PROFESSIONAL PAPER SJ2006-PP1

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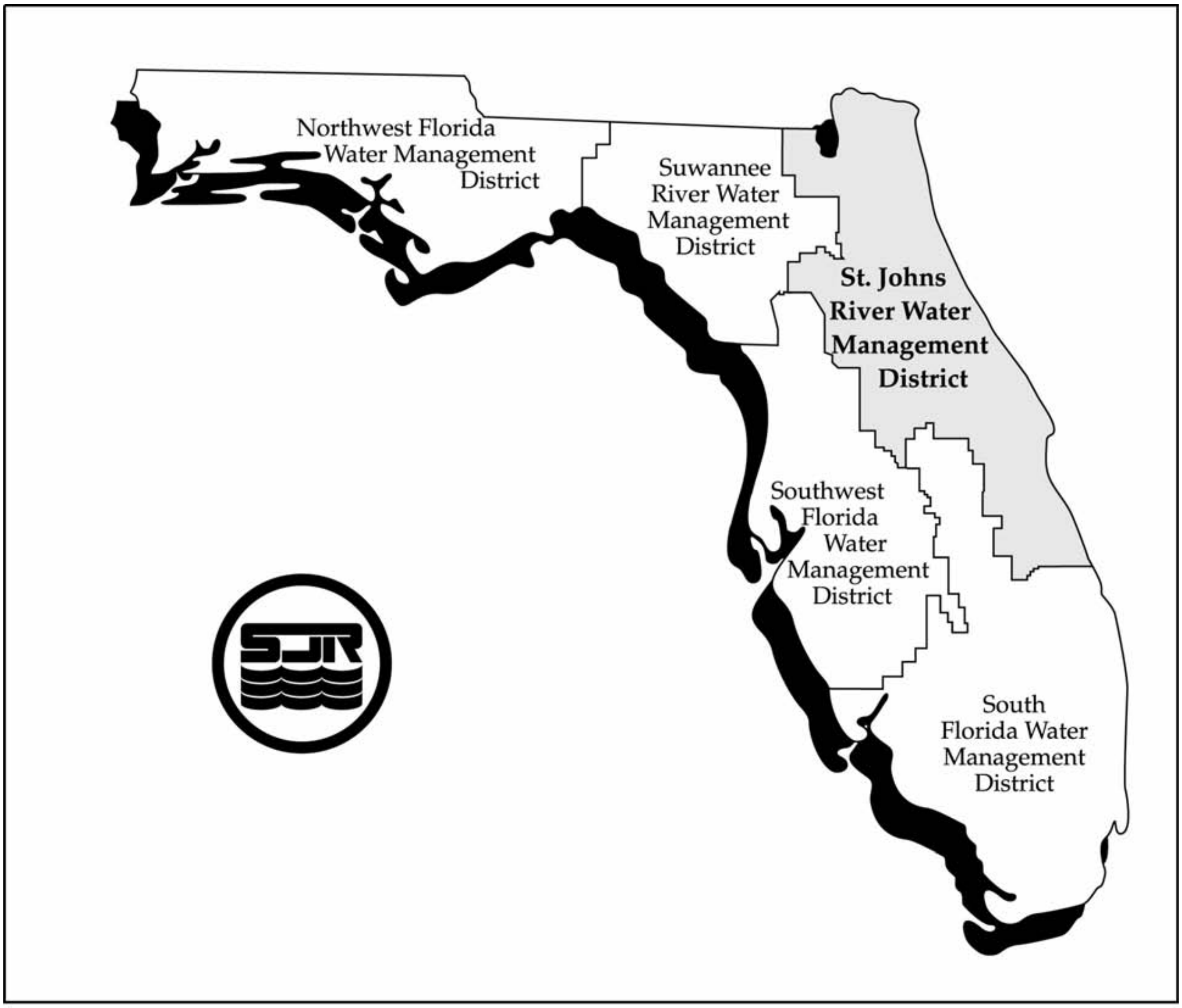
St. Johns River Water Management District
Palatka, Florida

2006



The St. Johns River Water Management District (SJRWMD) was created by the Florida Legislature in 1972 to be one of five water management districts in Florida. It includes all or part of 18 counties in northeast Florida. The mission of SJRWMD is to ensure the sustainable use and protection of water resources for the benefit of the people of the District and the state of Florida. SJRWMD accomplishes its mission through regulation; applied research; assistance to federal, state, and local governments; operation and maintenance of water control works; and land acquisition and management.

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ABSTRACT

A GIS-based model was developed to predict the likelihood of harm to lakes in the St. Johns River Water Management District (SJRWMD) from future groundwater withdrawals. Six spatial data layers representing hydrogeological features that characterize or influence lakes, including the thickness of the confining unit, head difference between the surficial and Floridan aquifer water levels, soil permeability, wetland frequency, topographic curvature (regionally high or low elevations), and topographic deviation (local hills and valleys), were combined to produce a map of lake susceptibility to groundwater withdrawals. This map was then combined with GIS layers representing SJRWMD lakes and estimated drawdown of the surficial aquifer for the year 2025 to produce a final map showing likelihood of harm to lakes within SJRWMD. Parts of Seminole County, Orange County, southeastern Lake County, and central Volusia County contained a high concentration of lakes at risk of harm from groundwater withdrawals by the year 2025, reflecting the occurrence of lakes susceptible to drawdown and modeled declines of surficial aquifer water levels in these areas.

INTRODUCTION

The St. Johns River Water Management District (SJRWMD) is mandated to identify "specific geographical areas that have water resource problems which have become critical or are anticipated to become critical within the next 20 years" (Section 62-40.520, *Florida Administrative Code).* As part of its effort to address this requirement (Vergara 2000), SJRWMD has examined the likelihood that unacceptable impacts (harm) would occur to lakes in SJRWMD as a result of projected future groundwater withdrawals. Although an earlier investigation (Kinser and Minno 1995) was conducted to estimate the likelihood of harm to native vegetation from groundwater withdrawals, the response of lakes was not specifically addressed. The investigation that is the subject of this document integrates regional hydrogeological characteristics and estimated groundwater level drawdowns to predict areas of SJRWMD where lakes may be at risk of harm.

Lakes are among SJRWMD's most valued resources. Their aesthetic appeal adds substantially to waterfront property values, which in turn generate tax revenues for local governments. Fish camps and other businesses provide lake visitors with supplies and services that benefit local economies directly. Commercial fishing on SJRWMD's larger lakes also produces some economic activity, but far greater benefits are produced from recreational boating and sport fishing. Some of the best bass fishing lakes in the world are located in SJRWMD, and trophy fishing, guide services, and high-stakes fishing tournaments generate substantial revenues for local economies. Swimming, fishing, and boating are among the most popular outdoor activities for many SJRWMD residents and out-of-state visitors. Lakes are frequent venues for duck hunting, bird-watching, photography, and other nature-related activities. Lakes are also used as sources of water for agricultural and landscape irrigation.

SJRWMD has over 2,900 lakes (Table 1). SJRWMD lakes range in size from 1 acre to approximately 46,000 acres and together cover about 5% of SJRWMD's surface area. While most of the lakes are small (median, 23 acres; mean, 151 acres), 12 have surface areas greater than 10 square miles each. Ten of Florida's 20 largest lakes, including Lake George, the second largest, occur in SJRWMD (Table 2). Almost 90% of SJRWMD's lakes occur in Lake, Marion, Osceola, Orange, Putnam, Seminole, and Volusia counties (Table 1) in areas of karst topography. Most of the lakes have resulted from sinkhole formation in ancient times.

In Florida, lake levels fluctuate in response to seasonal as well as year-to-year, or even multiyear, rainfall cycles. Depending upon the geological setting, including characteristics of the lake bottom and surrounding landscape, the natural range of fluctuation of Florida lakes may be only a foot or two or may be tens of feet. Anthropogenic activities, including the construction and operation of water control structures, discharge of storm water and other effluents, alteration of basin runoff characteristics, diversion of surface water for agricultural, navigational, or potable water use, and pumping of groundwater, may cause lake levels to fluctuate beyond their natural range and cause harm. Groundwater pumping, although less visible and more difficult to assess than other activities, has become an increasing concern in some parts of SJRWMD. Unfortunately, only a few peer-reviewed articles have been published on the effects of groundwater pumping on Florida lakes (Lopez and Fretwell 1992). A review of relevant literature indicated no systematic attempt had been made, prior to this investigation, to assess the potential of harm to lakes from groundwater withdrawals on a regional scale.

