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Haag, K.H., and Lee, T.M., 2010, Hydrology and Ecology of Freshwater Wetlands in Central Florida—A Primer: U.S. Geological Survey Circular 1342, p. 8-11

A 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

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. 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.

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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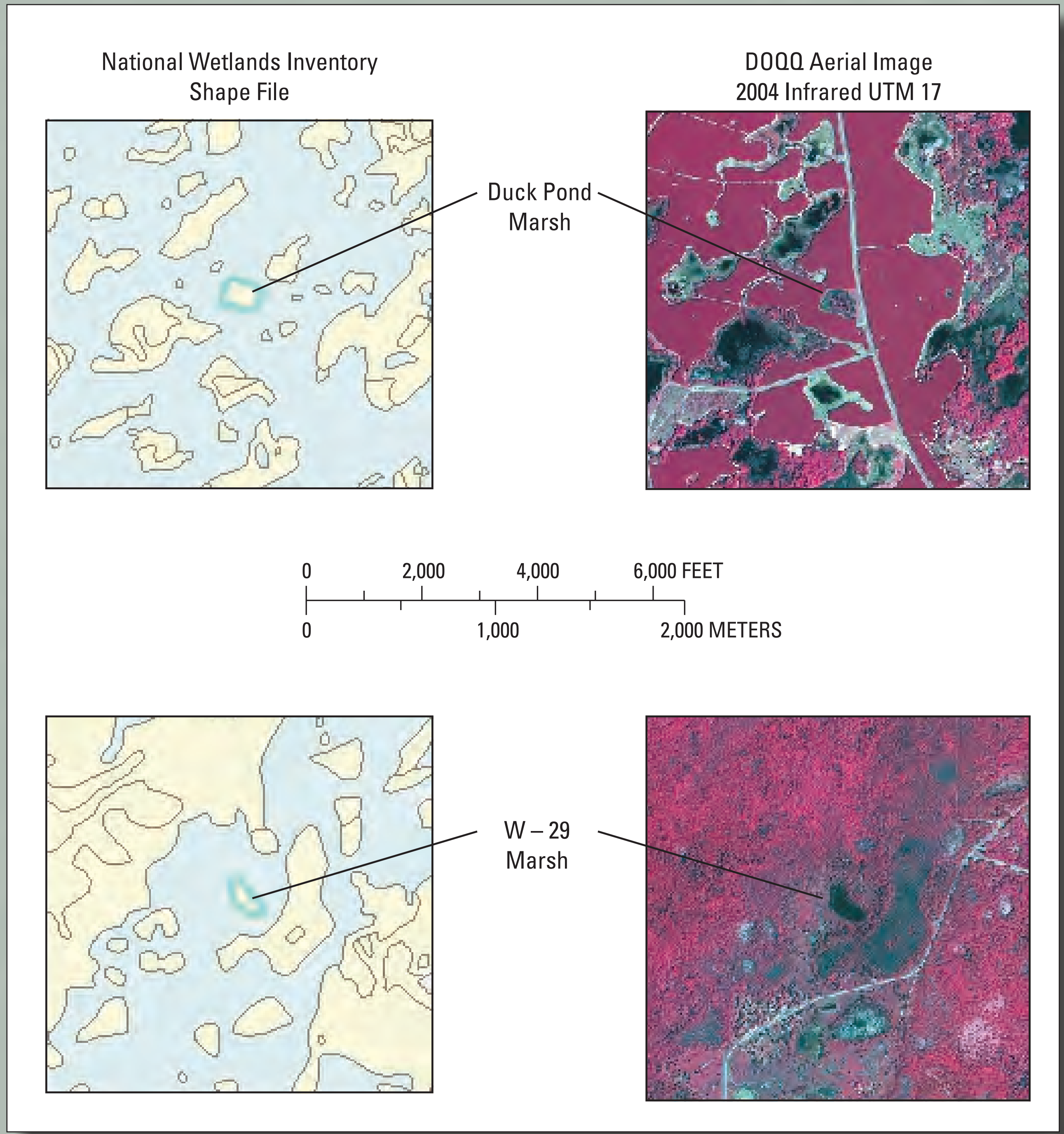

A–1. Digital orthophoto quadrangles (DOQs) are computer-generated images of aerial photographs in which the image displacement caused by uneven terrain and camera tilt have been removed.

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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 wetlands, 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).

