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MINIMUM LEVELS REEVALUATION FOR LAKES BROOKLYN AND GENEVA CLAY AND BRADFORD COUNTIES, FLORIDA

by

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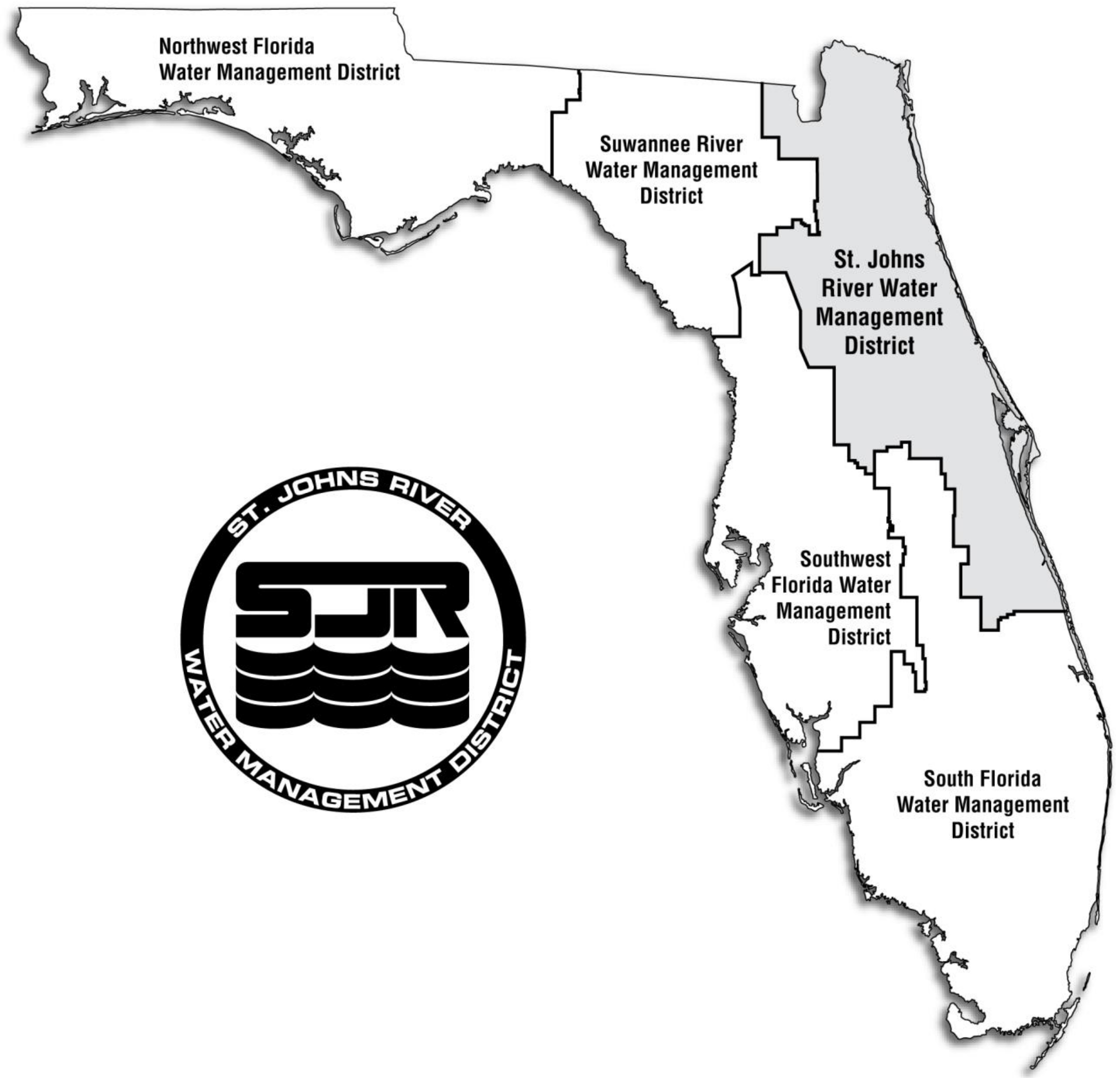

The St. Johns River Water Management District was created in 1972 by passage of the Florida Water Resources Act, which created five regional water management districts. The St. Johns District includes all or part of 18 counties in northeast and east-central Florida. Its mission is to preserve and manage the region's water resources, focusing on core missions of water supply, flood protection, water quality and natural systems protection and improvement. In its daily operations, the district conducts research, collects data, manages land, restores and protects water above and below the ground, and preserves natural areas.

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EXECUTIVE SUMMARY

As a part of fulfilling its mission and statutory responsibilities, the St. Johns River Water Management District (SJRWMD) establishes minimum flows and levels (MFLs) for priority water bodies within its boundaries. MFLs establish a minimum hydrologic regime and define the limits at which further consumptive use withdrawals would be significantly harmful to the water resources or ecology of an area. MFLs are one of many effective tools used by SJRWMD to assist in making sound water management decisions and preventing significant adverse impacts due to water withdrawals.

SJRWMD has completed a reevaluation of minimum levels for Lakes Brooklyn and Geneva in Clay and Bradford counties, Florida. Lakes Brooklyn and Geneva are sandhill lakes adjacent to the city of Keystone Heights, Florida. Lakes Brooklyn and Geneva are part of a chain of lakes and wet prairies in the Upper Etonia Creek Basin.

Minimum levels for both lakes were originally adopted in January 1996. The reevaluated minimum levels recommended for Lakes Brooklyn and Geneva are based on implementation of updated methods and more appropriate environmental criteria. The updated methods include results from a new regional steady state groundwater model and a local scale transient groundwater model used to quantify the effects of local and regional groundwater withdrawals, and the analysis of an additional 20 years of hydrologic data. The proposed minimum levels for Lakes Brooklyn and Geneva are based on the most up-to-date methods, criteria and data. Numerous criteria were investigated during the development of the proposed minimum levels that will protect relevant environmental values and beneficial uses at Lakes Brooklyn and Geneva. After peer review and staff evaluation of numerous criteria, 10 environmental metrics were chosen for evaluation and assessment at Lakes Brooklyn and Geneva.