The water budgets of most lakes may be described in terms of inflows and outflows of surface water and groundwater, precipitation, evapotranspiration, and storage. To fully understand and account for lake level fluctuation, the timing, magnitudes, and directions of each of these flows must be known. In the absence of this knowledge, less direct methods, such as the geographic information system (GIS) approach described in this paper, must be used.

The objectives of this investigation were to develop a GIS model to describe the potential for harm to lakes from groundwater withdrawals and to highlight those areas of SJRWMD at greatest future risk. The model was based on GIS layers that were considered to be predictive of groundwater-lake level interactions and on estimated changes in the elevation of the water level of the surficial aquifer from 1995 to 2025.

Table 1. Distribution and size of lakes in the St. Johns River Water Management District (SJRWMD), by county

County	Surface Area (acres)	Number	Largest Lake in County (acres)
Alachua	42,260	109	Orange Lake (12,706)
Baker*	0	0	None†
Bradford*	303	3	Lake Bedford† (196)
Brevard	16,628	94	Lake Washington (4,362)
Clay	16,232	69	Doctors Lake (3,397)
Duval	482	26	Unnamed lake (81)
Flagler	2,709	17	Lake Disston (1,844)
Indian River	7,191	22	Blue Cypress Lake (6,555)
Lake	96,341	606	Lake Griffin (16,505)
Marion*	24,644	234	Lake Weir† (5,760)
Nassau	119	3	Hampton Walker Lake (100)
Okeechobee*	290	11	Unnamed lake† (100)
Orange	57,539	505	Lake Apopka (30,671)
Osceola*	22,070	416	Taylor Creek Reservoir† (3,600)
Putnam	49,832	284	Crescent Lake (15,960)
Seminole	18,844	189	Lake Jesup (10,011)
St. Johns	1,289	10	Guana Lake impoundment (955)
Volusia	83,241	315	Lake George (46,000)
Total	440,014	2,913	

*County lies only partially within SJRWMD
†In SJRWMD portion of county

Source: Shafer et al. 1986; SJRWMD minimum flows and levels lakes database

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Table 2. Large lakes of the St. Johns River Water Management District

Lake Name	Size (acres)	Elevation (feet)	County
George	46,000	3	Volusia
Apopka	30,671	66	Orange
Griffin	16,505	59	Lake
Crescent	15,960	1	Putnam
Harris	13,788	63	Lake
Rodman Reservoir	13,000	20	Putnam
Orange	12,706	58	Alachua
Jesup	10,011	3	Seminole
Monroe	9,406	3	Volusia
Eustis	7,806	63	Lake

Source: Shafer et al. 1986

METHODS

An ARC/INFO GIS model (Figure 1) was developed to estimate the likelihood of harm to lakes throughout SJRWMD from groundwater withdrawals projected to occur by the year 2025. Six GIS data layers, each influencing or expressing groundwater-surface water interactions, were used as inputs to the model. These included the following:

1. Thickness of the confining unit
2. Head difference between the surficial and Floridan aquifer water levels
3. Soil permeability
4. Wetland frequency
5. Topographic deviation
6. Topographic curvature

These GIS layers were created or taken directly from SJRWMD's GIS database. The layers were converted from vector to raster format (ARC/INFO grids) with a cell size of 500 square feet. All layers were then scored and weighted as described herein and combined to produce a map showing areas of susceptibility to harm from projected groundwater withdrawals. Susceptibility was then classified on a relative scale of low (cell values of 1–30), moderate (cell values of 30–40), and high (cell values of 50–60). The first two quartiles of data values were placed in the low category, the third quartile in the moderate category, and the fourth in the high category. Other groupings were considered, but these were selected as the best to meet the goal of predicting which lakes in the district are at risk of harm from future groundwater withdrawals. A map layer of lakes found in SJRWMD was overlain onto the regional susceptibility map. Each lake was given the susceptibility to groundwater withdrawal rating associated with its location on the susceptibility map.

Last, the lake susceptibility map was overlain with the projected drawdown of water levels in the surficial aquifer for 2025 to produce a map showing likelihood of harm to lakes from future groundwater withdrawals. The surficial aquifer map was produced using steady-state regional groundwater flow models of the surficial and Floridan aquifers (Table 3).

For the GIS model, surficial aquifer water level drawdown was rated as either relatively low (less than 0.5 foot [ft]) or relatively high (greater than or equal to 0.5 ft), based upon the SJRWMD water supply planning constraint for lakes (CH2MHILL 1998). Lakes having low susceptibility to water level drawdown in areas expected to have no or relatively low surficial aquifer declines by the year 2025 were rated as having low likelihood of harm. In contrast, lakes with moderate or high susceptibility to water level drawdown in areas expected to have 0.5 ft or greater of surficial aquifer water level drawdown were rated as having relatively high risk of harm by the year 2025.

Data Layers

Thickness of the Confining Unit. SJRWMD staff (Boniol et al. 1993) created a GIS layer representing the confining unit thickness above the Floridan aquifer from geophysical and lithologic log data and previously published map data (Miller 1986). The elevation of the top of the Floridan aquifer was subtracted from the elevation at the top of the confining unit to obtain confining unit thickness. Values ranged from 10 ft to 540 ft, but most of the study area had values between 10 ft and 150 ft (Figure 2).

This layer is important for assessing the hydrologic connection between the Floridan aquifer and surface water bodies. Regions with a thick confining unit are not readily