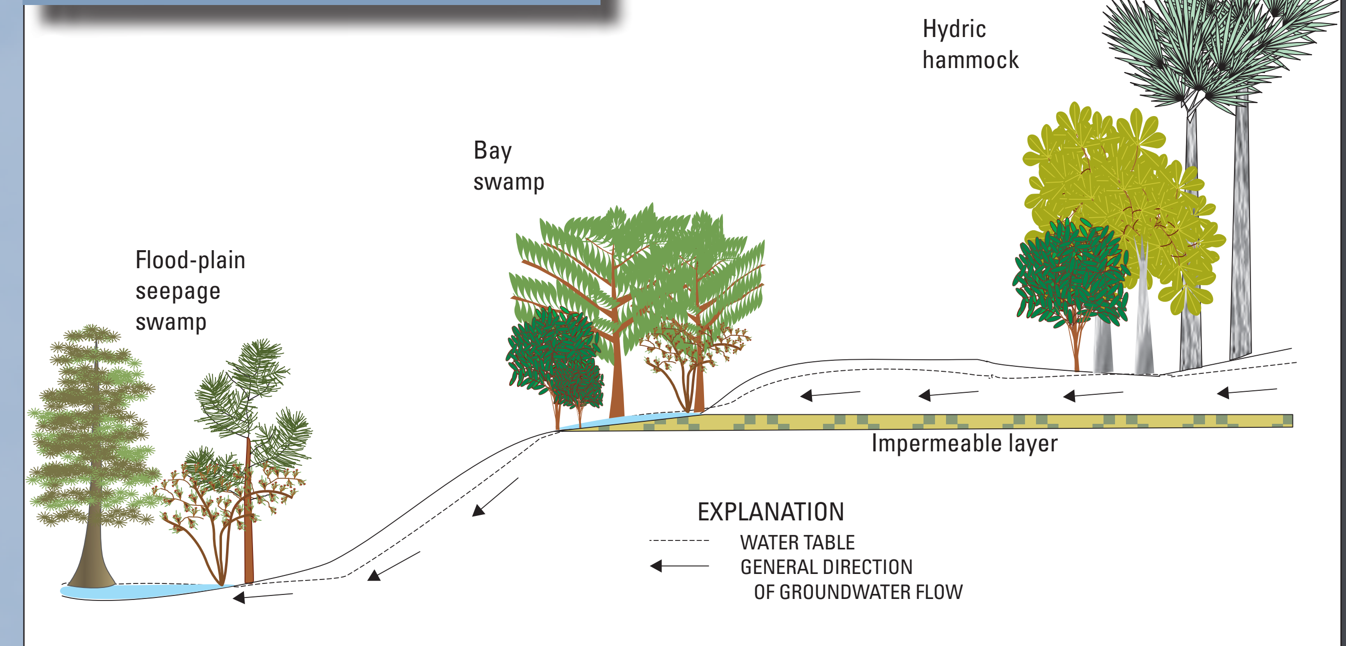
Bay heads are dense evergreen forests or shrub thickets with an understory of moss and ferns. The canopy is composed of densely-packed stands of fragrant sweetbay (*Magnolia virginiana*), swamp bay (*Persea palustris*), red bay (*Persea borbonia*), and loblolly bay (*Gordonia lasianthus*).

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

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.

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).

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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.

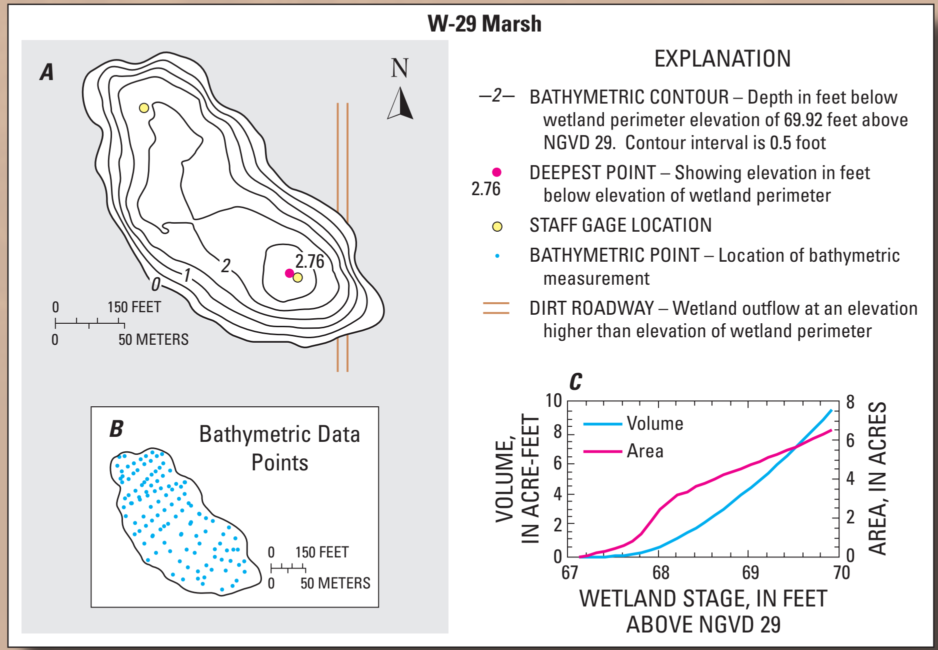
Flooded area, expressed as a percentage of the total wetland area, is a versatile and descriptive measurement that can be compared through time for an individual wetland or compared spatially for numerous wetlands in a region during a particular month or year (Haag and others, 2005; Lee and Haag, 2006). 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.