Proposed MFLs and current-pumping conditions were compared to determine lake freeboards/deficits for the final suite of environmental criteria. The most constraining of these were used to develop a minimum hydrologic regime (MFLs condition) for each lake. The local-scale Keystone Heights Transient Model (KHTM) and the regional-scale North Florida Southeast Georgia (NFSEG) groundwater models were used for both MFLs criteria determination and assessment. The status assessment for Lakes Brooklyn and Geneva indicate that they are currently not meeting their proposed MFLs. A comparison of the MFLs and current-pumping conditions for lakes Brooklyn and Geneva yields a P50 lake deficit of 1.6 feet and 0.3 feet, respectively. Therefore, Lakes Brooklyn and Geneva are in recovery, and a recovery strategy must be adopted concurrently with the MFLs. Consistent with the provisions for establishing and implementing MFLs provided for in section 373.0421, F.S., the recovery strategy for Lakes Brooklyn and Geneva MFLs identifies a suite of projects and measures that, when implemented, will recover these lakes from impacts due to withdrawals. In addition, the recovery strategy will also provide sufficient water supply options to meet all existing and projected reasonable beneficial uses.

Three minimum levels, a minimum P25, P50 and P75, are recommended for both Lake Brooklyn and Lake Geneva (Table ES-1). These three percentiles were calculated from the

MFLs condition exceedance curve for each lake. Adopting these three minimum levels will ensure the protection of the minimum hydrologic regime at low, average and high levels for Lakes Brooklyn and Geneva.

Table ES-1. Recommended minimum levels for Lakes Brooklyn and Geneva, Clay and Bradford counties, Florida.

System	Percentile	Recommended minimum lake level (ft; NAVD88)
Lake Brooklyn	25	111.5
	50	106.2
	75	98.6
Lake Geneva	25	101.7
	50	98.3
	75	89.3

SJRWMD concludes that the recommended minimum levels for Lakes Brooklyn and Geneva will protect relevant Rule 62-40.473, *F.A.C.*, environmental values, from significant harm due to water withdrawals. The recommended MFLs presented in this report are preliminary and will not become effective until adopted by the SJRWMD Governing Board, as directed in Rule 40C-8.031, *F.A.C.*

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ACRONYMS AND ABBREVIATIONS

F.A.C.	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
F.S.	Florida Statutes
GIS	Geographic Information System
IH	Minimum Infrequent High
KHTM	Keystone Heights Transient Model
MFLs	Minimum Flows and Levels
NAVD	1988 North American Vertical Datum
NGVD	1929 National Geodetic Vertical Datum
NFSEG	North Florida Southeast Georgia Groundwater Model
NRCS	Natural Resources Conservation Service
POR	Period of Record
SFWMD	South Florida Water Management District
SJRWMD	St. Johns River Water Management District
SRWMD	Suwannee River Water Management District
SWFWMD	Southwest Florida Water Management District
SSURGO	Soil Survey Geographic database
UFA	Upper Floridan aquifer
USGS	U.S. Geological Survey

GLOSSARY

Acoustic Doppler Profiling (ADP): Bathymetric data collection method that uses sound waves to measure depth and/or velocity. A Hydrosurveyor™ profiler and software were used to collect bathymetric data for Lakes Brooklyn and Geneva.

Atlantic Multidecadal Oscillation (AMO): an ongoing series of long-duration changes in the sea surface temperature of the North Atlantic Ocean, with cool and warm phases that may last for 20-40 years at a time and a difference of about 1°F between extremes. These changes are natural and have been occurring for at least the last 1,000 years.

Current-pumping Condition: A long-term simulated water level (lake or aquifer) time series that represents what water levels would be if "current" groundwater pumping was present throughout the entire period of record. The average groundwater pumping over the latest five-year period is used to estimate "current" groundwater pumping.

Deficit: The amount of water needed to recover an MFL that is not being achieved.

Digital Elevation Model (DEM): Arrays of regularly spaced elevation values referenced horizontally either to a Universal Transverse Mercator (UTM) projection or to a geographic coordinate system. The grid cells are spaced at regular intervals along south to north profiles that are ordered from west to east.

Environmental Criteria: Specific ecological or human use functions evaluated when setting or assessing an MFL.

El Nino Southern Oscillations (ENSO): periodic departures from expected sea surface temperatures (SSTs) in the equatorial Pacific Ocean. These warmer or cooler than normal ocean temperatures can affect weather patterns around the world by influencing high- and low-pressure systems, winds, and precipitation.

Freeboard: The amount of water available for withdrawal before an MFL is not achieved.

Frequency Analysis: a statistical method used to estimate the annual probability of a given hydrological (exceedance or non-exceedance) event; used to assess the current status of an MFL by comparing the frequency of critical hydrological events under current-pumping conditions to the frequency of these events based on recommended minimum levels.

Hydrologic Regime: The variation of high and low water levels (or flows) regularly repeated over time within a specified period of record for a specific water body.

Minimum Hydrologic Regime: A hydrologic regime that is lower than the no-pumping condition, that protects relevant environmental values from significant harm.

MFLs Condition: The minimum hydrologic regime necessary to protect a water body from significant harm. The MFLs condition represents an allowable change from the no-pumping condition for the entire period of record. It represents a lowering of the no-pumping condition, but only to the degree that still protects a water body from significant harm. The MFLs Condition is based upon the minimum flow or level that is most constraining to water withdrawal, for a given water body.

Minimum Flows and Levels (MFL): The point at which additional withdrawals will result in significant harm to the water resources or the ecology of the area (Sections 373.042 and 373.0421, F.S.).

No-pumping Condition: A long-term simulated (lake or aquifer level) time series that represents what water levels would be if there were no impact due to groundwater pumping.

Pacific Decadal Oscillation (PDO): a long-lived El Niño-like pattern of Pacific climate variability.

Threshold: The allowable change to an environmental criterion, from the no-pumping condition.

INTRODUCTION

The St. Johns River Water Management District (SJRWMD) completed a reevaluation of minimum levels for Lakes Brooklyn and Geneva in Clay and Bradford counties, Florida. Minimum levels for both lakes were adopted January 1996 (Table 1). According to Florida Statute, Minimum Flows and Levels (MFLs) are to be reviewed periodically and revised if necessary (Section 373.042(3), *Florida Statutes* (*F.S*)).

The reevaluated minimum levels recommended for Lakes Brooklyn and Geneva are based on implementation of updated methods and more appropriate environmental criteria. The updated methods include results from a new regional steady state groundwater model and a local scale transient groundwater model used to quantify the effects of local and regional groundwater withdrawals, and the analysis of an additional 20 years of hydrologic data. These changes ensure that the minimum levels for Lakes Brooklyn and Geneva are based on the most up-to-date methods, criteria and data.