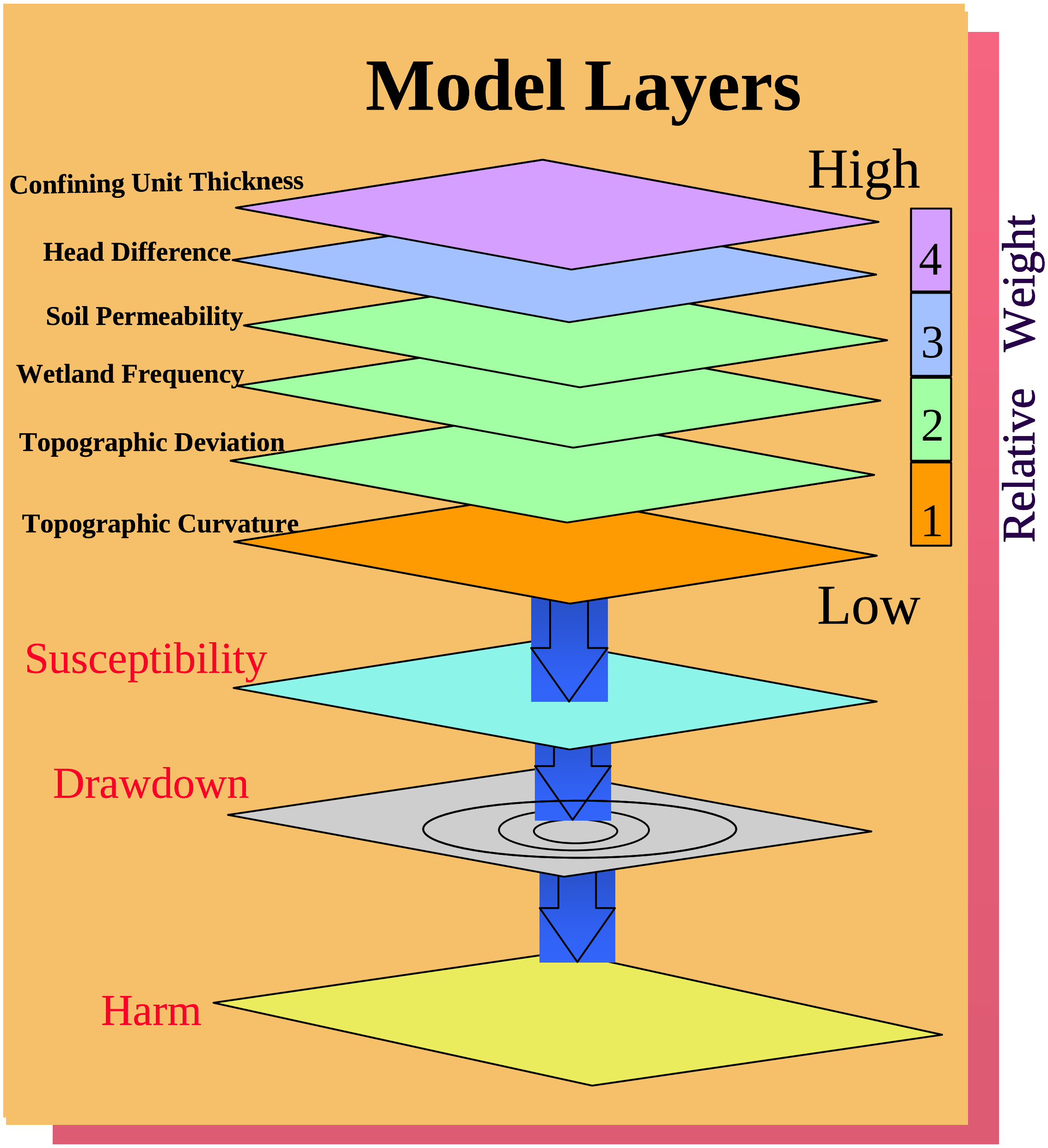

Figure 1. Graphical representation of the GIS model used to estimate the likelihood of harm to lakes from groundwater withdrawal in the St. Johns River Water Management District by the year 2025

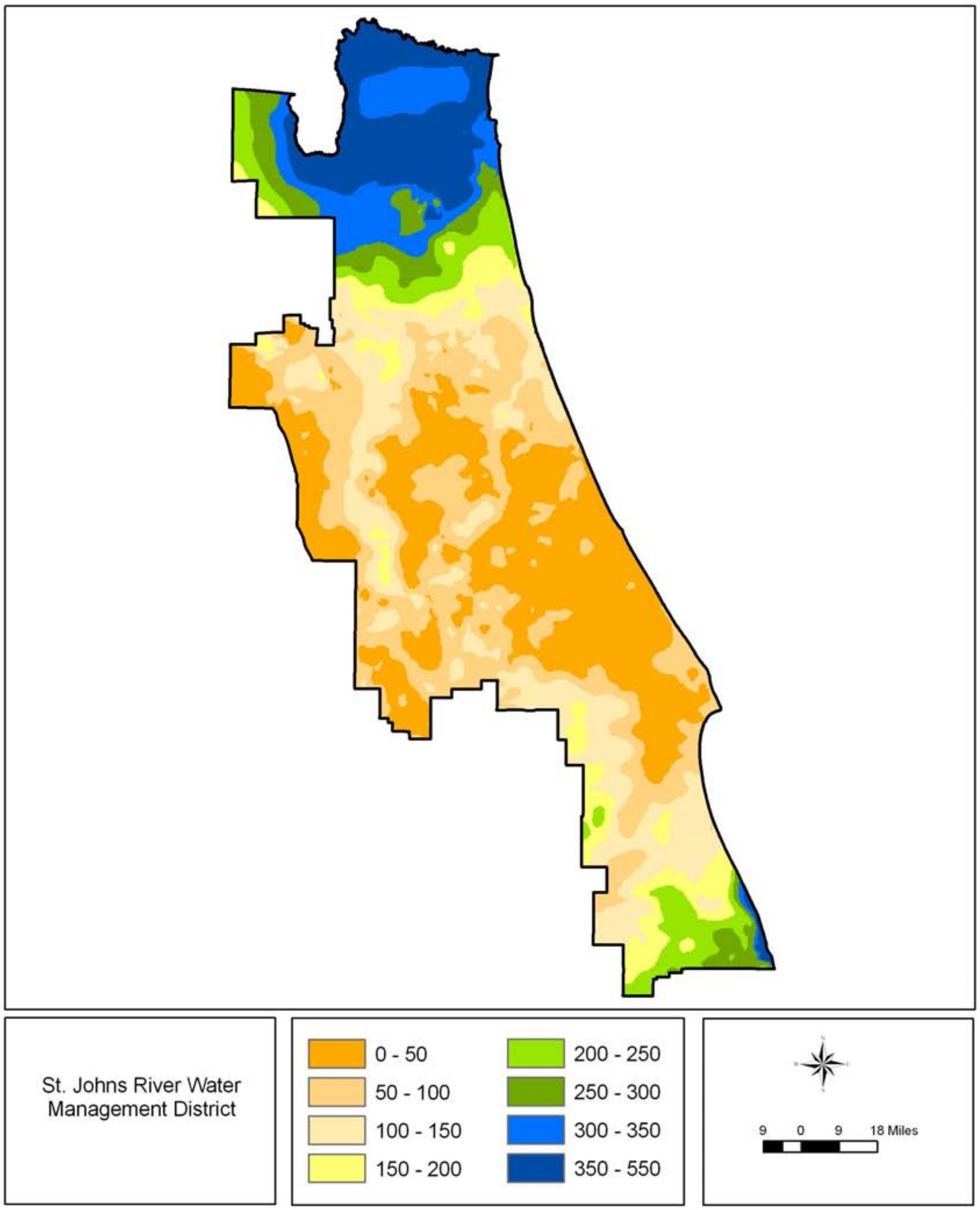

Figure 2. Thickness of the confining unit (in feet) in the St. Johns River Water Management District, northeastern Florida

Table 3. Summary of the analytical and regional numerical groundwater flow models used to derive the 2025 surficial aquifer drawdown map of the St. Johns River Water Management District

Analytical Groundwater Flow Models	
Area Modeled	Model Documentation
Palm Coast Utilities Wellfield area, Flagler County	Rabbani et al. 2005 (draft)
City of St. Augustine Wellfield, St. Johns County	Toth 2001a
Tillman Ridge Wellfield, St. Johns County	Toth 2001b
City of Vero Beach and Indian River County wellfields, Indian River County	Toth 2001c
Regional Numerical Groundwater Flow Models	
Area Modeled	Model Documentation
Duval (in part), St. Johns, Nassau, and Clay counties, Florida; Camden, Charlton, and Ware counties, Georgia	Birdie 2005 (draft)
Parts of Columbia, Baker, Duval, Union, Bradford, Clay, Alachua, Putnam, Marion, and Levy counties	Motz and Dogan 2002
Volusia and parts of Flagler, Putnam, Lake, and Seminole counties	Williams 2005 (draft)
Flagler, northern Brevard, and parts of Volusia, Putnam, Lake, and Seminole counties	McGurk and Fischl-Presley 2002

influenced by fluctuations in the potentiometric level of the Floridan aquifer. The thicker the confining unit, the more likely a lake will be poorly connected to the Floridan aquifer. Although most, if not all, lakes in SJRWMD are hydrologically connected to the Floridan aquifer, those in areas with thicker confining units are more likely to have poorer connections than those in areas with thinner confining units.

Head Difference Between the Surficial and Floridan Aquifer Water Levels. The GIS layer representing head difference between the surficial and Floridan aquifers shows recharge and discharge areas of the Floridan aquifer. This layer was developed by subtracting the 1990 potentiometric surface of the Floridan aquifer from the water table elevation of the surficial aquifer system (Boniol et al. 1993). These maps of the aquifer levels were derived from data collected during the dry season (May) of a relatively dry year to provide a greater degree of environmental protection than if a wetter time period had been used. Positive head difference indicates recharge to the Floridan aquifer. Areas with a negative head difference experience discharge from the Floridan aquifer system. Head difference values within SJRWMD varied from –110.42 ft to 231.41 ft (Figure 3).

In general, high recharge areas, with positive head differences, appear to correlate with high fluctuations in lake levels, whereas low recharge or discharge areas are associated with more stable lake levels. Water levels in lakes located in recharge areas, in which the general groundwater movement is downward, are more susceptible to impacts from groundwater withdrawals than those within discharge areas of the Floridan aquifer.