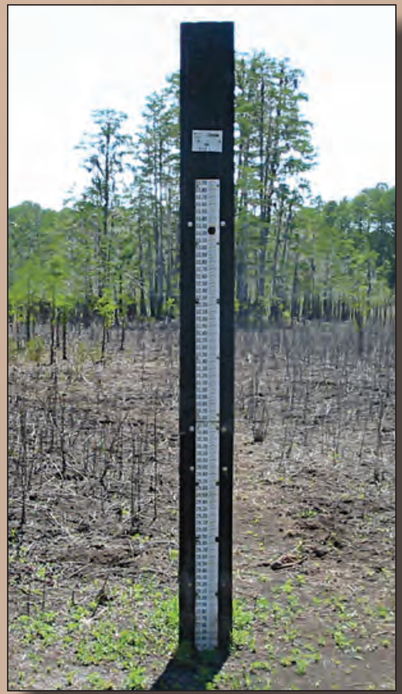
The size of the flooded area can be determined for a given water-surface elevation if a bathymetric map exists for a wetland. Bathymetric maps show contours of bottom depth throughout a body of water, and bathymetric mapping is a well-established tool in lake studies where the depth of a lake bottom 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.

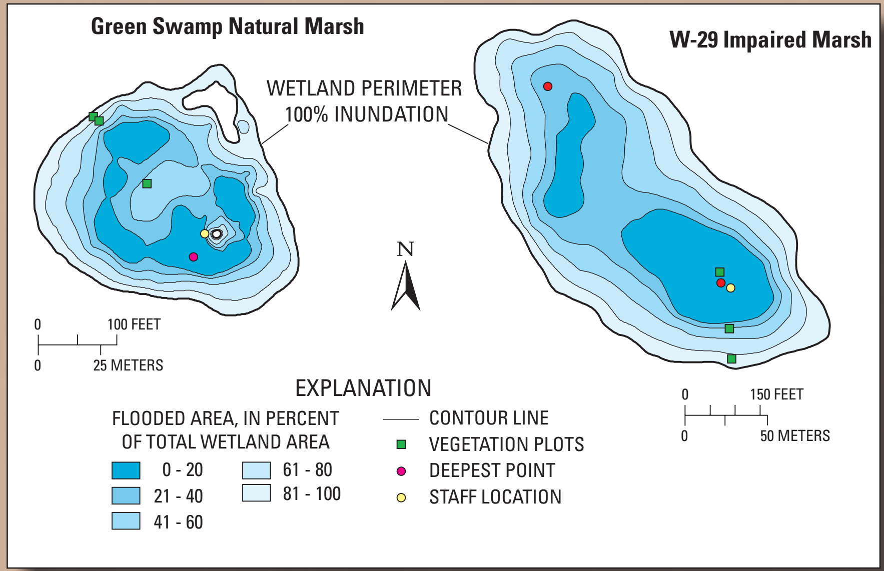


Figure C–1B. Maps generated from bathymetric data that are used to contour the shape of the flooded area as different percentages of the total wetland area become flooded (above, modified from Lee and others, 2009).

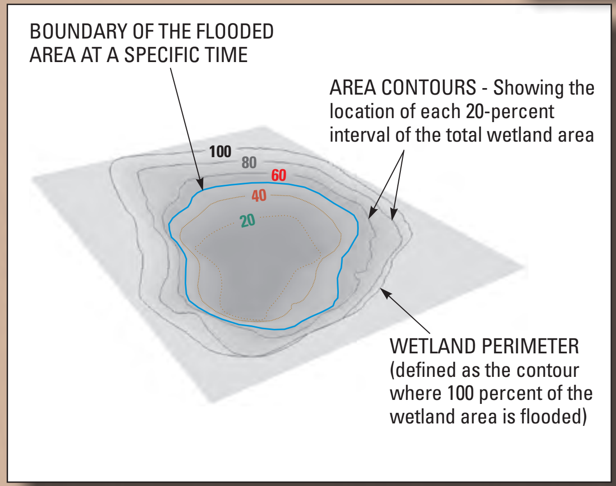


Figure C–2. Conceptualized wetland showing the boundary of the flooded area located in different 20-percent intervals of the total wetland area (left).

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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 ≥ 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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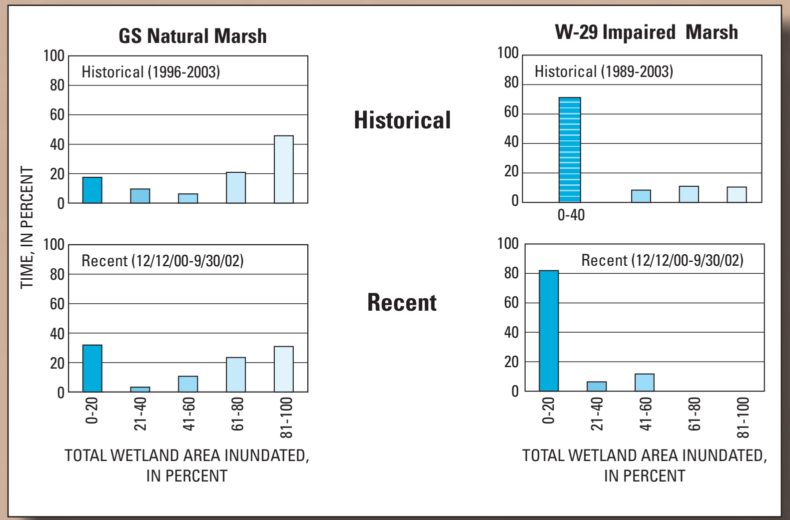