Table 1. Adopted (1996) minimum levels for Lakes Brooklyn and Geneva, Clay and Bradford Counties, Florida

System	Minimum Level	Level (ft NAVD88 / NGVD29)	Hydroperiod Category
Lake Brooklyn	Frequent high	113.5 / 114.6	Temporarily flooded
	Average	106.9 / 108.0	Typically saturated
	Frequent low	99.9 / 101.0	Semipermanently Flooded
Lake Geneva	Frequent high	101.9 / 103.0	Seasonally Flooded
	Average	99.9 / 101.0	Typically saturated
	Frequent low	97.4 / 98.5	Semipermanently Flooded

LEGISLATIVE OVERVIEW

SJRWMD establishes minimum flows and levels for priority water bodies within its boundaries (section 373.042, F.S.). Minimum flows and/or levels for a given water body are limits "at which further withdrawals would be significantly harmful to the water resources or ecology of the area" (section 373.042, F.S.). Minimum flows and/or levels are established using the best information available (section 373.042(1), F.S.), with consideration also given to "changes and structural alterations to watersheds, surface waters, and aquifers and the effects such changes or alterations have had, and the constraints such changes or alterations have placed, on the hydrology of the affected watershed, surface water, or aquifer...," provided that none of those changes or alterations shall allow significant harm caused by withdrawals (section 373.0421(1)(a), F.S.).

The minimum flows and levels section of the State Water Resources Implementation Rule (rule 62-40.473, Florida Administrative Code [F.A.C.]) also requires that “consideration shall be given to natural seasonal fluctuations in water flows or levels, nonconsumptive uses, and environmental values associated with coastal, estuarine, riverine, spring, aquatic, and wetlands ecology.” The environmental values described by the rule include:

1. Recreation in and on the water;
2. Fish and wildlife habitats and the passage of fish;
3. Estuarine resources;
4. Transfer of detrital material;
5. Maintenance of freshwater storage and supply;
6. Aesthetic and scenic attributes;
7. Filtration and absorption of nutrients and other pollutants;
8. Sediment loads;
9. Water quality; and
10. Navigation.

MFLs are used in SJRWMD’s regional water supply planning process (Section 373.709, F.S.), the consumptive use permitting program (Chapter 40C-2, F.A.C.), and the environmental resource permitting program (Chapter 62-330, F.A.C.).

SJRWMD MFLs Program Overview

SJRWMD is engaged in a districtwide effort to develop MFLs for protecting priority surface water bodies, watercourses, associated wetlands, and springs from significant harm caused by water withdrawals. MFLs provide an effective tool for decision-making regarding planning and permitting of surface water or groundwater withdrawals.

The purpose of setting MFLs is to answer an overarching question: What hydrologic regime is needed to protect critical environmental functions and values of a priority water body from significant harm due to withdrawal?

As described above, MFLs are not meant to represent optimal conditions, but rather set the limit to withdrawals, beyond which significant harm would occur. A fundamental assumption of SJRWMD’s approach is that alternative hydrologic regimes exist that are lower than a pre-withdrawal regime but still protect critical environmental functions and values of MFLs water bodies from significant harm caused by water withdrawals.

The SJRWMD MFLs approach involves two separate, but interrelated, components: 1) MFLs Determination; and 2) MFLs Assessment. The first involves determining a minimum hydrologic regime (MFLs condition) necessary to protect relevant water resource values. The second involves comparing this MFLs condition to a current-impacted regime (current-pumping condition) to determine the current status of the MFLs. The overall approach involves environmental assessments, hydrologic modeling, independent scientific peer review, and rulemaking.

Many SJRWMD MFLs define a protective frequency of high, intermediate, and low hydrologic events (i.e., a minimum hydrologic regime; Neubauer et al. 2008). However, for some priority water bodies, for which an event-based approach is not appropriate, a protective minimum hydrologic regime is established based on a percentage of change allowable from a more natural (no-pumping impact) condition. No matter how environmental thresholds are set, or how many MFLs are adopted for a water body, the most constraining (i.e., most sensitive to pumping) MFL is always used for water supply planning and permitting. If the status assessment indicates that an MFL is currently not being met or is projected to not be met during the 20-year planning horizon, a district must adopt a recovery or prevention strategy concurrently with the adoption of the MFL. A recovery strategy is required when an MFL is not currently being met. A prevention strategy is required when an MFL is projected to not be met over the 20-year planning horizon.

SETTING AND DESCRIPTION

LOCATION AND PHYSIOGRAPHIC SETTING

Lakes Brooklyn and Geneva are sandhill lakes in Clay and Bradford counties, adjacent to the city of Keystone Heights, Florida (Figure 1). They are among the most studied and modeled lakes in the district (Appendix A). Lakes Brooklyn and Geneva are part of a chain of lakes and wet prairies in the Upper Etonia Creek Basin (UECB). From highest to lowest elevation, these water bodies include: Blue Pond, Lowery Lake, Magnolia Lake, Alligator Creek, Lake Brooklyn, Keystone Lake, Lake Geneva, Oldfield Pond, Halfmoon Lake, Putnam Prairie, Goodson Prairie, and Etonia Creek.

Alligator Creek is an intermittent stream that connects Blue Pond, Lowry Lake, Magnolia Lake and Lake Brooklyn (Figure 1). Alligator Creek provides inflows at the north shore of Lake Brooklyn and, during high water levels, outflow occurs on the southwestern shore of the lake. This outflow drains to Keystone Lake, which discharges to Lake Geneva, and ultimately to Etonia Creek and the St. Johns River (Motz et al 1991).

The Keystone Heights region sits at the southern end of the Trail Ridge, a formation of relatively high elevation sand hills traversing southern Georgia through northern Florida. The Trail Ridge is a former coastal dune formation that extends from Keystone Heights into southeastern Georgia (Force and Rich, 1989; Appendix A). Elevations along the Trail Ridge are amongst the highest in northeast Florida. The lakes in the UECB form a chain of decreasing elevation that fosters seepage and sheet flow from the higher elevation lakes into the lower ones (Annable and Motz, 1996). Elevation in the Trail Ridge area can decline as much as 100 feet per mile (Clark et al., 1964) and elevation in the UECB ranges from 100 feet NAVD88 to 205 feet NAVD88 (Gordu 2014).

