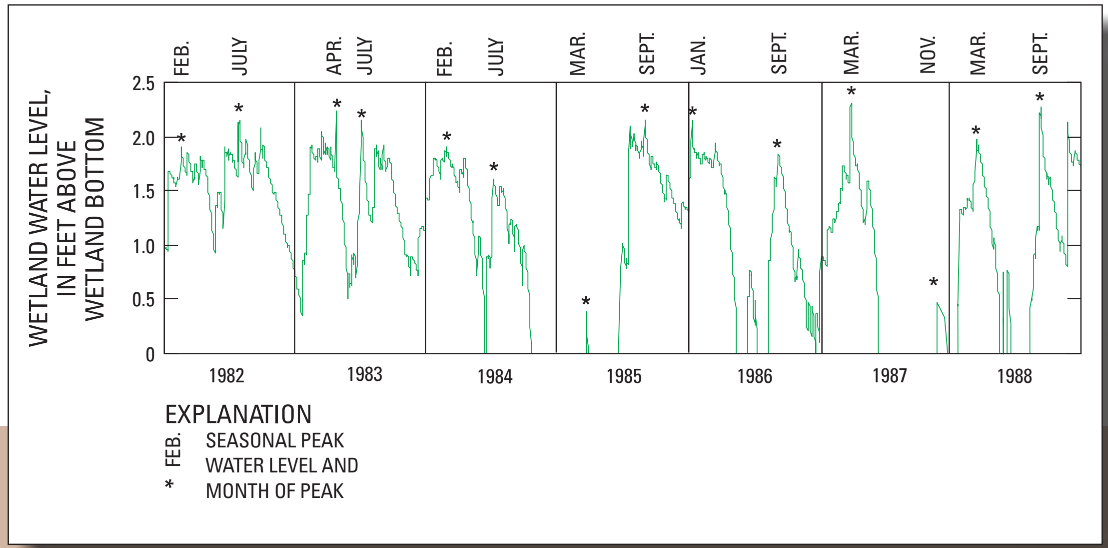


Figure 11. Seasonal variation in the wetland water level in an isolated wetland (GS-2) in the Green Swamp area of Lake County, Florida (data from Southwest Florida Water Management District, 2009b).

C Wetland Bathymetry and Flooded Area

Hydrologic conditions have been monitored in isolated wetlands throughout Florida for several decades by local, regional, and State agencies. Typically, hydrologic conditions are monitored by determining the wetland water level at a staff gage located at a fixed point (preferably near the deepest point) in a wetland (fig. C–1A). However, because wetland depths and shapes vary substantially, water levels among individual wetlands are not directly comparable. Moreover, it is difficult to translate periodic and widely distributed water-level measurements into a regional view of wetland hydrologic status. The usefulness of long-term data sets of wetland water levels would greatly increase if the data described not only the depth of water at a point in the wetland, but also the amount of the total wetland area that was flooded at a specified time.

Flooded area, expressed as a percentage of the total wetland area, is a versatile and descriptive measurement that can be compared through time for an individual wetland or compared spatially for numerous wetlands in a region during a particular month or year (Haag and others, 2005; Lee and Haag, 2006). Comparing the flooding patterns of natural wetlands to flooding patterns in wetlands affected by human activities also provides a useful tool for assessing how those activities currently affect wetlands, and for predicting future wetland conditions.

The size of the flooded area can be determined for a given water-surface elevation if a bathymetric map exists for a wetland. Bathymetric maps show contours of bottom depth throughout a body of water, and bathymetric mapping is a well-established tool in lake studies where the depth of a lake bottom is usually determined using sonar instruments towed by boats. Bathymetric maps also can be constructed for isolated wetlands. Because water levels in isolated wetlands fluctuate seasonally and many wetlands dry out, wetlands are usually shallow enough to wade or to walk through during part of the year. For this reason, land-surveying techniques can be used to map the bottom elevation of an isolated wetland. Alternatively, if the wetland is flooded, the bottom elevation can be derived by subtracting measured water depths from the elevation of the water surface. Measurements can be made along lines or transects across the wetland (fig. C–1A), and the location of the measured points can be determined using digital geographic positioning system (GPS) technology or by using set distances along compass lines (Haag and others, 2005). For wetlands that are partially flooded, the approaches can be combined (Haag and others, 2005). The bathymetric data then can be used to define the relations between the wetland water level (stage), size of the flooded area, and volume of water in the wetland at a given stage (C–1A). The density of bathymetric data points affects the accuracy of subsequent estimates of wetland flooded area and stored water volume (Haag and others, 2005).

Accurate determination of a wetland perimeter is necessary to establish the elevation at which a wetland is said to be 100-percent inundated or flooded (fig. C–1B). Wetland perimeter determinations sometimes rely on hydric soils indicators. The presence of soils with a color and consistency that results from continuous inundation can mark the wetland perimeter. A wetland perimeter also can be determined from vegetation indicators. For example, the position of saw palmetto can be used because these plants cannot tolerate inundation for more than a few weeks. Other vegetation indicators of wetland perimeters have been documented for central Florida (Carr and others, 2006).

Bathymetric mapping data can be used to show areas of the wetland bottom that would be flooded as each 20-percent interval of the total wetland area becomes flooded (fig. C–2). Once bathymetric data have been used to generate stage-volume and stage-area curves, then historical wetland water levels can be used along with these curves to reconstruct historical changes in wetland flooded area (fig. C–3). Historical flooding behavior in isolated wetlands then can be summarized using flooded-area duration graphs. These graphs display the percentage of the total historical time that the flooded area of the wetland occupied different intervals of the total wetland area (fig. C–3). The historical time period depends upon the number of years that wetland water levels have been measured.

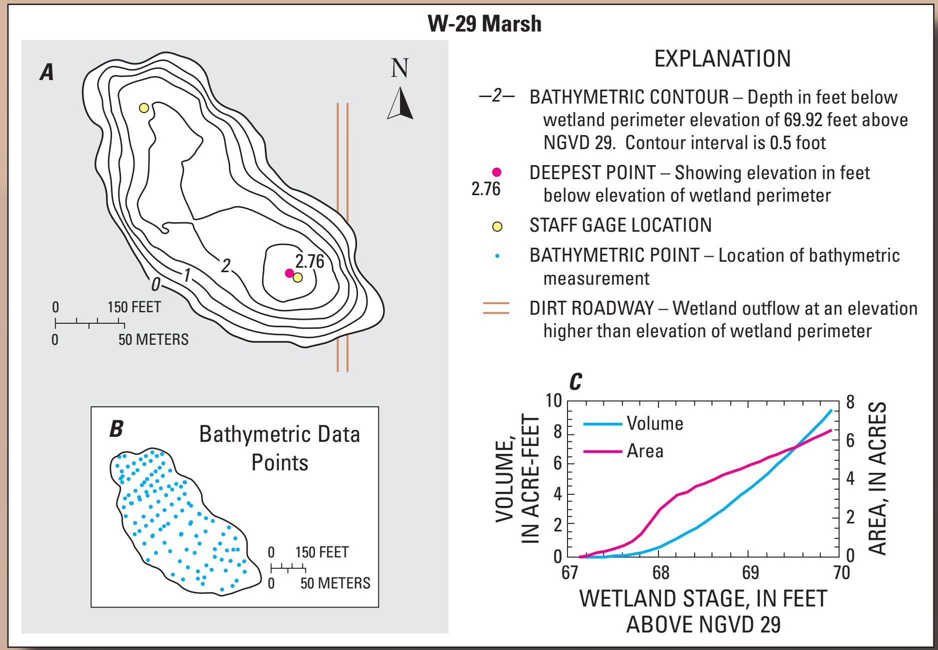
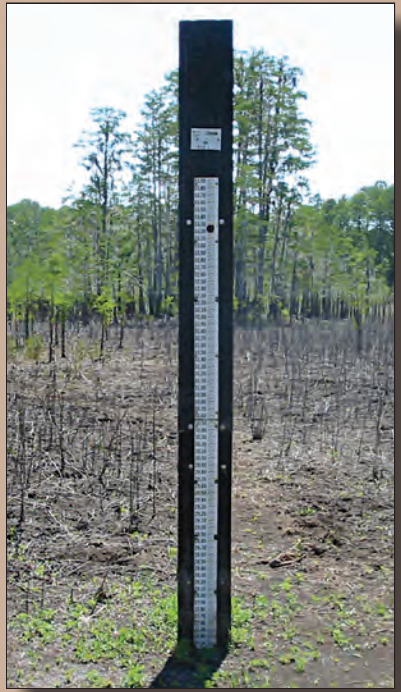


Figure C–1A. *A,* Wetland bathymetric contours, *B,* density of bathymetric data points, and *C,* stage-volume and stage-area curves for W-29 Marsh, Cypress Creek Well Field, Pasco County, Florida (right; modified from Lee and others, 2009).



Above: The elevation of the wetland bottom, used to draw bathymetric contours, is most easily measured during the dry season when many wetlands have little or no standing water. Photographer credit: Dan Duerr, U.S. Geological Survey.

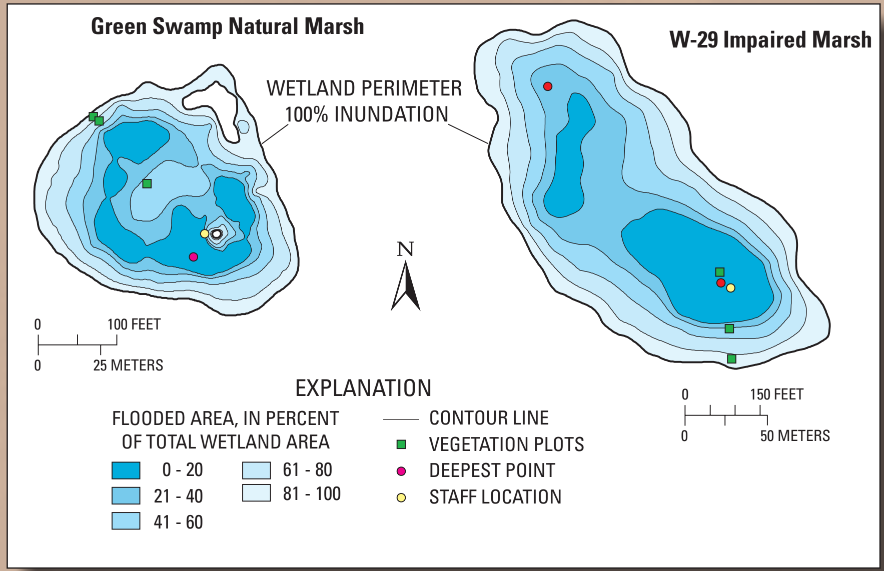


Figure C–1B. Maps generated from bathymetric data that are used to contour the shape of the flooded area as different percentages of the total wetland area become flooded (above, modified from Lee and others, 2009).

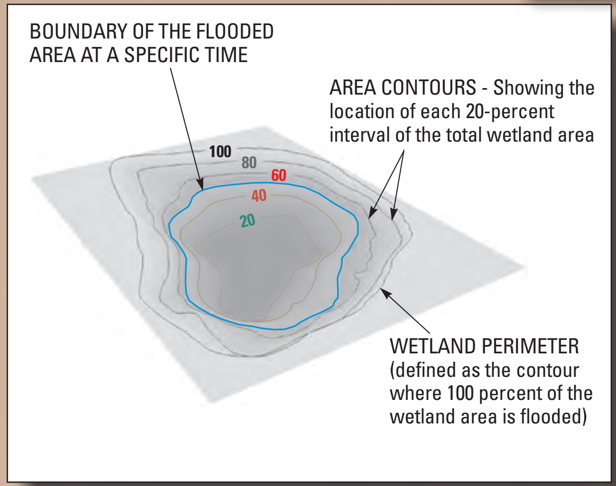


Figure C–2. Conceptualized wetland showing the boundary of the flooded area located in different 20-percent intervals of the total wetland area (left).

C Continued

A similar flooding pattern was observed in isolated wetlands in west-central Florida that were located in similar physical, hydrologic, and climatic settings, even though the wetlands were of different sizes (Lee and others, 2009). However, markedly different flooding patterns can result from human-induced changes to wetlands. For example, the flooded extent will be smaller in a wetland affected by groundwater withdrawals compared to a wetland unaffected by withdrawals (Haag and others, 2005; Lee and others, 2009) (fig. C–4). When flooded areas are compared using this approach, the percentage of the total wetland area that is no longer flooded, and therefore is vulnerable to ecological change, becomes quantifiable. Vegetation is adapted to survive short-term variations in flooding. However, when changes in flooded area become long-standing, the vegetation will change and so will the area of the original wetland that continues to function as a wetland (Haag and others, 2005).

Land-surveying methods similar to those used in isolated wetlands are used to define the elevation profile of riverine and flood-plain wetlands. The areal extent of numerous riverine wetlands has been mapped throughout central Florida, and the extent and frequency of flooding has been determined as part of a regulatory process for recommending the minimum flows and levels for rivers in Florida (Lewelling, 2003; Lewelling, 2004; Munson and Delfino, 2007; Munson and others, 2007; Neubauer and others, 2008). The extent of historical flooding in riverine wetlands is determined by calculating the area of the wetland flooded by streamflows that occur across a range of magnitudes and frequencies. An example of the variation in streamflow is provided for a 10-mi reach of the Hillsborough River, between **river miles** 29.1 and 39.2. The most infrequent flood peaks, with a recurrence interval less than 10 percent (discharge percentile $\geq$ 90), flood the largest areas of the flood plain (fig. C–5) and the increase in inundated area is greater in a downstream direction.

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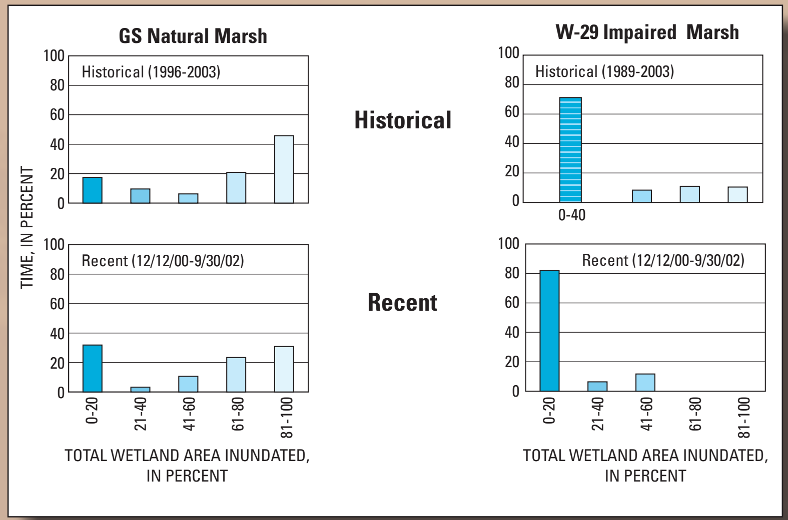
Figure C–3. Comparison of the flooded area of a natural wetland (GS Natural Marsh, Sumter County, Florida) and an impaired wetland (W-29 Impaired Marsh, Pasco County, Florida) during recent and historical time periods to indicate wetland areas that are not routinely flooded (right; modified from Lee and others, 2009).



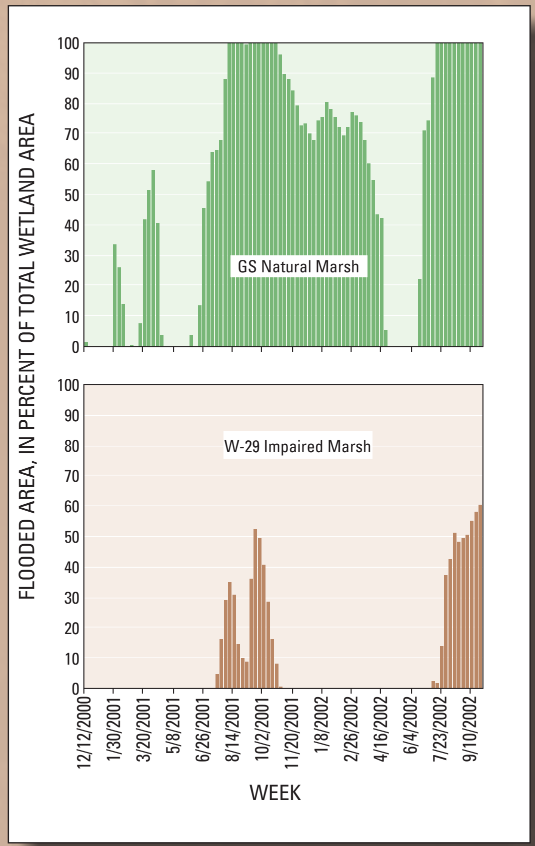
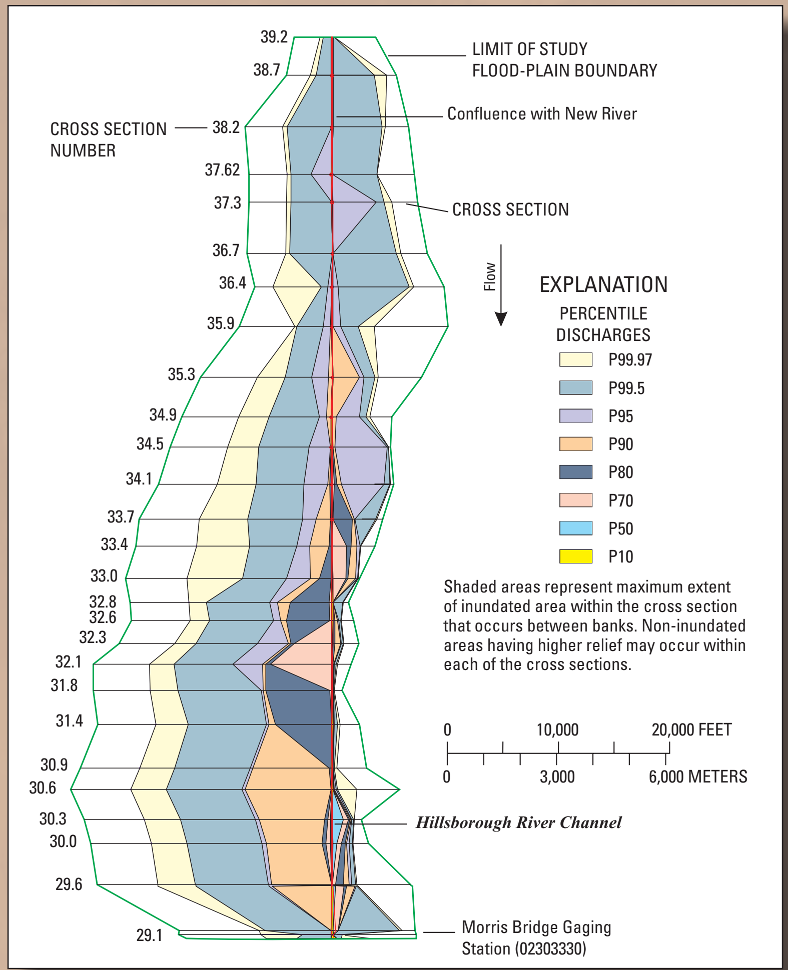


Figure C–4. Percentage of the total wetland area flooded on average each week in a natural and an impaired marsh. (Flooded areas beyond 100 percent of the total wetland area are not shown) (above; modified from Lee and others, 2009).

Figure C–5. The Hillsborough River inundates increasing areas of flood-plain wetlands as the river flow increases (right; modified from Lewelling, 2004).



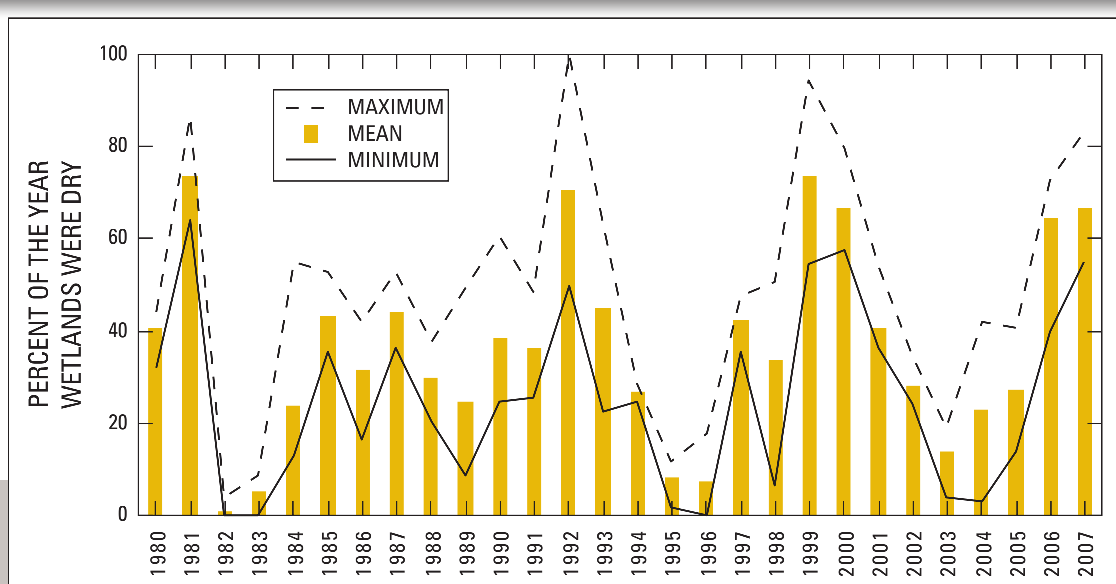
Water levels monitored during nearly three decades (1980–2007) in Green Swamp cypress wetlands fluctuated in response to widely varying annual rainfall. Rainfall data collected at the Bartow, Florida, climate station (National Oceanic and Atmospheric Administration, 2008), less than 50 mi from the Green Swamp, varied more than 40 in/yr during this time period—from 35.31 to 79.61 in. Although the six wetlands were located several miles apart, they demonstrated similar flooding patterns during the 28-year period (fig. 12). The correspondence in the duration and timing of dry days among these six wetlands is due to their similar hydrologic response to regional rainfall patterns, and indicates that patterns observed at these six wetlands may occur in numerous other wetlands in the same region. On average, during the 28-year period, each wetland was dry approximately 40 percent of the year (35–41 percent) and wet the remainder of the year (59–65 percent). However, between years wetland hydrologic conditions varied as widely as the annual rainfall, with the average dry period ranging from 5 to 75 percent of the year (fig. 12).

As annual rainfall increases, the amount of time wetlands are dry generally decreases, although the same annual rainfall can generate a different number of dry days depending upon the seasonal distribution of rainfall. However, the decrease in the number of dry days with increasing annual rainfall has a limit, as illustrated by the following example. The isolated cypress wetlands in the Green Swamp were dry about 54 percent of the year, on average, when the annual rainfall was less than 45 in/yr, which occurred in 9 of the 28 years (fig. 13). When annual rainfall was 45 to 55 in/yr, and was closer to average (about 52 in/yr), the wetlands were dry about 38 percent of the year, or close to the long-term average condition (approximately 40 percent of the year). When the climate was wetter than average (rainfall 56–65 in/yr), the wetlands were dry about 22 percent of the year. When the annual rainfall was far above average (more than 65 in/yr), the amount of time the wetlands remained dry stayed about the same (24 percent of the year). Thus, the number of dry days was about the same whether the year was wet or extremely wet (fig. 13). This pattern prevails because isolated wetlands are shallow and lack the capacity to store the excess rainfall. Regardless of the additional rainfall, once the wetlands fill, the excess rainfall spills out and runs off, leaving wetlands to dry out similarly when the wet season ends.

Surface-Water Flow in Wetland Drainage Basins

Surface water is rainfall that has not infiltrated the soil and entered the groundwater system, and has not returned to the atmosphere as evapotranspiration. Surface water flows overland following a gradient from areas of higher elevation to areas of lower elevation, and eventually collects in wetlands,

Figure 12. Average percentage of the year when six isolated cypress wetlands in the Green Swamp area of Lake and Sumter Counties, Florida, were dry during 1980–2007 (data from Southwest Florida Water Management District, 2008).



lakes, streams, and rivers, before flowing into the oceans. Surface water contributes to wetlands in central Florida as **overland flow**, channelized streamflow, and outflow from nearby lakes and ponds. Isolated wetlands (by definition) receive inflow from streams only during times of very high rainfall when other nearby surface features overflow. Flood-plain wetlands receive overbank flow from rivers and streams when river stage is high. Usually there is a delay between the onset of rainfall and the peak river flows that cause flood-plain wetland inundation.

Under average rainfall conditions, most isolated wetlands retain direct rainfall within the wetland boundaries and also are able to store runoff from the immediate surrounding land surface. Under the wettest conditions, however, some isolated wetlands overflow. Water spills out through inconspicuous surface channels, and flows into wetlands at successively lower elevations, conveying runoff across an almost imperceptibly sloping land surface to the lowest elevation in the drainage basin—typically a stream or river. It has been suggested that the definition of isolated wetlands be refined to include the recurrence interval of wetland outflows, for instance, in months, years, or decades (Winter and LaBaugh, 2003). Because of the lack of monitoring data, however, this level of understanding is not yet attainable for most central Florida wetlands.

The role of wetlands as headwaters to Florida streams is well recognized, and in fact, most Florida streams originate in swamps (Livingston, 1990). The Green Swamp, which covers about 870 mi^2 of wildlife management area in Hernando, Lake, Pasco, Polk, and Sumter Counties, is a region of high groundwater levels and vast wetland areas, and it is the headwaters to four major rivers originating in central Florida (Brown, 1984). The frequency and magnitude of flows between wetlands in undeveloped basins such as the Green Swamp are likely to be considerably different than those in drainage basins where the land-surface elevations between wetlands have been altered by land development and ditching. In both settings, however, wet-season connections are an important pathway for wetland colonization by plants and animals that otherwise are isolated from one another.

Primer Facts

Surface water is rainfall that has not infiltrated the soil and entered the groundwater system, and has not returned to the atmosphere as evapotranspiration. Surface water flows overland following a gradient from areas of higher elevation to areas of lower elevation, and eventually collects in streams, rivers, lakes, and wetlands, before flowing into the oceans.

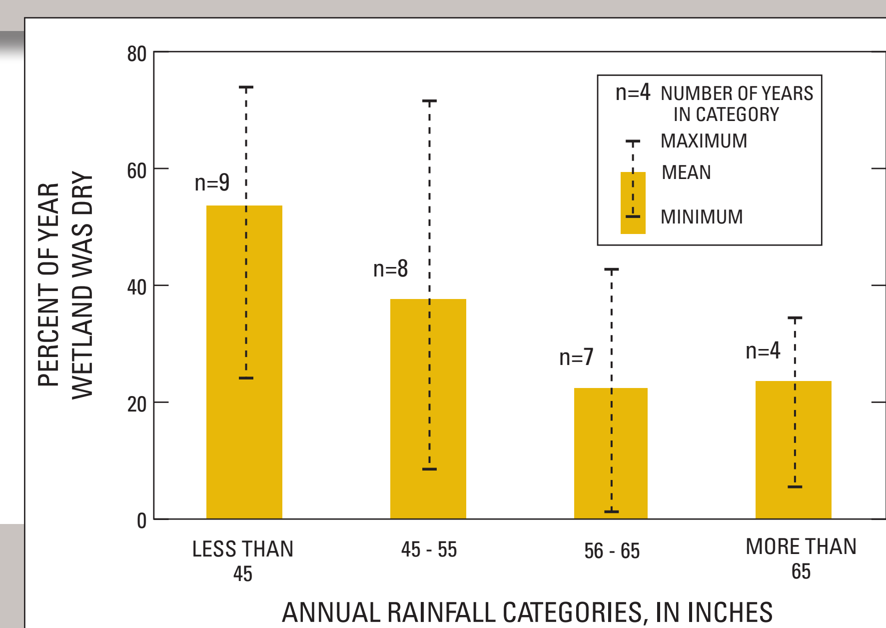


Figure 13. Percentage of the year an isolated cypress wetland (GS-2) in the Green Swamp area of Lake County, Florida, was dry during 1980–2007, for years with rainfall in a given category at Bartow, Florida (data from Southwest Florida Water Management District, 2008).

Central Florida encompasses the drainage basins of seven major rivers (fig. 14), and wetlands are present in the headwater areas of each basin. These drainage basins are the Upper St. Johns River, Middle St. Johns River, Kissimmee River, Ocklawaha River, Peace River–Myakka River, Tampa Bay tributaries (the Hillsborough, Alafia, and Manatee Rivers), and Withlacoochee River. Wetlands occupy different percentages of the respective land areas of the seven drainage basins (fig. 14). The Ocklawaha River drainage basin has the smallest percentage of wetland area (7 percent), whereas the Upper St. Johns River drainage basin has the greatest percentage (32 percent).

Until recently, the shallow and inconspicuous surface-water channels that link wetlands together at high water levels have been difficult to map and therefore are difficult to describe. The relief of most of these features is far less than the 5-ft contour intervals commonly used to define land-surface elevations. In the Green Swamp, for example, the land surface was described as sloping about 3.3 ft in 2.7 mi along one northwest-southeast transect (Brown, 1984). Many forested wetlands in central Florida, in fact, are present in patches across a landscape referred to simply as “flatwoods.”