Figure C–3. Comparison of the flooded area of a natural wetland (GS Natural Marsh, Sumter County, Florida) and an impaired wetland (W-29 Impaired Marsh, Pasco County, Florida) during recent and historical time periods to indicate wetland areas that are not routinely flooded (right; modified from Lee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

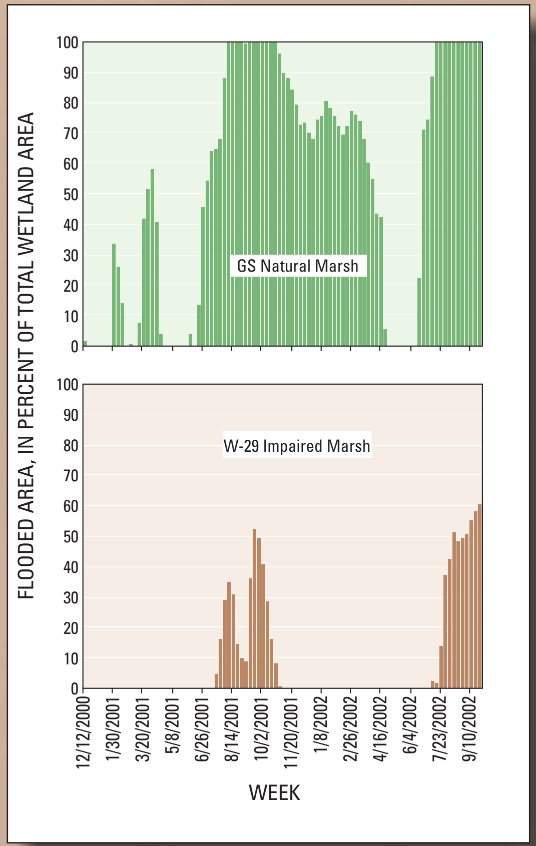

Figure C–4. Percentage of the total wetland area flooded on average each week in a natural and an impaired marsh. (Flooded areas beyond 100 percent of the total wetland area are not shown) (above; modified from Lee and others, 2009).

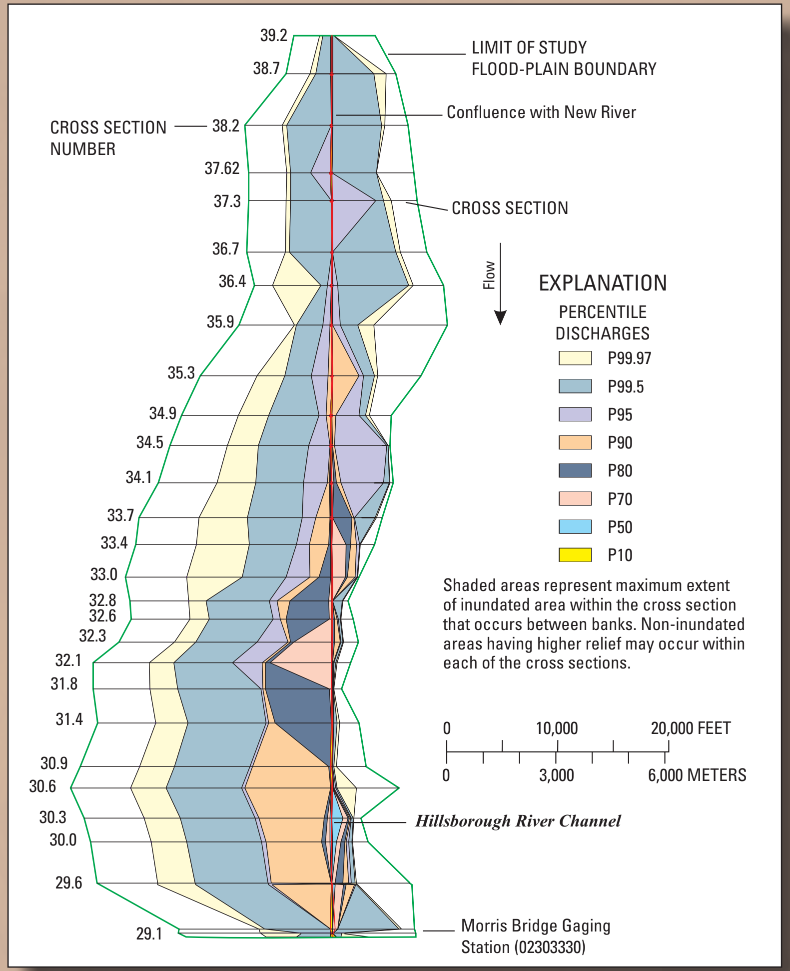

Figure C–5. The Hillsborough River inundates increasing areas of flood-plain wetlands as the river flow increases (right; modified from Lewelling, 2004).