Lakes in the UECB vary in stage stability. Of 121 Florida lakes, for which long-term stage data are available, some lakes within the UECB are among the most stable (e.g., Blue Pond) and some are among the most variable (e.g., Lake Brooklyn; Motz et al., 1991). Lake stage in the UECB correlates well with water table depth in the surficial aquifer (Annable and Motz 1996), but the degree of hydraulic conductivity to the aquifer is inconsistent between lakes (Clark et al., 1964). The conductivity between the Upper Floridan aquifer (UFA) and lakes of the UECB results from sinkhole formation (Schiffer 1998, Kindinger 1999). Numerous collapse features lacking restrictive clay horizons have been identified within Lake Brooklyn (SDII 1992). Lake stage in the UECB is influenced by the depth to the surficial aquifer system and UFA. This relationship between lakes and groundwater result in the UECB being an important recharge source to the UFA (Bentley 1977, Merritt 2001).

The drainage basin area for Lake Brooklyn is approximately 11,136 acres, and approximately 22,720 acres for Lake Geneva (Motz et al., 1991). The lakes are within the Interlachen Sand Hills Physiographic Division (4b) of the Central Lakes District, which is characterized by thick sand and gravel deposits. Many lakes within this region are characterized by high connectivity to the UFA. Consistent with this general pattern, Epting et al. (2008) classified Lakes Brooklyn and Geneva as isolated / intermittent sinkhole lakes with high leakage to the

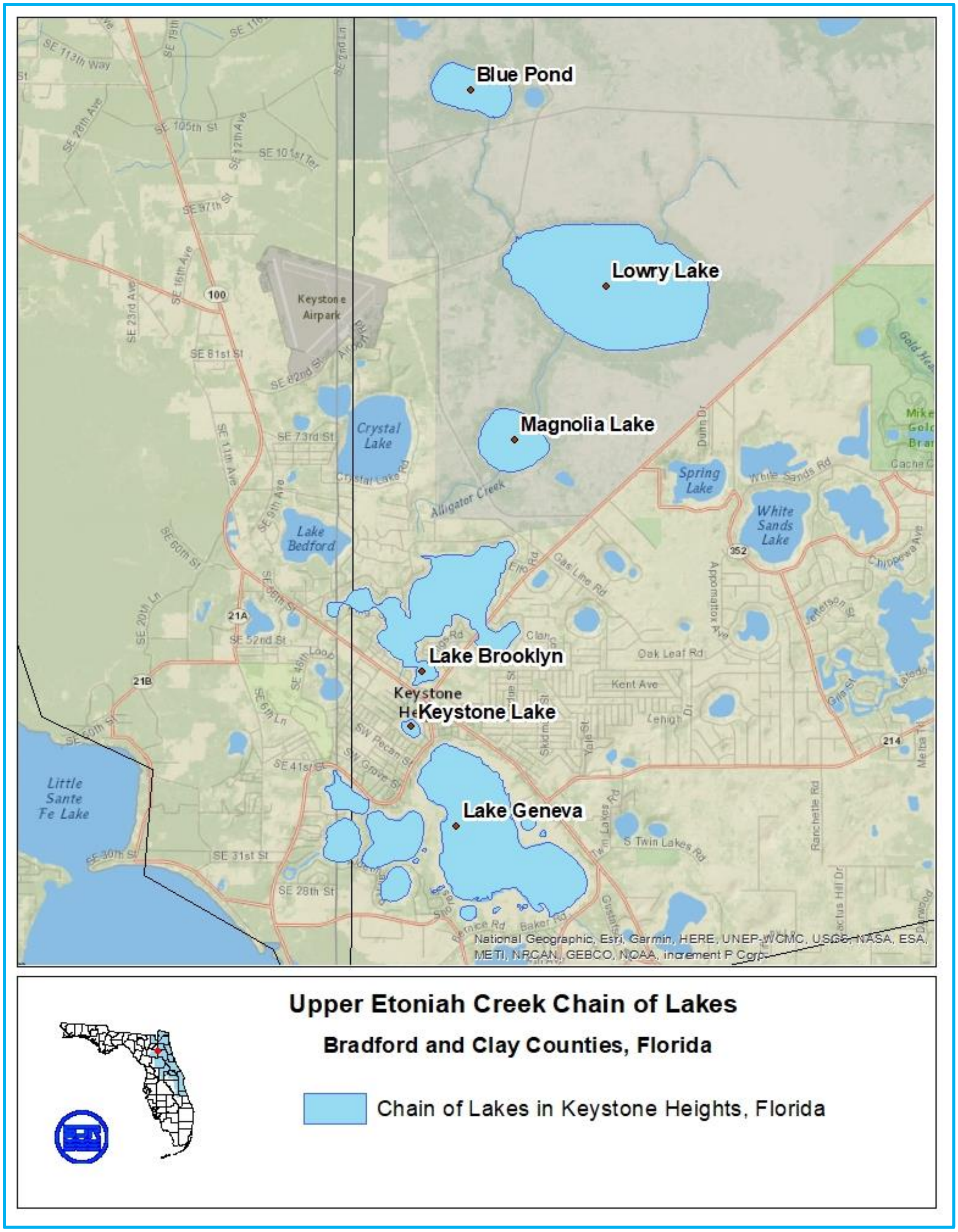

Figure 1. Upper Etonia Creek Basin (UECB) chain of lakes, including Lakes Brooklyn and Geneva, in Keystone Heights, Florida.

UFA. This lake type is characterized by a large water level fluctuation range and includes isolated ridge lakes with low surface water outflow. Lake Geneva has been an isolated lake since the 1970s, except for a very brief period in 1998 (see Appendix A for more details on physiography of Lakes Brooklyn and Geneva and Appendix B for more information on lake level fluctuation). Information on surface water basin characteristics, including land use, wetlands, hydric soils, and water quality, is located in Appendix C.

Digital Elevation Models

Digital elevation models (DEM) were created for Lakes Brooklyn and Geneva using 2012 light detection and ranging (LIDAR) data, acoustic doppler profiler (ADP) data and elevation data surveyed along numerous transects. Maps depicting DEM data for Lakes Brooklyn and Geneva are presented in Figures 2 and 3, respectively. The DEM for Lake Geneva only includes the main eastern lobe. This portion of the lake is more connected to the UFA and is the part of the lake for which hydrological and environmental analyses were conducted.

Based on the high-resolution DEM, Lake Brooklyn has a surface area of approximately 672 acres when the lake stage is at the outlet elevation, 116.5 feet NAVD88. The deepest portion of Lake Brooklyn is approximately 40 feet deep. Lake Geneva has a surface area of approximately 1,700 acres when the lake stage is at 106.4 feet NAVD88. The deepest portion of Lake Geneva, in the eastern lobe, is approximately 37 feet deep. Both lakes have complex morphologies comprised of shallow solution basins and submerged ridges. Consequently, water depths vary significantly across both lakes.