The channels connecting wetlands to other wetlands or to streams become evident when land-surface elevations are

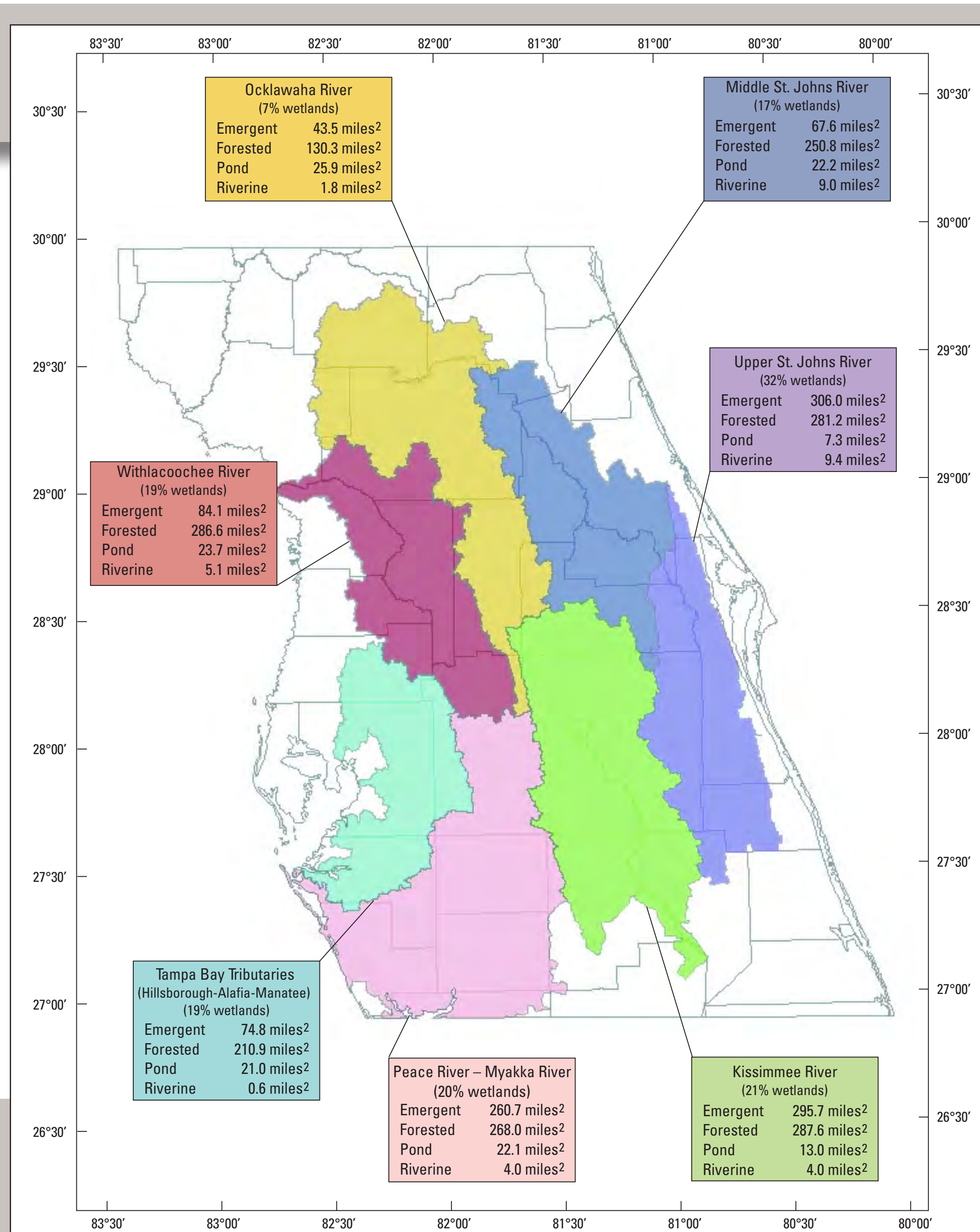
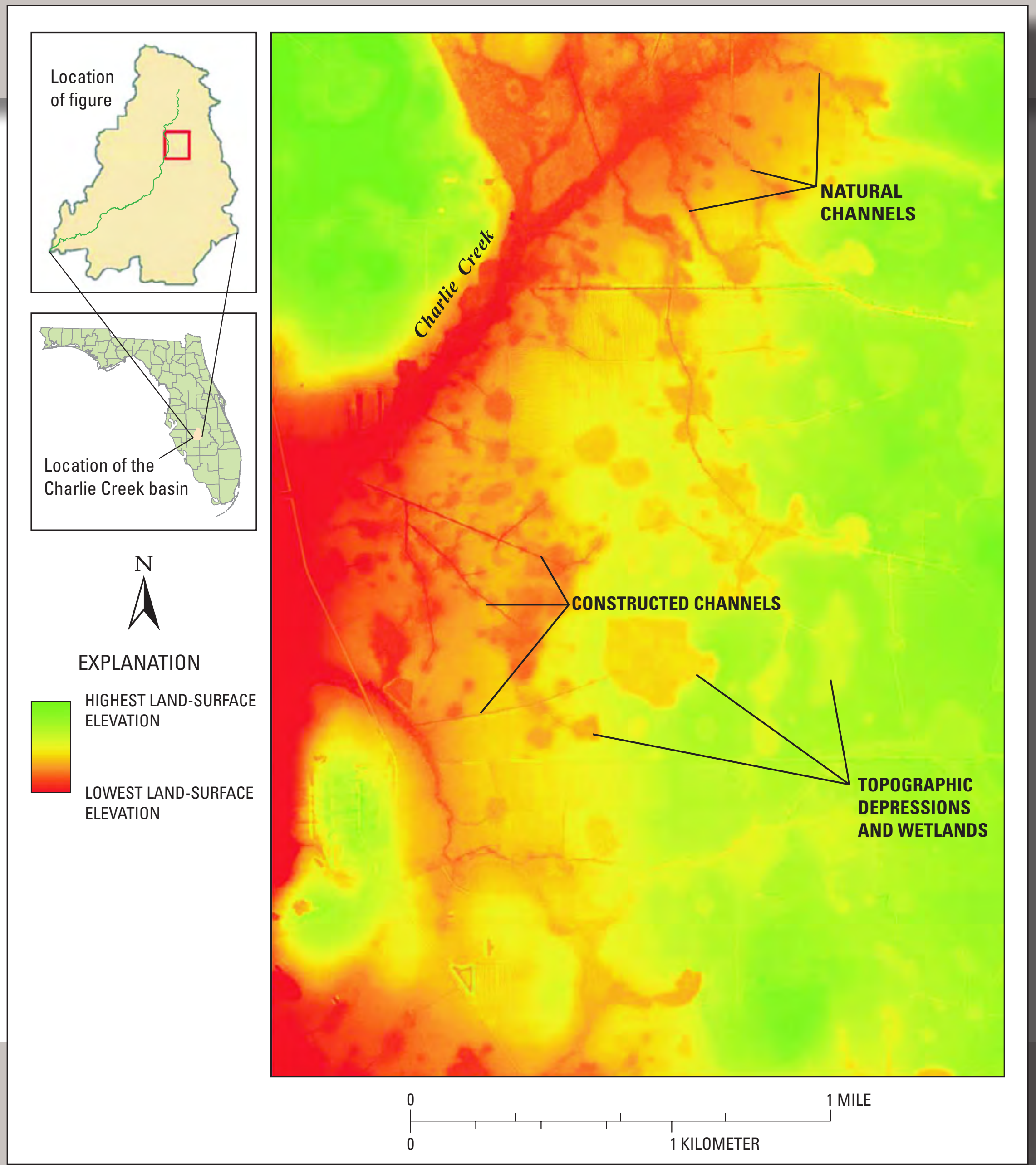
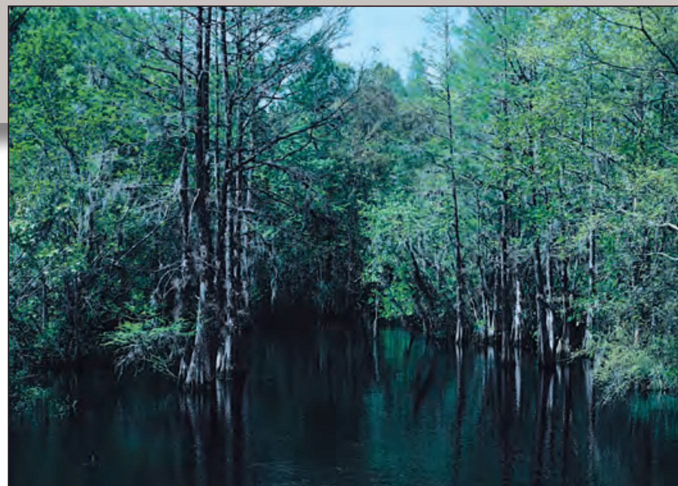


Figure 14. The percentages of selected types of wetlands in the seven major drainage basins in central Florida.

resolved to dimensions of centimeters or inches. In Hardee County, for example, isolated wetlands are evident in a digital elevation map of the northeast part of the Charlie Creek drainage basin (T.M. Lee, U.S. Geological Survey, written commun., 2008) (fig. 15). The topographic features shown in figure 15 are derived from remote-sensing, and light detection and ranging (LIDAR) techniques (Al Karlin, Southwest Florida Water Management District, written commun., 2008). The usually isolated wetlands shown can alternatively divert runoff from or deliver runoff to Charlie Creek, a tributary stream to the Peace River-Myakka River drainage basin. Much of the land (up to 30 percent) in the Charlie Creek basin is used for grazing cattle and for other kinds of agriculture. When mapped using high resolution techniques, elevation differences that are less than 1 ft reveal the pleated furrows and mounds of the farmed plots, and also the ditches that were plowed into wetlands to drain them to nearby streams (fig. 15). Constructed channels follow the slope of the land toward the stream and connect wetlands across distances of 0.5 mi or more despite the low relief. Natural flow channels also can be seen linking low-elevation wetlands to the stream. The density of isolated wetlands may increase closer to the river because the erosion and flooding associated with the stream can enhance the karst subsidence

Figure 15. High resolution (LIDAR) digital elevation map showing constructed and natural flow channels connecting topographic depressions and wetlands to a stream in the Charlie Creek drainage basin, Hardee County, Florida (LIDAR data from Al Karlin, Southwest Florida Water Management District, written commun., 2008).





Above: Flood-plain forest along the Withlacoochee River. Photographer credit: Paul Fellers, Lake Region Audubon Society.

Below: Anclote River. Photographer credit: Dan Duerr, U.S. Geological Survey.

processes that create topographic depressions (Metz and Lewelling, 2009). The importance of wetlands for water-quality enhancement is greater in upstream reaches of drainage basins than in downstream reaches because they occupy a higher proportion of the land surface in headwaters, relative to the size of the streams, than in downstream areas. Alterations that affect the functioning of wetlands adjacent to small streams in the upstream parts of drainage basins can substantially affect stream hydrology, water quality, and ecology (Brinson, 1993).

The collective importance of wetlands as a water resource in central Florida becomes evident when the volume of water cycling through wetlands in a drainage basin is compared to the streamflow in the same drainage basin. For example, wetlands compose about 23 percent of the comparatively small (88 mi^2) Anclote River drainage basin in Pasco County. About 1,200 cypress wetlands and 400 marshes are present in the drainage basin upstream from the USGS streamflow gage at Elfers, Florida, based on the National Wetland Inventory (fig. 16). This density is approximately equivalent to two cypress wetlands and one marsh wetland for every 100 acres of drainage basin, given that cypress wetlands average about 9 acres in size and marshes average about 3 acres in size in this drainage basin. If these wetlands have mean water depths approximately equal to the average depths for the marsh and cypress wetlands studied by Haag and others (2005) (1.16 and 0.69 ft, respectively), the filled wetlands in the Anclote River drainage basin would store a volume of water equal to about 20 percent of the average annual discharge from the basin. This finding is based on an average annual daily discharge of 62.8 ft^3/s at the USGS Anclote at Elfers gage from 1947 to 2008 (U.S. Geological Survey, 2009a). If wetlands dry and refill more than once in a year (the natural pattern), then this percentage would increase. The importance of wetlands as water bodies in central Florida is revealed by extension when it is considered that the average annual discharge for the seven principal streams in central Florida is in excess of 8,595 ft^3/s (Fernald and Purdum, 1998).

Wetlands function as headwaters to many streams in central Florida; therefore, maintaining the connectivity of wetlands to other surface-water features is fundamental to maintaining streamflows. Just as rivers experience the contrasts of flood peaks and low-flow conditions, isolated wetlands are water bodies that experience hydrologic extremes. Although isolated wetlands are unconnected to other surface-water bodies most of the time, their infrequent, but natural cycles of overflow require that surface-water connections be preserved to maintain their hydrologic status, just as the flood-plain corridors are preserved along rivers. Rivers at low and average streamflows typically stay within a narrowly incised stream channel and infrequently inundate the adjacent flood plain with its forested wetlands. In a far more subtle fashion, isolated wetlands accommodate average and low water-level conditions by flooding only the areas concentric to their deepest points, whereas extreme high water levels get distributed well beyond the wetland perimeters into lower elevation wetlands in the basin.

Infiltration, Groundwater Movement, and Groundwater/Surface-Water Interactions

Water enters the ground through infiltration, which includes the downward movement of precipitation through

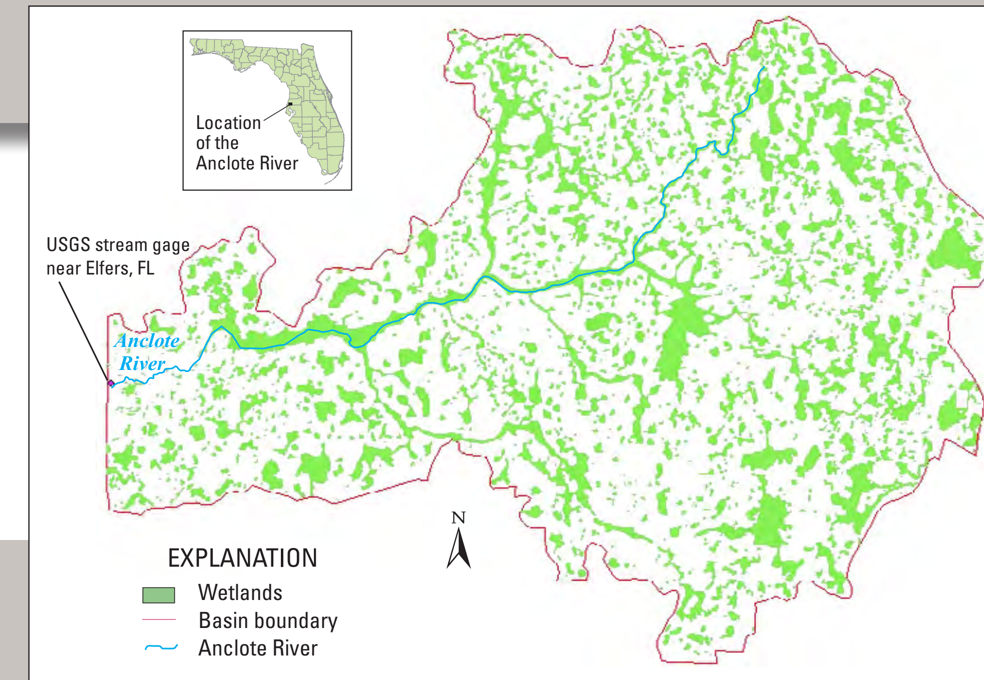


Figure 16. Wetlands in the Anclote River drainage basin in Pasco County, Florida (U.S. Fish and Wildlife Service, 2009a).

soils and rocks in the **unsaturated zone** (where the pores in the soil and rock are filled with air and water), and seepage from stored surface water in wetlands, lakes, and rivers. In this process, called groundwater recharge, water continues to move downward until it reaches the **saturated zone** (where all the pores in the soil or rock are filled with water). The top surface of the saturated zone is referred to as the water table, and all water below the water table is groundwater. Groundwater moves vertically and laterally in the saturated zone through the shallow aquifer (sometimes called the surficial aquifer system) and also through the deeper intermediate and regional aquifer systems in response to differences in hydraulic **head**. Hydraulic head, or potential, is determined by both elevation and pressure. The pressure is maintained by overlying layers of relatively impermeable rock containing clay, silt, and other nonporous material. Differences in hydraulic head can cause groundwater to move upward toward the land surface or into surface-water bodies, including wetlands, in a process called groundwater discharge. This process also occurs through springs, seeps, or even artesian wells.

Many wetlands in central Florida are closely connected to the groundwater system. Wetlands that receive groundwater inflow from the surficial aquifer system or the shallow Upper Floridan aquifer are considered to be in a groundwater discharge setting. If wetlands supply water to the underlying aquifer, they are considered to be in a recharge setting. The timing and magnitude of water movement are determined by the elevation difference between the wetland water level and the underlying aquifer water level. When the wetland water level is higher than the aquifer water level, the wetland recharges the aquifer. Alternatively, when the underlying aquifer water level is higher than the wetland water level, groundwater can discharge into the wetland. These movements of water can occur vertically and/or laterally. The rate of water movement is determined by the permeability of the geologic deposits and the water levels in the aquifers. Flow paths in some isolated wetlands change seasonally, whereby they may become **discharge wetlands** during the rainy season, and **recharge wetlands** during the dry season. Other isolated wetlands have flow paths that vary spatially. These “flow through” systems can receive groundwater discharge in one part of the wetland where the surrounding water table is higher than the wetland elevation, and also recharge the aquifer in another part of the wetland where the surrounding water table is lower than the wetland elevation.

Flood-plain wetlands also may have complex flow paths, receiving groundwater inflow from upslope areas and gaining water from or losing water to the adjacent river channel, depending on the river stage. In flood plains that receive groundwater inflow, there is a complex community of tiny invertebrates that live in the subsurface, or hyporheic zone, of the flood-plain bottom and associated wetlands. Many of these organisms spend their entire lives in this underground zone where recharging and discharging waters mix. Other invertebrates use the hyporheic zone as a refuge during dry periods and then recolonize the surface of streambeds and adjacent flood-plain wetlands once surface-water flow resumes (Hancock and others, 2005).

In some regions of the United States, wetlands that appear to be isolated have a subsurface connection to nearby surface water by way of the aquifer, and are an integral part of the groundwater flow system (Winter, 1998; Winter and

LaBaugh, 2003). In much of central Florida, however, groundwater in the surficial aquifer system typically travels only very limited horizontal distances before recharging deeper aquifers, making groundwater connections between wetlands and lakes less common. Factors that influence this subsurface connectivity include the aquifer thickness, separation distance, wetland depth, depth of the nearby water body (lake or river), and elevation differences (Lee, 2002).

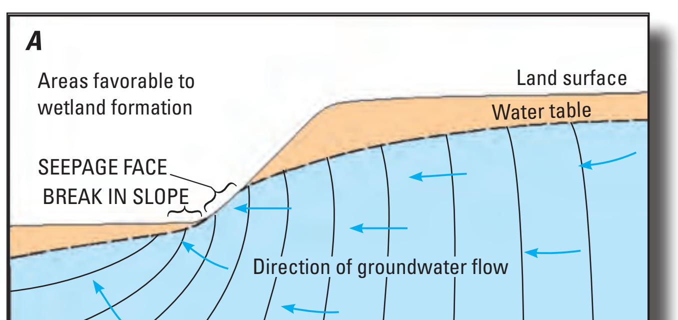
The exchange of water between wetlands and groundwater is an important hydrologic process throughout Florida. This is especially true in central Florida, where the highly permeable limestone of the Upper Floridan aquifer is closer to land surface than elsewhere in the State, and more thinly covered by a clay confining unit than in other areas (fig. 6). It is the proximity of this soluble limestone to land surface in central Florida, and the relatively thin blanket of the clay confining unit and surficial sand deposits, that create the distinctive karst terrain in the region (White, 1970). Dissolution of the limestone by infiltration of rainfall, which is mildly acidic (Riekerk and Korhnak, 1992), causes a distinctive pattern of land subsidence that promotes formation of the numerous small depressions that become wetlands, lakes, and sinkholes in the region (fig. 5) (Sinclair and others, 1985; Tihansky, 1999). The limestone beds of the Upper Floridan aquifer dip southward and increase in distance below land surface from north to south along the Florida peninsula. South of Lake Okeechobee, the Upper Floridan aquifer is not used for water supply, principally because of the unsuitable water quality.

The majority of wetlands in central Florida interact with groundwater in the surficial aquifer system. A few wetlands (for example, River Styx in Alachua County) are found where groundwater from the Upper Floridan aquifer discharges at the land surface (Feature B—Seepage Wetlands). In general,

the interaction between groundwater and individual wetlands depends upon the localized pattern of groundwater flow in the surficial aquifer and the rate of groundwater movement (Winter and Woo, 1990). The direction and rates of groundwater movement depend on the geometry and permeability of geologic materials around the wetland (commonly called the hydrogeologic setting), and breaks in land slope near the wetland (fig. 17*A-C*).

Three general groundwater flow patterns are favorable for wetland formation (Winter and others, 1998). These flow patterns are favorable because the water table in the surficial aquifer intercepts the land surface. Wetlands can form at seepage faces that are present at breaks in the land slope (fig. 17*A*), a flow pattern somewhat less common in the low relief landscape of central Florida than it is in the Florida panhandle. When the water table in the surficial aquifer slopes toward a river, groundwater commonly discharges in the wetlands on flood plains near river channels (fig. 17*B*). When rain and runoff accumulate in depression wetlands, the sustained flow of water out of the wetland and into the underlying aquifer creates a recharge mound in the water table (fig. 17*C*). The relation between groundwater flow patterns and wetlands is complicated because flow patterns may change seasonally and may not persist year-round.

Recharge mounds in the water table have been the most persistent groundwater flow features observed around a number of isolated marsh and cypress wetlands in the flatwoods of west-central Florida (fig. 18) (Lee and others, 2009). These mounds embody the valuable storage function provided by wetlands in central Florida. Water slowly moves downward and laterally from the wetland into the surficial aquifer, "mounding up" until it moves downward to the intermediate confining unit. Subsequent vertical movement can ultimately result in recharge to the Upper Floridan aquifer.



Primer Facts

The source of water to wetlands can be *A,* from groundwater discharge at seepage faces and breaks in slope of the water table, *B,* from streams, and *C,* from precipitation in cases where wetlands have no stream inflow and groundwater gradients slope away from the wetland.

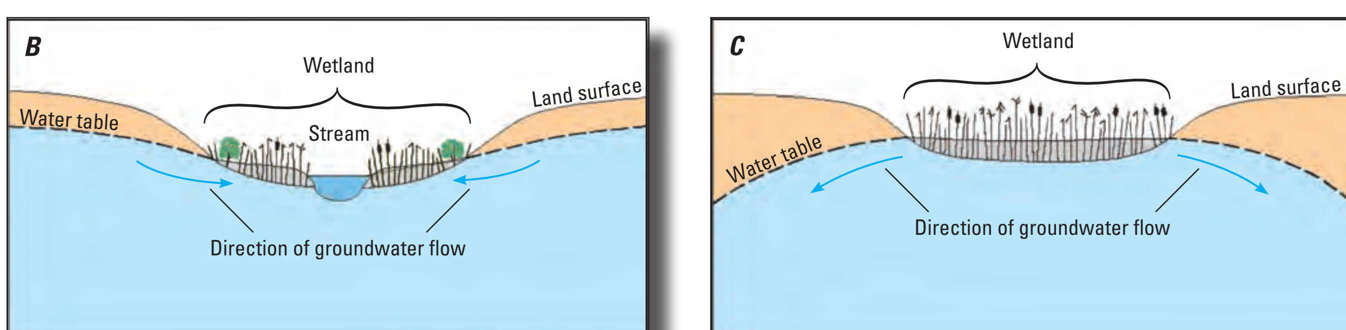
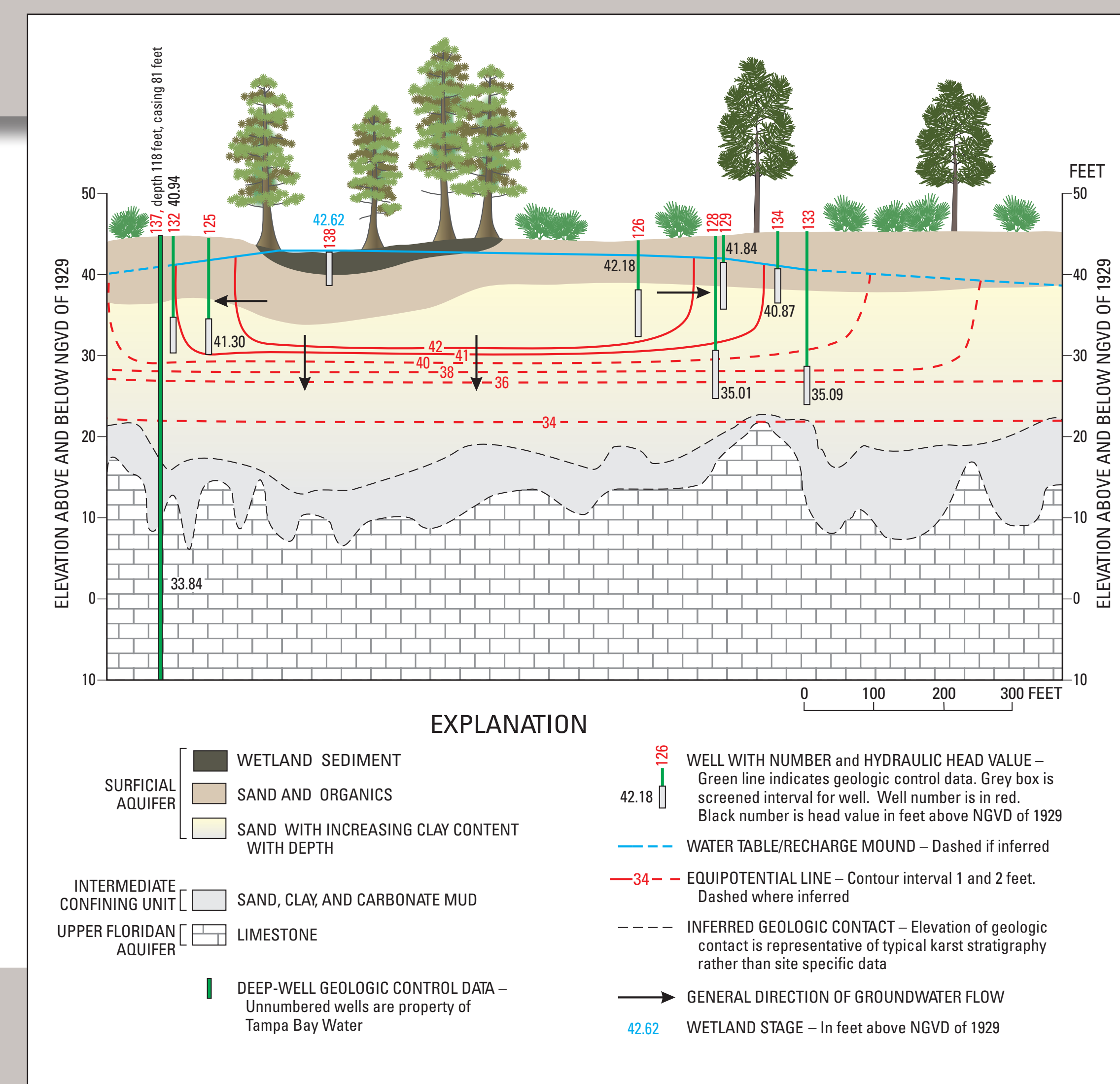


Figure 17. Typical groundwater flow configurations around wetlands (modified from Winter and others, 1998).

Figure 18. Hydrogeologic section through an isolated wetland (S-68 Cypress) in Pasco County, Florida, showing the water table and the direction of groundwater flow (modified from Lee and others, 2009).



Under the wettest conditions, the water table also could rise higher than the wetland water level on one side of the wetland, allowing groundwater to move laterally through the wetland, and eventually recharge the Upper Floridan aquifer. For example, a marsh in Martin County exhibited a pattern of horizontal flow to the adjacent surficial aquifer (Wise and others, 2000). In both settings, however, the surficial aquifer recharges the deeper Upper Floridan aquifer.

In some central Florida counties, freshwater wetlands are present in groundwater discharge areas where water from the Upper Floridan aquifer discharges upward to the intermediate aquifer system and surficial aquifer. An example of such an area is the Charlie Creek drainage basin in Hardee County (fig. 19). An extensive groundwater discharge area is present around headwater wetlands in the northern part of the basin, as well as along stream channels and near sinkholes where the land surface drops abruptly and is often below the potentiometric surface in the Upper Floridan aquifer. Because confining clays commonly separate the Upper Floridan and surficial aquifers, upward flow may be slow. However, when discharge conditions exist they preclude downward losses from the surficial aquifer, allowing more runoff from wetlands into streams. Excessive groundwater withdrawals from the Upper Floridan aquifer can convert discharge areas to recharge areas and reduce streamflow.

In karst areas, groundwater withdrawals can have a substantial effect on groundwater/surface-water interactions.

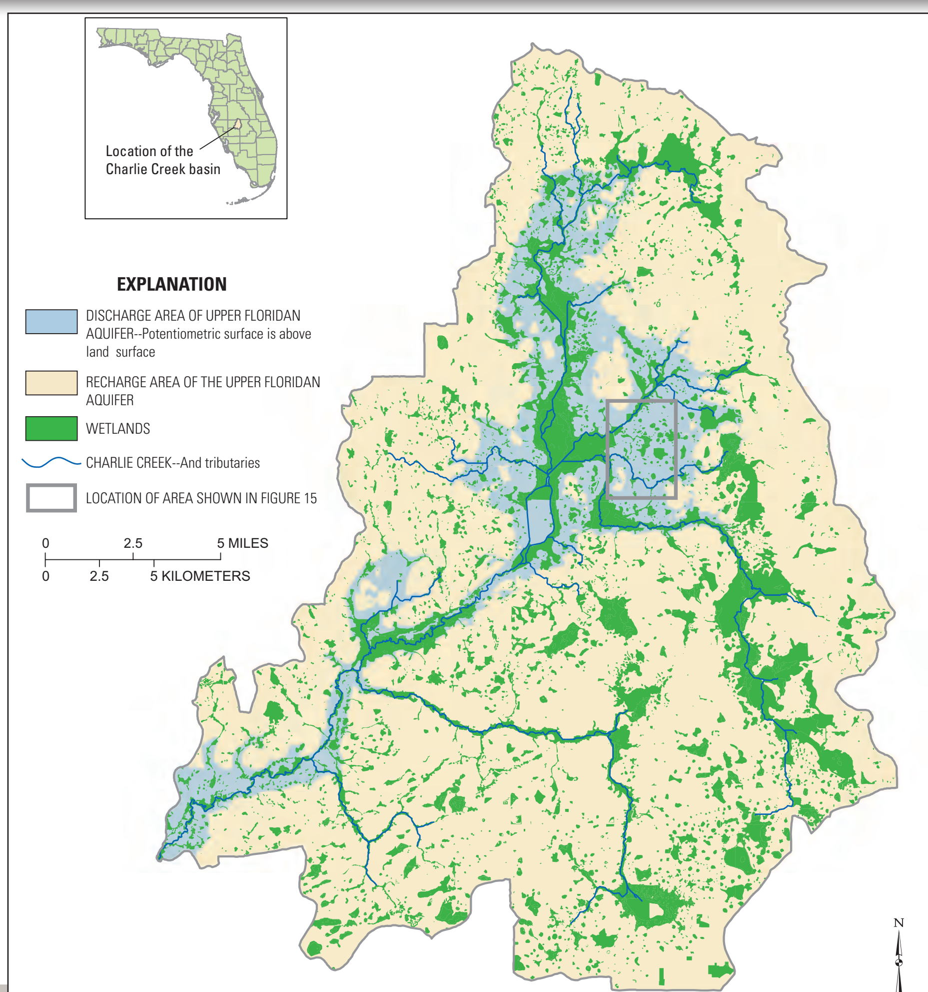


Figure 19. Discharge and recharge areas of the Upper Floridan aquifer and the location of wetlands and stream channels in the Charlie Creek drainage basin of Hardee County, Florida, for September 2006 (Ortiz, 2007; LIDAR data from Al Karlin, Southwest Florida Water Management District, written commun., 2008).