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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

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.

EXPLANATION
- WETLAND PERIMETER
- FLOODED WETLAND AREA
- DRY WETLAND AREA
- I INFLOW VOLUME
- O OUTFLOW VOLUME

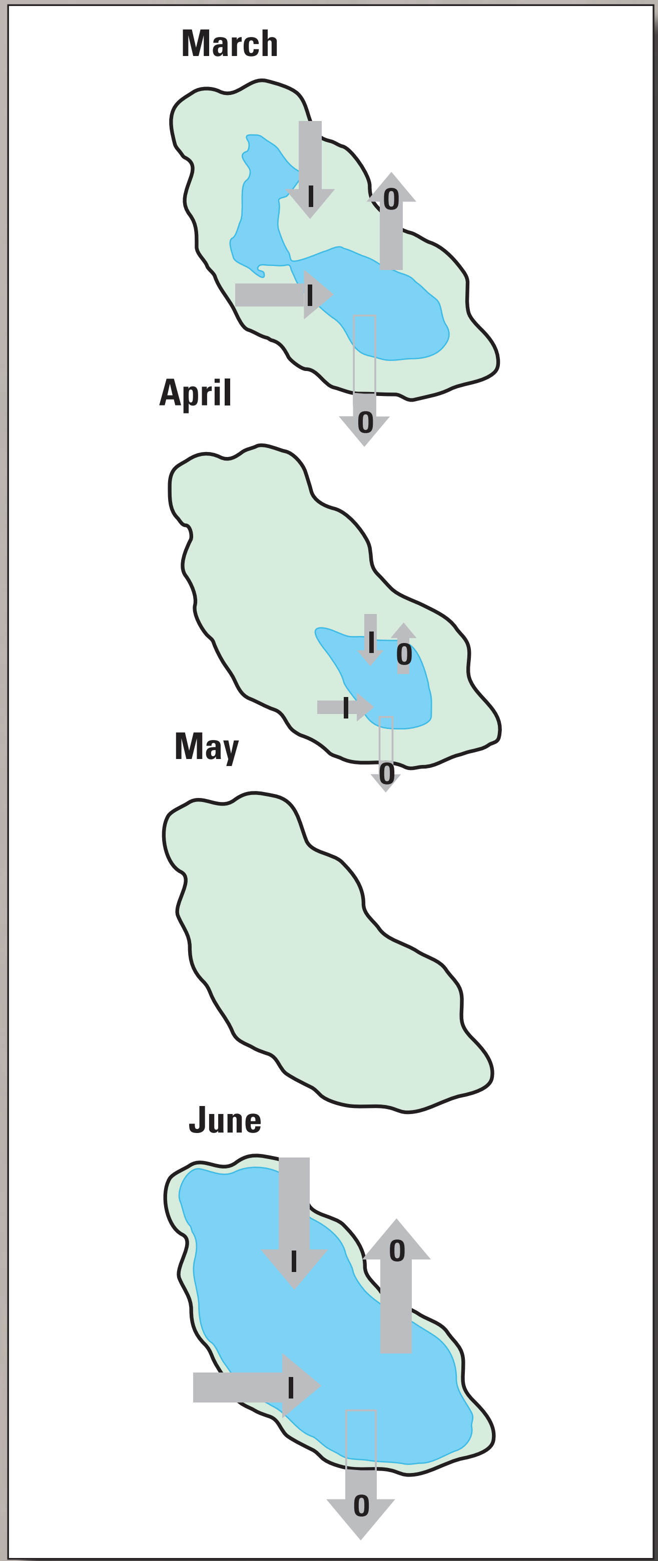

Figure D–1. Conceptualized wetland showing seasonal changes in the magnitude of water-budget components. Relative size of arrows indicates differences in volume. Volumes of the water-budget components change with the size of the flooded area.

Haag, K.H., and Lee, T.M., 2010, Hydrology and Ecology of Freshwater Wetlands in Central Florida—A Primer: U.S. Geological Survey Circular 1342, p. 44-47

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.

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.

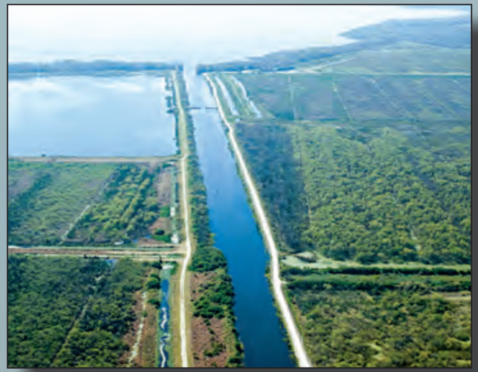
In 1941, a levee was built across the north shore of the lake and 20,000 acres of shallow wetlands north of the levee (about one-third of the lake area) were drained for muck farming operations. Muck is dark soil rich in decaying plant material, and it was left behind when the wetlands were drained. 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 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).