Hydrology

Water Level Data

Water level data for Lakes Brooklyn (SJRWMD station 03360373) and Geneva (SJRWMD station 11590497) have been collected from July 1957 to 2020 (Figure 4). Lake Brooklyn's hydrograph reflects the influence of periodic surface water inflow and a high connectivity with the UFA. Lake Geneva has a markedly different hydrograph shape, relative to Lake Brooklyn. This is because Lake Geneva is less connected to the UFA and does not receive any surface inflows from upstream water bodies during long periods of low rainfall. A summary of water level statistics for both lakes, from 1957 to 2020, is provided in Table 2.

Table 2. Water level (WL) summary statistics for Lakes Brooklyn and Geneva; elevations in NAVD88

Descriptive Statistic	Brooklyn Stage (ft)	Geneva Stage (ft)
Mean	103.0	95.2
Standard Error	0.1	0.0
Median	104.4	97.2
Standard Deviation	8.6	7.2
Range	31.4	25.5
Minimum	85.0	80.9
Maximum	116.4	106.4

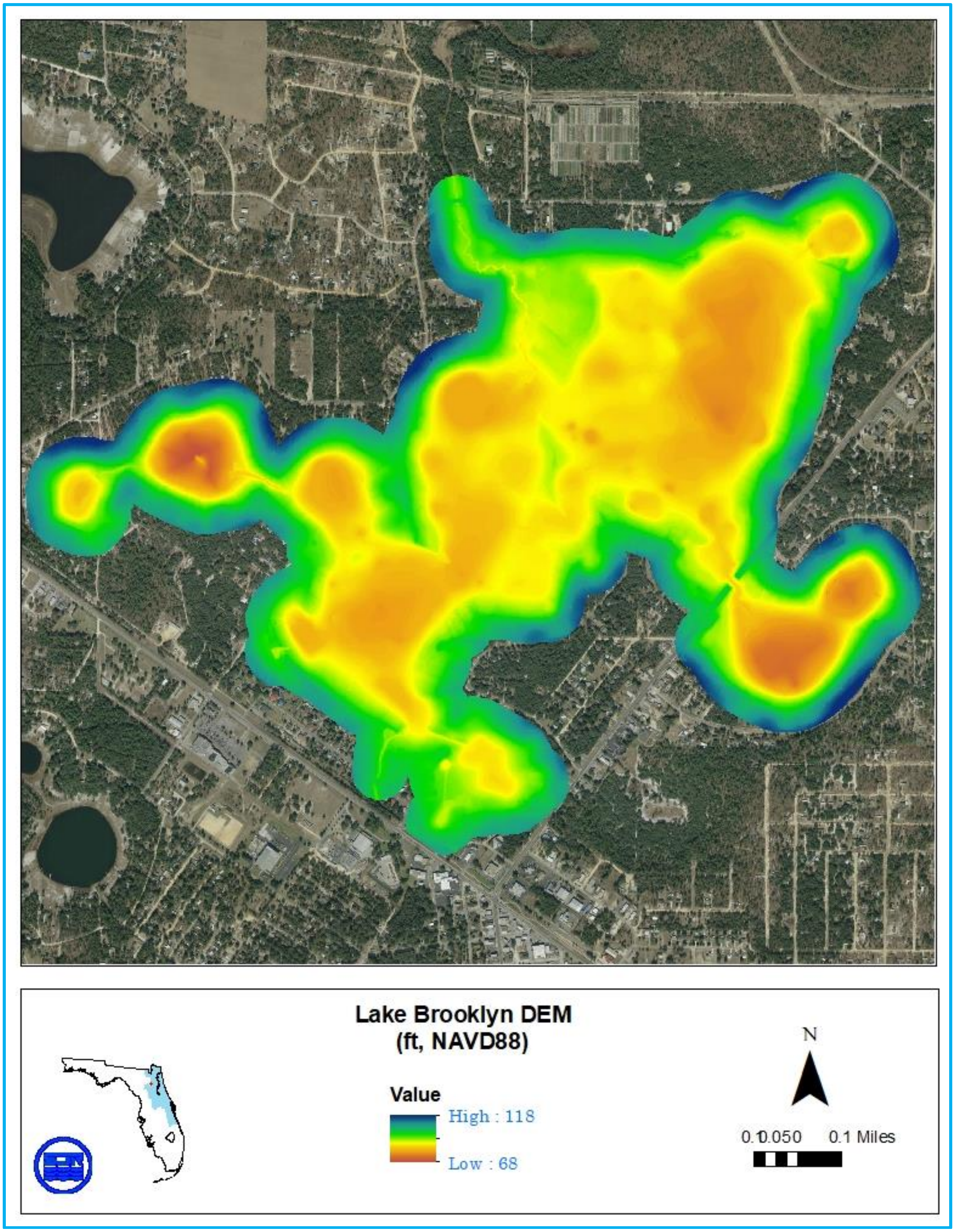

Figure 2. Digital elevation model data for Lake Brooklyn.