Soil Permeability. The soil permeability layer was created from the STATSGO soils database (USDA-SCS 1991; USDA-NRCS 1994). Susceptibility of soils to dewatering was rated as "high" (>6 inches per hour [in/hr]), "moderate" (0.6 to 6 in/hr), or

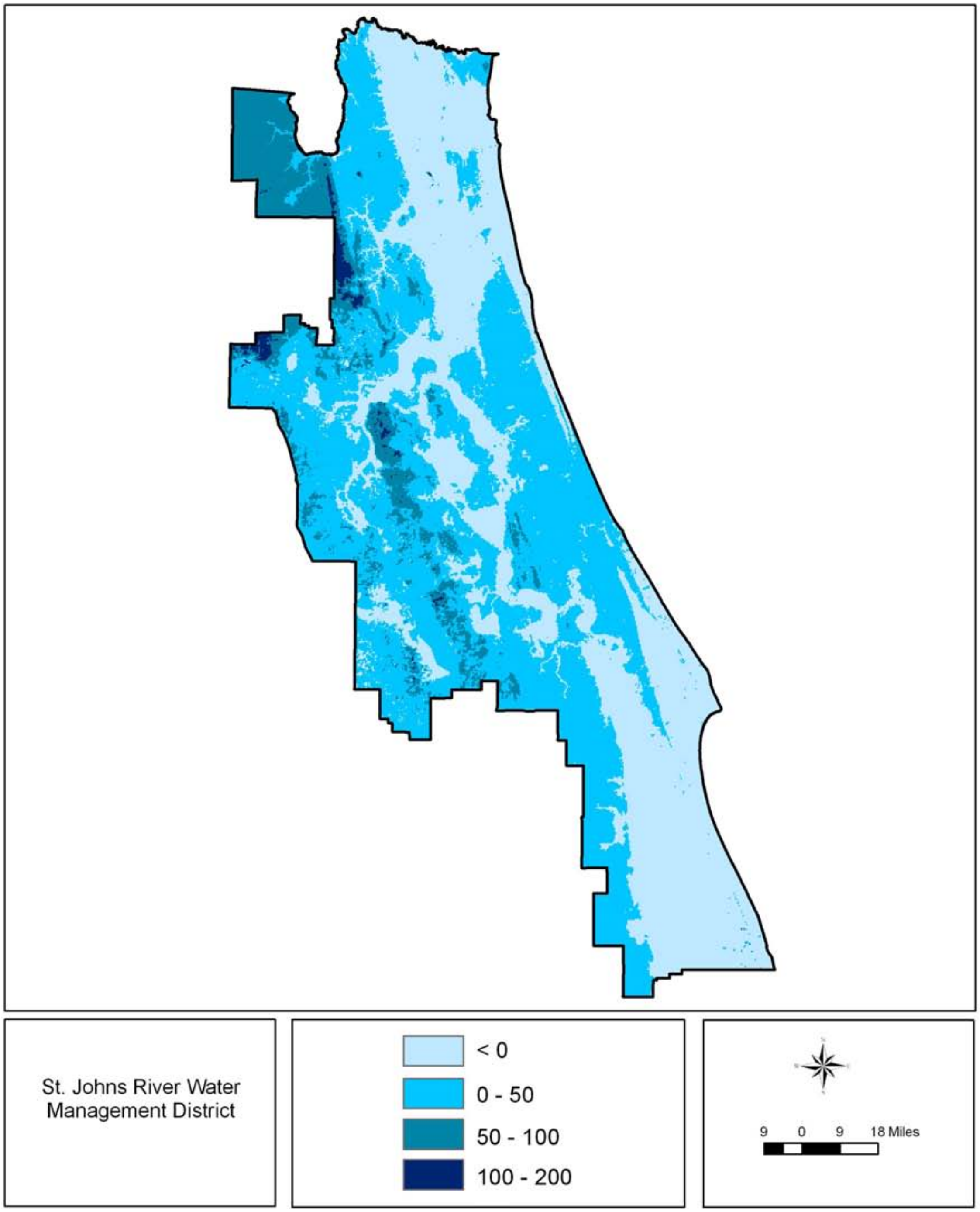

Figure 3. Head difference (in feet) between the surficial and Floridan aquifers in the St. Johns River Water Management District, northeastern Florida

“low” (<0.6 in / hr), based on the permeability of the most limiting horizon in the soil profile.

Because STATSGO map units could contain up to 21 different components, the percentages of soils with high, moderate, and low susceptibility were calculated for each map unit. The entire map unit was then given the same susceptibility rating as exhibited by the majority (70% or higher) of the soils within the unit. A mixed class (moderate + high) was used for map units where no one class represented a majority (Figure 4).

Soil permeability not only controls surface runoff input to lakes, but also affects leakance from lake bottoms to the Floridan aquifer. Regions with low permeability soils, which are characterized by high runoff and low leakance rates, are likely to have relatively stable lakes.

Wetland Frequency. The wetlands GIS layer was extracted from SJRWMD’s 1986–90 land use / land cover map (SJRWMD et al. 1990). The layer was generalized by summing the number of wetland cells within a 1-mile-diameter circle around each grid cell, using the focal sum grid function (Figure 5). The 1-mile-diameter circle was chosen to represent the area of local influence.

Wetland frequency indicates the stability of lake levels. Abundant lakeshore wetlands indicate that severe or frequent water level fluctuation has not often occurred. The risk of increased lake level fluctuation resulting from groundwater withdrawals was assumed to decrease with increasing wetland area around a particular grid cell. This was verified by comparing the extent of wetlands bordering lakes near sea level, such as those along the St. Johns River, to the much lesser extent of wetlands bordering lakes at higher elevations, such as those on the trail, Mount Dora, or DeLand ridges.

Topographic Deviation. The topographic deviation layer was created from the districtwide topography GIS layer (SJRWMD 2000) to indicate whether mapped areas were on terrain of relatively high elevation or occupying broad valleys or depressions. This layer was developed by calculating the deviation from the mean elevation of the surrounding area within a moving circular window 4 miles in diameter. The resulting layer was then subtracted from the original districtwide topography layer to obtain the topographic deviation layer (Figure 6).

Topographic deviation emphasizes the predominant regional topographic pattern in an area. In a regional perspective, lakes in lower topographic settings are more likely to have stable water levels. They generally lie in discharge areas of the Floridan aquifer and because of their position in the landscape, receive both runoff and seepage from surrounding uplands.

Topographic Curvature. A second topographic layer, topographic curvature, was created from the topography GIS layer (SJRWMD 2000) to indicate whether mapped areas were hills or valleys. This was accomplished by running the CURVATURE and FOCALMEAN grid functions using a 1-mile-diameter circle around each grid cell to represent local conditions. Negative values indicated depressions (basins) and positive values, hills (Figure 7).

Lakes located within large depressions are likely to have more-stable water levels because of their larger catchment areas and their ability to intercept lateral seepage.