Table 1. Counties having the greatest groundwater withdrawals from the Upper Floridan aquifer, 2000 (Marella, 2004).

County	Withdrawals, in million gallons per day
Polk	317.73
Orange	280.46
Hillsborough	194.86
Duval[1]	150.00
Pasco	139.24
Highlands	133.77
Brevard	123.55
Manatee	118.25
Osceola	114.65
DeSoto	110.01
Volusia	96.72
Lake	90.41
Seminole	88.20
Hardee	81.73
Indian River	74.01
Marion	66.04
Alachua	59.16
Hernando	49.32
Okeechobee	47.76
St. Lucie	46.98

[1]County not included in the central Florida study area.

Groundwater withdrawals from the Upper Floridan aquifer are concentrated in central Florida, although 59 of the 67 counties in the State use the aquifer as the primary source of groundwater (Marella, 2004). Of the 20 counties with the largest groundwater withdrawals from the Upper Floridan aquifer, all except Duval are in the central Florida study area (table 1).

Monitoring Hydrologic Characteristics in Wetlands

Some wetland hydrologic characteristics can be measured using relatively simple instruments deployed to record key indicators, such as wetland water level, rainfall, and groundwater levels in the drainage basin surrounding the wetland (fig. 20). Long-term records of hydrologic data in wetlands are an invaluable tool for resource managers because they assist in determining changes in wetland size, flooding patterns, and responses to changes in rainfall and other climatic variables.

Although rainfall can be monitored in or near individual wetlands, evapotranspiration measurements commonly require sophisticated instruments, and evaporation instrumentation is typically mounted on a tower in a location representative of a specified environmental setting. As of 2009, there were at least

Primer Facts

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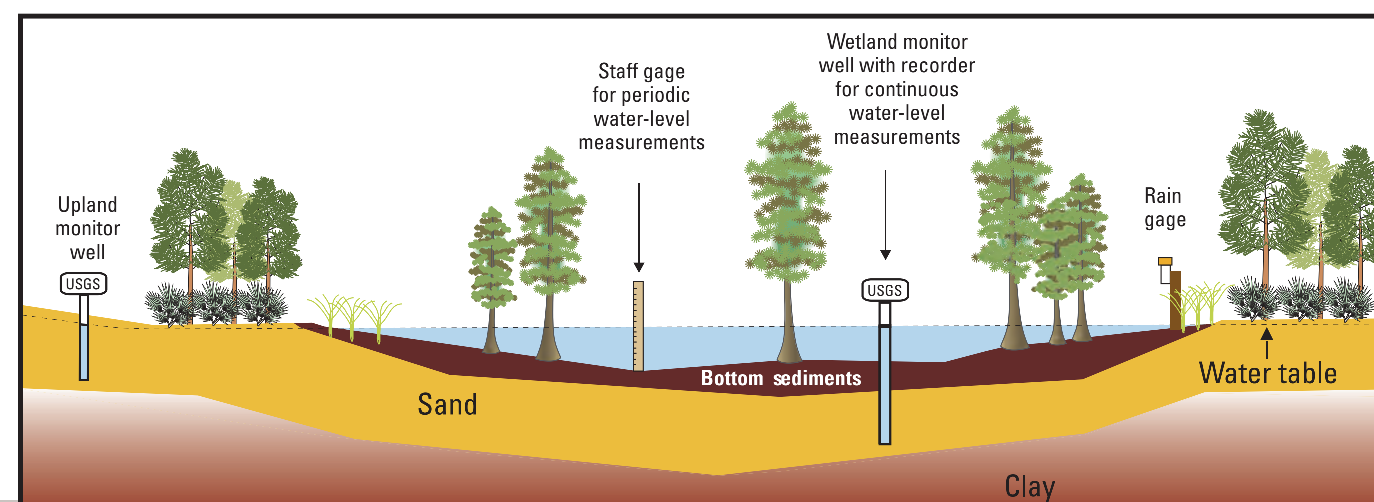

Figure 20. Instrumentation for hydrologic monitoring in Florida wetlands.

20 micrometeorological stations for measurement of evapotranspiration located throughout Florida in various environmental settings, including an Everglades slough, several lakes, slash pine plantations, and agricultural areas with differing types of crop cover. Additional stations are planned or have already been installed in cypress, wet prairie, and marsh settings. Included in the types of data collected at the evapotranspiration stations are rainfall, air temperature, relative humidity, and wind speed. Additional data used in estimates of evapotranspiration are collected through the National Oceanic and Atmospheric Administration Geostationary Operational Environmental Satellite network and include the areal distribution of solar insolation (the amount of sunlight received on the Earth’s surface) and albedo (the ratio of the light reflected by the Earth to that received by it) (U.S. Geological Survey, 2008c).

Water Quality and Soils in Wetlands

Wetland water quality is affected by rainfall, groundwater inflow and outflow, surface-water inflow and outflow, and the presence or absence of oxygen (**aerobic** or **anaerobic** conditions, respectively), which determines the biological activity of microbial organisms in wetlands. The biological activity of microorganisms involves complex chemical reactions in wetland water and soils that transform nitrogen, sulfur, carbon, phosphorus, and other elements into forms useable by bacteria, algae, plants, and other organisms (Richardson and Vepraskas, 2001). Moreover, the **residence time** or retention time of water in wetlands, which is a hydrologic characteristic, helps determine how much and how fast the various chemical constituents change and what kinds of chemical and biological transformations occur. A sufficient residence time is necessary for the breakdown and mineralization of organic material that would otherwise accumulate in wetlands. This is one reason why it is often detrimental to wetland function to create a channel across a wetland that might increase outflow rates and decrease residence time.

Rainfall is one of the important sources of water in many Florida wetlands, and strongly affects wetland **pH**, dissolved constituents, **specific conductance**, and **alkalinity**. Florida wetlands that derive most of their water from rainfall typically have a low pH (4.0–5.5), because the average pH of rainfall in Florida ranges from 4.3 to 4.7, and is about 4.7 in central Florida (Fernald and Purdum, 1998). These wetlands also have low concentrations of dissolved constituents (fig. 21) and are poorly **buffered** because concentrations of calcium, magnesium, potassium, sodium, chloride, sulfate, and bicarbonate are very low in rainfall—typically less than 5 mg/L. Specific conductance, a measure of the total amount of dissolved constituents in water, ranges from 35–115 µS/cm in northern Florida cypress wetlands (Ewel, 1990). Studies in west-central Florida indicate that specific conductance ranges from 50 to 275 µS/cm. Alkalinity, a measure of the buffering capacity of the water in the wetlands, also is low in central Florida wetlands (less than1.0–18.0 mg/L as calcium carbonate).

Surface-water inflow is an important source of water to wetlands in central Florida, but it is difficult to assess because the topography is relatively flat in many areas and the catchment area of wetlands may be small or large depending on very slight changes in land surface elevation. Studies of cypress wetlands in Florida pine flatwoods in Alachua County indicate that the rain-catchment area is 2–3 times larger than the vegetated wetland area (Riekerk and Korhnak, 2000). Catchment areas were calculated using a water-budget approach (Feature D—The Use of **Water Budgets** to Describe Wetlands). Much of the catchment area beyond the palmetto fringe in that study consisted of saturated soils, and under those conditions runoff would be greater than during drier conditions.

Surface-water runoff may carry suspended sediment into wetlands. Surface-water runoff may have higher **dissolved oxygen** concentrations than water in some receiving isolated wetlands due to simple physical aeration. It also may contain elevated concentrations of nutrients if the area drained has soils enriched with fertilizers or other sources of nitrogen and phosphorus.

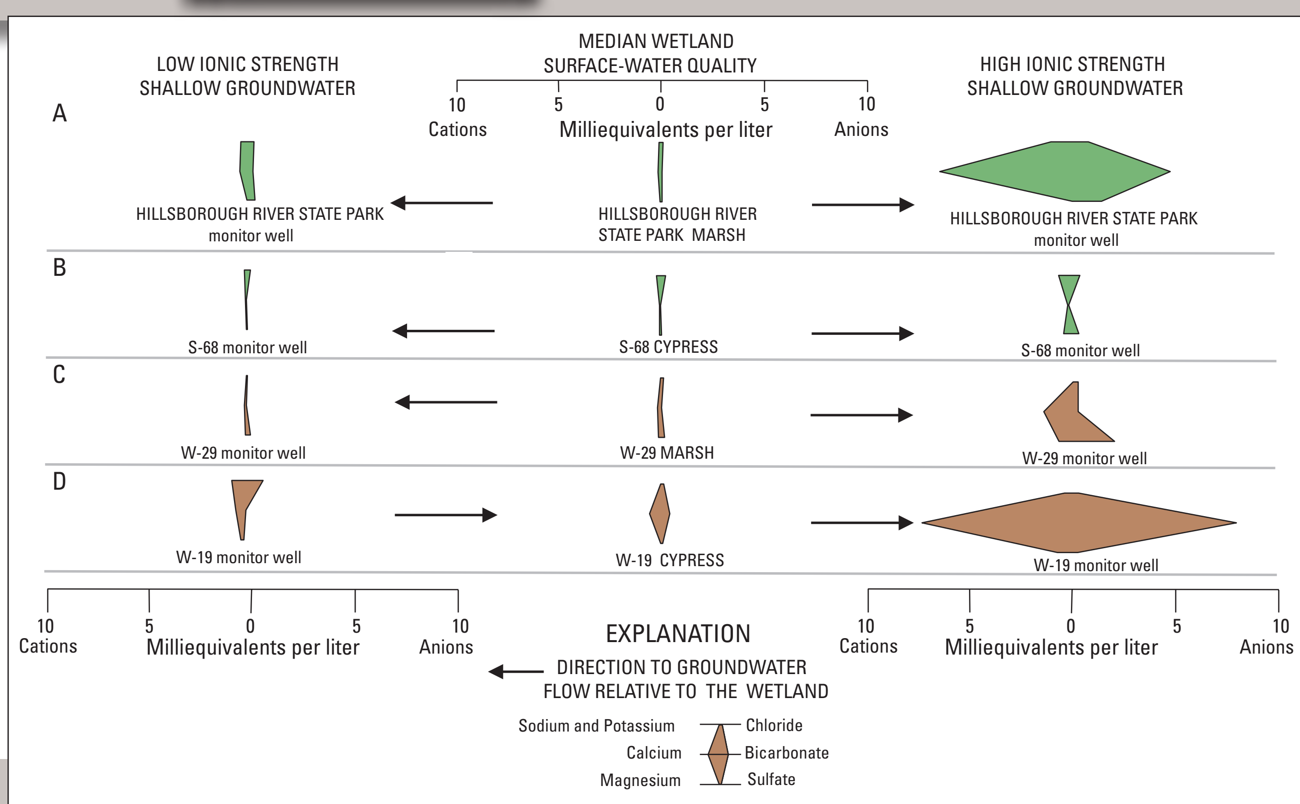

Figure 21. Comparison of water quality in wetland surface water and shallow groundwater at selected wetlands in central Florida illustrated using Stiff diagrams that show the relative amounts of dominant cations and anions (modified from Lee and others, 2009).

Above: Sundew (*Drosera capillaris*) growing on acidic wetland soils.
Photographer credit: Michael Hancock, Southwest Florida Water Management District.

D Use of Water Budgets to Describe Wetlands

A wetland water budget incorporates all identifiable sources of water gain and loss in a particular wetland during a specified time period—a day, week, month, or year. If these sources can be reliably quantified, the water budget then can be used to estimate the change in water storage in the wetland during that same period. The ability to predict those changes, particularly in relation to changes in climate or by human activities, is useful to water managers in local, regional, and State agencies, and refining water-budget approaches to wetlands is of interest throughout central Florida.

There is particular interest in estimating water budgets for the design of mitigation wetlands related to projects that alter or eliminate existing wetlands. Water-budget studies can be used to develop more accurate predictions of the long-term persistence and functioning of these mitigation wetlands, especially under changing climate conditions.

If there is no change in the quantity of water stored in a wetland, then the inputs balance the outputs, and wetland water levels do not change. In central Florida, however, wetlands are dynamic systems and the quantity of water stored does change measurably over short periods, and more substantially over longer periods of time (Lee and others, 2009). For an isolated wetland (one that is not connected by streams to other surface-water bodies) the change in the wetland water volume over an interval of time equals the difference between the inflow and outflow volumes, as expressed in the following equation:

$$\Delta S = P - ET + R + G_i - L \qquad (1)$$

where

ΔS	is change in wetland volume,
P	is precipitation,
ET	is evapotranspiration,
R	is runoff into the wetland,
G_i	is groundwater inflow, and
L	is leakage, defined as the wetland water that leaks out to the underlying groundwater.

There is no surface-water outflow component if water budgets are calculated during periods of time when wetland water levels do not rise above the elevation of the wetland perimeter. A surface-water outflow term must be added to the equation, however, if water-budget periods include times when wetland water levels rise above the elevation of their perimeter.

A substantial amount of data is needed to develop a wetland water budget. The relative size of the components of a wetland water budget varies with the size of the flooded area (fig. D–1). One critical element is a detailed topographic survey of the wetland so that the surface-water volume in the wetland can be calculated accurately as the wetland stage changes over time.

Water-budget components also vary spatially across the State. In central Florida, evapotranspiration is less in the northern counties than in southern counties because solar radiation is lower in the north. Wetlands on the central ridge generally have higher leakage compared to those in the coastal plain where the water table is higher.

Some components of a wetland water budget are more easily measured than others, and the more accurate these measurements and estimates are, the more reliable the wetland water budget will be. Precipitation is recorded at weather stations, but these are typically some distance away from the wetland under study. Many factors affect the accuracy of weather station data and their applicability to wetlands in the region. Urbanization, elevation differences, lake effects, and wind conditions can cause substantial variations in precipitation from one place to another in central Florida.

Primer Facts

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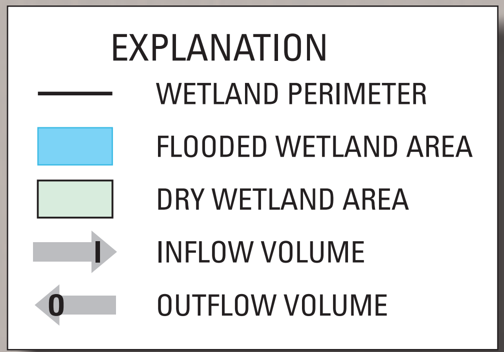

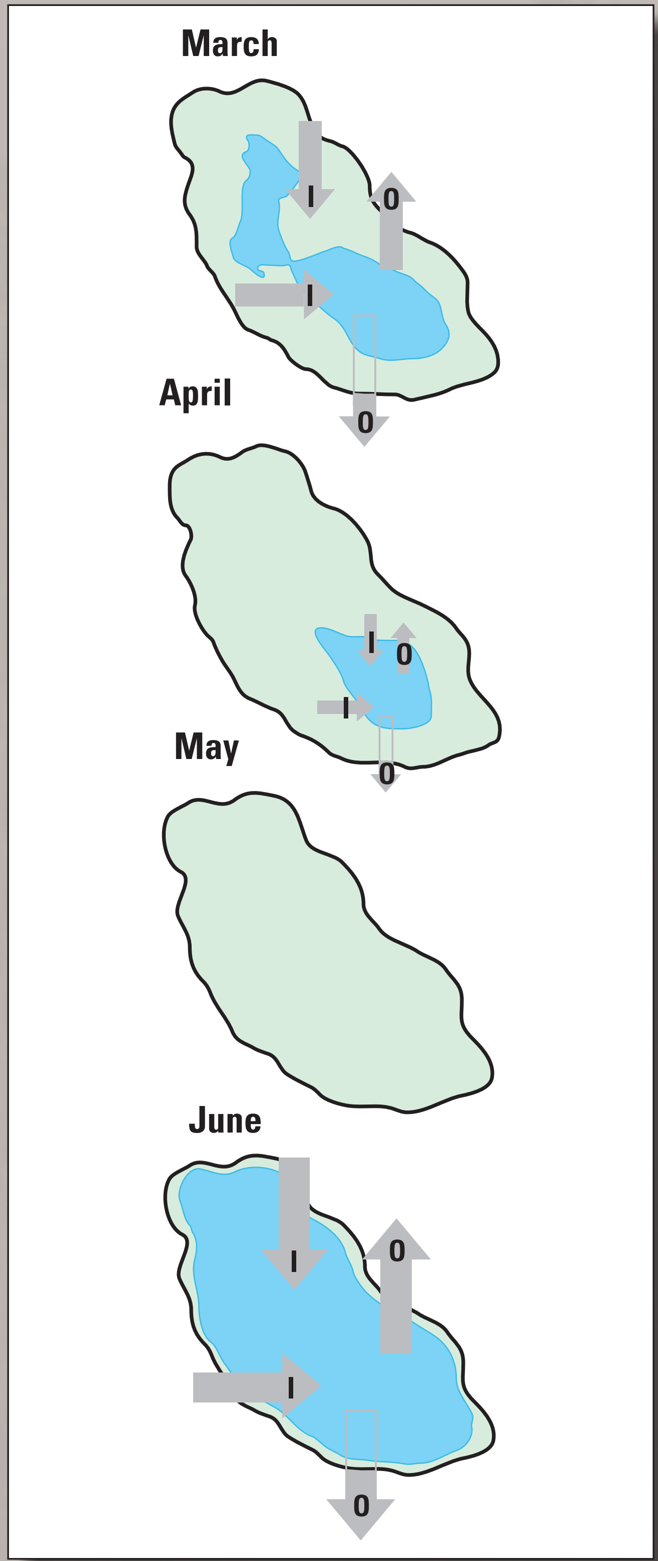

Figure D–1. Conceptualized wetland showing seasonal changes in the magnitude of water-budget components. Relative size of arrows indicates differences in volume. Volumes of the water-budget components change with the size of the flooded area.

D Continued

Rain gages located within or at the edge of wetlands can provide highly accurate rainfall data, but the data must be collected at frequent intervals and collection devices must be carefully maintained.

Surface-water runoff into a wetland comes from several sources. There may be indirect runoff to isolated wetlands from the surrounding watershed as sheetflow or shallow channel flow. Streams occasionally overflow their banks and lakes can overtop their shorelines, thereby contributing surface water to wetlands. Inflow to wetlands must be gaged to measure water volume gain accurately. Likewise, surface-water outflow from a wetland during periods of heavy rainfall must be gaged using a weir or other device to accurately measure the water volume lost.

Groundwater can contribute inflow to a wetland if the groundwater level is at or above the wetland stage. The water levels in monitor wells outside the wetland perimeter can indicate whether shallow groundwater is discharging to a wetland as a contributing water source. A network of at least three monitoring wells is needed to determine the hydraulic gradient or general direction of groundwater flow in the vicinity of a wetland. Water-level measurements in the well network should be collected over time, because the direction of groundwater flow can change seasonally with increasing or decreasing rainfall and evapotranspiration. The rate of groundwater flow can be determined using information about the hydraulic conductivity of the geologic material in the wetland basin. Differences in water quality (including pH and specific conductance) between wetland water and the shallow groundwater around a wetland can be used to infer groundwater movement into or out of a wetland.

Leakage occurs when the groundwater level is below the bottom of a wetland and the wetland is not well confined by clay or other relatively impermeable material. The process also occurs around the wetland perimeter when the water level in adjacent groundwater is lower than the wetland water level. Leakage can be in a downward direction, or it can occur laterally into the wetland basin. This leakage recharges the shallow aquifer. Leakage from wetlands can be induced or accelerated when the water table is lowered by activities such as groundwater withdrawal.

The process of evapotranspiration includes water lost as evaporation from open water or soil, and water lost as transpiration through plants. Evapotranspiration varies with the evaporative demand of the atmosphere and the availability of water. Rates of evapotranspiration are highest in wetlands and lakes where water is near or above land surface, and lowest along the ridges where the soil is permeable and the depth to the water table is greater. There are concerted efforts in central Florida to develop improved estimates of evapotranspiration in a range of habitat and land-use types using technologically advanced climate stations. These more refined estimates can yield substantially improved estimates of evapotranspiration for use in wetland water budgets.

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Above: Saw palmetto (*Seranoa repens*) may surround isolated cypress wetlands, and grow up to the perimeter. It will not grow in the wetland basin, where there is frequent or prolonged inundation. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Many of the vital elements necessary for plant and animal life move through wetland environments in complex cycles that are influenced by microbial communities adapted to life in either aerobic or anaerobic conditions. When soils are saturated with water, conditions in most of the soil substrate are anaerobic, as is the case with much of the substrate in wetlands. However, conditions are often aerobic at the soil/water interface. When wetland soils dry out during the dry season (October–May in much of central Florida), air enters the pore spaces and creates an aerobic environment. Wetlands naturally oscillate between being flooded and dry over space and time and, therefore, support a greater variety of microbial processes that transform essential elements than is found in upland areas.

Sulfur and carbon are vital elements that have a gaseous phase in their cycling. Organic sulfur from the breakdown of decaying animal and plant material is transformed into hydrogen sulfide under anaerobic conditions (in the absence of oxygen) and released into the atmosphere with the characteristic “rotten egg” smell commonly associated with wetlands. Hydrogen sulfide also can be transformed into sulfate and attached (adsorbed) to clay in the sediment or released into the atmosphere where it is converted to sulfur dioxide. Dissolved organic carbon and particulate organic carbon can form from the breakdown of plant and animal material in wetland water and soils. These organic carbon compounds can be taken up and broken down under anaerobic conditions by bacteria to form methane gas, or swamp gas, which is released to the atmosphere when wetland sediments are disturbed. Respiration of organic carbon compounds under aerobic conditions generates carbon dioxide, which is released to the atmosphere, where it is sometimes referred to as a greenhouse gas.

Nitrogen (N) is an element that is abundant in the atmosphere as nitrogen gas (N_2) (fig. 22). Dead and decaying wetland plants and animals release nitrogen as ammonia (NH_3)

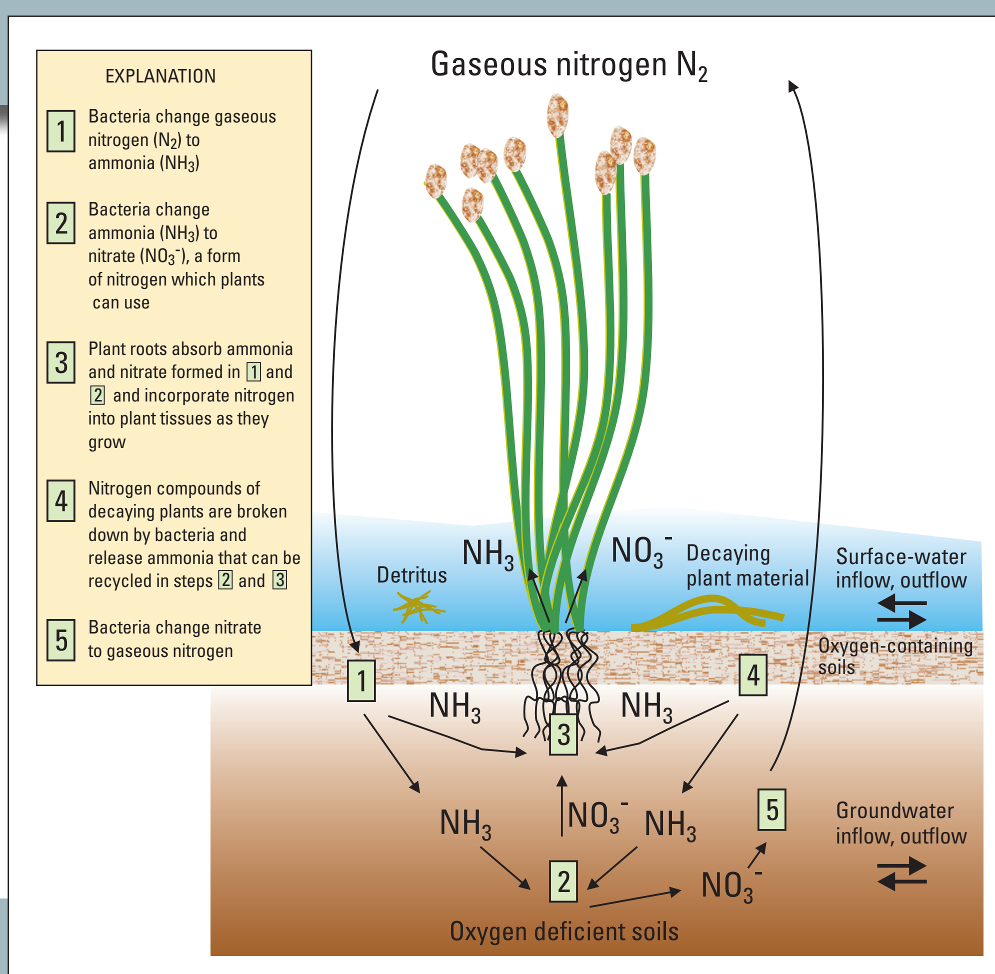


Figure 22. Simplified nitrogen cycle in wetlands (modified from Carter, 1996).

under anaerobic conditions in a process called ammonification. Once the ammonia is exposed to oxygen, such as in the aerobic layer at the soil-water interface, it is transformed to nitrate (NO_3^-). The nitrate may be taken up by plants as an essential nutrient, or it may become adsorbed to soil particles. If excess nitrate is bound up in anaerobic sediments, it can be converted back to nitrogen gas by microbial processes called denitrification and returned to the atmosphere. Otherwise, it can leach downward and dissolve in the groundwater.

Phosphorus (P) is an element essential for plant and animal life that does not have a gaseous phase, but instead is cycled solely in the sediments and waters of wetlands (fig. 23). Most of the time, the majority of the phosphorus in a wetland is bound to organic litter and peat, and to inorganic sediments. Phosphorus is often a limiting plant nutrient in wetland ecosystems, including marshes and deep-water swamps, because it has to be in an inorganic form and water soluble to be taken up by plants. If those conditions are not met, then the element is not bioavailable for plant growth until it has been chemically transformed. Particulate organic phosphorus (phosphorus bound to organic matter such as peat and to clay particles) as well as dissolved organic phosphorus molecules (such as phosphoproteins and phospholipids) cannot be absorbed by plants because they are large molecules. The main inorganic form of phosphorus is called orthophosphate (PO_4^-) and it is the most bioavailable form to plants. Some inorganic phosphorus binds to metals (such as iron and aluminum), rendering it insoluble and thereby unavailable for plant absorption. These insoluble inorganic phosphates often precipitate from the water column onto the wetland sediment surface. When wetland sediments are resuspended, depending on the pH of the water and the dissolved oxygen concentrations, phosphorus can be transformed and become more bioavailable. Generally, phosphorus is most bioavailable at a slightly acidic to neutral pH.

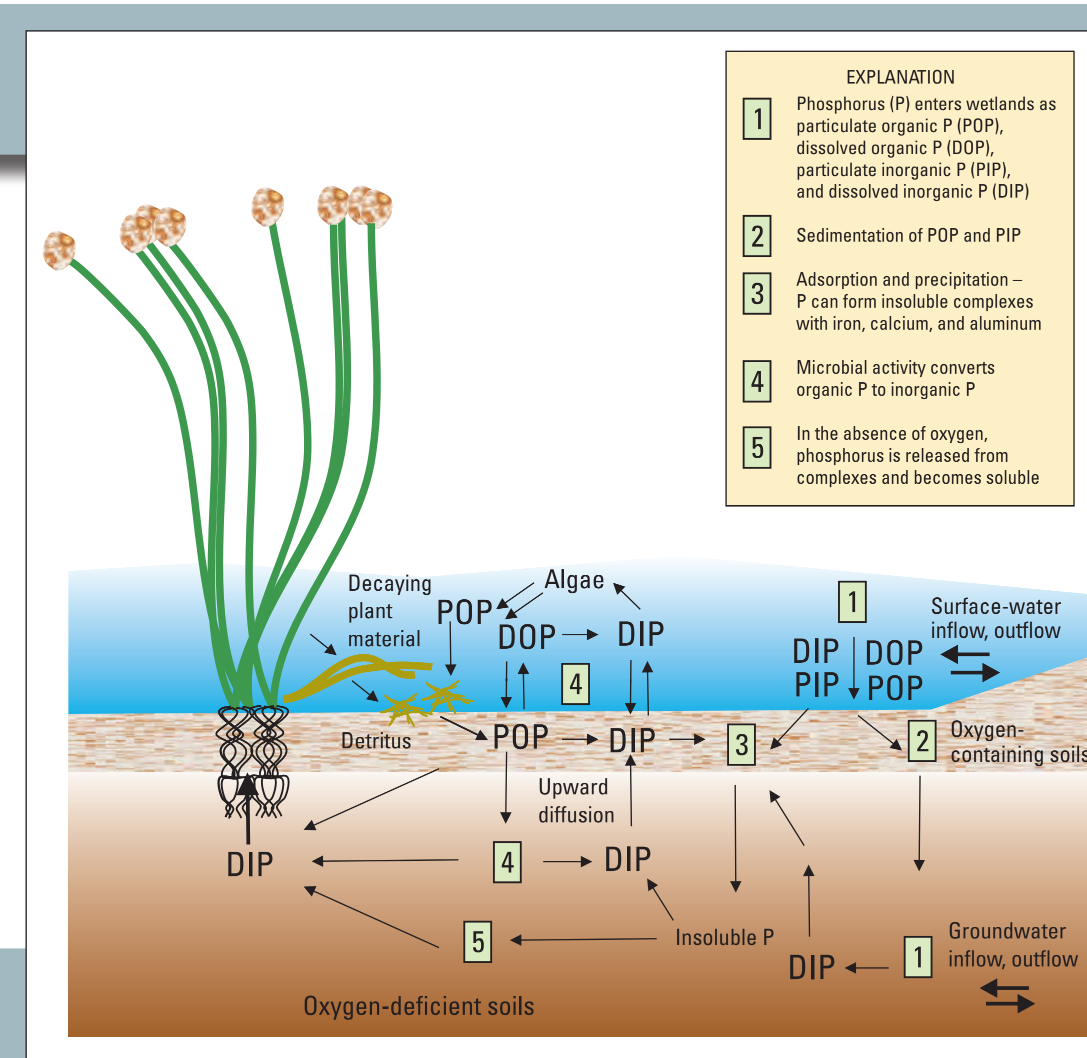


Figure 23. Simplified phosphorus cycle in wetlands.