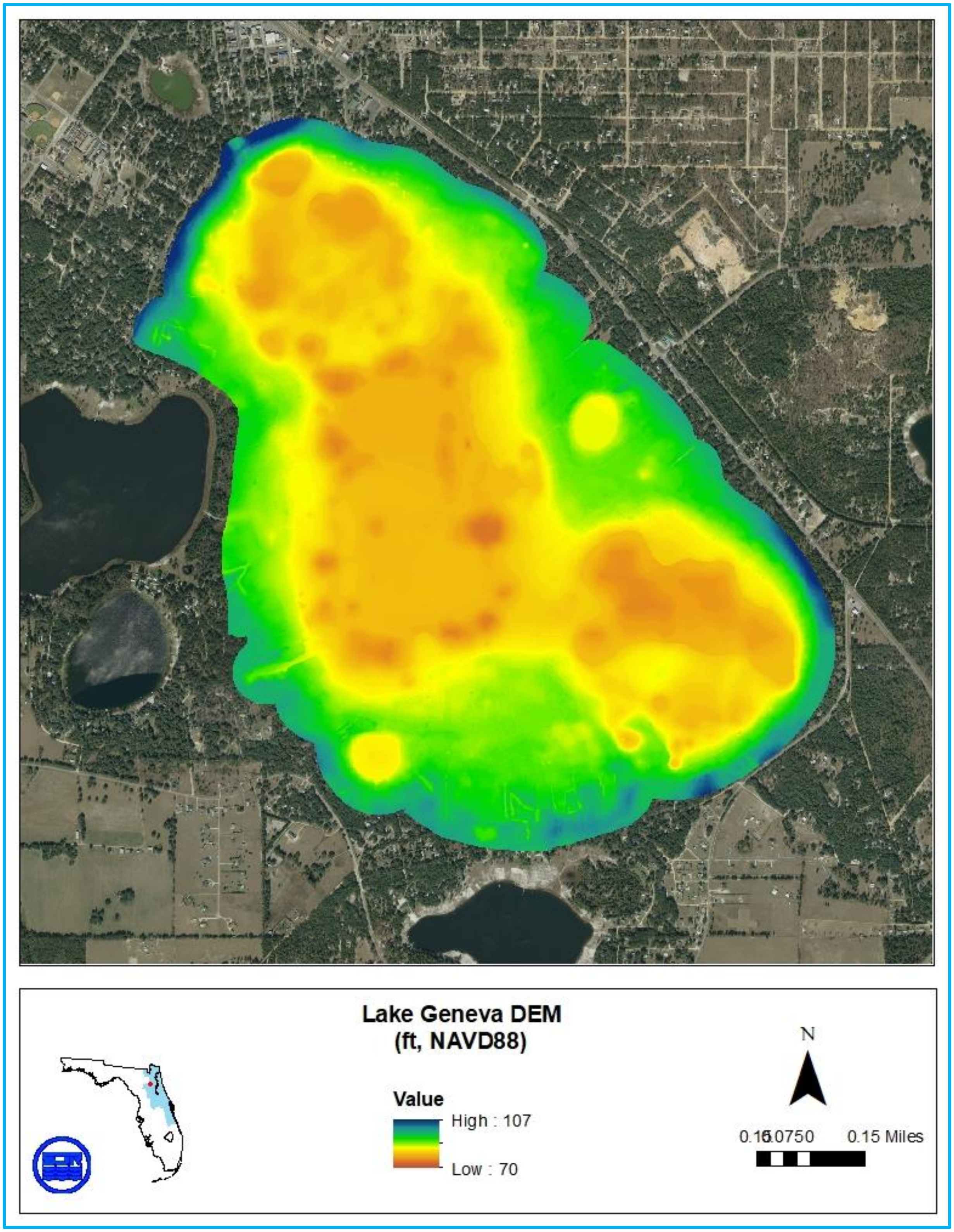

Figure 3. Digital elevation model data for Lake Geneva.

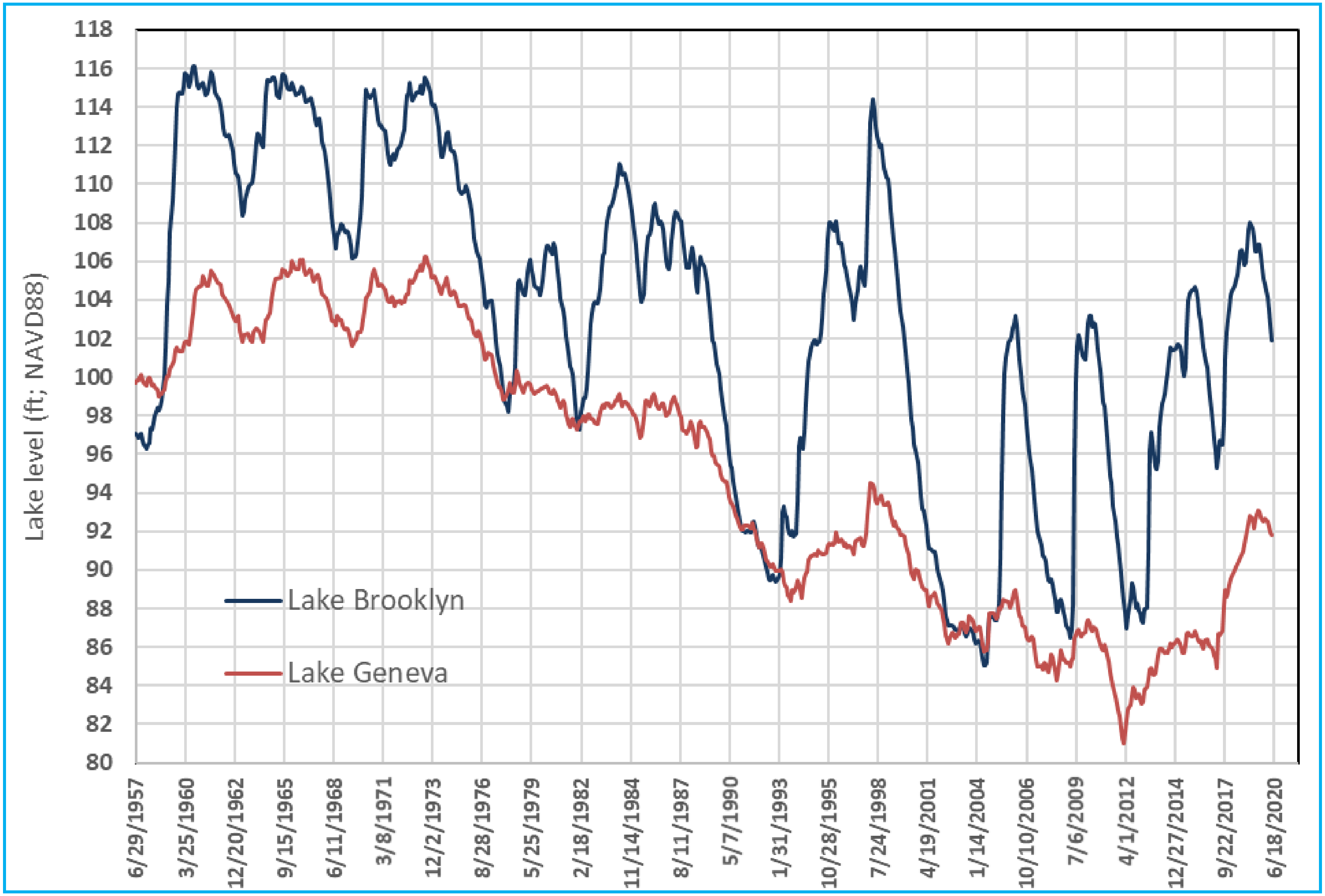

Figure 4. Lake Brooklyn and Lake Geneva water levels (1957 to 2020).

The stage fluctuations for Lake Brooklyn (approximately 31 feet) and Lake Geneva (approximately 26 feet) (Table 2) are among the largest in Florida. Only 4 percent of 121 Florida lakes studied by Motz et al. (1991) exceeded a 20 feet range of fluctuation.