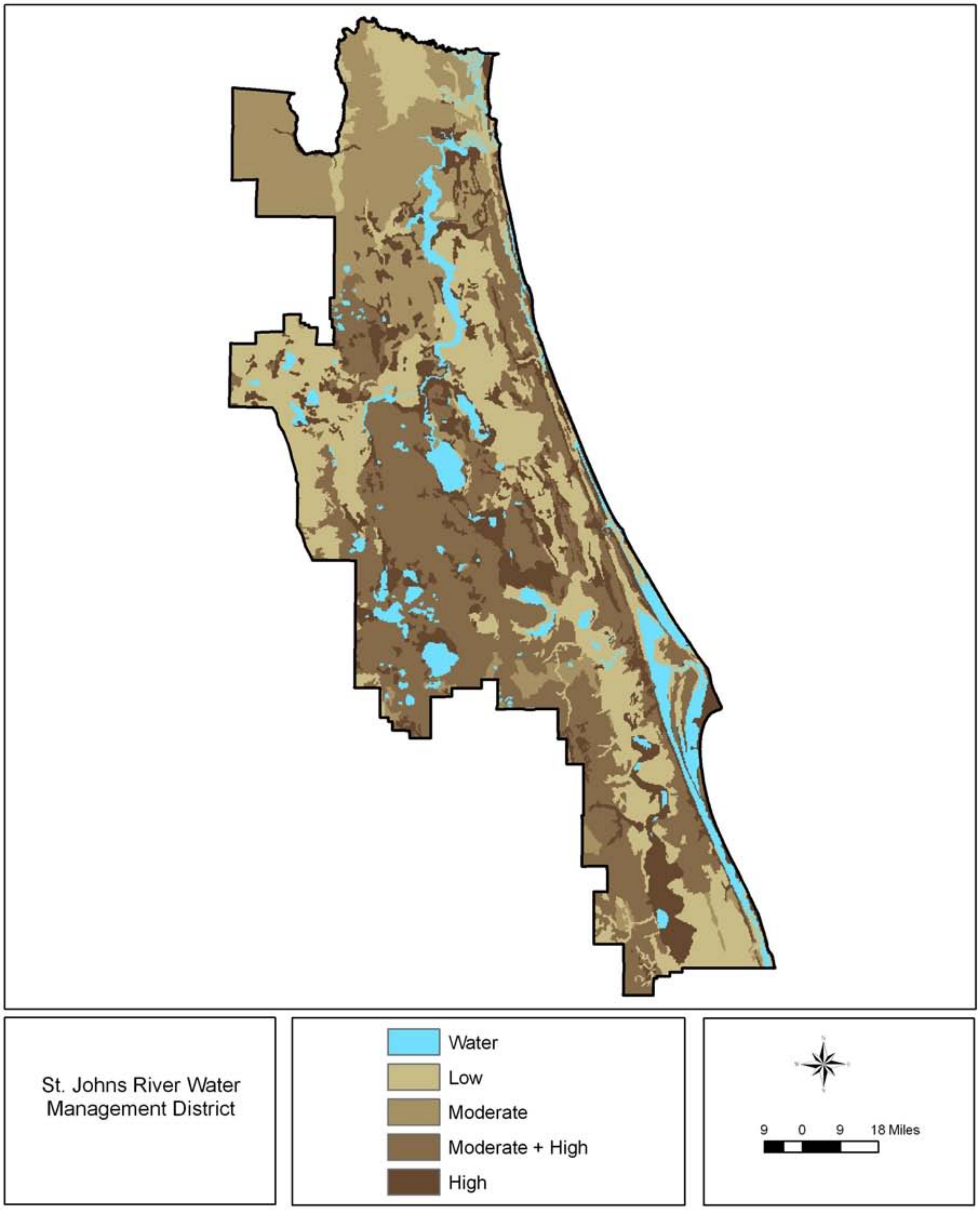

Figure 4. Soil permeability in the St. Johns River Water Management District, northeastern Florida

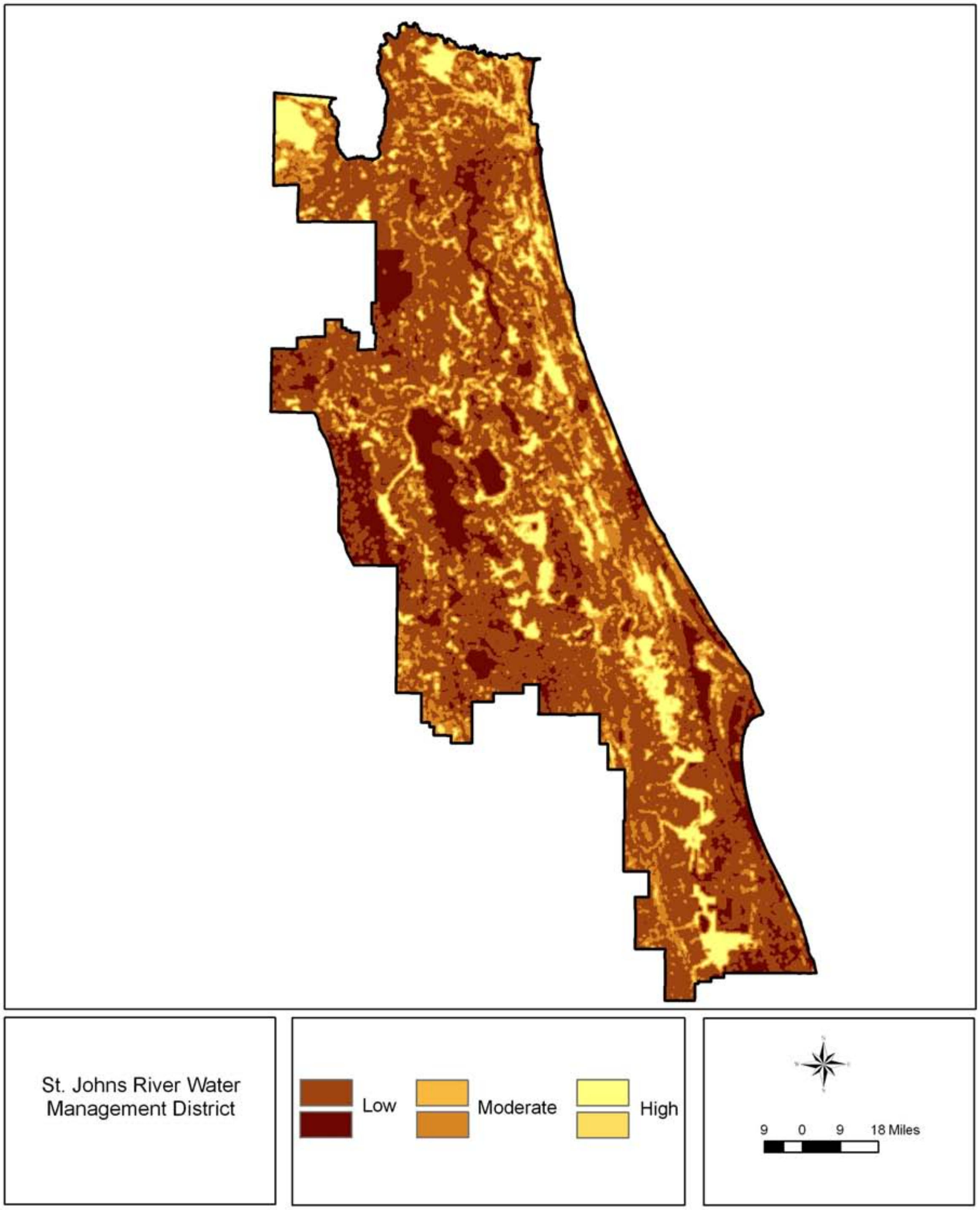

Figure 5. Wetland frequency in the St. Johns River Water Management District, northeastern Florida