Left: Carnivorous pitcher plants (*Sarracenia purpurea*) grow in wetlands with low nutrient availability and they use insects and small invertebrates as a source of nitrogen. Photographer credit: Dan Duerr, U.S. Geological Survey.

Right: Soil subsidence is measured near the base of wetland trees in the Eldridge Wilde Well Field in west-central Florida. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Concentrations of plant nutrients (the bioavailable forms of nitrogen and phosphorus) are minimal in rainwater. Therefore, many wetlands have low concentrations of plant nutrients because their primary water source is rainfall. Concentrations typically are less than 100 µg/L for individual forms of nitrogen and phosphorus (Ewel, 1990). Concentrations of nutrients also are generally low in wetlands that have groundwater inflow (unless there is contamination from surface-water sources that contain fertilizers or wastewater). For example, in some wetlands, the breakdown of nitrogen is very slow, and carnivorous plants consume insects and small invertebrates as a source of nitrogen.

Wetland soils are described as hydric because they develop under conditions of saturation or flooding that are prolonged enough to allow anaerobic conditions to develop. Anaerobic conditions develop when soil is saturated because the pore spaces in the soil are filled with water instead of air. Saturated soil can be up to 90-percent water by weight under flooded conditions. The small amount of oxygen present in the water is quickly used up by microorganisms in the saturated soil. Furthermore, oxygen from the atmosphere moves 10,000 times more slowly into saturated soil than into the air-filled pores in drained soil. The breakdown of organic matter in the absence of oxygen is very slow, and explains why organic matter accumulates in thick layers in wetlands flooded during much of the year.

Some wetlands maintain a mineral soil, whereas other wetlands develop organic soils. Mineral (inorganic) soils by definition have less than 20 to 35 percent organic matter. Most mineral soils in Florida have a neutral to slightly acidic pH, although mineral soils in flood-plain wetlands have a higher pH because of the calcium carbonate content of river water. Many flood-plain wetlands have mineral soils that are dry during low-flow periods. When the mineral soils are flooded permanently or semi-permanently, they develop a black, blue-gray, or neutral gray color due to the transformation (reduction) of iron in the absence of oxygen. Iron in its reduced form is more soluble and can be easily leached out of wetland soils. When these mineral soils are no longer flooded and dry out, the iron oxidizes and turns a reddish or yellow-brown color. Sometimes wetland plants transfer oxygen down to their root zone as they grow in saturated soils, and iron is oxidized along the thin traces of small plant roots, leaving behind a net-like orange-red pattern.

Organic wetland soils develop over time as partially decayed vegetation accumulates, as it does in many palustrine and lacustrine wetlands. Compared to mineral soils, organic soils typically are darker in color and have a lower pH, higher porosity, higher water-holding capacity, and often lower nutrient availability. The plant decomposition results in fragmented plant fibers that retain compounds like wax that are not water soluble, and lose cellulose and plant pigments that are water soluble. In muck soils (which are black), more than 65 percent of the plant material is decomposed material, whereas in peat soils (which tend to be brown), less than 35 percent of the plant material has decomposed. Peat tends to accumulate in deep marshes with long hydroperiods that prevent oxidation. Many of the organic compounds in the decomposing plant material leach out and are available to stimulate plant growth in these systems. When organic soils dry out, the peat or muck will compact and oxidize upon exposure to air. This compaction can be a problem in chronically dewatered wetlands as the soil surface subsides and trees begin to fall.

The cycle of drying and flooding determines the availability (alternating presence and absence) of oxygen in wetland soils. Oxygen affects the rate of breakdown of plant material, and accelerates the decomposition of dead plants that accumulate in wetlands. Oxygen also affects the biochemical reactions in wetlands, and in turn the form, solubility, and mobility of minerals such as iron, manganese, and other elements. The degradation of plant material and the transformation of minerals result in distinctive soil color patterns and banding, which have broad use in wetland delineation, an integral part of the wetland regulatory process. The patterns of color in wetland soils also can be used to infer patterns of wetland hydrology (inundation and drying) over time.

There are seven orders (major types) of **hydric soils** that are present in central Florida (histosols, alfisols, spodsols, entisols, mollisols, inceptisols, and utilisols), and a complex system of soil taxonomy (naming conventions) has been developed to identify and describe subgroups within those major orders (Carlisle and Hurt, 2007). Wetland ecosystems can be associated with all of the major soil orders. A complete list of soil map units (by county) that have hydric soils as a principle component is in the Hydric Soils of Florida Handbook (Carlisle and Hurt, 2007). Soils are often used to identify the areal extent of wetlands (wetland delineation), and wetland delineation has important ramifications for land use and land management.

The inherent ability of wetlands to transform many water-quality constituents has led to their use as "treatment" wetlands to specifically improve the quality of surface water or other water sources prior to discharge to rivers or lakes, or to recharge to the surficial or Upper Floridan aquifer. For example, wetlands are being constructed near the outflow of Lake Hancock in Polk County to improve the water quality of the lake outflow before it is discharged into the upper Peace River (Southwest Florida Water Management District, 2006). Marsh wetlands have been restored or constructed to improve the quality of water in Lake Apopka (St. Johns River Water Management District, 2004; 2006) (Feature E—Marsh Restoration—A Key to Improving Water Quality in Lake Apopka).

There are numerous examples of wetlands being used for treatment of wastewater effluent in central Florida, and the treatment goals differ among the projects. Gainesville Regional Utilities in Alachua County has proposed an infiltrating wetland to treat wastewater effluent prior to aquifer recharge (Wetland Solutions, Inc., 2007). The treatment wetlands are designed to reduce nitrate nitrogen concentrations below the drinking water standard of 10 mg/L by optimizing natural microbial processes that eliminate nitrate nitrogen. Constructing the wetlands on soils with high permeability would have the added advantage of facilitating groundwater recharge while also creating wetland habitat. The city of Clermont has proposed adding treated wastewater effluent to a freshwater marsh in Lake County. The marsh is shallow and has a long hydroperiod (8–10 months). Water-budget analyses (Feature D—Use of Water Budgets to Describe Wetlands), soil evaluations, and vegetation studies were used to determine the ability of the wetland to take up, store, and process potentially large quantities of phosphorus (Dolan and others, 1981). In 1985, the city of Orlando began construction of a wetland complex to treat wastewater before it is discharged into the St. Johns River. The treatment wetland was supplied with more than 2 million wetland plants, and once it became established, more than 170 different bird species and numerous other wildlife species were observed in the wetland.

E Marsh Restoration—A Key to Improving Water Quality in Lake Apopka

Marsh restoration has proven to be a critical component to the improvement of water quality in Lake Apopka, which has been referred to as the most polluted large lake in Florida (St. Johns River Water Management District, 2006). Lake Apopka is a 31,000-acre natural lake in Orange and Lake Counties that forms the headwaters of the Ocklawaha River. The lake, which is the fourth largest in the State, was an important tourist attraction in the 1940s, and supported a robust recreational fishing industry. Fishing cabins dotted the shoreline, and contributed to the local economy. Birds also were abundant, and more than 335 species have been observed by birdwatchers on the north shore of the lake.

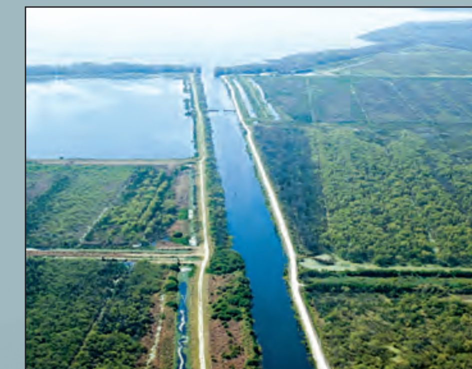
The lake has sustained substantial alterations over a long period of time. The alterations began in 1888 with the construction of the Apopka-Beauclair Canal (fig. E-1), which lowered lake levels by about 30 percent. During the land boom of the 1920s, towns on the lake shore began dumping raw sewage and wastewater from citrus processing plants into Lake Apopka.

In 1941, a levee was built across the north shore of the lake and 20,000 acres of shallow wetlands north of the levee (about one-third of the lake area) were drained for muck farming operations. Muck is dark soil rich in decaying plant material, and it was left behind when the wetlands were drained. The subtropical climate allowed farmers to produce as many as three crops per year in the exposed fertile soils. Farmlands were typically flooded to kill nematode plant parasites, and this sediment-laden water was then drained back into the lake until it was needed for crop irrigation. The accumulated sediments eventually raised the lake bottom by about 5 ft. Hurricane winds in 1947 hastened the demise of the lake by removing vast beds of emergent vegetation (Bachmann and others, 2001), and in 1947 the first algae bloom was documented. Treated wastewater discharges from shoreline communities through the 1980s also added to the nutrient load, and direct discharges from citrus processing plants until the 1980s further contributed to nutrient enrichment of the lake. The destruction of the north shore marshes not only reduced the natural cleansing capacity of the lake, but also greatly increased the pollution load as billions of gallons of nutrient-rich and pesticide-laden irrigation water subsequently drained unabated into the lake (St. Johns River Water Management District, 2006).

The large amounts of suspended sediments and nutrients, especially phosphorus, added to the lake during a 50-year period resulted in chronic algae blooms and a reduction in lake water clarity (Bachmann and others, 2005). These water-quality changes eventually killed rooted and submersed aquatic vegetation, and the subsequent loss of vegetated spawning beds ended the recreational fishery in the lake. However, the dead plants and fish were not removed from the system, and their decaying tissues further enriched the lake in nitrogen, phosphorus, and other compounds. As noted earlier, Lake Apopka ultimately became the most polluted large lake in Florida (Lowe and others, 2001). Lake Apopka received further attention in 1998 when hundreds of migratory birds died in and near the north shore following the flooding of 6,000 acres of former farms, which attracted birds and fish (Lightfoot, 2001). High concentrations of organochlorine pesticides, including toxaphene, were subsequently found in the soils.

Efforts to restore the lake to its natural condition and to improve water quality to Class III status (fit for recreation) began in the 1980s. The 1985 Lake Apopka Restoration Act provided for planning, diagnostic studies, and feasibility studies. The 1987 Surface Water Improvement and Management Act included Lake Apopka as a priority water body requiring restoration. Finally, the 1996 Lake Apopka Improvement and Management Act authorized the St. Johns River Water Management District to set criteria that could be used to limit future phosphorus discharges into the lake, and provided funding for a mandatory buyout of the farms on the north shore of the lake. This buyout of about 90 percent of the farms was completed in 1999. The restoration of Lake Apopka is expected to last at least 25 years, and will use a comprehensive approach (St. Johns River Water Management District, 2006).

Wetlands were an important functional part of the historic Lake Apopka ecosystem, and they play a crucial role in lake



Left: The Lake Apopka Marsh Flow-way Project will help improve water quality in the lake. Photograph credit: St. Johns River Water Management District.

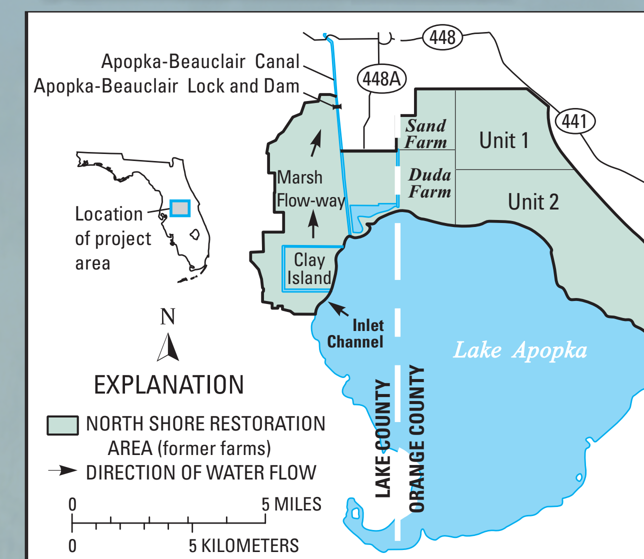


Figure E–1. The Lake Apopka Restoration project area (modified from St. Johns River Water Management District, 2006).

restoration efforts (St. Johns River Water Management District, 2006). Native emergent plants established in the lake will stabilize lake sediments and improve shoreline aquatic habitat. The North Shore Muck Farm Restoration Project will include about 13,000 acres of former farm land. Much of the acreage will be flooded to a shallow depth using a variety of water-control structures to promote the growth of wetland vegetation and thereby provide habitat for ducks, wading birds, and other wildlife.

The Lake Apopka Marsh Flow-way Project, which will restore about 3,400 acres of farmland, is designed to filter up to 98 percent of the lake waters twice yearly as they circulate through a series of wetland cells managed as emergent marshes. The flow-way, in reality a type of "treatment" wetland, is on the northwest shore of the lake and is designed to reduce phosphorus concentrations by 30 to 50 percent and suspended particulates by up to 90 percent. A portion of the treated water is returned to the lake and the remainder is sent downstream through the Apopka-Beauclair Canal (St. Johns River Water Management District, 2009).

Above: Birds are abundant in the Lake Apopka ecosystem and vulnerable to contaminants. Photograph credit: St. Johns River Water Management District.

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Ecology of Freshwater Wetlands in Central Florida

Wetland ecology is dependent on the complex and dynamic interactions between the hydrologic, physical, chemical, and biological components of wetland ecosystems. The water source and hydrologic regime directly influence water-quality characteristics, such as pH, dissolved oxygen concentration, and nutrient availability. These characteristics then determine the biological community response, which may in turn alter the physical environment and the water quality of the wetland. Wetlands vary over time in the composition of their plant and animal communities as the wetlands experience wetter or drier conditions. Those conditions are influenced by hydrologic processes, human activities, and other disturbances such as fire. The latter, when coupled with fluctuating water levels, can maintain the ecological integrity of Florida wetlands, especially marshes (Kushlan, 1990). The distribution of plant species, and the observed cycles of plant colonization and replacement in wetlands, result in a continuum of overlapping sets of species that respond to both subtle and conspicuous environmental cues. The aquatic animal populations in Florida wetlands, with the exception of birds, are not as diverse as those in the northern temperate wetlands (Kushlan, 1990). The population of wetland birds, however, is very diverse, and is expanded seasonally in winter by birds migrating from northern latitudes, and in summer by birds migrating from the Caribbean and South America (Sunquist and others, 2002).

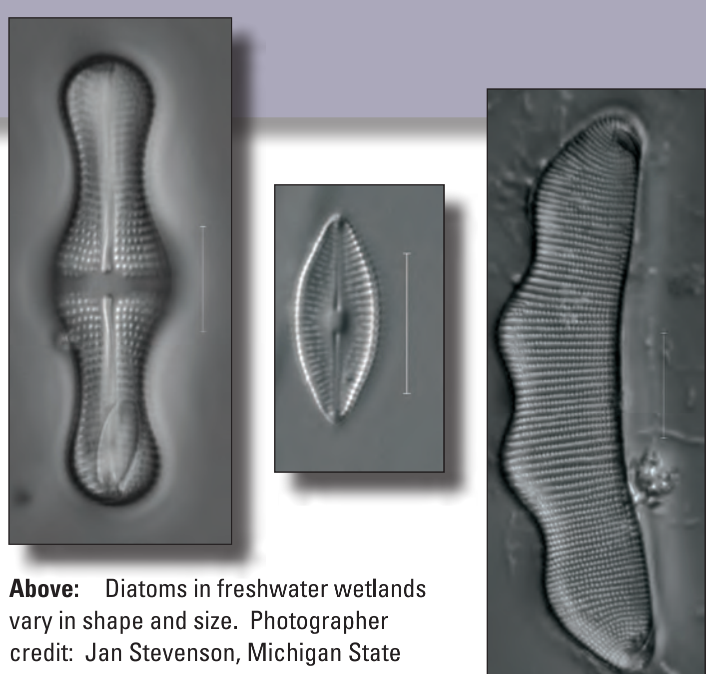
Wetlands are a part of the larger landscape units in which they are distributed, and the terrestrial area or upland surrounding a wetland is an integral part of the wildlife habitat that wetlands provide. Many animals are dependent for essential parts of their life cycles on the terrestrial habitats that connect and surround wetlands, and wildlife activities such as nesting, hibernation, aestivation (resting during dry periods), foraging/feeding, and dispersal all require adjacent terrestrial habitat and protected corridors.

Bacteria and Algae

Bacteria are probably the most abundant organisms in wetlands, but their small size makes them difficult to sample and their contribution to wetland characteristics and processes are complex. These single-celled organisms mediate and control the rates of many vital transformations of important compounds in wetlands, such as carbon, nitrogen, phosphorus, and sulfur. Bacteria are critical for the breakdown of plant leaves, stems, and roots as plants die and fall to the bottom of wetlands. They also break down woody debris that would otherwise accumulate and quickly fill forested wetland basins. Finally, bacteria decompose and remineralize the many dead invertebrates and other animal remains that are deposited in wetlands. Perhaps most importantly, they have evolved into forms that can thrive under both the aerobic (oxygen-rich) and anaerobic (oxygen-depleted) conditions found throughout wetlands, so that the transforming functions are continuous and uninterrupted regardless of wetland state. Most bacteria get their energy from the breakdown of other organic materials and are described as heterotrophic. The Cyanobacteria (also known as blue-green bacteria or blue-green algae) is a unique group of autotrophic bacteria that converts light into energy through photosynthesis. Cyanobacteria can fix atmospheric nitrogen and when they die, nitrogen is added to the wetland ecosystem. Some Cyanobacteria, such as *Lyngbya, Nostoc, Oscillatoria,* and *Schizothrix,* produce mucilaginous sheaths along their filaments and form dense mats in wetlands.

Algae are a diverse group of simple single-celled plants that convert light into energy through photosynthesis using pigments such as chlorophyll. These plants contribute substantially to the high productivity of wetlands, and have a vital role in absorbing atmospheric carbon dioxide and dissolved nutrients such as phosphorus. Algae in freshwater wetlands include filamentous, unicellular, and colonial green algae, diatoms with glass-like silicaceous outer skeletons, eulgenoids, desmids, dinoflagellates, and numerous other groups (Stevenson and others, 1996).

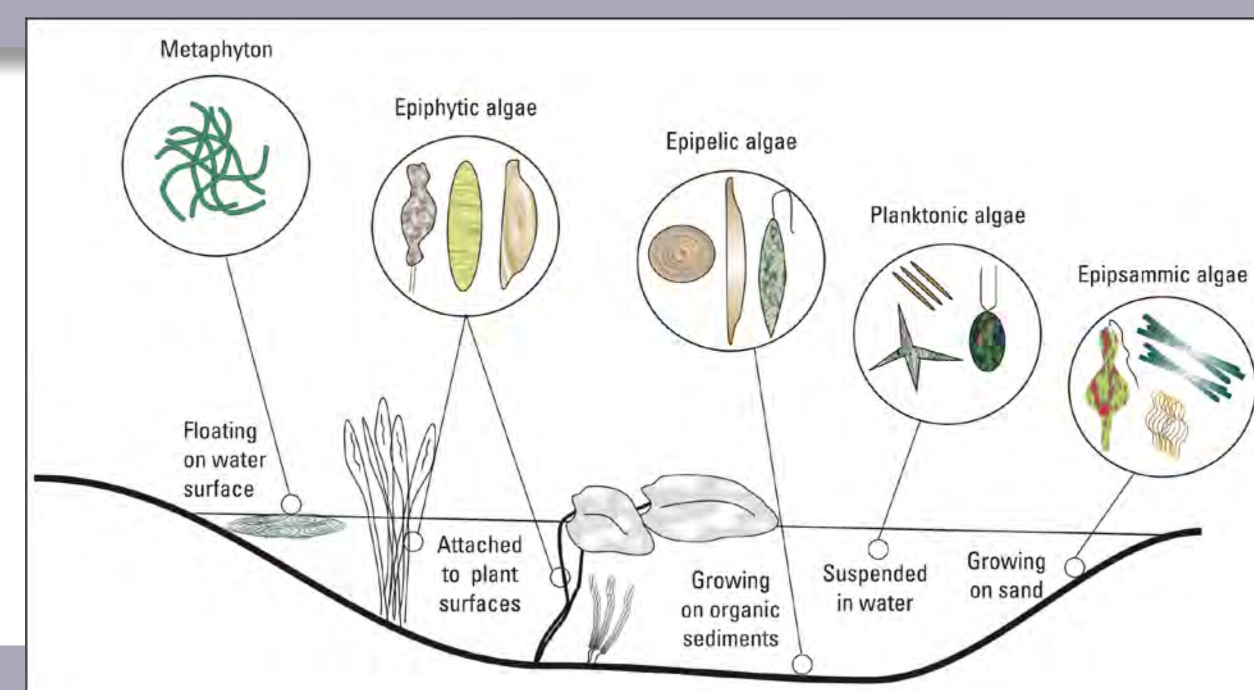
Algae grow on many different surfaces in virtually all classes of wetlands (fig. 24). The algae that grow on the surface of soft organic and inorganic bottom sediments are called epipelon, and algae that grow on sand are termed epipsammon. Small amorphous masses of bottom-dwelling (benthic) algae can sometimes float to the wetland water surface, buoyed by accumulated gas bubbles. Epiphyton are algae that grow on plant surfaces, such as the stems and leaves of submersed, emergent, and floating plants, as well as on the bases of tree trunks and cypress knees. Periphyton is a term that refers to communities of benthic algae, associated organisms including cyanobacteria and fungi, and calcium carbonate. These communities can form thick tangled mats that have structure and coat the wetland bottom and the surfaces of higher plants. Periphyton often has a distinct appearance that varies from one wetland to another depending on water-quality conditions.



Above: Diatoms in freshwater wetlands vary in shape and size. Photographer credit: Jan Stevenson, Michigan State University.

Below: Filamentous green algae growing on an algae sampler from a marsh in Pasco County. Photographer credit: Kim Haag.

Figure 24. Algae habitats in wetlands.



Left: Cypress trees on the riverine flood plain adjacent to the Suwannee River. Photographer credit: Scott Orr, U.S. Geological Survey.

Some types of filamentous algae that grow submersed in open water, such as the stoneworts *Chara* spp. and *Nitella* spp., have a growth structure resembling that of higher plants. Other algae form clouds of loosely aggregated filaments that float at the surface of wetlands (the metaphyton), and take advantage of available sunlight. The mostly single-celled algae that grow in the open water are called phytoplankton. Some phytoplankton species grow attached to one another in balls or filaments (colonial algae) with a small number of single cells of the same species grouped together. Phytoplankton sometimes have become dislodged or detached from algal masses growing on the soft bottom sediments and live for a time in the open water. Alternatively, phytoplankton in the water column can eventually settle to the bottom and begin growing there. This kind of internal cycling of algae from one habitat to another is characteristic of the overall internal cycling found throughout isolated wetlands.

Algae are a vital biological component of wetlands and play an essential role in the chemical and biological processes that characterize these systems. As important primary producers in wetlands, algae convert solar energy and dissolved nutrients into plant cells. In that process, they generate oxygen, raise the pH of the water, and decrease the concentration of carbon dioxide. During the night, algae consume oxygen when they undergo respiration, and they can cause oxygen depletion (anoxia) in parts of a wetland if the algal mats are large. Algae are a food source for many invertebrates, in particular zooplankton, crayfish, snails, and larval flies. Some fish also feed on algae, especially in the summer months when aquatic insects may be less abundant.

Algae are a source of dissolved organic material (dissolved organic carbon, for example) in wetlands. If they are growing on the wetland bottom, algae may be a sink for phosphorus because the algae tend to absorb substantial amounts of phosphorus directly from the sediments before it can be released to the overlying wetland water column. In **alkaline** systems with a pH greater than 7.4, such as those found in wetlands augmented with groundwater, algae contribute to sediment formation as they precipitate calcium from the augmentation water into encrusting deposits of calcium carbonate. Algae growing on plant stems and leaf surfaces may accelerate the breakdown of those plants as they die and decay, and speed up the return of dissolved nutrients and organic materials to the wetland ecosystem.

Communities of Aquatic Plants

The communities of aquatic plants that populate wetlands give them much of their distinctive character and appearance, although the various wetland communities described in this section can be present in one or several different wetland systems. For example, forested wetland communities are present in Palustrine, Lacustrine, and Riverine System wetlands. Likewise, emergent wetland communities are present in both Palustrine and Lacustrine System wetlands.

Aquatic plants are a relatively small group of vascular plants adapted to survive and flourish under conditions that characterize wetlands: intermittent flooding of variable duration, a range of water depths, and saturated, oxygen-depleted soils. The following are some of the most obvious adaptations of aquatic plants:

- Buttressed tree trunks of cypress, water tupelo, and swamp black gum provide additional support in the water.
- Modified root systems (such as cypress knees) extend above ground to increase the opportunity for oxygen uptake.
- Floating leaves have a thickened cuticle to prevent water absorption and maximize exposure to sunlight.
- Floating stems filled with air spaces allow plants to root in shallow water and float at the surface.

Right: Ferns and colorful lichens growing in forested wetlands. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Left: Bromeliads such as the quill-leaf airplant (*Tillandsia fasciculata*) add color to forested wetlands in spring and early summer. Photographer credit: Paul Fellers, Lake Region Audubon Society.

- Prolonged seed viability allows germination to be postponed until favorable hydrologic conditions occur.
- Spongy tissue in leaves, roots, and stems provides buoyancy and an oxygen reservoir.

Aquatic plants, especially submersed and emergent species, provide food and habitat for invertebrate populations, which in turn support fish, birds, and other predators in the food web. The decay and accumulation of aquatic vegetation contribute to the internal cycling of nutrients in wetlands, and the buildup of organic material on the wetland bottom.

Forested Wetlands

Trees are the dominant plants in forested wetlands. Common tree species include cypress and several hardwoods such as sweet bay, sweet gum, elm, oak, and red maple. Community composition in forested wetlands is dependent on patterns of seasonal flooding and small differences in the surface elevation of the wetland bottom.

Cypress strands in riverine flood plains that have some water flow support bald cypress (*Taxodium distichum*), whereas isolated still-water cypress domes are most often dominated by pond cypress (*Taxodium ascendens*). The largest bald cypress tree in the United States can be found in western Seminole County, and is estimated to be 3,500 years old. The pond cypress trees that grow in isolated wetlands are often shorter at the wetland edge than in the middle, giving the wetlands a "dome-like" profile. This pattern occurs because the conditions for growth, primarily the long hydroperiod, are much better in the center of the dome as opposed to the edges. Cypress trees are called deciduous conifers, because they lose their needles each winter and regrow them in the spring. In addition to cypress, some of the most common trees in forested wetlands in central Florida are cabbage palm (*Sabal palmetto*), dwarf palmetto (*Sabal minor*), red maple (*Acer rubrum*), sweet gum (*Liquidambar styraciflua*), sweet bay magnolia (*Magnolia virginiana*), swamp bay (*Persea palustris*), and loblolly bay (*Gordonia lasianthus*). Swamp laurel oak (*Quercus laurifolia*) is one of the most flood tolerant of the oaks, and grows in areas that are flooded for as much as half of the growing season. Like cypress, trees in the genus *Nyssa* require periodic drought for germination. The most common species are swamp tupelo (*Nyssa sylvatica* var. *biflora*) and water tupelo (*Nyssa aquatica*). Slash pine (*Pinus elliottii*) is found in some Florida cypress domes and swamps. Pond pine (*Pinus serotina*) is found at the edges of bay swamps that burn every 15 to 20 years, because the cones require fire to open and germinate.

Other plants are commonly found in the forested wetlands of central Florida because of the vertical structure and basal hummocks provided by the trees themselves. Epiphytes (or "air plants") grow on the trees in wetlands, but are not parasitic because they use the trees only as a surface for attachment. They also take advantage of the condensation and rainfall that collects on the trees. Examples of epiphytes in swamps are orchids, bromeliads, lichens, mosses, and some species of ferns. Some of the richest communities of lichens are in cypress wetlands, where they can add bright color, and some species are particular to only one species of tree. Bromeliads such as *Tillandsia* also add bright points of color on trees and shrubs when the flowers are present. More than 20 species of vines often can be found growing on trees and other woody plants in swamps and wet woodlands, as well as along the perimeters of freshwater marshes and at the edges of lakes. Native vines include climbing hempweed (*Mikania scandens*), bamboo vine (*Smilax laurifolia*), saw greenbrier (*Smilax bono-nox*), grapevine (*Vitis* spp.), poison ivy (*Toxicodendron radicans*), and rattan vine (*Berchemia scandens*). Skunk vine (*Paederia foetida*) is an invasive plant from Asia that is now found throughout the southeastern United States, including Florida, where it appears to prefer sunny flood plains and bottom lands.