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

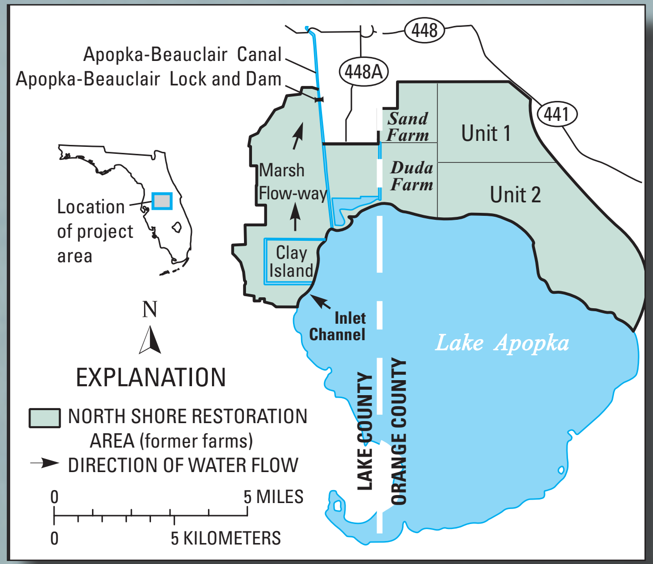


Figure E–1. The Lake Apopka Restoration project area (modified from St. Johns River Water Management District, 2006).

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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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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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 bioindicators 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_2M 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

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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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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

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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.

Haag, K.H., and Lee, T.M., 2010, Hydrology and Ecology of Freshwater Wetlands in Central Florida—A Primer: U.S. Geological Survey Circular 1342, p. 76-79

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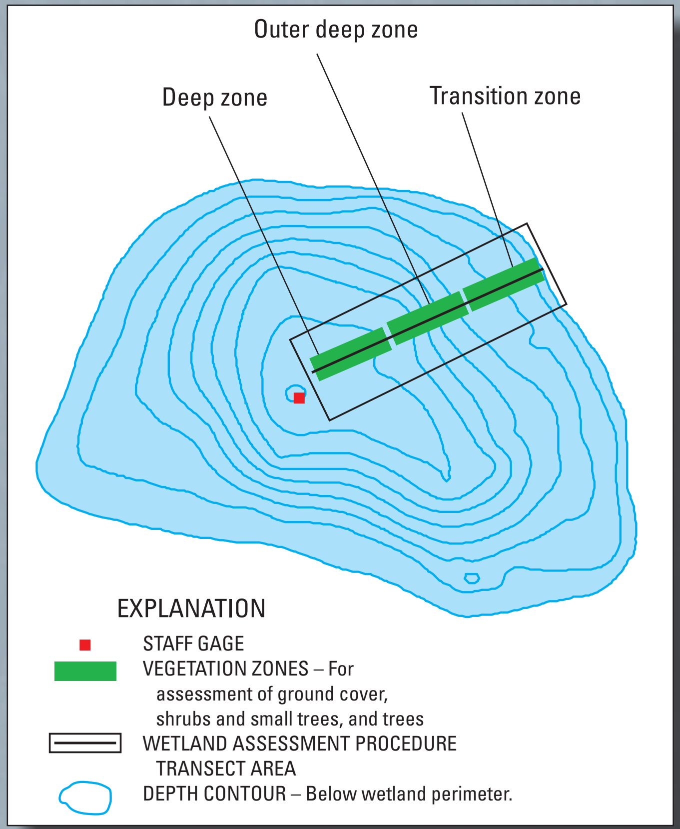

Figure H–1. Conceptual drawing of a Wetland Assessment Procedure transect for monitoring and periodic evaluation of wetlands included in Tampa Bay Water's Consolidated Water Use Permit.

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

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.

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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*).