The maximum observed water elevation (116.4 feet NAVD88) for Lake Brooklyn was recorded in October 1960, weeks after Hurricane Donna passed over Florida. The minimum observed water elevation (85.0 feet NAVD88) for Lake Brooklyn was recorded in July 2004. The maximum observed water elevation (106.4 feet NAVD88) for Lake Geneva was recorded in July 1973. The minimum observed water elevation (80.9 feet NAVD88) for Lake Geneva was recorded in June 2012 (see Appendix B for more details on water level data for both lakes).

Rainfall

A composite rainfall dataset was compiled for Lakes Brooklyn and Geneva because there is no rainfall gauge near Keystone Heights with a long-term rainfall record (Figure 5). The composite rainfall record was made from the following gauges: several Gainesville NOAA gauges from 1900 to 1989; Lake Brooklyn gauges from 1989 to 1991; Lake Geneva gauges with some additions from Lake Brooklyn from 1991 to 2001; Lake Lily gauges in 2002; and Goldhead State Park gauges from 2002 to 2020. Over the long-term record, annual rainfall has ranged from 32.8 to 73.3 inches, and average annual rainfall over the period of record (POR) is 50.8 inches.

Analysis of Water Level Declines

Significant downward trends in water levels have been observed at Lakes Brooklyn and Geneva over the past 40 to 50 years with declines of approximately 8 and 12 feet, respectively since 1960s. The deficit in cumulative rainfall has also increased over the past 40 to 50 years. The influences of climate (i.e., long-term rainfall variation) and regional groundwater pumping on lake levels were analyzed to understand the primary cause(s) of lake level declines. The following sections summarize this analysis; additional details are included in Appendix B.

Long-term Rainfall Analysis

Analysis of declines in lake levels without understanding the influence of climate (i.e., climatic cycles) on lake systems would be difficult. According to the Florida Climate Institute, climatic cycles such as El Nino Southern Oscillations (ENSO), Atlantic Multidecadal Oscillation (AMO) and the Pacific Decadal Oscillation (PDO) have the strongest influence on Florida’s climate variability (Kirtman et al., 2017). A review of long-term trends in rainfall shown in Figure 5 indicates a potential 70- to 80-year rainfall cycle in which the period from 1945 to 1965 was generally very wet and the periods from 1910 to 1920 and from 1995 to 2005 were generally very dry. The wet and dry periods in the long-term rainfall pattern coincide with the warm and cool phases of AMO.

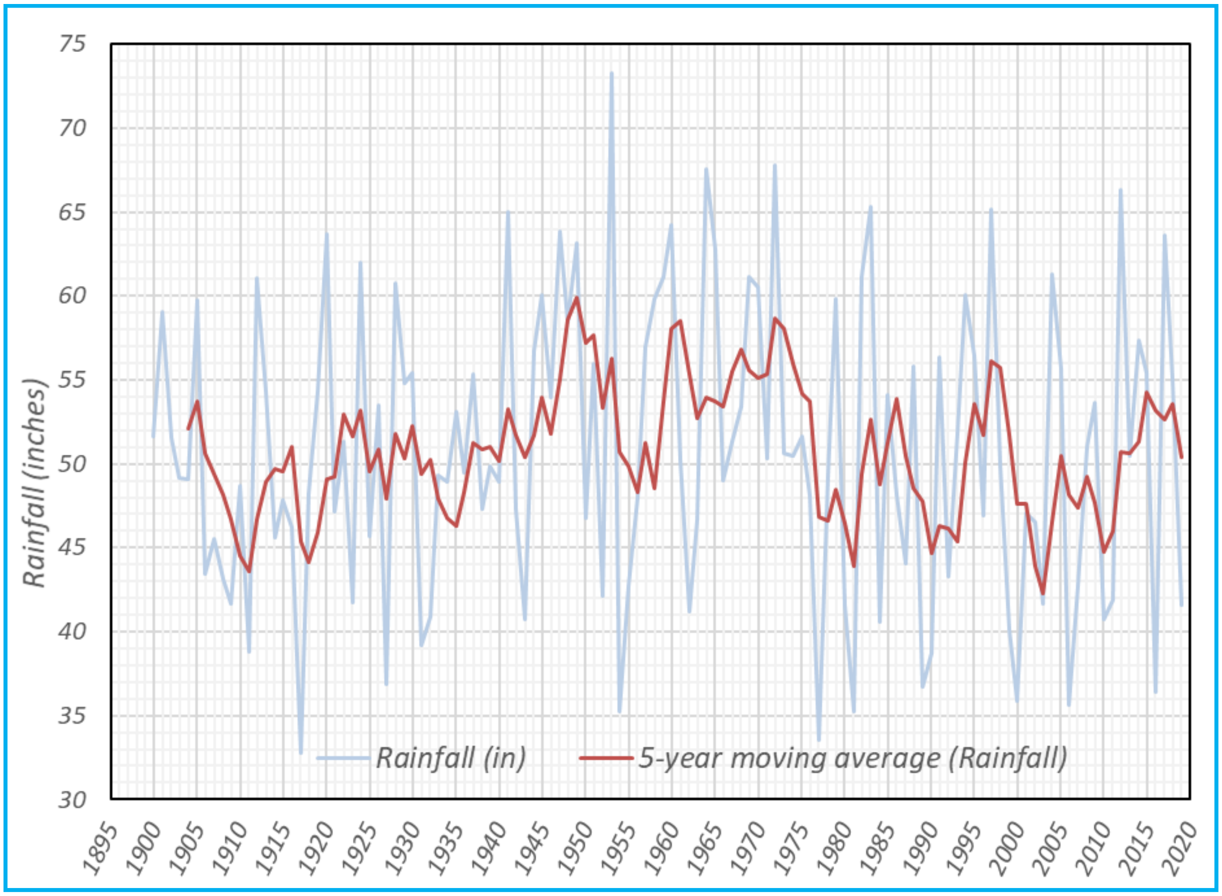

Figure 5. Composite Gainesville and Keystone Heights rainfall, and 5-year moving average rainfall.

Long-term lake level trends were also reviewed to determine if there is any relationship between the rainfall and climatic cycles and the lake levels. Long-term trends in Lakes Brooklyn and Geneva water levels are cyclic, similar to the rainfall and AMO cycles. Lake levels were high during the wet period (1945 to 1965) and were low during the dry period (1995–2005). A close examination of lake levels indicates that there is a delayed response to rainfall. As shown in Figure 5, there has been an increasing trend in rainfall in the region since the early 2000s. A similar increasing trend can be observed in lake levels (Figure 4). However, the increasing trend in Lake Brooklyn levels appears to begin in 2004–2005 whereas the increasing trend in Lake Geneva levels appears to begin in 2013–2014. Data suggest that these lakes respond to rainfall with a delay of 2 to 10 years. This could be attributed to the effect of storage in the regional aquifer and watershed and the delay in upstream flows reaching the lakes. Lake Brooklyn responds much quicker than Lake Geneva to recent increases in rainfall trends because Lake Brooklyn has been receiving a significant amount of surface inflows from upstream lakes whereas Lake Geneva has been receiving none and has been driven primarily by groundwater levels.