Ground-cover plants are often sparse in forested wetlands, due to prolonged inundation and because the canopy prevents light penetration. Common ground-cover species include swamp fern (*Blechnum serrulatum*), cinnamon fern (*Osmunda cinnamomea*), royal fern (*Osmunda regalis*), and chainfern (*Woodwardia* spp.). In wetlands, aquatic mosses are far less abundant than vascular plants. Aquatic mosses are present primarily in wetlands of the Riverine System and in permanently flooded and intermittently exposed parts of some wetlands in the Lacustrine System. The most common genera include *Sphagnum, Fissidens, Drepanocladus,* and *Fontinalis*.

Scrub-Shrub Wetlands

The dense, low-growing woody vegetation in scrub-shrub wetlands is, by definition, less than about 20 ft tall. This vegetation includes both true shrubs that never attain a greater height, and young trees of other species that never attain their maximum height (120 ft for some species) due to the harsh conditions. A variety of herbaceous plants also are present in scrub-shrub wetlands, and are generally indicative of a wetland area that is undergoing environmental change due to some type of disturbance, such as increased or decreased water flow, recent fire, or increased silt deposits from surrounding areas that have been clear cut. Some scrub-shrub wetlands are a successional stage that will ultimately become a forested wetland, whereas other scrub-shrub wetlands are stable communities. Common scrub-shrub plants include swamp honeysuckle (*Rhododendron vicosum*), elderberry (*Sanbucus nigra canadensis*), willow (*Salix* sp.), primrose willow (*Ludwigia peruviana*), buttonbush (*Cephalanthus occidentalis*), dahoon holly (*Ilex cassine*), gallberry (*Ilex glabra*), Virginia willow (*Itea virginica*), and wax myrtle (*Myrica cerifera*). Walter's viburnum (*Viburnum obovatum*) is a colonial shrub with a much-branched trunk that forms a dense tangle of arching trunks and branches along seasonally inundated shallow stream banks, sloughs, hydric hammocks, and river flood plains. Many shrub species also are present in forested wetlands; for example, fetterbush (*Lyonia lucida*) is very common in Florida swamps. An invasive plant of concern that crowds out native species in scrub-shrub wetlands is Brazilian pepper (*Schinus terebinthefolius*).

Emergent Wetlands

Emergent wetlands such as marshes and wet prairies have erect, rooted, herbaceous (non-woody) vegetation during most of the growing season in most years. These wetlands support a wide variety of grassy and broad-leaved herbaceous plants that typically extend above the wetland water surface. A variety of emergent marshes and wet prairies are present in central Florida, and they often derive their names from the dominant plants or plant associations found in them. For example, a "maidencane marsh" is named after the dominant maidencane grass (*Panicum hemitomon*), whereas a "flag marsh" is populated by fire flag (*Thalia geniculata*) and other plants with flag-shaped leaves. Although marshes may have one or two dominant plants, other plant species commonly are present, adding to the characteristic diversity of many marsh communities. Marshes in central Florida also can be grouped into systems that tend to be distributed most frequently in particular geographic areas (Kushlan, 1990). They include flatwoods marshes, highlands marshes, St. Johns River marshes, and Kissimmee River marshes. These marsh systems may vary somewhat in their predominant plant associations. Paynes Prairie is a large highlands marsh in Alachua County that includes a mosaic of saw grass, water lily, and maidencane marshes (Feature F—Paynes Prairie—A Dynamic Highlands Marsh Ecosystem).

Freshwater emergent marshes typically have zones of vegetation that are distributed across a gradient of water depths. Floating and submersed species (see Pond and Aquatic Bed Wetlands) grow in the wetland center where water is deepest and the hydroperiod may be 9 months or more. Common floating plants include duckweed (*Lemna minor*) and salvinia (*Salvinia rotundifolia*), whereas common submersed plants include bladderworts (*Utricularia* spp.) and pondweeds (*Potomogeton* spp.). Moving away from the wetland center, the water typically becomes shallower and the hydroperiod becomes shorter. Some of the most commonly found **emergent plants** at shallower depths are maidencane (*Panicum hemitomon*), pickerelweed (*Pontederia cordata*), lemon bacopa (*Bacopa caroliniana*), arrowheads (*Sagittaria* spp.), beakrushes (*Rhynchospora* spp.), sedges (*Carex* spp.) and spikerushes (*Eleocharis* spp.). Along the wetland edges, in the zone transitional to uplands, the ground may be flooded rarely and in many wetlands the ground is moist, but never inundated. Species commonly found along the wetland edge include blue maidencane (*Amphicarpum muhlenbergianum*), spadeleaf (*Centella asiatica*), Baldwin's spikerush (*Elocharis baldwinii*), dog fennel (*Eupatorium* spp.) and St. Johns wort (*Hypericum* spp.).

Marshes with short hydroperiods, such as flatwoods marshes, have patterns of seasonal plant dominance in addition to spatial dominance. For example, maidencane and floating hearts are dominant in spring, and beakrush and bald rush become more abundant later in the year (Kushlan, 1990). Other seasonal vegetation patterns related to hydrology include flowering phenology (flower blooming and other regularly recurring biological phenomena that are influenced by climate), whereby shorter emergent species bloom in early spring when the water is shallow, and taller emergent species flower in summer and fall when water is deeper.

Wet prairies are a special type of emergent wetland that are flooded less frequently than any other type of Florida marsh, with a typical hydroperiod of only 50–100 days per year (Duever, 1997). The soils in wet prairies are sandy, and peat formation is curtailed by their short period of inundation. In wet prairies, the need for adaptation to widely fluctuating hydrologic conditions is especially pronounced, and the plant species that populate these prairies must have ample tolerance for both flooding and drying. For example, species with shallow root systems, such as St. Johns wort, die when the prairies dry out but readily reseed once water returns (Kushlan, 1990). Wet prairies have a short hydroperiod, and because they support both aquatic and upland species at different times of the year, and wet prairies can be extremely diverse communities. Dominant grasses include bluestems (*Andropogon* spp.), blue maidencane (*Amphicarpum muhlenbergianum*), carpetgrass (*Axonopus* spp.), maidencane (*Panicum hemitomon*), whitetop sedge (*Dichromena colorata*), and wiregrass (*Aristida stricta*). Other common (and colorful) plants include blue-eyed grass (*Sisyrinchium nashii*), hatpins (*Eriocaulon compressum*), meadow beauty (*Rhexia* spp.), and yellow-eyed grass (*Xyris* spp.). Wet prairies are maintained as grasslands without trees or even large shrubs by periodic fires, usually at 1- to 5-year intervals. The **invasive species** melaleuca (*Melaleuca quinquenervia*) is a tree that can thrive in wet prairies in spite of their characteristic hydroperiod, and melaleuca control is required for effective wetland management. More than half of the parks and preserves in central Florida have patches of wet prairie, and prime examples are in the Kissimmee Prairie Preserve State Park and Myakka River State Park (Duever, 1997).

Left: Marsh beggar-tick (*Bidens mitis*) in bloom in a wet prairie in Alachua County. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Left: Brazilian pepper (*Schinus terebinthefoious*). Photographer credit: Kim Haag, U.S. Geological Survey.

Right: Yellow-eyed grass (*Xyris caroliniana*). Photographer credit: Kim Haag, U.S. Geological Survey.

F Paynes Prairie—A Dynamic Highlands Marsh Ecosystem

Paynes Prairie is a unique highlands marsh ecosystem that covers about 21,000 acres and presently includes the largest freshwater marsh and wet prairie in north-central Florida (Florida Department of Environmental Protection, 2002). This part of central Florida is characterized by karst topography with associated uplands, shallow lakes, prairies, and numerous large sinkholes.

Many marshes and lakes in the area are hydrologically unstable because, over time, solution features form and wetlands can be drained, or previously functional drainages become blocked and surface depressions can reflood (Kushlan, 1990). The dynamic drainage patterns characteristic of the region have had substantial consequences for the Paynes Prairie ecosystem, most notably an extraordinarily wide range of water levels in historical times.

History and Hydrology

Paynes Prairie is perched above a 6-ft layer of sandy clay. This relatively impermeable surficial layer was deposited by an ancient surface-water body flowing over the more permeable sands and limestone characteristic of most of the Florida peninsula (Myers and Ewel, 1990). Today, Paynes Prairie is a large highland marsh in Alachua County, but in the 1600s, the largest cattle ranch in Spanish Florida, named La Chua, was based at the prairie. When William Bartram visited the area in 1774, he described the basin as dry grassland called the Alachua Savannah (Myers and Ewel, 1990). The area was occupied by the Seminole Indians in the early 1800s, and the modern name is thought to be derived from a Seminole Chief named King Payne. The major drainage feature within the prairie, Alachua Sink, became plugged in the early 1870s. The basin filled with water and developed into Alachua Lake, which supported steamboat operations. By 1891, the lake water level began to decline, and within 2 years a large marsh was formed (Myers and Ewel, 1990). In the 1900s, cattle operations began on the prairie, but the State ultimately determined that the habitat was worthy of preservation, and in 1971, Paynes Prairie became the first State preserve in Florida.

Similar highland marshes of substantial size are found throughout central Florida, although many have been drained for agricultural purposes (Kushlan, 1990). The existence of these marshes is attributable to the alternating effects of compaction of surface sediments that retard water loss and the formation of solution features that drain surface water into the aquifer.

Vegetation and Wildlife

There are at least 20 distinct biological communities in Paynes Prairie. Four hundred and twenty-two plant species in 108 families have been identified from the deep water marshes, shallow wet prairies, and pasture lands (Easterday, 1982; Patton and Judd, 1986). Fluctuations in rainfall have caused variations in the aquatic and upland vegetation present. For example, studies by Jacobs and others (2002) indicated that maidencane (*Panicum hemitomon*) and swamp smartweed (*Polygonum hydropiperoides*) were common in wet prairies when rainfall was near average, but during dry periods mock bishop's weed (*Ptilimnium capillaceum*), dog fennel (*Eupatorium capillifolium*), and other plants tolerant of dry conditions became widespread. The ecosystem is vulnerable to invasion by non-native plants. The variety of habitat types provides a rich matrix for wildlife, including alligators, bison, wild horses, and over 270 species of birds. The proximity of a busy State highway, and the associated wildlife mortality, has yielded a wealth of data on resident wildlife as chronicled by observations of wildlife killed in collisions with motor vehicles (Smith and Dodd, 2003).

Protection and Management

Many small highland marshes in central Florida have been drained for farming or grazing, whereas others have been mined for peat (Kushlan, 1990). Paynes Prairie is one of the few large highland marshes that is protected. In addition to being the first State preserve, Paynes Prairie was designated as a National Natural Landmark by the U.S. Department of the Interior in 1974, and all waters within the preservation area are designated as Outstanding Florida Waters.

Above: Wild horses graze on wet pastures at Paynes Prairie. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Above: Paynes Prairie. Photographer credit: Margaret Glenn, Institute of Food and Agricultural Sciences, University of Florida.

An Outstanding Florida Water is a water body designated as being worthy of special protection because of its natural attributes. This special designation is intended to protect existing good water quality. Surface waters are susceptible to contamination by excess nutrients associated with development (Dugger, 1976). Paynes Prairie Preserve State Park is designated as a multiple-use feature designed to protect the water quality of the area, preserve the flood storage capacity of the Prairie Creek system, and provide natural resource-based public outdoor recreation and other related uses (Florida Department of Environmental Protection, 2002). Management goals include controlling water depth and flooding frequency so that they imitate the conditions that existed in the late 1700s when William Bartram first visited the site. An alternate management strategy has been suggested that would incorporate manipulation of water levels over a wider range in 30- to 50-year cycles (White, 1974).

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Pond and Aquatic Bed Wetlands

Pond and aquatic bed wetlands are dominated by plants that grow on or below the water surface during much of the growing season in most years and, therefore, require regularly and semi-permanently flooded wetland habitat. The plants may be attached to the wetland bottom, or they may be unattached and float on the surface. Common submersed species include coontail (*Ceratophyllum demersum*), milfoil (*Myriophyllum* spp.), bladderworts (*Utricularia* spp.), and naiad (*Najas* spp.). Rooted species that have floating leaves include water lilies (*Nymphaea* spp.), floating-leaf pondweed (*Potamogeton natans*), and water shield (*Brasenia schreberi*). Common species that float freely on the wetland water surface and are not rooted include duckweed (*Lemna* spp.), giant duckweed (*Spirodela* spp.), mosquito fern (*Azolla* spp.), and water-meal (*Wolffia* spp.). Invasive floating aquatic plants of particular concern include water hyacinth (*Eicchornia crassipes*) and water lettuce (*Pistia stratiotes*), because they tend to crowd out native vegetation in wetlands where they become established. Hydrilla (*Hydrilla verticillata*) is a submersed invasive species of concern.

Aquatic Insects and Other Invertebrates

The aquatic insects and other invertebrates inhabiting submersed and emergent aquatic plant beds can be abundant, and they serve as an important food source for many other organisms in the food web of central Florida wetlands. Small side swimmers (Amphipoda) feed on fragments of partially decayed plant material (detritus), which collects in a thin film on submersed plant leaves and stems. Seed shrimp (Ostracoda) are tiny benthic invertebrates that swim among the submersed aquatic plants in wetlands and eat detritus and plant material such as algae. Amphipods and ostracods are primary consumers (eating plant material) that provide food for the numerous larger insects and invertebrate predators found in wetlands. Crayfish (*Procambarus* sp.) and glass shrimp (*Palaemonetes* sp.) are widespread and feed on decaying plants materials,

Above: Floating and emergent wetland plants. Photographer credit: Kim Haag, U.S. Geological Survey.

Below: Crayfish (*Procambarus* sp.) are omnivorous consumers in wetlands where they feed on a variety of insects, worms, tadpoles, dead organisms, and vegetation. Photographer credit: Laura Line, Water & Air Research, Inc.

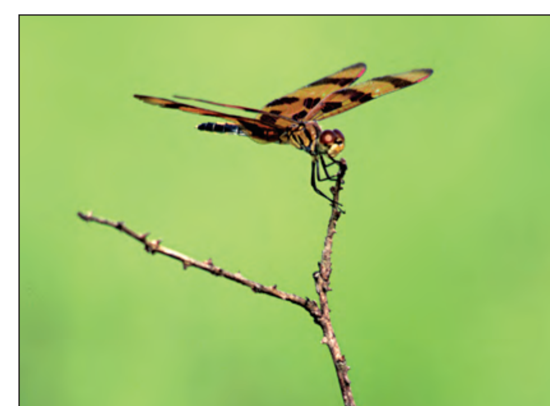
many of which support a rich microbial layer that has high nutritional value.

Snails and mollusks are found in wetlands with some groundwater or surface-water inflow, because the pH and the calcium carbonate concentration are high enough in those wetlands to allow for shell formation. Common wetland snails include the pouch snail (*Physella* sp.), ash gyro (*Gyraulus parvus*), marsh rams-horn (*Planorbella trivolvis*), banded mystery snail (*Viviparous georgianus*), and the Florida apple snail (*Pomacea paludosa*). The native apple snail is the largest snail in North America, and clusters of its large white eggs can be seen above the water line on emergent vegetation in April and May (U.S. Geological Survey, 2009b). Small mollusks (which have a pair of shells) commonly found in wetlands include the Asiatic clam (*Corbicula fluminea*) and fingernail clams (*Musculium* spp., *Sphaerium* spp.). Freshwater limpets (Ancylidae), which have a single thin shell, are found in some wetlands with a relatively low pH.

Many mayflies (Ephemeroptera) are filter feeders or collectors who remove organic material from plant surfaces and from the water column. Beetles (Coleoptera) are mostly predators or omnivores whose adults live on the water surface and on plant surfaces, and whose larval stages are submerged during their development. Adults in this abundant group are well adapted to the low-oxygen concentrations characteristic of most central Florida isolated wetlands because they use atmospheric sources of oxygen. True bugs (Hemiptera) are not as numerous in many wetlands as the beetles, but are often represented by many different species, including water scorpions, water striders, water boatmen, and the giant water bug. Dragonflies and damselflies (Odonata) are predators both as aquatic nymphs and as flying adults in and around wetlands. Odonates are especially common in wetlands with submersed aquatic vegetation such as bladderworts (*Utricularia* spp.), because the nymphs can prey on other invertebrates that cling to the feathery leaflets. Larval flies (Diptera), especially midges (Chironomidae) and mosquitoes (Culicidae), are well adapted to living in the low dissolved-oxygen environments in Florida wetlands. For example, midge larvae use red hemo-globin-like pigments to increase their ability to absorb oxygen.

Wetland hydrology affects wetland insects and other invertebrates in numerous direct and indirect ways (fig. 25).

Below: The dragonfly *Celithemis eponia*, commonly known as the Halloween pennant for the bright orange and yellow coloring on its wings, is a frequent visitor to central Florida wetlands. Photographer credit: Michael Hancock, Southwest Florida Water Management District.



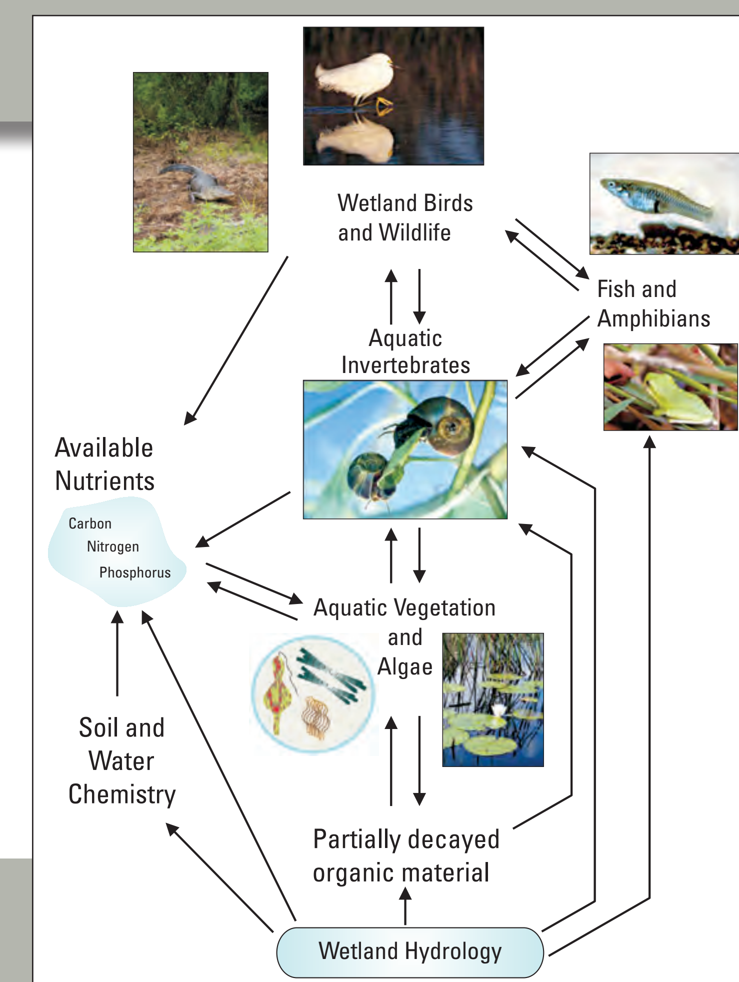


Figure 25. Effects of hydrology on wetland invertebrates and other biota (right).

Left: Mosquito fish (*Gambusia affinis*) may be abundant in isolated wetlands, where they feed on mosquito larvae and other small invertebrates. Photographer credit: Robert McDowall.

Right: Redear sunfish (*Lepomis microlophus*) live in shallow vegetated areas of flood-plain wetlands and feed on invertebrates. Photographer credit: Noel Burkhead ©, U.S. Geological Survey. Published with permission.

These effects differ in magnitude and relative importance in isolated wetlands compared to riverine wetlands or fringing wetlands. For example, a flood pulse causes rapid and sudden input of sediment and nutrients to flood-plain wetlands when a river overflows its channel and the wetlands are inundated. However, rainfall and associated runoff to isolated wetlands may result in a more gradual influx of nutrients, and flooding following rainfall (which is typically low in nutrients) may actually dilute nutrient concentrations in isolated wetlands. Aquatic invertebrate populations tend to be larger in wetlands without fish, or in wetlands with submersed and emergent vegetation, such as marshes, where fish cannot easily find them. Moreover, wetlands that have some surface-water connection to other nearby wetlands may have more diverse amphibian and fish populations because of the increased opportunity for recolonization after a dry period. However, fish predation can reduce invertebrate populations substantially, and may reduce wetland bird populations through its impact on their invertebrate food supply (Kushlan, 1990).

Fish, Amphibians, and Reptiles

Fish are typically small in isolated depression wetlands because these wetlands are generally shallow systems. Nearly all fish in isolated wetlands in central Florida are less than 6 in. long, and if no deep holes are present to act as a refuge where standing water remains even during seasonal drought conditions the majority of fish are less than 3 in. long (Main and others, 2007). Fish in isolated wetlands are adapted to a range of conditions that include low pH, low specific conductance (20–460 µS/cm), and low dissolved oxygen concentrations (0.5–4.5 mg/L). Many live near the water surface, where they can take advantage of the thin film of oxygen-rich water. The eastern mosquitofish (*Gambusia affinis*) is one of the most abundant fish species in isolated Florida wetlands. Other common species include the redfaced topminnow (*Fundulus cingulatus*), least killifish (*Heterandria formosa*), pygmy killifish (*Leptolucania ommata*), Everglades pygmy sunfish (*Elassoma evergladei*), and the blue spotted sunfish (*Enneacanthus gloriosus*). When a connection develops between isolated freshwater wetlands and other surface-water bodies, there is an opportunity for fish to repopulate wetlands that have experienced seasonal drying and lost their fish populations.

Flood-plain wetlands provide habitat for larger fish, which may use wetlands during some or all of their life cycles. Fish habitats are more diverse in flood-plain wetlands than in isolated depression wetlands because the deposition and erosion of sediments cause meandering of shallow channels on the flood plain that create temporary wetlands. Connections with the main river channel open and close periodically and fish have opportunities to return to the main channel when flood-plain wetlands dry up seasonally. Some fish use flood-plain wetlands to complete their lifecycle, primarily for spawning and as nursery areas for juvenile fish. Fish spawning requires slow moving or still water, which is characteristic of flood-plain wetlands. Other fish move into flood-plain wetlands, whenever they are flooded, to exploit rich-feeding areas. Invertebrates tend to be abundant in flood-plain wetlands because of the presence of decaying plant material, algae, and other food sources. Common groups of fish in flood-plain wetlands include many species that live in the rivers themselves such as sunfish (*Lepomis* spp.), bass (*Micropterus* spp.), and minnows (*Notropis* spp.)

Wetlands along lake margins are commonly used by large fish for spawning and nesting. These wetlands contain aquatic plants that conceal newly hatched juvenile fish, and the shallow water limits the size of aquatic predators. Small fish species inhabit lake-margin wetlands for the same reasons. The abundant invertebrates that live in these wetlands provide a rich food supply for fish regardless of their life history stage. Common fish species in lake-margin wetlands include crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), red ear sunfish (Lepomis microlophus), and largemouth bass (*Micropterus salmoides*).

Most of the fish in central Florida wetlands are omnivorous and live off a diet of algae, plant material, insects, and other invertebrates; mosquito larvae are a common source of food. Because of size constraints, very few fish species consume other fish. The small size of most wetland fish make them ideal prey for numerous animals, including large aquatic insects such as giant water bugs (Belostomatidae), larger fishes like the largemouth bass, amphibians such as the bullfrog (*Rana catesbeiana*), reptiles like the American alligator (*Alligator mississippiensis*), birds such as the snowy egret (*Egretta thula*), and mammals like the racoon (*Procyon lotor*).

Central Florida wetlands contain many amphibians and reptiles, primarily frogs, salamanders, alligators, turtles, and water snakes. Amphibians are most numerous in isolated wetlands that dry out seasonally and do not have large fish, which would otherwise prey on them. Frogs and salamanders live entirely in the water during their egg and larval stages, whereas adult amphibians spend part of the time in nearby upland habitats (Feature G—Amphibians as **Bioindicators** in Wetlands). This life-history aspect is one important reason to protect upland areas around wetlands (wetland buffer zones), which enable the free movement of amphibians between habitats.

G Amphibians as Bioindicators in Wetlands

Large and diverse communities of amphibians (frogs and toads) are commonly found in and around central Florida wetlands, and recent interest has developed in using amphibians as bioindicators of wetland condition. Bioindicators are living organisms that are sensitive to changes within ecosystems such as wetlands.

Approaches using amphibian bioindicators may involve individual indicator species, entire species assemblages, or comprehensive indicator communities whose presence, numbers, and conditions are indicative of a particular set of environmental conditions (Adamus, 1996). Several factors have led to the recent interest in using amphibians as bio-indicators of wetland condition. They include the sensitivity of amphibians to changes in water quality and habitat modification in wetlands, and the documented worldwide decline in amphibian populations associated with wetlands (Stuart and others, 2004). A number of studies indicate that amphibians may be ideal bioindicators of wetland condition because factors that negatively affect amphibian populations also affect overall wetland condition.

Why Are Amphibians Useful Bioindicators?

Amphibians are widespread in central Florida and are found in many different types of wetlands. They have a two-stage life cycle, whereby they breed and spend their larval stages in aquatic habitats and then move to nearby upland habitats as adults. Therefore, they are potential indicators of environmental disturbance in wetlands and associated uplands (Delis and others, 1996; Mushinsky and others, 2004). Because amphibians have relatively short life cycles, and can respond to stress within a short time, scientists can quickly acquire and analyze monitoring data and determine the occurrence of ecosystem stressors (Rapport, 1992).

Amphibian skin is highly permeable, and this permeability allows them to absorb moisture through their skin. Therefore, water-borne substances can move relatively freely into their bodies, making them sensitive to contaminants in water, soil, and air (Lehitinen and others, 1999). After absorption, many toxic compounds are accumulated and stored in amphibian fatty tissue, so they can be efficiently sampled.

Amphibians are adapted to survive normal fluctuations in wetland hydroperiods. Because many central Florida wetlands are seasonally dry, amphibians can serve as year-round (instead of seasonal) indicators to help estimate the average length of the wetland inundation period. For example, the average hydroperiod of a wet prairie wetland in central Florida is 150 to 200 days per year (CH$_2$M Hill, 1996). If the hydroperiod length is decreased or increased, then amphibian populations may fluctuate in size (Guzy and others, 2006). By estimating the average population size over several years at a particular wetland, it is possible to determine when disturbance has caused changes in bioindicator species populations. This is possible by categorizing wetlands based on amphibian reproductive success variables (Mushinsky and others, 2004), and using them in a “reference conditioning approach” (Snodgrass and others, 2000). Reference conditioning is an assessment technique that compares a site with substantial human disturbance to a similar site with minimal disturbance.

A further advantage of using amphibians as bioindicators is that many frogs and toads can be identified without physically capturing them. Many frogs and toads have their own distinctive and characteristic call or chorus. By using amphibian chorus calls, species can be identified reliably in an area (Southwest Florida Amphibian Monitoring Network, 2009). Therefore, a wetland can be characterized without sacrificing any animals.

What Factors Contribute to Amphibian Declines?

There are several factors that may contribute to a decline in amphibian populations. The most prominent factor is loss and fragmentation of habitat (Dodd and Smith, 2003). Studies have directly related amphibian declines to land-use disturbances that range from wetland modification to wetland elimination (Lehitinen and others, 1999). Amphibian

Primer Facts

A further advantage of using amphibians as bioindicators is that many frogs and toads can be identified without physically capturing them. Many frogs and toads have their own distinctive and characteristic call or chorus. By using amphibian chorus calls, species can be identified reliably in an area (Southwest Florida Amphibian Monitoring Network, 2009). Therefore, a wetland can be characterized without sacrificing any animals.

Above: The squirrel tree frog (*Hyla squirella*) is found in marshes, mixed hardwood swamps, and cypress swamps. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

G

Continued

colonization of created (mitigation) wetlands is often slow because amphibians often preferentially return to their original breeding ground, even if newly excavated or impounded wetlands are nearby (Pechmann and others, 2001).

Changes in hydrology and hydroperiod can affect the reproductive success rate in amphibians (Snodgrass and others, 2000; Means and Means, 2008). If the inundation period is decreased or eliminated due to drainage, then larval amphibians will not metamorphose into adults, reducing the reproductive success rate substantially. Alternatively, if the wetland hydroperiod is increased due to prolonged flooding or **wetland augmentation** and fish colonize the wetlands, then the reproductive success rate also can decrease because of fish predation (Snodgrass and others, 2000).

Amphibians can act as sentinel species that are affected early or quickly by various types of chemical contamination in wetlands. Industrial and agricultural chemicals, including pesticides, may cause amphibian deformities (Power and others, 1989). Increases in the incidence of pathogens and parasites may be symptomatic of amphibians weakened or stressed by factors affecting wetlands. Disease reduces reproductive success, and infected amphibians often develop deformities (Blaustein and Johnson, 2003a). However, when using amphibians as bioindicators, it is necessary to discriminate between factors directly related to wetland condition and other factors that have a negative effect on amphibian populations but are not directly related to wetland condition. For example, predation and competition by introduced species, such as the Cuban tree frog (*Osteopilus septentrionalis*), can reduce amphibian populations (Gamradt and Kats, 1996), but they are not indicative of wetland condition. Ultraviolet exposure (UV–B), which has increased in intensity worldwide because of the thinning ozone layer, can cause deformities in tadpoles (Blaustein and Johnson, 2003b), lowering reproductive success and increasing predation.

Assessing wetlands using bioindicators such as amphibians is a useful technique because it allows researchers to determine the condition of the entire system using a single method. Common amphibian characteristics, such as their small size, two-stage life cycle, susceptibility to contaminants, and ease of detection without being collected, make amphibians a potentially useful indicator species assemblage for central Florida wetlands (Mushinsky and others, 2004).

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Left: The barking tree frog (*Hyla gratiosa*) breeds in wetlands and shallow ponds from March to August. Photographer credit: Henry R. Mushinsky, University of South Florida.

Below: *Ambystoma cingulatum*, the flatwoods salamander, is a Federally Threatened amphibian species. It is found in seasonally wet pine flatwoods that support long leaf pine, slash pine, and wiregrass, and it breeds in marshy ponds, borrow pits, and swamps. Photographer credit: Jamie Barichivich, U.S. Geological Survey.