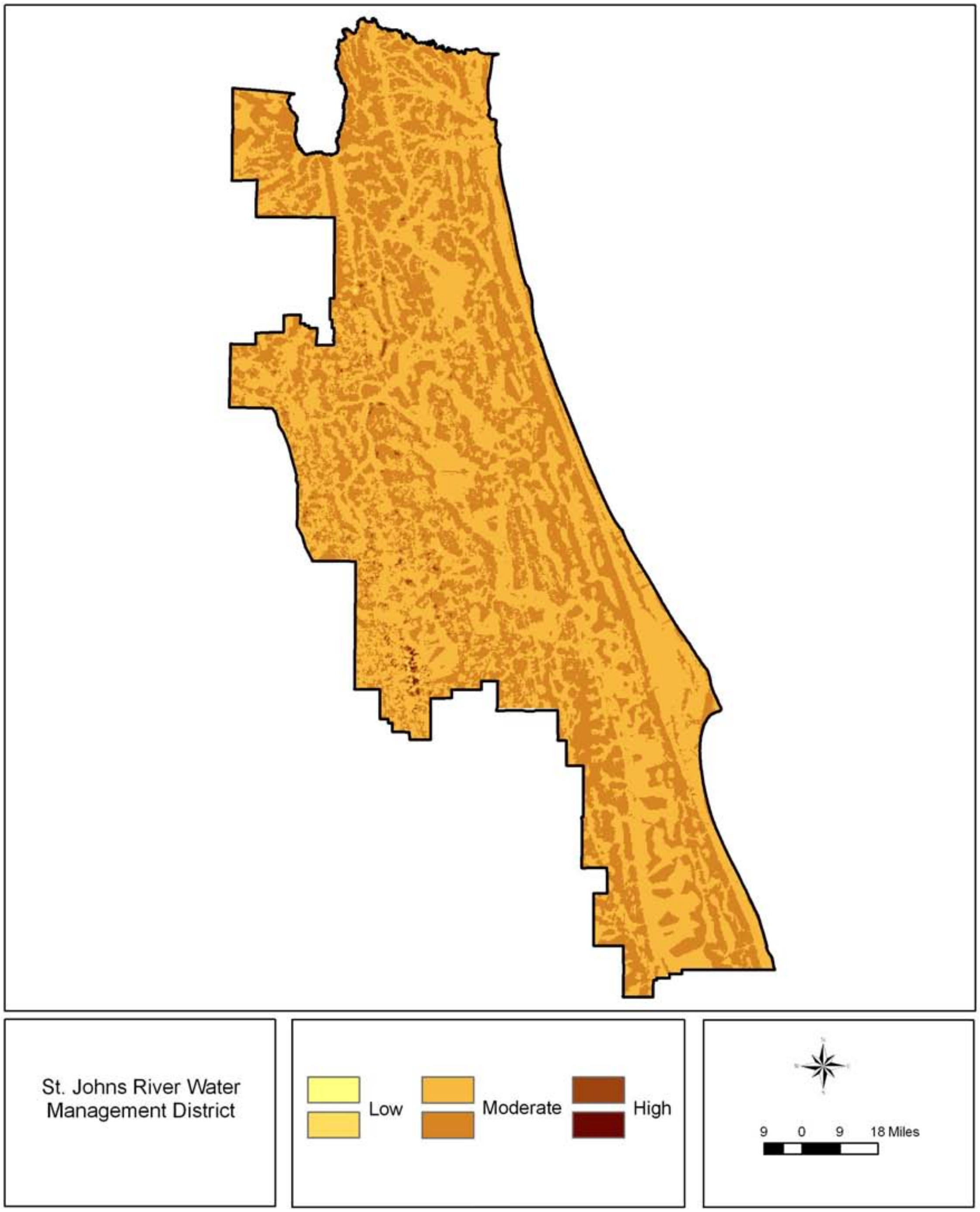

Figure 6. Topographic curvature (hills versus depressions) in the St. Johns River Water Management District, northeastern Florida

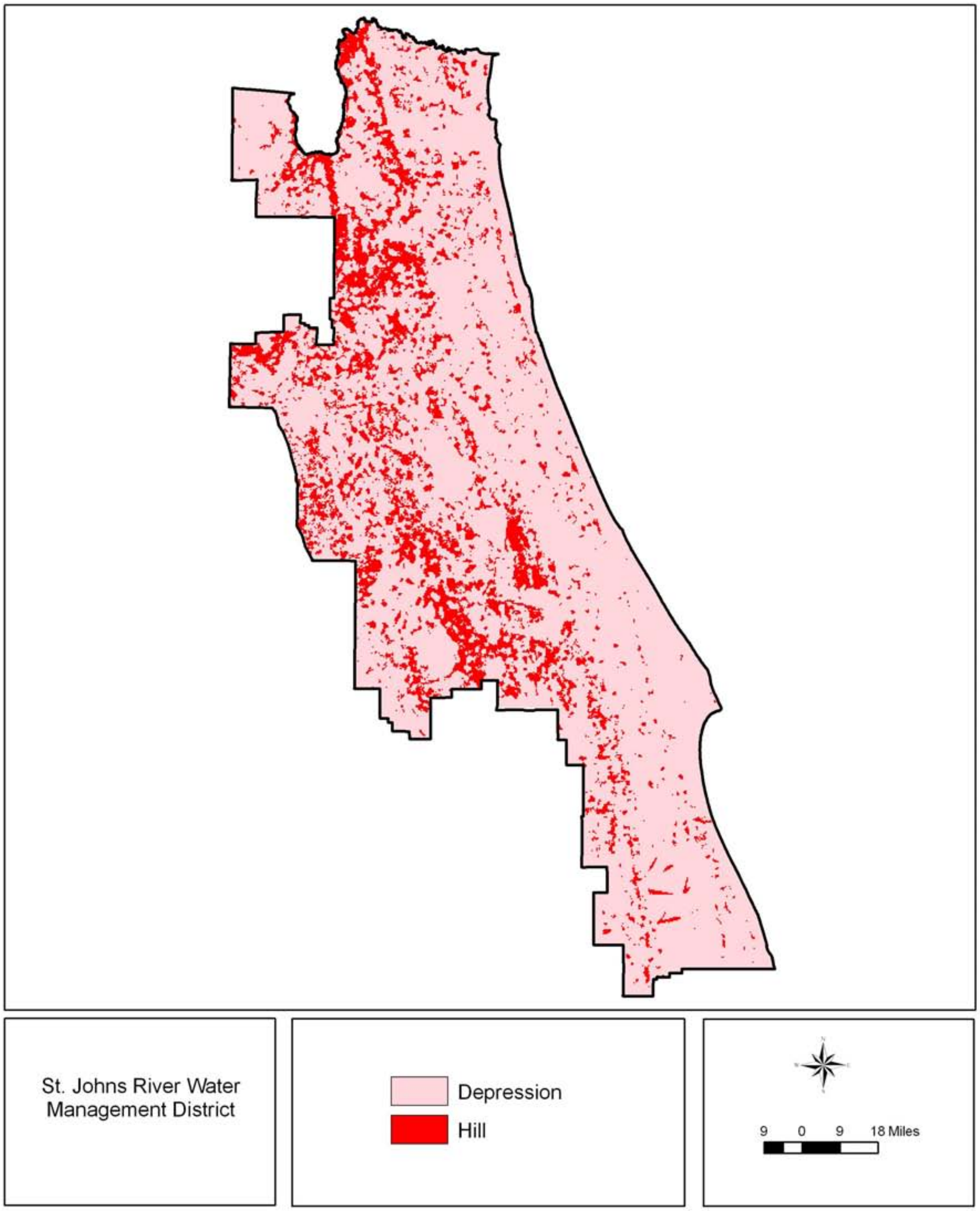

Figure 7. Topographic deviation from mean elevation (feet NGVD) in the St. Johns River Water Management District, northeastern Florida

Topographic curvature and deviation considered together provide valuable information about the susceptibility of lakes to drawdown resulting from groundwater withdrawals. For example, lakes in topographic depressions at low elevation were likely to have more-stable water levels. Also, topographic curvature, deviation, and soil permeability provide some insight concerning surface runoff to lakes.

Estimated Drawdown. The estimated drawdown data layer was developed using groundwater models (Table 3) to predict declines in the elevation of surficial aquifer system water levels by the year 2025. This layer was compiled from both analytical groundwater flow models using a two-layer simulation (Motz 1978) and regional numerical groundwater flow models using finite-difference simulation (McDonald and Harbaugh 1988; Harbaugh and McDonald 1996). These models account for the extent and significance of confining layers lying between the aquifer systems in conjunction with data on current and projected future withdrawal rates. Projected surficial aquifer drawdowns were rated on a scale of relatively low or relatively high corresponding to declines less than 0.5 ft and those equal to or greater than 0.5 ft, respectively (Figure 8). The 0.5-ft threshold is a general limit at which harm to lakes would be expected to begin (CH2M HILL 1998) and is not proposed or intended for use as a specific field or regulatory criterion.

GIS Analysis

A SUN Ultra station using Solaris 2.5 and running ARC/INFO 7.0 was used as the GIS platform for this study. The cells within five of the six GIS data layers were rescaled from 0 to 5, based on the value of the measured variable in relation to its significance in controlling or expressing groundwater-lake level interactions (Table 4). Topographic curvature was more simply scored as being either a hill or a depression. A secondary weighting factor (from 1 to 4) was applied to each of the six layers in proportion to the significance of the entire layer in causing or contributing to lake level fluctuations within the study area (Table 5). An overlay procedure in the GRID module of ARC/INFO was used to add the layers together to create a map of regional lake susceptibility to groundwater withdrawal. This map was then classified into regions of low, medium, and high susceptibility to groundwater withdrawal (Figure 9), and overlain with a layer of SJRWMD lakes as well as the projected 2025 surficial aquifer water level layer to produce the final likelihood of harm map (Figure 10).