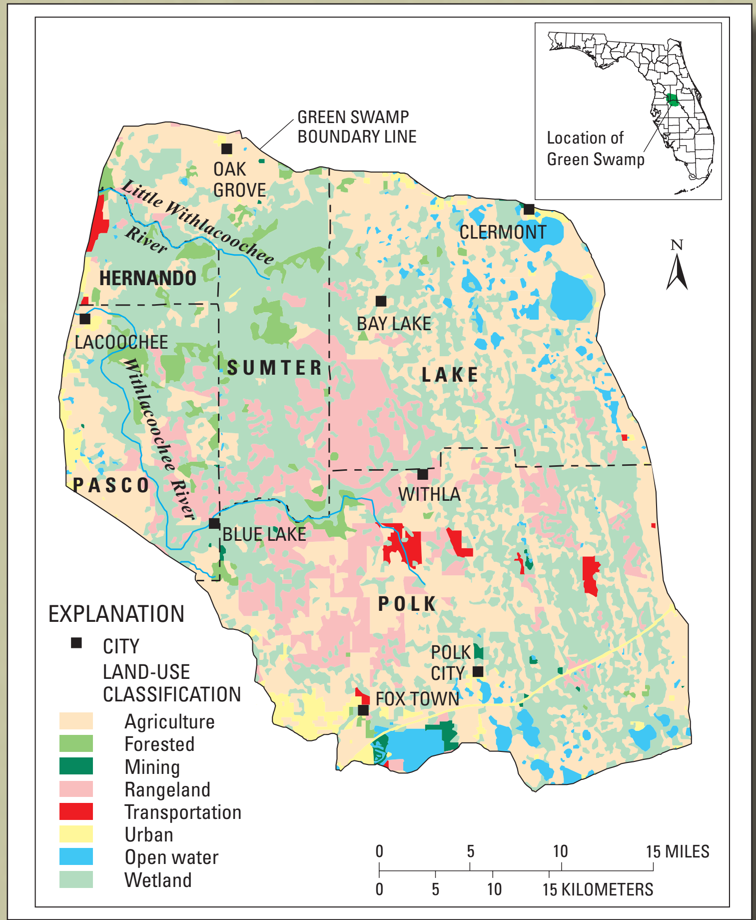

Figure I–1. Generalized land use in the Green Swamp.

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

Primer Facts

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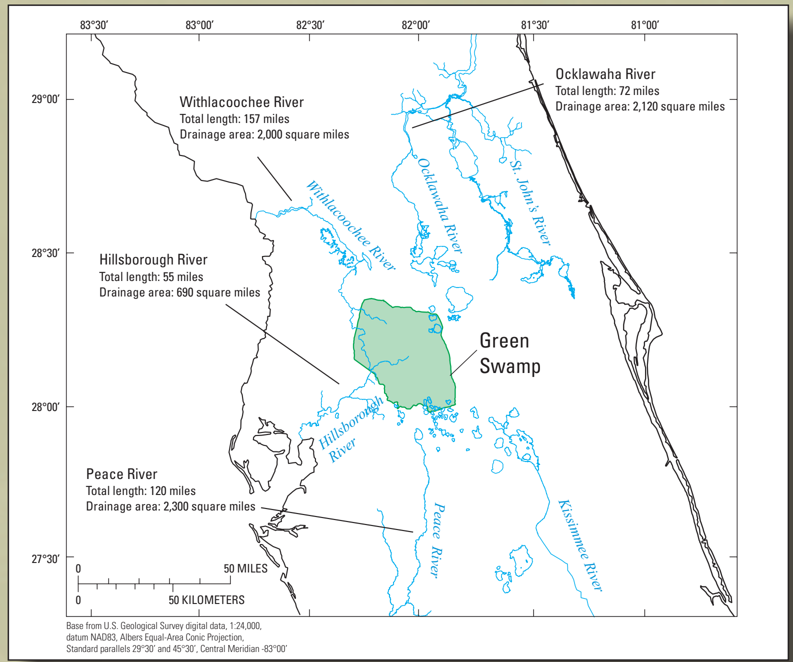

Figure I–2. The Green Swamp is the headwaters for the Hillsborough, Ocklawaha, Peace, and Withlacoochee Rivers.

Haag, K.H., and Lee, T.M., 2010, Hydrology and Ecology of Freshwater Wetlands in Central Florida—A Primer: U.S. Geological Survey Circular 1342, p. 82-85

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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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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.

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.

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 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.

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

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

Primer Facts

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).