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Above: The harmless yellow rat snake (*Elaphe obsolete quadrivittata*) is often found near hardwood hammocks, swamps, marshes, and wet prairies. Photographer credit: Dan Duerr, U.S. Geological Survey.

Above: The brown water snake (*Nerodia taxispilota*), which is not poisonous, is commonly found in rivers, cypress strands, swamps, lakes, and ponds. Photographer credit: Dan Duerr, U.S. Geological Survey.

Right: The American alligator (*Alligator mississippiensis*) feeds on fish, birds, and small mammals. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Numerous reptiles, including snakes, turtles, and alligators, spend much of their lives in wetlands. The black swamp snake (*Seminatrix pygaea*) is found in and around wetlands, primarily cypress swamps, marshes, and lake edges, and feeds on tadpoles, worms, small fish, frogs, and salamanders. The eastern mud snake (*Farancia abacura*) is found in swamps and other wetlands around lakes and rivers, where it feeds primarily on aquatic salamanders. The Florida banded water snake (*Nerodia fasciata pictiventris*) prefers the shallow waters of swamps, marshes, ponds, lakes, streams, and rivers where it feeds on live or dead fish, frogs, and aquatic invertebrates. The Florida cottonmouth, or water moccasin (*Agkistrodon piscivorus conanti*), lives in marshes, swamps, sloughs, rivers, lakes, ponds, reservoirs, retention pools, canals, and roadside ditches. Cottonmouths, which are venomous, feed on fish, frogs, mice, rats, and other small mammals.

Many turtles eat aquatic plants, and sleep and hide among them as well. The markings on their shells help camouflage their presence, and the shells of some turtles even mimic aquatic plants. The common cooter (*Pseudemys floridana*) is a basking turtle that spends much of the day lying in the sun on logs or floating mats of vegetation in marshes, and along rivers, streams, lakes, ponds, ditches, and sloughs. Cooters, which feed on aquatic plants, will slide into the water at any sign of danger. Florida redbelly turtles (*Pseudemys nelsoni*) also feed on aquatic plants in marshes, ponds, and lakes. The common snapping turtle (*Chelydra serpentine*) typically inhabits marshes, ponds, and lakes where it spends most of its time underwater and feeds on fish and other small animals.

The American alligator (*Alligator mississippiensis*) has an important function in wetlands, because it can create localized depressions or wallows that can retain water during dry periods. These "holes" are often connected by one or a series of channels that they excavate. The channels are used by turtles, fish, and many organisms as refuges or hiding places. Moreover, the soil and bottom material that alligators move aside as they thrash about to create their wallows form raised areas that harbor shrub species adapted to growing on these mounds. Alligator movements maintain small areas of open water that are colonized by many invertebrates, which provide food for wading birds and mammals such as raccoons. Alligators are top predators in marshes and swamps and control the numbers and distribution of prey organisms.

Birds and Other Wildlife

The aquatic vegetation in wetlands supplies birds and other wildlife with food and foraging grounds, nest-building materials, nursery areas, and shelter from weather and predation. Wetlands provide the principal habitat for almost all waterfowl, and about 75 percent of all waterfowl breed only in wetlands. The variety of vegetation types and the gradient of water depths in wetlands create a large number of micro-habitats for birds. Many groups of birds have become adapted to exploit the variety of wetland microhabitats. Among the wading birds, obvious adaptations include leg length and bill shape. Some of the most common wading birds are the herons, egrets, bitterns, rails, ibis, limpkins (*Aramus guarauna*), and the roseate spoonbill (*Platalea ajaja*). Seasonal variations in water level, temperature, and dissolved oxygen (which affects the supply of prey species) can result in changing species composition throughout the year at an individual wetland. The wood stork (*Mycteria americana*), snail kite (*Rostrhamus sociabilis*), and the Florida sandhill crane (*Grus canadensis pratensis*) are protected species found in Florida marshes.

Numerous paddling birds frequent wetlands year-round or seasonally. Their webbed feet, rear leg placement, and water-resistant feathers are important adaptations for wetland environments. The American coot (*Fulica americana*) has lobed feet that enable it to run across the water surface before taking flight. Coots and purple gallinules (*Porphyrula martinica*) feed among the floating and emergent vegetation, especially on surface-dwelling insects such as beetles and true bugs. A number of ducks migrate to Florida in the winter, or stop on their way to more southern latitudes, including the blue-winged teal (*Anas discors*), green-winged teal *(Anas crecca),* northern pintail *(Anas acuta),* American widgeon (*Anas americana*), lesser scaup (*Aythya affinis*), and greater scaup (*Aythya marila*). The ring-necked duck (*Athya collaris*) is an especially common overwintering duck species along the St. Johns River.

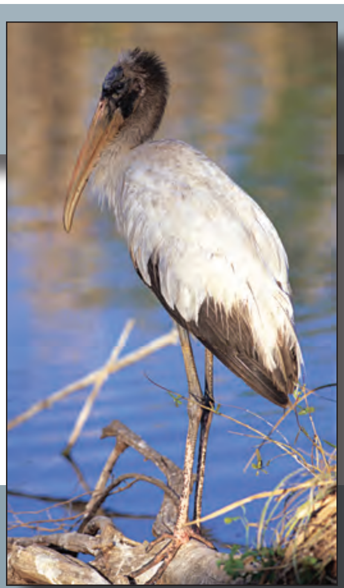
Wetland birds are more abundant in emergent wetlands, compared to other wetland types. At least 16 species of wading birds are found in Florida emergent wetlands (Collopy and Jelks, 1989). Some wading birds nest in swamp forests and forage in the nearby marshes. Others, such as the Florida sandhill crane and the whooping crane (*Grus americana*) graze and forage on surrounding uplands but use aquatic plants to build their nests and typically build those nests in wet prairies, small marshes, and well-vegetated small ponds. A large study of sandhill cranes in DeSoto, Hardee, Highlands, Manatee, Okeechobee, Polk, and Sarasota Counties indicated that successful breeding is positively related to annual rainfall, because preferred nesting areas only hold water when there is adequate rainfall (Layne, 1983). Reduced hydroperiods in wetlands used for nesting by sandhill cranes, either from below-average rainfall or drainage projects, would likely have a negative effect on their populations.

Birds can serve as indicators of wetland ecosystem integrity because they are often closely associated with a particular ecosystem or habitat type, and any changes in the ecosystem will be reflected in bird population changes (Batzer and others, 2006). For example, aquatic vegetation is vitally important to bird populations using wetlands; in particular, submersed vegetation provides a substrate for prey species. Shoreline vegetation, such as pickerelweed, maidencane, and other low grasses, allows wading and paddling birds to forage and move about in a sheltered microhabitat rich in invertebrates and hidden from many predators. The spread of cattails along the shores of wetlands may result in declines of wading and paddling birds because its dense growth makes bird movement difficult. Wetlands with disturbed edges or that receive excess nutrients are most susceptible to cattail invasion and spread. Water birds also can serve as indicators of wetland pollution by heavy metals, radionuclides, pesticides, and pharmaceuticals/personal care products present at levels that might otherwise go undetected (Feature E—Marsh Restoration—A Key to Improving Water Quality in Lake Apopka). This is because birds feed at higher levels of the food web, and the levels of contaminants present in wetlands are magnified as they move up through the food chain.

Mammals are not as abundant in Florida wetlands as they are in wetlands in other parts of the country (Kushlan, 1990). Many mammals that live in or near central Florida forage for food in wetlands where they find abundant prey. They generally spend the rest of their time in surrounding uplands, although wetland vegetation also provides protective cover. Some mammals commonly found in central Florida wetlands include the cotton mouse (*Peromyscus gossylinus*), marsh rice rat (*Oryzomys palustris*), golden mouse (*Ochrotomys nuttali*), meadow jumping mouse (*Zapus hudsonius*), marsh rabbit (*Sylvilagus palustris*), nutria (*Myocastor coypus*), and river otter (*Lutra canadensis*). The Florida water rat (*Neofiber alleni*) feeds on the roots and shoots of plants such as the cattail, and is a species that inhabits an ecological niche filled by the muskrat in marshes farther north. Other larger mammals that use wetlands occasionally include the white-tailed deer (*Odocoileus virginianus*) and raccoon (*Procyon lotor*).

Two mammals in particular have the capacity to do harm to wetlands. The feral hog (*Sus scrofa*) is an invasive species that was brought to Florida from Spain in 1539. Foraging by these large mammals damages the community structure of wetlands by changing the vegetation species composition. For example, in the wet prairies of the Savannas Preserve State Park in St. Lucie County, an assessment of overturned ground from rooting activity by feral hogs indicated that almost 20 percent of the marsh periphery was damaged (Engeman and others, 2003). Because the park is home to a number of threatened and endangered plant species, damage of this magnitude is a substantial concern to park managers. The nutria is another invasive mammal species. Thirteen nutria were brought to the United States in 1937 to produce fur for the fashion industry. A hurricane in 1940 destroyed the nutria cages, releasing the rodents into the wild. They subsequently began to thrive in swamps and wetlands, where they live in shallow burrows and feed voraciously on aquatic plants. Their foraging and feeding are destructive to central Florida wetlands.

Above: The diet of the white ibis (*Eudocimus albus*), which feeds by probing with its long beak, includes small fish and reptiles, frogs, and aquatic insects. Photographer credit: Michael Hancock, Southwest Florida Water Management District.



Primer Facts

Woodstorks (*Mycteria americana*) are a protected species found in Florida marshes and cypress wetlands. They feed by holding their bill open in the water until a fish or other prey is detected. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Right: White-tailed deer (*Odocoileus virginianus*) browse on emergent and woody plants in wetlands. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Left: Marsh rabbits (*Sylvilagus palustris*) are good swimmers that move about primarily at night and feed on marsh plants. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Below: Feral hogs (*Sus scrofa*) are widely found in flatwoods with freshwater marshes, ponds, sloughs, and cabbage palm (*Sabal palmetto*) hammocks. Their rooting, wallowing, and foraging are ecologically destructive, and they compete for food with native wildlife species. Photographer credit: Dan Duerr, U.S. Geological Survey.

Left: A cypress wetland in Volusia County showing evidence of recent fire, and regrowth of ferns, palmetto, and other ground cover. Photographer credit: Steve Miller, St. Johns River Water Management District.

Effects of Fire on Wetland Ecology

Fire, principally caused by lightning, is a natural occurrence in Florida wetlands, and examples of charcoal embedded in peat deposits demonstrate the historical frequency. Fire limits the invasion of woody vegetation, thereby affecting the plant composition in wetlands. It is critical in reducing the volume of accumulated litter, which would eventually fill a wetland and accelerate the natural progression to a drier community type. Fire also transforms organic carbon into inorganic carbon and aids in releasing nutrients back into the wetland ecosystem when burned material is inundated during the rainy season. Fire is relatively rare (once in 50 to 100 years) in bottom-land forests, more frequent in wet flatwoods such as pond pine (once in 15–50 years), and relatively common (once in 1–3 years) in shallow Florida marshes (Kushlan, 1990).

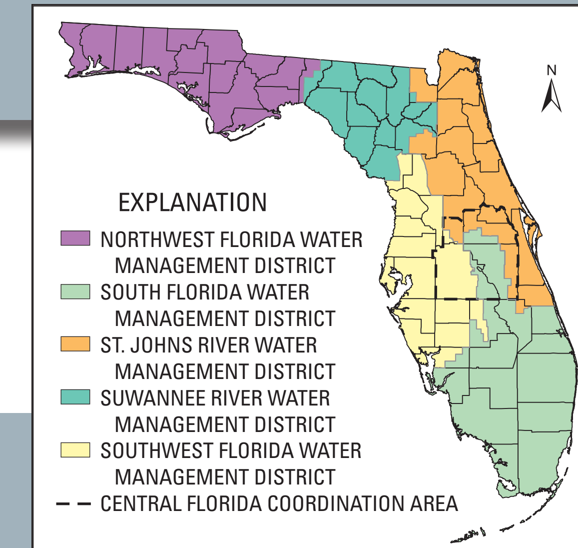
Fire can kill many trees in flood-plain forests, and may foster decay and rot in surviving damaged trees. The thin bark of water tupelo, black tupelo, laurel oak, and water oak provide little protection from fire. The thicker bark of cypress, sweetbay, and red maple make them more resistant to damage by fire. Most of the tree species with thicker bark will reproduce following fire if the roots have not been damaged or killed. Trees growing in thick accumulations of peat are more likely to be severely damaged by the high heat of peat fires than trees growing in more mineral soils, where fire temperatures tend to be lower. However, if the peat is in direct contact with the water table (and therefore saturated), fire frequency and severity are low. Some wetland plant species adapted to withstand fire have seeds and other structures that only disperse following exposure to fire.

Although lightning continues to cause natural fires, roads, agriculture, and urban development now limit the spread of fires that help maintain wetlands. Prescribed burns are used to mimic the pattern of natural fires to maintain ecosystems in wetland forests as well as upland forests. Prescribed fires can reduce the accumulation of plant material periodically, and limit the possibility of rare but catastrophic fires fueled by excessive vegetation.

Human Activities that Affect Wetlands in Central Florida

Humans affect wetlands in central Florida through wetland protection, mitigation, alteration, and destruction. Wetland protection is a relatively recent human activity. In Florida, the State and the U.S. Army Corps of Engineers protect wetlands by regulating development in areas near wetlands, by acquiring wetlands and areas adjacent to wetlands, and by requiring local governments to produce long-term plans to ensure wetland protection. Wetland mitigation also is a recent phenomenon, and includes wetland enhancement, restoration, creation, and preservation. Wetland alteration has a long history, usually a result of hydrologic modifications such as dredging, filling, drainage, and water contamination. Alterations typically produced wetlands of smaller size, shorter hydroperiod, and impaired function. However, downgradient drainage impediments such as roads, dikes, or berms can result in increased wetland acreage. Wetland destruction sometimes causes wetland loss over a large area, but more often wetland loss is cumulative and involves the elimination of increasing numbers of small wetlands over time. This incremental and cumulative wetland loss can greatly change the ecological landscape.

Figure 26. Florida Water Management Districts.



Wetland Protection

Wetlands are protected at the Federal, State, and County level in Florida by a network of laws and regulations that often intersect and sometimes overlap in complex ways. Nongovernmental organizations such as the Audubon Society, Sierra Club, Nature Conservancy and others are interested and involved in the protection of wetland functions and values.

Wetlands are the only ecosystem specifically protected by law in the United States, and several Federal agencies provide wetland protection. The U.S. Army Corps of Engineers addresses wetland issues related to watercraft navigation and water supply. The U.S. Army Corps of Engineers also developed the Wetland Delineation Manual (U.S. Army Corps of Engineers, 1987), which is used by all Federal agencies (and many others) for legally determining wetland boundaries. The U.S. Environmental Protection Agency, in partnership with State and local governments, is responsible for restoring and maintaining the chemical, physical, and biological integrity of the Nation's waters and thus, has authority to protect wetland resources as an integral part of those waters. The U.S. Fish and Wildlife Service manages fish and wildlife game species and protects threatened and endangered species within wetlands. The Natural Resources Conservation Service regulates agricultural activity that may affect wetland ecosystems.

Regulatory agencies in central Florida use their permitting programs as tools to guard against harm to wetlands, which are considered by law to be "waters of the State" and are protected as such. The Florida Legislature created a wetland regulation program called the Environmental Resource Permit (ERP) program, which was fully implemented by the Florida Department of Environmental Protection and the Water Management Districts (fig. 26) beginning in 1995. The Florida Department of Environmental Protection has two regulatory district offices in central Florida to ensure compliance with departmental rules, including those relating to wetlands. The ERP program requires that any person or organization that proposes the construction of new facilities (including those that are residential, commercial, governmental, or highway related) and/or proposes to fill a wetland must have an approved ERP. The ERP also addresses stormwater runoff quality and quantity. An ERP is approved for a specific purpose, and typically contains a number of conditions that must be met by permittees. It is the intent of the State ERP Program that there be "no net loss" in wetlands and other surface-water functions. The permit not only requires that "primary impacts" will not be harmful, but also mandates that "secondary impacts" due to construction will not cause harm to wetlands and their wildlife. Finally, although a project may not cause harm in and of itself, permit applicants must demonstrate that their activities will not contribute to unacceptable cumulative adverse effects on wetlands in a given drainage basin when combined with existing, permitted, or pending projects.

The Water Management Districts require permittees to complete Environmental Monitoring Reports as part of the ERP Program. For example, the Southwest Florida Water Management District has standardized guidelines for their Environmental Monitoring Report, which allows the District to determine compliance status and overall success of mitigation projects. Included in the report is a detailed wetland site map, one or more monitoring areas with permanent "photo points," and a transect from the perimeter to the deepest point in the wetland with plots that are monitored for changes in vegetation, wildlife, and hydrologic condition (Feature H—Wetland Assessment and Monitoring in Central Florida — Approaches and Strategies).

H Wetland Assessment and Monitoring in Central Florida—Approaches and Strategies

The periodic assessment and monitoring of wetlands typically focuses on tracking changes in the hydrologic and biological components of these systems at intervals ranging from months to years. Any assessment and monitoring program must be preceded by efforts to accurately delineate, map, and classify the subject wetlands. Accurate and reliable wetland delineation and classification is largely based on three factors—water, soils, and vegetation.

Florida has adopted a wetland delineation methodology that is binding on all State, regional, and local governments throughout Florida (Section 373.421, Florida Statutes). This methodology, adopted as Chapter 62–340 of the Florida Administrative Code, is a unified statewide approach to wetland and other surface-water delineation and is specific to Florida, in recognition of the vegetative, hydrologic, and soil features that are unique to Florida. The Florida Department of Environmental Protection Wetland Evaluation and Delineation Section performs formal wetland delineations, provides training in wetland delineation and classification, provides technical assistance to other sections of the Department, and ensures the consistent statewide use of the Florida Unified Wetland Delineation Methodology. Wetlands are delineated and mapped on an "as requested" basis related to permitting of individual projects.

The U.S. Fish and Wildlife Service National Wetlands Inventory has produced maps of wetlands in Florida (Feature A—Wetland Mapping and the National Wetlands Inventory), although these maps typically are not at a level of resolution adequate for State permitting purposes. The U.S. Fish and Wildlife Service also has produced periodic reports for Florida summarizing the "status and trends" of wetland gains and losses over time (Frayer and Hefner, 1991; Dahl, 2005). This determination of wetland status and trends is based on a random sample of about 600 4-mi^2 plots selected throughout the State. In addition, the Florida Department of Environmental Protection and the Water Management Districts provide a status of wetlands and the functions they provide as part of their permit application review process.

Successful biological monitoring and assessment of Florida freshwater wetlands requires a robust classification scheme that consistently groups ecosystems with similar biological characteristics and similar responses to disturbance. In addition to the U.S. Fish and Wildlife Service wetland classification system developed by Cowardin and others (1979), several other schemes are used to classify Florida freshwater wetlands. The Florida Land Use and Cover Classifications System (FLUCCS) was developed by the Department of Transportation and is used by a number of other State agencies. The Florida Natural Areas Inventory (FNAI), published by Florida State University (1990) in cooperation with several other State agencies, includes numerous wetland communities. The Florida Department of Environmental Protection, in conjunction with the University of Florida Center for Wetlands, has published a classification scheme with wetland classes that apply to central Florida wetlands (Doherty and others, 2000). This scheme uses a combination of hydrologic, geomorphologic, and biological characteristics (including dominant plant type) to group wetlands together for the purposes of detecting biological condition. There may be considerable overlap between these different classification schemes, but each has specific goals depending on the mission of the agency that developed it.

Monitoring and bioassessment can rely on several target communities—algae, wetland vegetation, macroinvertebrates, amphibians, and others. Algae are useful for wetland assessment because their species identification is well established and the ecological requirements of many algal species are published in the scientific literature. For example, the diatoms *Eunotia naegelii, Eunotia rhomboidea, and Frustulia rhomboides* have a preferred range of specific conductance of 65 to 90 µS/cm (Potopova and Charles, 2003). Therefore, these species would be expected to inhabit wetlands that do not receive groundwater, but would not be expected in wetlands that receive groundwater flow and therefore have a higher

Primer Facts

Monitoring and bioassessment can rely on several target communities —algae, wetland vegetation, macroinvertebrates, amphibians, and others. Algae are useful for wetland assessment because their species identification is well established and the ecological requirements of many algal species are published in the scientific literature.

Left: Hydrologic wetland assessments rely on periodic wetland water-level measurements at staff gages and continuous groundwater level measurements in monitoring wells. Photographer credit: Dan Duerr, U.S. Geological Survey.

Right: Algae growing on glass slides that are placed in a floating frame can be identified and used to characterize wetlands. Photographer credit: Kim Haag, U.S. Geological Survey.

H

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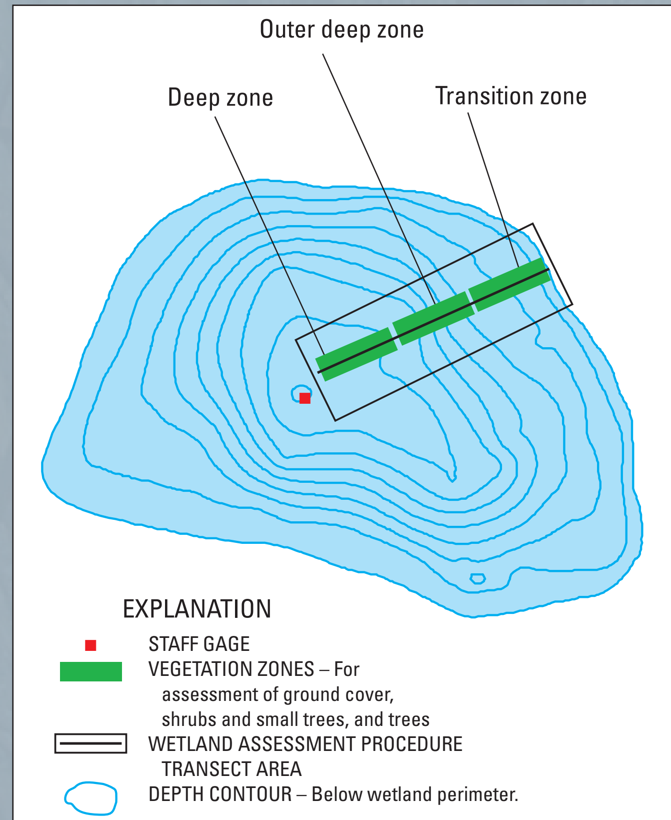

Figure H–1. Conceptual drawing of a Wetland Assessment Procedure transect for monitoring and periodic evaluation of wetlands included in Tampa Bay Water's Consolidated Water Use Permit.

specific conductance. Wetland vegetation can be used to compare the presence of taxa in reference sites (undisturbed sites) and sites with known disturbance. Individual plant species can be scored to determine which are unique to reference sites (often called sensitive, ubiquitous, or intolerant), or unique to disturbed sites (tolerant). The macroinvertebrate community can be used to develop measurements, called metrics, that identify dominant groups of aquatic invertebrate organisms, and to compare the relative abundance of those groups at reference sites and sites with known disturbance to compile a numerical score. Some of the available metrics include percent Diptera, percent Odonata, relative abundance of Ephemeroptera and Trichoptera, and others. Metrics that use macroinvertebrate abundance must have a seasonal component that adjusts for natural variation based on wet and dry conditions. The reproductive success of amphibians, and their abundance at reference and disturbed sites, is also used to assess and compare central Florida wetlands (Feature G—Amphibians as Bioindicators in Wetlands).

Systematic vegetation monitoring by the Southwest Florida Water Management District in isolated wetlands affected by groundwater withdrawals in the northern Tampa Bay area indicated that hydrologic changes in the wetlands affected wetland vegetation (Rochow, 1985; 1998). As a consequence, a standardized Wetland Assessment Procedure was developed by Tampa Bay Water; the procedure is part of their Environmental Management Plan used to manage the 11 Central System **well fields** (Tampa Bay Water, 2000). These well fields are part of the Tampa Bay Water's Consolidated Water Use Permit for the northern Tampa Bay area (Feature K—Aquifer Recovery in the Northern Tampa Bay Area and Effects on Wetlands). The Wetland Assessment Procedure was revised by the Southwest Florida Water Management District in 2005 (Southwest Florida Water Management District and Tampa Bay Water, 2005; Southwest Florida Water Management District, 2005), and is now used for other water-use permits in addition to Tampa Bay Water's Consolidated Permit. The objective of the Wetland Assessment Procedure is to collect information on vegetation, hydrology, soils, and other indicators of hydrologic changes in monitored wetlands caused by regional groundwater withdrawals. As of 2007, about 400 wetlands were being monitored annually using the procedure to provide a time series of assessment results. The results of this procedure include a record of dominant plant species in each wetland in three zones (transition, outer deep, and deep) along a transect that extends from the wetland edge to the deepest part of the wetland (fig. H–1). The assessment also derives numerical scores for different parts of the plant community (ground cover, shrubs and small trees, and medium to large size trees) for the entire wetland and additional information regarding indications of "stress" in the plant communities.

Above: Biological wetland assessment often includes vegetation sampling. Photographer credit: Kim Haag, U.S. Geological Survey.

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Although some details of permitting requirements differ among the Water Management Districts in central Florida, there are several examples of collaboration and coordination. One example is the 2006 Central Florida Coordination Area (fig. 26), which pertains to the geographic area where the boundaries of the St. Johns River, South Florida, and Southwest Florida Water Management Districts come together. The Central Florida Coordination Area ensures that consistent and streamlined permitting criteria are used by these three Water Management Districts as they develop and implement alternative water-supply projects to meet projected long-term needs for water supply. These alternative water-supply projects can have important implications for wetland stewardship.

State wetlands protection efforts are broadly based in Florida. According to Florida law, water is a public resource that is for the benefit of the entire State, and is not owned by individuals. The Water Management Districts are authorized to issue permits for the use of water, while also protecting the State's water resources. For example, the St. Johns River Water Management District and the Southwest Florida Water Management District require a Consumptive Use Permit for any well greater than 6 in. in diameter, or any water use that will exceed 100,000 gal/d. Permits are denied if the water withdrawal would cause unmitigated adverse effects on adjacent land use, including damage to wetlands. A systematic field inspection of wetlands in the area of proposed withdrawals and groundwater flow modeling are important tools in the environmental assessment of permit applications. Harm to wetlands from consumptive use can be avoided by altering the timing of withdrawals, plugging drainage ditches, or direct augmentation to raise water levels. Often, efforts to avoid harm to wetlands are sufficient and mitigation rarely has to be used in the permitting process.

Another way in which the Water Management Districts protect wetland resources in central Florida is through the Minimum Flows and Levels program. Minimum Flows and Levels are established to avoid substantial harm from permitted water withdrawals to water resources or ecology of rivers, lakes, springs, and wetlands (minimum levels only). Establishing minimum flows and levels is a requirement of the Florida State legislature for each of the Water Management Districts in the State, but the methods to establish Minimum Flows and Levels are developed and implemented by each Water Management District independently (Neubauer and others, 2008). However, efforts are made by Water Management Districts to make minimum flows and levels consistent throughout the State.

A unified statewide methodology for the delineation of the landward extent of wetlands (and surface waters) is included in the Florida Administrative Code (Chapter 62–340). The methodology is designed to be applied by the Florida Department of Environmental Protection in conjunction with the Water Management Districts in the State, and has been summarized in the Florida Wetlands Delineation Manual (Florida Department of Environmental Protection, 2009). The delineation method depends on a number of criteria, including the dominance of plant species, soils, and other hydrologic evidence. The manual provides reference site examples of wetland identification and delineation, and also includes a list of wetlands types found in Florida and community types not intended to be identified as wetlands. For example, Florida freshwater wetlands generally include swamps, marshes, bay heads, bogs, cypress domes and strands, sloughs, wet prairies, flood-plain swamps and marshes, and hydric seepage slopes, but do not include longleaf or slash pine flatwoods with understories dominated by saw palmetto.

Florida has a large and active land acquisition program, which has proven to be a substantial benefit to wetlands. The 1980 Conservation and Recreational Lands Program was the first major program to protect wetlands in the State. Since its inception, the program has acquired well over 1 million acres at a cost of nearly $2 billion. Increased efforts were mandated, and more stable funding was instituted in 1990 with the Preservation 2000 program. In 1998, a $3 billion wetlands programming and funding effort called Florida Forever was developed to enhance land acquisition. The program is overseen by the Florida Department of Environmental Protection and is administered by the Water Management Districts.

In some cases, State and Federal programs work in tandem to protect wetlands because the wetlands are located in areas where there are overlying jurisdictions, multiple land uses, or competing interests that complicate protection efforts. For example, the area of central Florida known as the Ocala National Forest lies between the Ocklawaha and St. Johns River in parts of Marion, Lake, Putnam, and Seminole Counties. The forest contains more than 600 wetlands, lakes, and ponds that provide recharge for the Floridan aquifer system. The Forest was dedicated by President Theodore Roosevelt more than 100 years ago, and is the oldest national forest east of the Mississippi. This multiuse area, where many types of aquatic and terrestrial recreation occur, provides habitat for many types of wildlife, and even contains a U.S. Navy bombing range where live impact training is held. Successful wetland protection and preservation in an area as dynamic as this exemplifies the potential for wetland protection available to all regions of the State. Maintaining a balance between conservation and development is an ongoing challenge to resource managers in the Green Swamp area of central Florida (Feature I—The Green Swamp and Use of Wetland Conservation Partnerships). Many Florida counties maintain a policy of "no net loss" of wetland functions due to development or other activities. Counties strive to avoid adverse effects to wetlands, to minimize unavoidable adverse effects where they will occur, and to compensate for adverse effects on wetlands through various types of mitigation.