Sensitivity Analysis

Prior to implementation of the full model, testing was conducted in a pilot area located in the vicinity of Winter Park and Orlando. In this area, satellite images were examined to investigate relative change in lake stage between wet and dry years. A change analysis of the satellite imagery showed that some lakes clearly changed size between the two dates, indicating a drop in water level, whereas the shorelines of others did not appear to recede. This technique was not chosen for use districtwide, however, because the depth profiles of lakes were believed to be generally too variable. In addition, stage data from individual lakes in the area were examined. The correlation between lake stage data and model results in the pilot area was poor, perhaps because of data inadequacies and due to artificial control of lake levels in urban areas and other anthropogenic changes. The sensitivity analysis could not be extended to the remainder of SJRWMD because stage data were available only for a relatively few lakes.

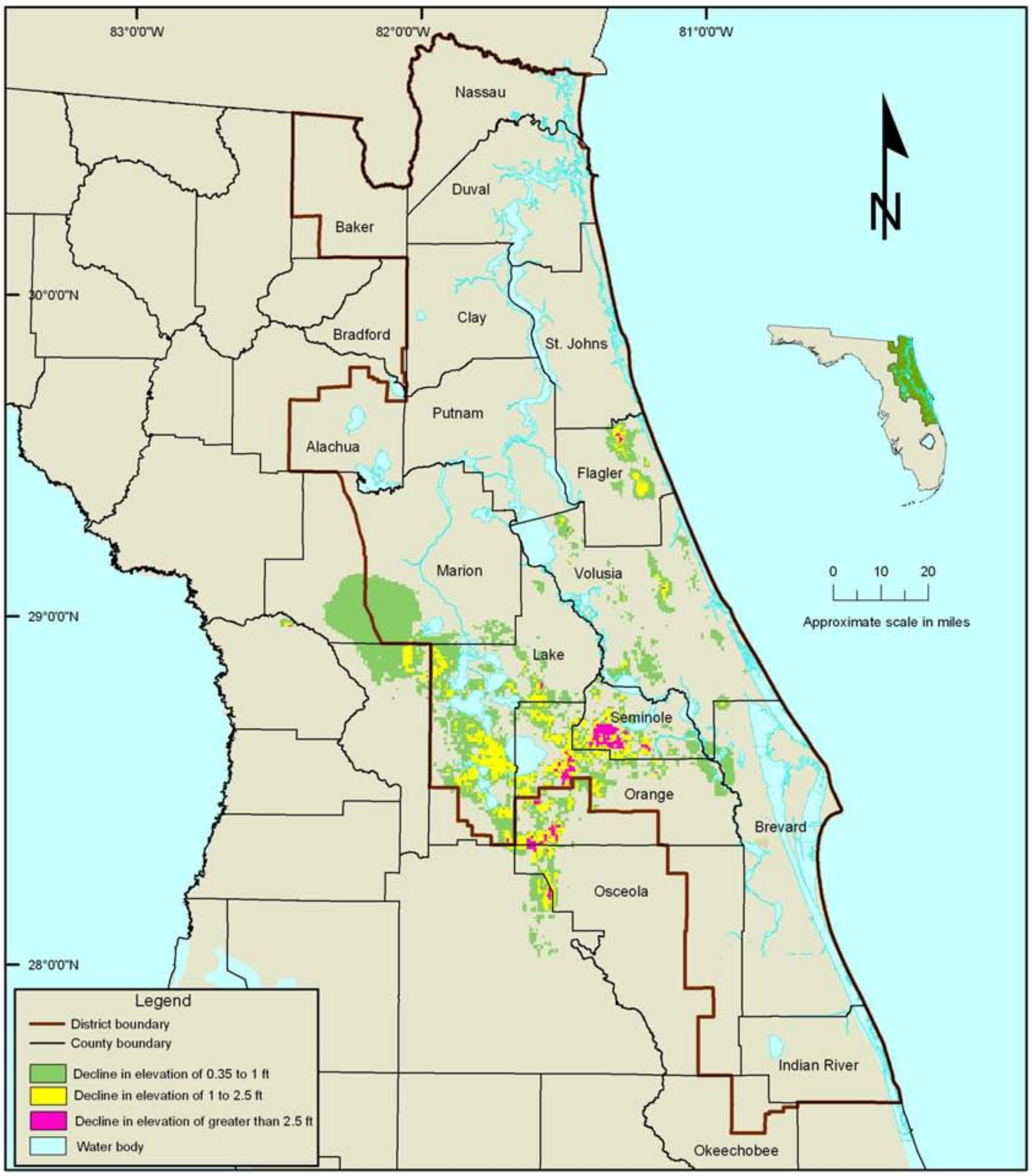

Figure 8. Projected drawdown of the surficial aquifer water table by the year 2025 in the St. Johns River Water Management District, northeastern Florida

Table 4. Weighting factor applied to the input layers of the map of regional lake susceptibility to groundwater withdrawal

Layer	Score					
	0	1	2	3	4	5
Confining unit thickness above the Floridan aquifer	NA	≥200 ft	150–200 ft	100–150 ft	50–100 ft	≤50 ft
Head difference between the surficial aquifer and the Floridan aquifer	≤0	0–50 ft	50–100 ft	100–150 ft	150–200 ft	>200 ft
Soil permeability	Low	NA	Low to medium	Medium	Medium to high	High
Number of wetland cells in a 1-mile-diameter circle	≥1,000	800–1,000	600–800	300–600	0.1–300	<0.1
Topographic deviation in a 4.3-mile-diameter circle	≤ –100	–100 to –50	–50 to 0	0 to 50	50 to 100	≥100
Topographic curvature (hill or depression) in a 1-mile-diameter circle	≥0 (depression)	0 to 1 (hill)	NA	NA	NA	NA

Note: ft = feet
NA = not applicable

Table 5. The secondary weighting factor applied to each of the input layers of the map of regional lake susceptibility to groundwater withdrawal

Layer	Weight
Confining unit thickness above the Floridan aquifer	4
Hydraulic head difference between the surficial aquifer and the Floridan aquifer	3
Soil permeability	2
Number of wetland locations in a 1-mile-diameter circle	2
Topographic deviation in a 4.3-mile-diameter circle	2
Topographic curvature (hill or depression) in a 1-mile-diameter circle	1