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

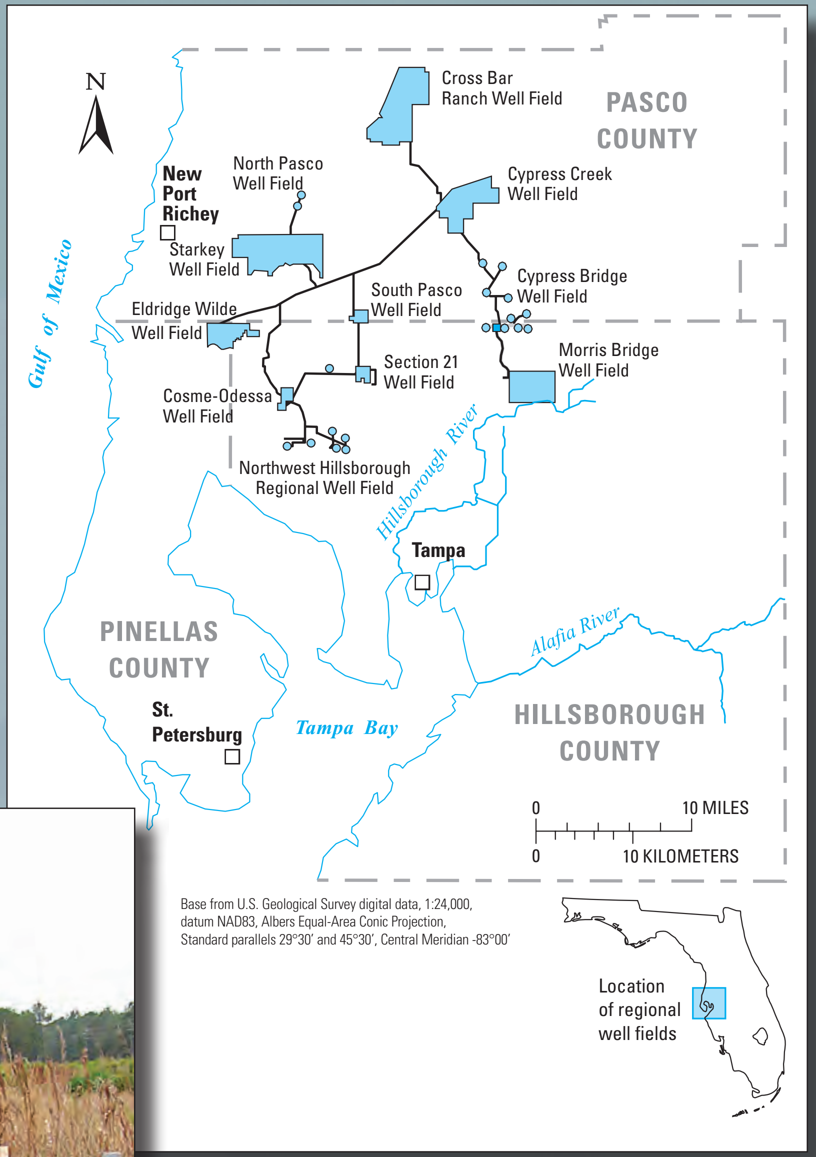

Figure K–1. The 11 regional well fields operated by Tampa Bay Water (above).

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

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K Continued

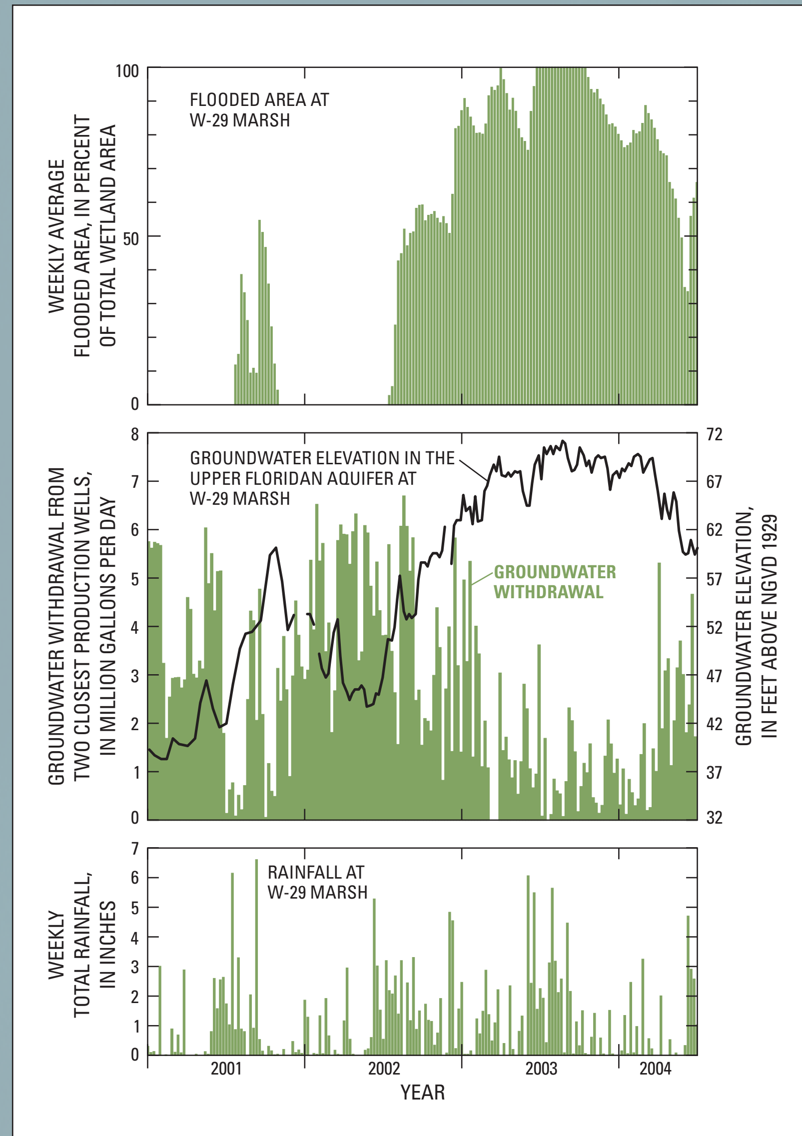

Figure K-2: Reductions in well-field groundwater withdrawals beginning in 2003, and above average rainfall in 2002 and 2003, allowed the recovery of groundwater levels in the Upper Floridan aquifer. W-29 Marsh on Cypress Creek Well Field responded with steadily increasing wetland flooded area (right).

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.

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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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.
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