Above: Almost 5,000 acres of cypress swamps, bay swamps, marshes, and other pristine lands in Highlands County were acquired in 1931 to protect them from agricultural development. The area became part of Highlands Hammock State Park, one of Florida's first four State parks. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Above: Marsh grass and wax myrtle (*Myrica cerifera*) in Conner Preserve marsh, Pasco County. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

I The Green Swamp and Use of Wetland Conservation Partnerships

The Green Swamp ecosystem occupies about 870 mi^2 in portions of Hernando, Lake, Pasco, Polk, and Sumter Counties, and is the second largest wetland system in the State, after the Everglades. The area is a complex mosaic of uplands, hydric hammocks, poorly drained pine flatwoods, bay swamps, shrub bogs, cypress swamps, and pastures (Ewel, 1990). About 60 percent of the area is in a natural and undisturbed condition; about half of the natural areas are wetlands (fig. I–1), 80 percent of which are forested. About 35 percent of the Green Swamp is used as agricultural land, and much of that is improved pasture. Less than 2 percent of the area is urban land (Brown, 1984).

Hydrology and Geology

Underlying the Green Swamp are three hydrogeologic units (Pride and others, 1966). The surficial aquifer system is directly below the land surface and is composed of sands and sandy clays. The surficial aquifer system is about 90 ft thick in the eastern part of the area and very thin or entirely absent in the western part. Beneath the surficial aquifer system is a clay layer that varies in thickness in the eastern part of the area, and is thin to absent in the western part of the area. Beneath the clay layer is the Floridan aquifer system, which has an average thickness greater than 900 ft and consists of the Suwannee Limestone, Ocala Limestone, and Avon Park Formation.

The Green Swamp is the headwaters of both the surface-water and the groundwater flow systems in central Florida. The drainage basin that includes the Green Swamp contains the highest potentiometric-surface elevation (groundwater elevation) of the Floridan aquifer system in central Florida (Spechler and Kroening, 2007). For example, the potentiometric surface elevation was measured at 133 ft NGVD 29 in September, 1979 (U.S. Geological Survey, 2009. The high potentiometric surface in the Green Swamp provides recharge for the Floridan aquifer system and maintains a potable groundwater supply in the region. Rainfall is the primary source of water to the Green Swamp, and water losses occur through evapotranspiration, groundwater seepage, and streamflow. Drainage from the Green Swamp forms the headwaters of four major Florida rivers (fig. I–2): the Ocklawaha River (the largest tributary to the St. Johns River), which flows north; the Hillsborough River and the Withlacoochee River, which flow west; and the Peace River, which flows south.

Throughout the Green Swamp, there is a gradual transition between shallow still-water depressions (cypress ponds) and depression channels that carry surface-water flow (cypress strands). The topography is typically so flat that surface flow is seldom observed (Ewel, 1990). Many other cypress ponds are isolated and are not sources of surface-water flow. The flat terrain allows much of the precipitation to be retained, and the numerous wetlands provide substantial water storage. The wetlands not only recharge the aquifer as water eventually percolates downward, but they also reduce flood peaks in rivers, and release water slowly into surface tributaries once rainfall diminishes after the wet season (Brown, 1984). The water that flows from the Green Swamp into rivers is generally of high quality because the long detention times within the basin eliminate much of the decaying plant material that creates oxygen demand in receiving rivers.

Plant and Animal Communities

The cypress domes in the Green Swamp share numerous plant species. The domes are shallow, forested, roughly circular depressions that have dome-shaped cross sections as a result of the concentration of tallest and oldest trees in the center. The boundaries of cypress domes are maintained by periodic fires that prevent the invasion of wetland tree species into the surrounding pine flatwoods (Florida Department of Environmental Protection, 2006). The Green Swamp ecosystem is one of the last contiguous wilderness areas in Florida, with diverse plant communities and wildlife habitats that host more than 330 species of animals, including 30 threatened or endangered species. This latter group includes the Florida scrub jay (*Aphelocoma coerulescens*), the wood stork (*Mycteria americana*), and the Florida black bear (*Ursus americanus floridanus*).

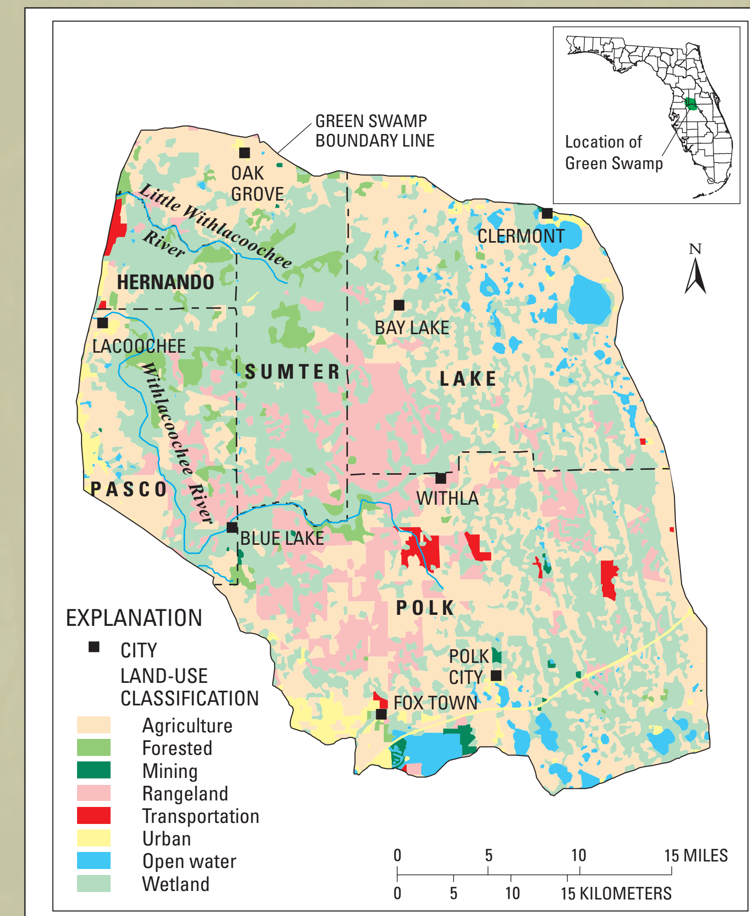

Figure I–1. Generalized land use in the Green Swamp.

Above: The red-tailed hawk (*Buteo jamaicensis*) searches for prey in the Green Swamp. Photographer credit: Paul Fellers, Lake Region Audubon Society.

Primer Facts

The water that flows from the Green Swamp into rivers is generally of high quality because the long detention times within the basin eliminate much of the decaying plant material that creates oxygen demand in receiving rivers.

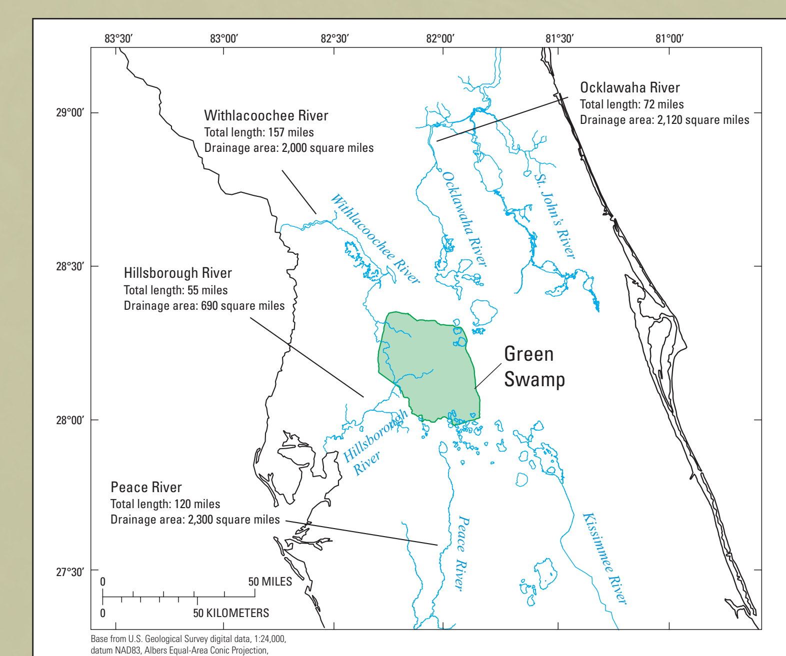

Figure I–2. The Green Swamp is the headwaters for the Hillsborough, Ocklawaha, Peace, and Withlacoochee Rivers.

1 Continued

Protection and Preservation

The Green Swamp has attracted attention in the water-resources community for decades. In the early 1960s, above-average seasonal rainfall and the effects of Hurricane Donna caused severe flooding in the area. Consequently, the U.S. Army Corps of Engineers developed a plan to use the Green Swamp as part of a structural flood-control system for central Florida (Southwest Florida Water Management District, 2009). A series of proposed levees and water control structures, called the Four Rivers Basins—Florida Project, would have inundated the area and effectively converted the Green Swamp into a flood-water detention basin. The Southwest Florida Water Management District made substantial land purchases in the Green Swamp in preparation for the project. However, concerns about disrupting a unique natural system, and further examination of the habitat and water-supply benefits of the area, led the Southwest Florida Water Management District to choose a non-structural approach to flood protection by leaving the Green Swamp in its natural state.

In 1974, as Walt Disney World opened to the east, a proposal was made to develop 2,000 acres of the Green Swamp (Southwest Florida Water Management District, 2009). By that time, however, there was an understanding of the critical hydrologic role that the Green Swamp plays in recharging the Floridan aquifer system, and the area was not developed. The State of Florida designated approximately 322,000 acres in Polk and Lake Counties, including the Green Swamp, as an Area of Critical State Concern under Chapter 380 of the Florida Statutes. This classification protects a resource of statewide importance that is threatened by unregulated development, and is intended to be a temporary designation that fosters action at the local level to sustain natural resources. The State land planning agency, the Florida Department of Community Affairs, eventually provided oversight for all new development activities in the Green Swamp. Local land development plan regulations must be consistent with this legislation. The 1985 Local Comprehensive Planning Act (Chapter 163, Florida Statutes) ensures that within the jurisdiction of Lake, Polk, Citrus, Sumter, and Hernando Counties, all natural land development limitations and suitabilities pertaining to the Green Swamp are identified as required by the Act.

In the early 1990s, the Green Swamp was added to a land acquisition program—Preservation 2000—that later became known as Florida Forever. The primary goals of the Green Swamp Florida Forever project (Florida Department of Environmental Protection, 2008) are to:

- Conserve and protect lands within areas of critical state concern;
- Conserve and protect significant habitat for native species or endangered and threatened species;
- Conserve, protect, manage, or restore important ecosystems, landscapes, and forests, in order to enhance or protect significant surface-water, coastal, recreational, timber, fish, or wildlife resources that local or State regulatory programs cannot adequately protect; and
- Provide areas, including recreational trails, for natural-resource-based recreation.

The Southwest Florida Water Management District has increased its holdings within the Green Swamp to more than 110,000 acres, and designated these holdings as the Green Swamp Wilderness Preserve. Other agencies, including the St. Johns River Water Management District, have purchased an additional 64,000 acres for use as State parks and wildlife management areas.

The Southwest Florida Water Management District also has purchased conservation easements in more than 6,000 acres of private lands for preservation, protection, recreation, and hunting. Conservation easements allow property owners to continue to own and use the land while protecting it from development. Altogether, the Green Swamp Land Authority and the Florida Department of Environmental Protection have established protection agreements or conservation easements for more than 40,000 acres of privately owned land (Ryan, 2006).

Private conservation organizations also have an active interest in the preservation and protection of the Green Swamp because of its hydrologic importance and importance as a wildlife habitat. The Sierra Club continues to work with the Southwest Florida Water Management District and St. Johns River Water Management District to encourage land acquisition in the Green Swamp through the Florida Forever Program and the Save Our Rivers Program. The Audubon Society works with allied organizations to accelerate acquisition programs and increase funding for public land management in the Green Swamp. Of particular interest to the Audubon Society are efforts to protect the bald eagle (*Haliaeetus leucocephalus*) through habitat conservation and preservation.

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Above: Pine-hyacinth (*Clematis baldwinii*) grows along the margins of swamps and wet pine woods of the Green Swamp. Photographer credit: Paul Fellers, Lake Region Audubon Society.

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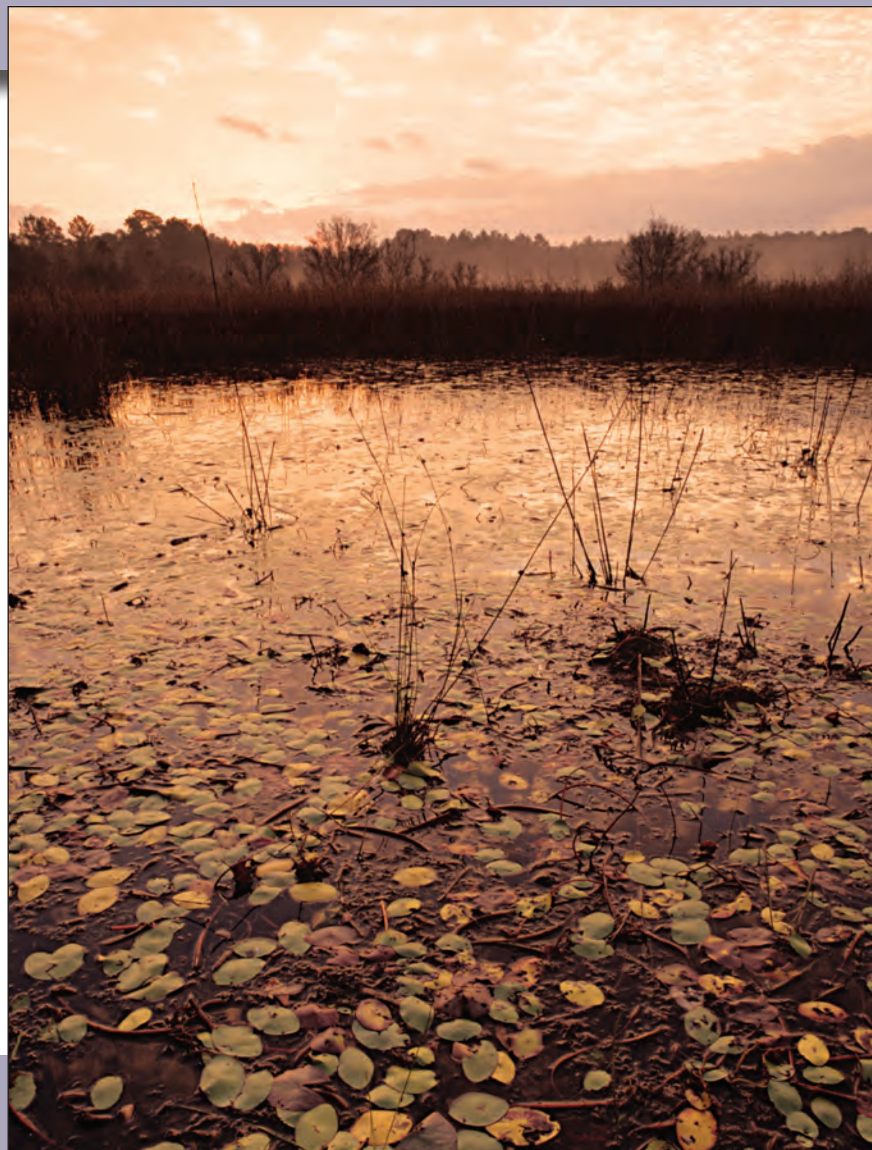

Primer Facts

Wetland mitigation refers to any wetland enhancement, restoration, creation, or preservation project that serves to offset adverse effects on wetlands.

Left: A deep marsh in Pasco County. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Wetland Mitigation

The term "wetland mitigation" refers to any wetland enhancement, restoration, creation, or preservation project that serves to offset adverse effects on wetlands (Florida Department of Environmental Protection, 2008b). Wetland mitigation is designed to compensate for the intentional destruction of wetlands by land development by requiring the creation of wetlands in an alternate area so as to maintain "no net loss" in wetland function. Wetland mitigation was set forth in Section 404 of the Federal Clean Water Act, which legally allows for the destruction of wetlands provided that their loss is compensated for by the restoration or creation of new wetland areas. Mitigation may be onsite, or it may be offsite if onsite mitigation does not have long-term viability or if offsite mitigation would provide greater ecological value (Florida Department of Environmental Protection, 2008b). Mitigation typically is located within the same drainage basin as the adverse effect to avoid potential unacceptable cumulative adverse effects within the basin.

Wetland enhancement and restoration ideally return a wetland ecosystem to a close approximation of its condition

Above: The addition of groundwater (augmentation) is a form of mitigation that maintains wildlife habitat at Duck Pond marsh in Pasco County. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

before disturbance (National Research Council, 1992). Wetland restoration has been defined as any manipulation of a site that contains or has contained a wetland to increase the wetland area or enhance natural qualities of the wetland (Kentula and others, 1993). The Kissimmee River Restoration, overseen by the South Florida Water Management District, is an example of a large wetlands restoration project in central Florida (Feature J—Restoration of Flood-Plain Wetlands in the Kissimmee River Basin). Regardless of size, successful restoration reestablishes critical ecological processes and functions related to chemical, physical, and biological wetland characteristics.

The National Research Council (2001) developed a list of guidelines for restoration of self-sustaining wetlands that relate to many of the major topics presented herein. They include: consideration of the landscape and climate; use of a landscape perspective; restoration of naturally variable hydrologic conditions; a preference for wetland restoration over creation; avoidance of overengineered structures; use of appropriate planting elevations, depth, soil type, and seasonal timing; provision of heterogeneous topography; attention to soil and sediment geochemistry, and groundwater quantity and quality; special consideration for seriously disturbed sites; and use of monitoring.

J Restoration of Flood-Plain Wetlands in the Kissimmee River Basin

The restoration of flood-plain wetlands in the Kissimmee River basin is part of the largest ecosystem restoration project ever attempted anywhere in the world (Dahm and others, 1995; South Florida Water Management District, 2009b). Efforts to return the hydrology of the Kissimmee River to pre-channelization conditions were initiated even before the channelization process was completed, because as flood-plain wetlands were incrementally lost during channelization, their ecological value became increasingly clear.

The Kissimmee River flows out of Lake Kissimmee in central Florida and historically flowed into Lake Okeechobee as a meandering river with a braided channel flanked by numerous wetlands (fig. J–1). These wetlands were home to an abundance of aquatic vegetation, wetland birds, fish, and invertebrates that inhabited the sloughs and backwaters surrounding the river on its 1- to 3-mi-wide flood plain. Prior to channelization, almost 95 percent of the flood plain was inundated more than 50 percent of the time, and about 75 percent of the flood plain was inundated almost 70 percent of the time (Toth and others, 1998). Flood-plain wetlands occupied about 45,000 acres and water depths averaged 1 to 2 ft (Toth, 1990).

A series of hurricanes in the 1940s prompted residents and land developers to call for flood-control measures that would avoid future flooding, and in response to these requests, the river was channelized by the U.S. Army Corps of Engineers from 1962 to 1971. As a result, the river was transformed into the C–38 canal, which is about 30-ft deep and about 300-ft wide. The canal was sectioned into a series of five pools each with a water-control structure. The pools were more similar ecologically to lakes than to a riverine habitat because the flow rate was so low. Approximately 30,000 acres of flood-plain wetlands were either converted into canal or drained and covered with canal spoil. The remaining flood-plain wetlands were mostly lost because they were cut off hydrologically from their water source (Koebel, 1995).

The ecological effects of the channelization were substantial. The mosaic of wetland habitats was greatly reduced, and in most areas eliminated. These included

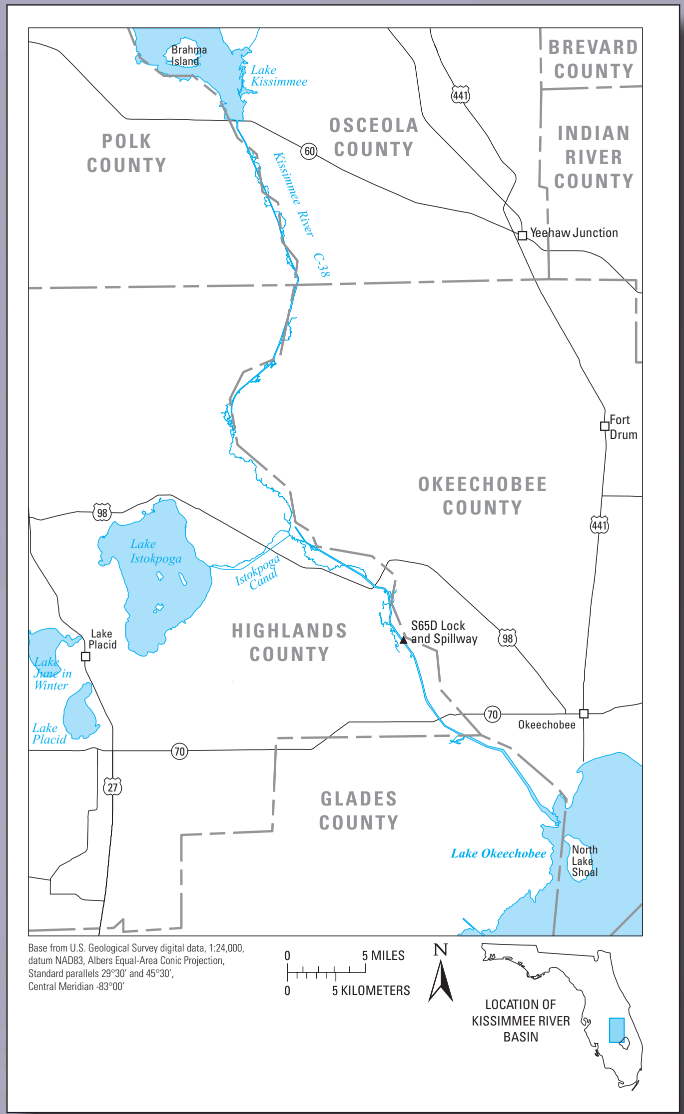

Figure J–1. The Kissimmee River showing channelized reaches and remnant meanders.

C-38 and remnant Kissimmee River post-channelization, circa 1980.

Restored Kissimmee River section Phase 1, February 2001 (Photographed in January 2003).

Above: The remnant and restored sections of the Kissimmee River and adjacent wetlands. Photograph credit: South Florida Water Management District.

backwater sloughs and ponds that supported shrub communities of willow and buttonbush, as well as broad-leaf marshes of pickerelweed, arrowhead, cutgrass, and maidencane. Also affected were cypress swamps, and red maple/popash forests. There was a decline of more than 90 percent in the use of the flood plain by overwintering water fowl (Weller, 1999). Among those species affected was the endangered wood stork. The largemouth bass fishery in the river declined substantially along with populations of other sport fish. These declines were caused by the loss of forage fish (including small-bodied wetland species such as the mosquitofish, least killifish, swamp darter, and sailfin molly), and also to the loss of shallow-water breeding and nesting habitat for sport fish. Moreover, the wetlands were no longer available to filter and retain nutrients, resulting in increased nutrient loads to Lake Okeechobee and exacerbated eutrophication in this historically nutrient-rich lake.

Efforts to return the hydrology of the Kissimmee River to pre-channelization conditions began during the latter stages of the channelization process. These efforts gained additional public support as evidence of the detrimental ecological effects increased. A number of plans were proposed to restore the flood-plain wetlands, complicated by the need to maintain navigation in the river and flood control in the basin during and after restoration. Excessive erosion of any backfilled canal sections was a concern. In addition, many people had moved onto the flood plain and could not be relocated easily.

J Continued

Large-scale modeling efforts were used to predict flow and sediment movement in the restored river. A pilot project backfilled a 1,000-ft section of C-38 canal in 1994 and removed spoil (dredged material left behind from the channelization) from about 12 acres of the adjacent flood plain. Evidence from this pilot project indicated increased use of the restored flood-plain area by spawning game fish, and increased use by waterfowl as well. The abundance and diversity of both fish and birds increased measurably. Subsequent projects backfilled additional sections of C–38 canal, each several miles long. Water flow was reestablished in the meandering Kissimmee River and periodic flood-plain inundation was restored. Ultimately, about 40 percent of the C–38 canal will be backfilled, restoring about 26,000 acres of flood-plain wetlands and 43 mi of meandering river channel. Following each backfill project, comprehensive monitoring has documented ecological improvements to the Kissimmee River system and associated flood-plain wetlands (South Florida Water Management District, 2009b). Of particular interest are increases in the number of shorebirds, wading birds, and duck species; the reduction of organic deposits on the river bottom and the redistribution of sand bars; an increase in the relative proportion of largemouth bass and sunfish in the fish community of the river; and an increase in the dissolved oxygen concentration in the river (South Florida Water Management District, 2009a).

The continued restoration of the Kissimmee River will depend on scientifically based planning, implementation, and monitoring of restoration efforts. Allowing water to flow slowly through the flood-plain wetlands on its way downstream should increase nutrient uptake and retention, and thereby improve water quality in Lake Okeechobee. Adaptive management of the restoration process will allow for adjustments to the implementation process to provide a sound and evolving basis for sequential phases of the flood-plain restoration and long-term sustainability of the Kissimmee River ecosystem.

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Right: Seasonal drying of wetlands may strand floating and submersed aquatic plants on the exposed wetland bottom. Such vegetation typically regrows when wetlands are subsequently reflooded. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

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In some situations, a number of wetland restoration alternatives may bring about the desired goals, and these alternatives typically have different costs associated with them. Water budget analyses (Feature D—Use of Water Budgets to Describe Wetlands) can be used as a tool to evaluate restoration alternatives and make the optimal choice at a particular site. For example, Levy Prairie in Alachua County was chosen for restoration and enhancement of waterfowl habitat. Several alternatives were identified for creating a permanently inundated wetland area of a specified depth in one part of Levy Prairie. Bathymetric mapping (Feature C—Wetland Bathymetry and Flooded Area) was used in conjunction with water-budget analyses to determine the best restoration alternative at the lowest cost (Kirk and others, 2004).

The Natural Resources Conservation Service administers the Federal Wetlands Reserve Program, which offers technical and financial support to provide landowners with the opportunity to protect, restore, and enhance wetlands on their property on a voluntary basis. The goal of the Natural Resources Conservation Service is to achieve the greatest wetland functions and values, along with optimum wildlife habitat, on every acre enrolled in the program and to establish long-term conservation and wildlife practices and protection. There are a number of Wetlands Reserve Program projects underway in central Florida, and several are planned at the Archbold Biological Station in Highlands County (Archbold Biological Station, 2005).

Wetland creation is the construction of a wetland in an area that was not previously a wetland and is isolated from existing wetlands. Wetland creation is often more difficult to achieve than wetland restoration and requires careful hydrologic analyses, detailed soils surveys, an understanding of drainage patterns, and the selection of plants to populate the wetland. One of the most critical factors in wetland creation is the selection of an appropriate site that is compatible with surrounding land uses and will allow a wetland to function naturally and sustainably. Long-term management and oversight is often needed, which can add to the cost of a project. Created wetlands need not be identical to a given natural wetland, but should resemble natural wetlands in function and composition (van der Valk, 2006).

The Florida Department of Transportation has a large and active program of regional multi-project mitigation to offset the adverse effects to wetlands by transportation projects. The Florida Department of Transportation works in conjunction with the Water Management Districts, who ultimately approve the proposed mitigation plans and assist in their implementation using Florida Department of Transportation funds.

Mitigation banking, a particular category of mitigation, refers to wetland acres that have been restored, enhanced, created, or preserved and set aside to compensate for future conversion of wetland habitats. The Florida Administrative Code contains a mitigation banking rule that specifies the guidelines for mitigation banking. Each applicant, public or private, must obtain an environmental resource/mitigation bank permit from the Florida Department of Environmental Protection or one of the Water Management Districts. A long-term management plan must be established to maintain the mitigation bank successfully. In essence, mitigation banking allows land developers and others to trade off planned wetland destruction by establishing in advance a “bank” of wetlands that protects existing habitats elsewhere. Although mitigation banking encourages restoration and can promote interconnected tracts of wetlands, it also allows for the destruction of smaller isolated wetlands that can provide important habitat for wildlife.

Left: Ditches alongside roads can provide habitat for perennial wildflowers such as Bartram’s sabatia (*Sabatia bartramii*). Photographer credit: Paul Fellers, Lake Region Audubon Society.

Wetland Alteration and Destruction

Wetlands are altered and ultimately may be destroyed as a result of human activities that cause physical, chemical, and biological alterations. Those activities include residential and commercial construction projects; flood-control activities involving dikes and levees along rivers; agricultural activities including diking, draining, and cultivation; road construction and the creation and maintenance of rights-of-way; livestock grazing; silvaculture and logging; mining; invasion by non-native plants and animals; and pollution from household and hazardous waste.

Physical alterations often attempt to convert wetland to dry land so it can be used for other purposes. Physical alterations that change wetland hydrology include filling to raise the bottom level of a wetland; draining the water by ditching, tiling, or pumping; excavating a wetland by dredging and removing soil and vegetation; diversion to prevent the flow of surface water into a wetland; and lowering the groundwater table to prevent groundwater inflow. Clearing vegetation by digging it up, applying herbicides, mowing, or scraping it away also changes wetland function, as does die-off of aquatic vegetation from shading of bridges or other platforms.

Groundwater withdrawal from aquifers is a relatively recent but important source of physical wetland alteration in parts of central Florida. Groundwater withdrawal from the Upper Floridan aquifer in west-central Florida has lowered the potentiometric surface in the aquifer. A lower potentiometric surface in the Upper Floridan aquifer can reduce the water levels in the surficial aquifer system and lower the stage (surface-water elevation) of wetlands in nearby areas (Haag and others, 2005). Lower water levels can cause subsidence and tree fall in cypress wetlands. The effects on wetland hydrologic condition may be reversible if groundwater withdrawals are reduced in volume (Feature K—Aquifer Recovery in the Northern Tampa Bay Area and Effects on Wetlands). Other physical alterations, such as flooding behind dams or diverting surface-water flow into a wetland can cause excessive inundation of wetlands, resulting in their conversion to permanently flooded systems such as ponds or small lakes.

Right: Tree fall in a forested wetland can open the canopy, allowing more light and providing habitat for emergent vegetation such as the southern swamp lily (*Crinum americanum*). Photographer credit: Dan Duerr, U.S. Geological Survey.