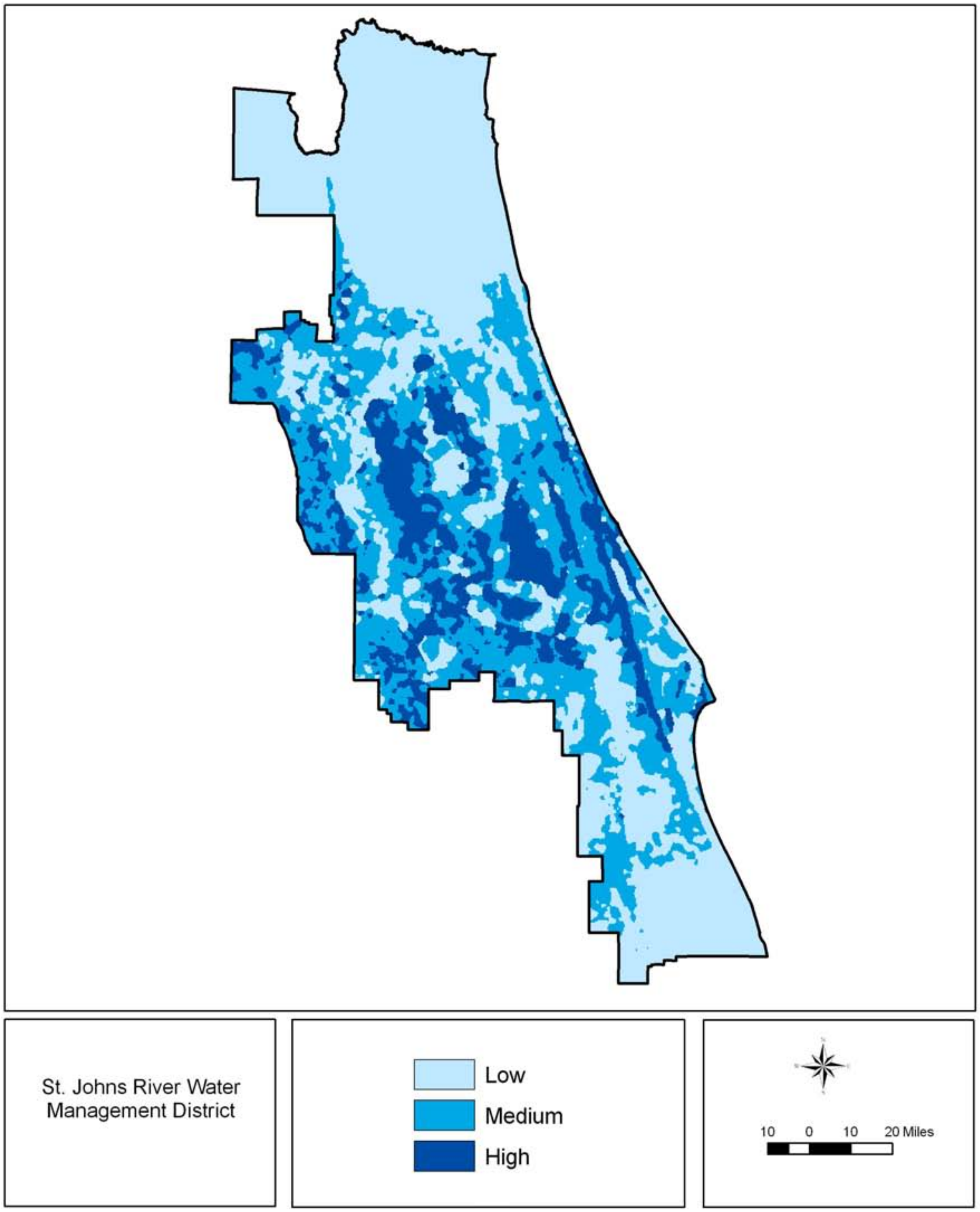

Figure 9. Regional lake susceptibility to groundwater withdrawals in the St. Johns River Water Management District, northeastern Florida

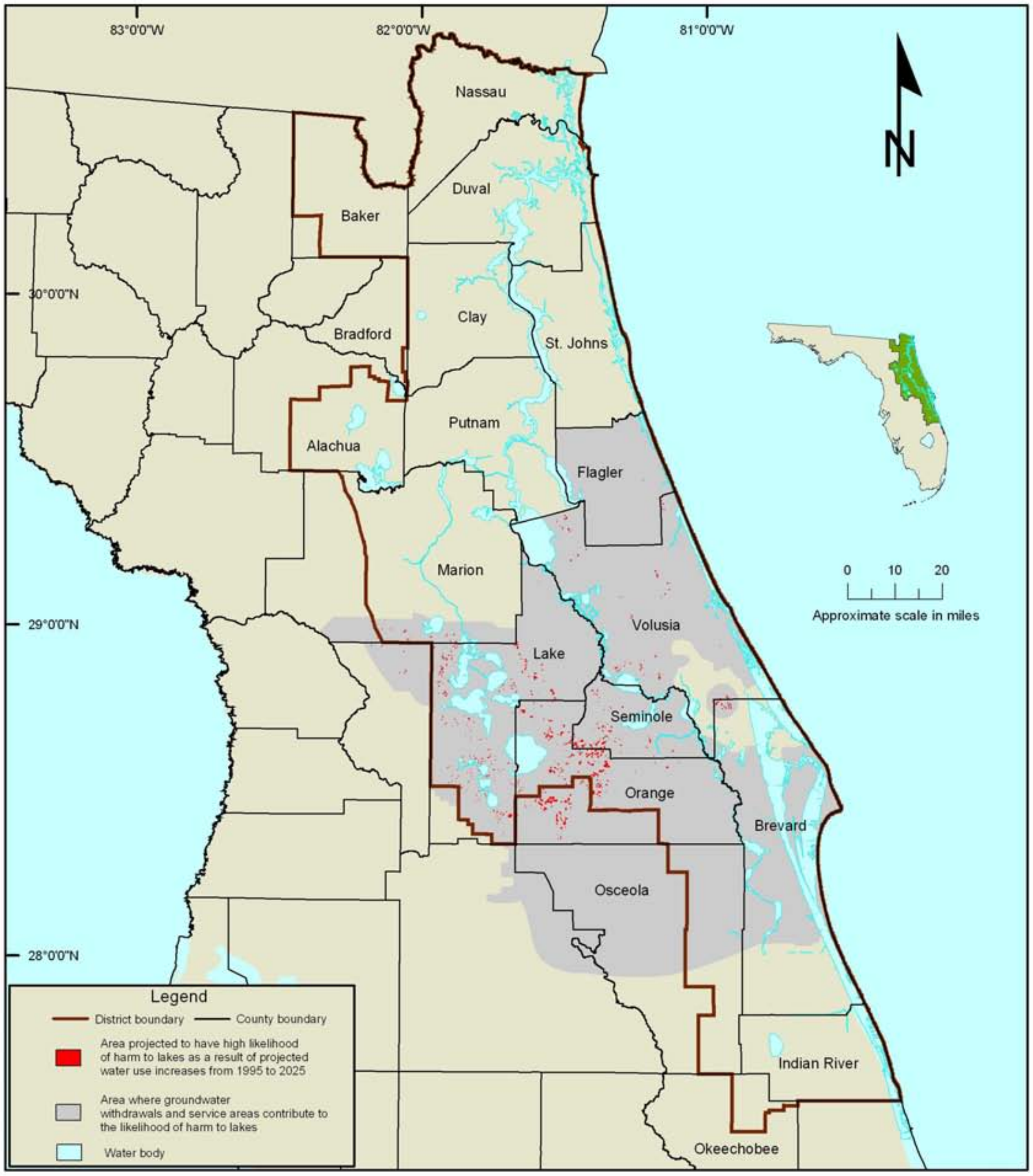

Figure 10. Lakes in the St. Johns River Water Management District predicted to decline in stage by 0.5 feet or more from groundwater withdrawals by the year 2025

The weighting used in the model was also tested and the results compared. Generally, it was found that the model was very robust. Unless the weighting of layers was greatly changed, similar results were obtained.

RESULTS AND DISCUSSION

The susceptibility of lake levels to groundwater withdrawal varies (Figure 10). Lake susceptibility is low in most of the northern third of SJRWMD, including Nassau, Baker, and Duval counties, all but the southwest corner of Clay County, and the northern half of St. Johns County. Indian River County, Okeechobee County, and the St. Johns River valley in Brevard County are also areas of low susceptibility. Most of the remainder of SJRWMD have medium or high susceptibility. The major exceptions are lowlands associated with coastal lagoons, the valleys of the St. Johns and Ocklawaha rivers, and portions of Orange Creek Basin. Areas of high susceptibility lie along major ridges, including the Atlantic Coastal Ridge in Brevard and Volusia counties, the Crescent City, DeLand, Mount Dora, and Lake Wales ridges, and the Marion Upland, although additional areas of high susceptibility occur elsewhere. The general distribution of lake susceptibility is primarily determined by the confining unit thickness and vertical head difference layers. Local patterns are influenced by soil, wetland, and topography layers.

The likelihood of harm to lakes map represents the intersection of lake susceptibility and modeled drawdown in surficial aquifer water levels. Lakes in susceptible areas having drawdowns of 0.5 ft or greater are shown as having a high likelihood of harm (Figure 10). Based on this work, Lake, Seminole, Orange, and Osceola counties contained a high concentration of lakes at risk of harm from groundwater withdrawals, reflecting the extent of modeled drawdown in this susceptible area. Other areas identified as being at risk lie in parts of Volusia County and small sections of Flagler and Brevard counties.

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