K Aquifer Recovery in the Northern Tampa Bay Area and Effects on Wetlands

The Upper Floridan aquifer is the primary source of drinking water for residents in west-central Florida. Reliance on the Floridan aquifer system to meet water demands statewide has increased substantially since 1950 (Marella, 2004), and groundwater withdrawals totaled about 2,453.21 Mgal/d in the 27 counties of central Florida in 2000. The cumulative effects of increasing groundwater withdrawals have lowered the potentiometric surface in the Upper Floridan aquifer, inducing downward leakage from the overlying surficial aquifer system and lowering the water table. This leakage of water to the Upper Floridan aquifer has lowered the water levels in numerous wetlands (and lakes) in the central Florida region.

Tampa Bay Water is the regional utility that provides drinking water for Tampa, St. Petersburg, New Port Richey, and 15 other municipalities (Tampa Bay Water, 1998). The utility provided an estimated 180 Mgal/d to more than 2.5 million customers in Hillsborough, Pinellas, and Pasco Counties in 2007. In fact, Tampa Bay Water is the second largest water supplier in Florida, following Miami-Dade Water and Sewer Department (Marella, 2004). Tampa Bay Water is regulated by the Southwest Florida Water Management District, which issues permits for water use within the district boundaries, including pumping of groundwater and diversions of surface water. Southwest Florida Water Management District has established minimum flows and water levels for rivers, streams, and aquifers (and minimum levels for wetlands and lakes), which act as guidelines that can be used to minimize adverse effects on these systems.

In order to protect wetland and lake resources, and meet established minimum flows and levels, Tampa Bay Water committed to reduce groundwater withdrawals and optimize the distribution of those groundwater withdrawals from their regional well fields (Tampa Bay Water, 1998). To accomplish the goal of reducing groundwater withdrawals, the withdrawal permit for the 11 groundwater well fields in the northern Tampa Bay area (fig. K–1) was reduced from 158 to 90 Mgal/d on a 12-month moving average basis by 2008. To compensate for decreased groundwater withdrawals, a mix of alternate sources was used including groundwater, direct surface-water withdrawals, offsite reservoir storage, and desalinated seawater.

To optimize groundwater withdrawals from the regional well fields, the well fields were interconnected and an Optimized Regional Operations Plan was designed (Tampa Bay Water, 2008). This plan uses computer modeling tools and field data to examine current water levels in the surficial aquifer system on a weekly basis and to rotate groundwater pumpage away from areas with the lowest surficial aquifer water levels. By rotating groundwater pumpage based on surficial aquifer system water levels, the detrimental effects of groundwater withdrawals on any one well field are minimized, and water levels in the surficial aquifer system, lakes, and wetlands are kept as high as possible under the prevailing rainfall conditions and current water demands.

Most of the wetlands and lakes in the northern Tampa Bay area are replenished by rainfall and overland flows, and can receive groundwater discharge if aquifer levels are sufficiently high. Under predevelopment conditions, the potentiometric surface was much higher in west-central Florida than it is presently (Marella, 2004), and therefore, many wetlands probably received considerable groundwater discharge. The reductions in groundwater withdrawals have elevated the potentiometric surface in the Upper Floridan aquifer in the vicinity of the 11 well fields (Tampa Bay Water, 2008). Therefore, wetland water levels are expected to return to levels more like those prior to development, especially

Primer Facts

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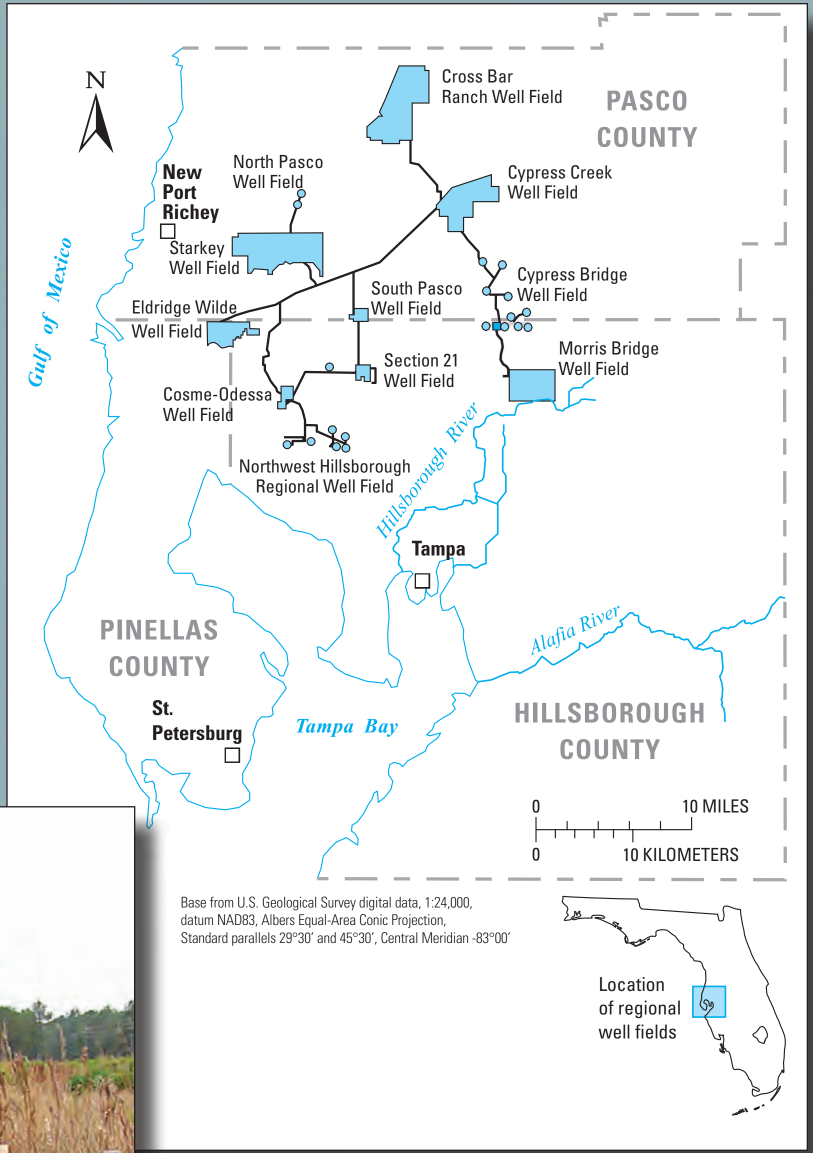

Figure K–1. The 11 regional well fields operated by Tampa Bay Water (above).

Left: Measuring the groundwater level in a wetland monitor well. Photographer credit: Patricia Metz, U.S. Geological Survey.

K

Continued

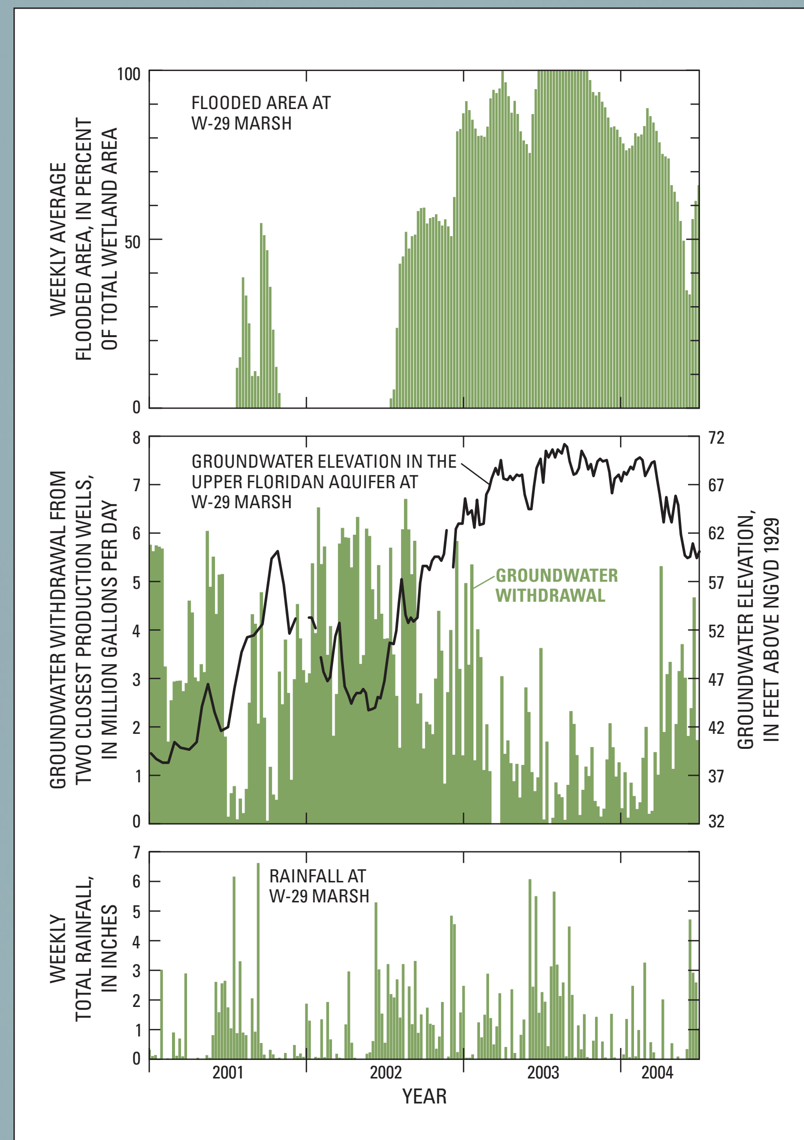

Figure K-2: Reductions in well-field groundwater withdrawals beginning in 2003, and above average rainfall in 2002 and 2003, allowed the recovery of groundwater levels in the Upper Floridan aquifer. W-29 Marsh on Cypress Creek Well Field responded with steadily increasing wetland flooded area (right).

during periods of average to above-average rainfall (fig. K–2). Even with the recovery in the Upper Floridan aquifer, however, reservoir levels will be lower during periods of below-average rainfall, and Tampa Bay Water may require higher than permitted groundwater withdrawal rates from the well fields to meet regional drinking-water demands (Tampa Bay Water, 2008). Daily water levels in wetlands and lakes on and in the vicinity of the well fields may periodically fall below their minimum levels, but the median water levels in wetlands should not fall below their minimum levels (Southwest Florida Water Management District, 1997). Other management tools, including groundwater augmentation of wetland water levels, may be needed to avoid harm to some wetlands.

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Right: Water level indicators such as the lower extent of the moss collar on cypress trees can indicate the extent of recent water levels in forested wetlands. Photographer credit: Michael Hancock, Southwest Florida Water Management District.

Left: The deepest part of W-29 Marsh was dry in 2001 (left), when the potentiometric surface in the Upper Floridan aquifer was low.

Right: The deepest part of W-29 Marsh was flooded in 2003 (right) when aquifer water levels were higher. Photographer credits: Terrie M. Lee, U.S. Geological Survey.

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Physical alterations on property adjacent to wetlands (within about 750–1,200 ft) have been shown to affect wetland plant diversity, including the total number of plant species and the number of individuals in each species. This is because activities that disturb the soil alter the distribution and abundance of seeds available to sprout and grow in wetlands (Houlahan and others, 2006). In addition, nutrient inputs promote plant growth, and plant seeds from garden species in urban areas disrupt native plant communities.

Chemical alterations to wetlands include pollution that raises nutrient levels or introduces toxic compounds. Agricultural and urban runoff to wetlands often results in the addition of excess nutrients, particularly nitrogen and phosphorus. Wetlands have the ability to remove limited quantities of excess nutrients from the water column because they are taken up by algae and wetland vegetation. Elevated nutrient concentrations that cause excessive algal growth can result in the depletion of the already naturally low dissolved oxygen concentrations found in many wetlands. Runoff or leachate from improperly capped or lined landfills has the potential to contaminate wetlands. Stormwater runoff also may contaminate wetlands with oils, greases, and heavy metals from roads and parking lots. Some of those substances, especially heavy metals, may be toxic, whereas others contribute to oxygen depletion as they break down. Wetland bacteria may have the ability to break down or bioaccumulate some toxic substances.

Runoff also may contribute pesticides used on residential and commercial property and roadway easements to nearby wetlands. Pesticides (insecticides, herbicides, fungicides), especially those that are persistent in the environment, can cause mortality of birds, amphibians, and other wetland wildlife. Mosquito control compounds also may eliminate aquatic insects that are important to the wetland food web. Herbicides used to control invasive aquatic plants in public canals and lakes may end up in runoff and damage native wetland plants as well as the target plants.

An important biological alteration that disrupts natural communities and degrades wetlands is the introduction of exotic and invasive species. An exotic species is any species distributed outside of its natural range and dispersal potential, and includes its seeds, eggs, spores, or other biological material capable of propagating that species; exotic species are also known as introduced, alien, or nonindigenous species (National Invasive Species Council, 2006). An invasive species is an exotic species that becomes established in natural or semi-natural ecosystems or habitats, is an agent of change, threatens native biodiversity (of species, populations and/or ecosystems), and whose introduction does or is likely to cause economic or environmental harm or harm to human health (National Invasive Species Council, 2006). Exotic species that can cause alteration and destruction of wetlands include plants, fish, mammals, and other organisms.

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Below: Egg mass of the invasive apple snail (*Pomacea insularum*) on a tree in the flood plain of the Hillsborough River. Photographer credit: Dan Duerr, U.S. Geological Survey.

Two important examples of invasive trees that can degrade and damage wetlands in central Florida are the Australian melaleuca (*Melaleuca quinquenervia*) and Brazilian pepper (*Schinus terebinthefolius*). Melaleuca was introduced to help dry and dewater wetland areas and facilitate development. It has since spread widely and has replaced native vegetation in many wetlands. Control and eradication of melaleuca is an expensive undertaking because the tree produces very large numbers of seeds, and there are no animal species in Florida that consume these seeds. Mature melaleuca trees commonly form dense stands that virtually crowd out all native plant and animal species, especially in disturbed areas. Their growth pattern also allows wildfires to spread more quickly and at a higher temperature. A combination of chemical and biological methods are now showing some success for melaleuca control. Brazilian pepper also has disrupted wetlands throughout central Florida. Imported from South America as an ornamental plant, its seeds are spread widely by birds and mammals, and also by flowing water. Brazilian pepper trees produce a dense canopy that shades out all other plants and provides a poor habitat for wildlife, greatly reducing the quality of biotic communities in the State.

There are numerous examples of invasive submersed, floating, and emergent aquatic plants that have caused alteration and degradation of wetlands in central Florida, including water-hyacinth (*Eichhornia crassipes*), hydrilla (*Hydrilla verticillata*), water lettuce (*Pistia stratiotes*), East Indian hygrophila (*Hygrophila polsperma*), West Indian marsh grass (*Hymenachne amplexicaulis*), torpedo grass (*Panicum repens*), parrot's-feather (*Myriophyllum aquaticum*), and wetland nightshade (*Solanum tampicense*) (University of Florida, 2009). The University of Florida Institute of Food and Agricultural Sciences Center for Aquatic and Invasive Plants in Gainesville is a multidisciplinary research, teaching, and extension unit directed to develop environmentally sound techniques for the management of aquatic and natural area weed species and to coordinate aquatic plant research activities within the State. Aquatic plant management efforts using a combination of biological, mechanical, and chemical methods have shown success in maintenance control of several invasive species, and efforts are ongoing to improve success with species that degrade wetlands, lakes, and rivers.

Some invasive animal species that have the potential to degrade wetlands in central Florida include the Asian swamp eel (or rice eel) (*Monopterus albus*), round goby (*Neogobius melanostomus*), Asian clam (*Corbicula fluminea*), island applesnail (*Pomacea insularum*), greenhouse frog (*Eleutherodactylus planirostris*), and Cuban treefrog (*Osteopilus septentrionalis*). These species damage and degrade wetlands primarily by outcompeting native species. More information about the distribution and biology of invasive aquatic species can be found at the Nonindigenous Aquatic Species information resource of the USGS (*http://nas.er.usgs.gov*). Located at the USGS Southeast Ecological Science Center, Gainesville, this site has been established as a central repository for spatially referenced reports of nonindigenous aquatic species.

Right: The invasive species parrot's-feather (*Myriophyllum aquaticum*). Photographer credit: Dan Duerr, U.S. Geological Survey.

Potential Effects of Global Climate Change on Wetlands

Wetlands are strongly affected by climate variation, in particular temperature and rainfall (Mullholland and others, 1997). Changes in climate are predicted to occur in the 21st century and beyond; the most commonly accepted general circulation models for the United States simulate increases in temperature and atmospheric carbon dioxide (CO_2), and alterations in precipitation patterns, with change unevenly distributed across the country (Burkett and Kusler, 2000).

Temperature is an important factor in controlling plant species distributions, and the warmer temperatures predicted as part of climate change in Florida likely mean higher winter minimum temperatures (Box and others, 1993). The higher winter minimum temperatures and reduced frequency of freezing conditions could facilitate a northward shift in the distribution of many invasive plants, most of which originated in the tropics. Invasive plant species from the tropics to which wetlands are particularly vulnerable include hydrilla (Ficke, 2005), melaleuca (*Melaleuca quinquenervia*) and Brazilian pepper (*Schinus terebinthefolius*) (Box and others, 1993). Many invasive fish and other vertebrates that are tropical in origin, like the Asian swamp eel (*Monopterus albus*), could also move northward under warmer conditions (Mulholland and others, 1997).

Wetlands are vulnerable to changes in water balance driven by global climate change, including an increase or a decrease in the volume of various water sources, and changes in the rate of evapotranspiration (Brinson, 2006). Water balance is more difficult to predict than temperature change, because it also depends on precipitation, which in turn influences evapotranspiration. Wetlands that depend primarily on precipitation as a water source may be more vulnerable to climate change than those that receive a greater proportion of water from groundwater discharge (Winter, 2000).

A warmer and drier climate in the southeastern United States would probably affect populations of bald cypress (Middleton, 2006). Leaf litter production is lowest and tree regeneration is poorest in areas near the edge of the bald cypress geographic range. Stresses exhibited now in these areas are expected to manifest themselves in lower regeneration rates as climate changes across the southern part of the range. Changing climate also may reduce the seed bank density of associated herbaceous swamp species, because germination of many species depends on moisture conditions in the soil and seed density in the seed bank. If the climate becomes warmer and drier, a number of plant species may not be able to move northward fast enough to avoid local elimination, in particular because aquatic seeds disperse southward on most rivers (Middleton, 2003). The St. Johns River is an exception to this pattern, however, because it flows north.

Left: Wetlands in Citrus County provide flood control, aquifer recharge, and opportunities for recreation. Photographer credit: Dan Duerr, U.S. Geological Survey.

Changes in water balance will likely affect wetland communities more than upland ecosystems for several reasons (Burkett and Kusler, 2000). Wetland plants are sensitive to small changes in the level of the water table and the degree of soil saturation. Development and the associated changes that accompany it (construction of roadways, ditching, diking, and drainage) have altered surface drainage patterns, fragmented existing wetlands, and often obstructed the ability of wetland plants to migrate to preferred habitat as water levels change. Other changes to water quality, including pollution and nutrient enrichment, have already stressed many wetlands, impairing their ability to accommodate further changes in water balance.

Riverine and lacustrine wetlands are not isolated, and their hydroperiods are substantially influenced by adjacent surface waters. Under wetter climate conditions, riverine and lacustrine wetlands could increase in size and vegetation **biomass** if surface slopes are gradual. If the shorelines are steep, rising water levels during a wetter period could reduce the amount of fringing wetlands around lakes, and increased velocity of runoff along rivers could erode wetland areas. A drier period with lower lake levels would result in establishment of aquatic plants farther toward the lake from the shoreline, displacing natural habitat for water fowl and wildlife. Under prolonged dry conditions, lakes in central Florida would be at risk. As the groundwater level drops, crevices and cavities in the limestone aquifer are emptied and sinkholes can form (Tihansky, 1999). A recent sinkhole occurred under Lake Scott in Polk County in 2006, and drained the entire lake in only a few days. Riverine wetlands, which can be spring fed, would likely become smaller if climate conditions become drier, and some rivers may be transformed from gaining to losing streams. The Peace River, in the southern part of central Florida, illustrates an extreme example of this situation whereby drier conditions are coupled with long-term groundwater withdrawal to support agriculture, urban water supply, and phosphate mining (PBS&J Science and Engineering, 2007). The potentiometric surface of the Upper Floridan aquifer has declined to such an extent that springs, which had previously discharged to the Peace River and provided base flow, now divert water from the river into underlying aquifers (Metz and Lewelling, 2009).

Increased concentrations of atmospheric carbon dioxide from the burning of fossil fuels could stimulate wetland plant growth and biomass accumulation (Mendelson and Rosenberg, 1994). Wetlands provide more long-term storage of carbon than upland systems (Burkett and Kusler, 2000). Increased wetland plant growth is a potential enhanced “sink” for atmospheric carbon dioxide, as are wetland restoration and creation projects (Burkett and Kusler, 2000). However, a drier climate could accelerate the release of sequestered carbon dioxide in wetland sediments through decomposition, oxidation, or more frequent fires (Intergovernmental Panel on Climate Change, 2006).

Primer Facts

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Wetlands in Central Florida—A Summary of Our Understanding

Wetlands are among the most dynamic ecosystems in central Florida. They are distributed across a variety of landscape types and are present within isolated depressions, around the fringes of lakes, and along the flood plains of rivers. They undergo continuous changes in water depth, the extent of the flooded area, and the frequency of flooding. Wetland water quality changes continually, depending on the predominant water source and biological activities that take place in the water and soils. Wetlands are inhabited by a large number of plants uniquely adapted to changing water levels, and they are colonized by a variety of animals that can take advantage of the available food and shelter that wetlands offer. Finally, wetlands are vulnerable to changes in land use and the many human activities that occur within their drainage basins and often close to their boundaries.

Wetlands as a landscape feature are often admired from afar for their beauty and their value to society, but in proximity they are often misunderstood and unappreciated. In a natural or undeveloped setting, wetlands store water and alleviate flooding following heavy rainfall, provide for water-quality enhancement during the intervals when they hold water, contribute to the recharge of the aquifer, prevent shoreline erosion especially along rivers, and function as valuable plant and wildlife habitat. Wetlands also provide recreational opportunities and aesthetic value to many residents. However, in a developed or agricultural setting, wetlands can be viewed as an impediment to residential and commercial construction, transportation infrastructure, agricultural activities, and water-resource development. Managing wetlands to maintain their ecosystem functions on a sustainable basis is a goal of many water-resource agencies. This goal has become even more challenging under the prevailing conditions of global climate change. Viewing wetlands in the context of their drainage basins, with respect to both hydrology and ecology, is a promising approach to wetland protection, conservation, and sustainability.

Grand Swamp, Disney Wilderness Preserve, Florida.
Photographer credit: Clyde Butcher ©1998. Published with permission.

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Glossary

A

Acidic Term applied to water or other substances with a pH less than 5.5.

Alkaline Term applied to water or other substances with a pH greater than 7.4.

Alkalinity A measure of the capacity of water to neutralize acids.

Aerobic Having or providing oxygen.

Anaerobic Lacking oxygen.

Aquatic Living or growing in or on water.

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

B

Bathymetry The measurement of water depth at various places in a wetland, lake, or other water body.

Bioindicator A species used to monitor the health of an environment or ecosystem.

Biomass The amount of living matter, in the form of organisms, present in a particular habitat, usually expressed as weight per unit area.

Buffered A solution that has the ability to resist a change in pH upon addition of an acid or a base.

C

Carbonates Rock composed chiefly of carbonate minerals such as limestone and dolomite.

Confining layer A body of relatively impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers that restricts the movement of water into and out of those aquifers.

Cypress wetland A poorly drained to permanently wet depression dominated by cypress trees.

D

Discharge wetland A wetland that contains surface water at a lower elevation than the surrounding water table, causing an inflow of groundwater to the wetland.

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

Drainage basin A part of the surface of the Earth that drains into a body of water by way of overland flow or streamflow.

E

Ecology The science of the relations between organisms and their environment.

Emergent plants Erect, rooted, herbaceous plants that may be temporarily to permanently flooded at their base but do not tolerate prolonged inundation of the entire plant.

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

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

F

Flood duration The amount of time that a wetland contains standing water.

Flood frequency The average number of times that a wetland contains standing water during a given period.

Flood plain Flat or nearly flat land adjacent to a stream or river that experiences occasional or periodic flooding.

G

Groundwater Water below the land surface in the saturated zone.

H

Head The measurement of water pressure above a common datum, usually measured as a water surface elevation, expressed in units of length, in a piezometer (a specialized type of water well).

Hydric soils Soil that is wet long enough to periodically produce anaerobic conditions, thereby influencing the growth of plants.

Hydrologic cycle A term describing the circulation of water from the ocean, through the atmosphere, to the land, and back to the ocean by overland and subterranean pathways and by way of the atmosphere; also includes the paths by which water is returned to the atmosphere without reaching the ocean.

Hydrology The science of the water of the Earth.

Hydroperiod The seasonal pattern of the water level in a wetland.

Hyporheic zone The zone beneath a stream bottom where a mixture of surface water and groundwater can be found.

I

Infiltration The flow of water into the Earth through pores in the soil at the land surface.

Invasive species An exotic species that becomes established in natural or semi-natural ecosystems or habitats, is an agent of change, threatens native biodiversity (of species, populations and/or ecosystems), and whose introduction does or is likely to cause economic or environmental harm or harm to human health.

Isolated wetland A wetland with no apparent surface-water connection to streams, rivers, estuaries, or the ocean.

J

K

Karst A region underlain by limestone that contains solution cavities, and where the physical features of the land surface include large and small depressions.

L

M

Marsh A frequently to continually wet depression characterized by emergent herbaceous vegetation.

N

O

Overland flow Nonchannelized flow of water that usually occurs during and immediately following rainfall.

P

Percolation The flow of water through a porous substance, usually in a vertical direction. Rainfall that reaches the land surface infiltrates the surface and percolates downward.

Permeability The capacity of soil to conduct water flow; also known as hydraulic conductivity.

pH A measure of the hydrogen ion concentration of a liquid.

Potentiometric surface The surface that represents the level to which water will rise in a tightly cased (sealed) well.

Precipitation Water from the atmosphere that reaches the land surface as rain, frozen rain, or snow.

Q

R

Recharge wetland A wetland that contains surface water at a higher elevation than the adjacent water table, causing an outflow of wetland water to groundwater.

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

River mile Measure of distance in miles along a river from its mouth. River mile numbers begin at zero and increase farther upstream.

Runoff Nonchannelized surface-water flow.

S

Saturated zone The zone below the land surface in which soil or rock is saturated with water under hydrostatic pressure.

Scrub A general term for short, dense vegetation dominated by shrubs (woody plants less than 20 ft high), which typically forms an intermediate community between grass and forest.

Seasonally flooded Wetlands that are flooded for extended periods during and following the wet season, but with no remaining surface water by the end of the dry season.

Seepage A process in which water moves slowly through the surface and subsurface environments, or the actual water involved in this process.

Seepage wetland A wetland on sloped or flat sands or peat with high moisture levels maintained by downslope seepage.

Shrub A woody plant which at maturity is usually less than 20 ft high and generally exhibits several erect, spreading, or prostrate stems, and has a bushy appearance.

Sinkhole A funnel-shaped depression in the surface of the Earth caused by dissolution of underlying limestones.

Slough A slow moving body of water occupying a shallow, poorly-defined channel that is slightly deeper than the surrounding area. Sloughs may be intermittent.

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

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

Swamp A water-saturated area, intermittently or permanently covered with water, vegetated with trees and shrubs.

T

Transpiration The processes by which plants take water from the soil, use it in plant growth, and then transpire it to the atmosphere in the form of water vapor. Evaporation and transpiration are collectively referred to as evapotranspiration.

U

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

V

W

Water budget An accounting of the inflow to, outflow from, and storage within a wetland, lake, or drainage basin.

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

Well field An area developed by a local or regional water authority where groundwater is withdrawn from the aquifer and sent to a treatment or distribution system.

Wetland An ecosystem characterized by the presence of shallow water or flooded soils for part of the growing season, plants adapted to a wet environment, and soil indicators of flooding (hydric soils).

Wetland augmentation The addition of water from an external source to increase the water level in a wetland.

X

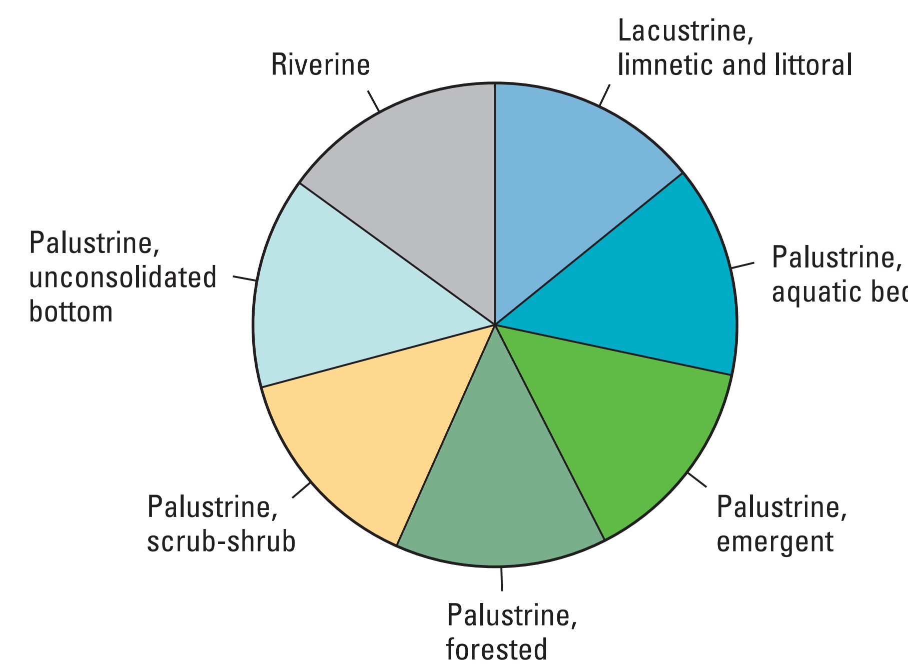
Y

Z

Appendix

This appendix includes maps showing the distribution of wetlands by type and pie diagrams showing the percent of each wetland type in each county of central Florida.

PIE CHART EXPLANATION



Note: Appendix maps are in a separate PDF file.

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