Lakes Brooklyn and Geneva are sensitive to prolonged periods of below average rainfall, because they are located within an area of thick sand deposits and are highly connected to the

UFA. Cumulative (i.e., back to back) years of below-average rainfall makes the landscape very dry, contributing to declines in surface water inflows, and reducing recharge to groundwater. Both reduction in surface water inflows and recharge to groundwater result in lower lake levels. From the 1930s to the early 1970s, there was a cumulative rainfall surplus of approximately 150 inches (Figure 6). From the early 1970s to 2012, there was a rainfall deficit of approximately 105 inches (Figure 6). This period of reduced surface water inflows and groundwater recharge corresponds to a period of water level decline at Lakes Brooklyn and Geneva. The Standardized Precipitation Index (SPI) was calculated to characterize meteorological drought near Lakes Brooklyn and Geneva. SPI results support the findings of the cumulative rainfall analysis. As shown in Figure 7, a wet period (blue areas) was observed from the late 1940s to the late 1970s, followed by several severe dry periods (red areas) after the late 1970s. The latter is the same period when water levels at Lakes Brooklyn and Geneva declined.

A comprehensive body of literature also corroborates that there is a strong correlation between lake levels and rainfall with increasing levels correlated with above average annual rainfall, and declining water levels correlated with below average annual rainfall (Yobbi and Chappell 1979, Motz et al. 1991, Robison 1992, Motz et al. 1994, Motz et al. 1995). Clark et al. (1963) conducted a study focusing on Lake Brooklyn in 1963 after the Lake Brooklyn water level declined approximately 20 feet in three years. The purpose of the study was to determine the reason for the decline in the lake levels. A water budget analysis was performed, and the study concluded that more than three years of drought in conjunction with high rates of leakage caused the significant declines in lake levels.

Historical Groundwater Pumping Impact Assessment

Lakes Brooklyn and Geneva were developed from collapse or subsidence sinkholes, creating a high degree of connection to the UFA. This makes them sensitive to changes in the groundwater system. In addition, because these lakes are located at the potentiometric high of the UFA, which is the source of water for several groundwater basins in north Florida, they are also vulnerable to potential impact from regional groundwater pumping (Figure 8). Therefore, potential impacts to Lakes Brooklyn and Geneva were assessed for both local and regional pumping.

MFLs are established to set the limit at which further withdrawals would be significantly harmful to water resources. To aid in the estimates of potential impact on these lake levels from groundwater pumping, monthly groundwater use data was compiled for Alachua, Clay, Duval, Putnam and Bradford counties from 1957 to 2018 (Figure 9). The pumping in 2019 and 2020 was not included because complete datasets of 2019 and 2020 pumping were not available at the time of analysis. These five counties were selected because regional groundwater modeling efforts, such as the Northeast Florida (NEF) and North Florida Southeast Georgia (NFSEG) regional groundwater flow models, demonstrated that

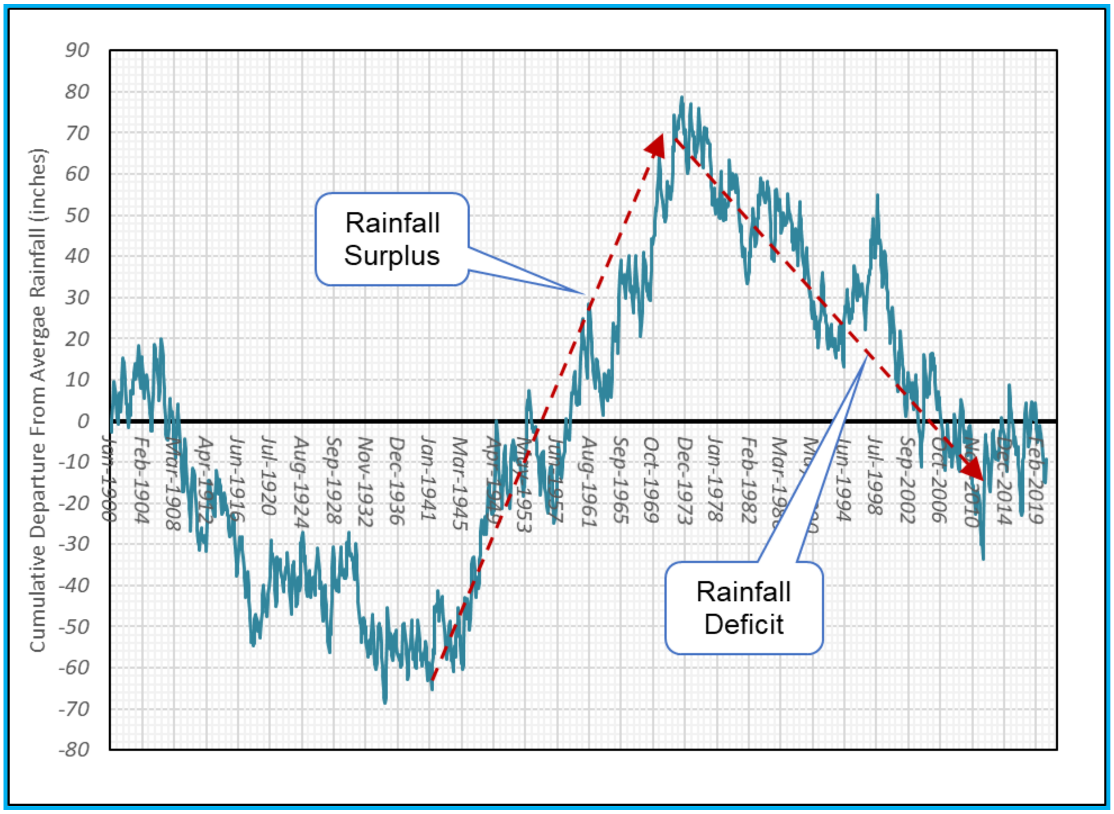

Figure 6. Cumulative Departure from Average Rainfall (Composite of Gainesville and local Keystone Heights rainfall stations).

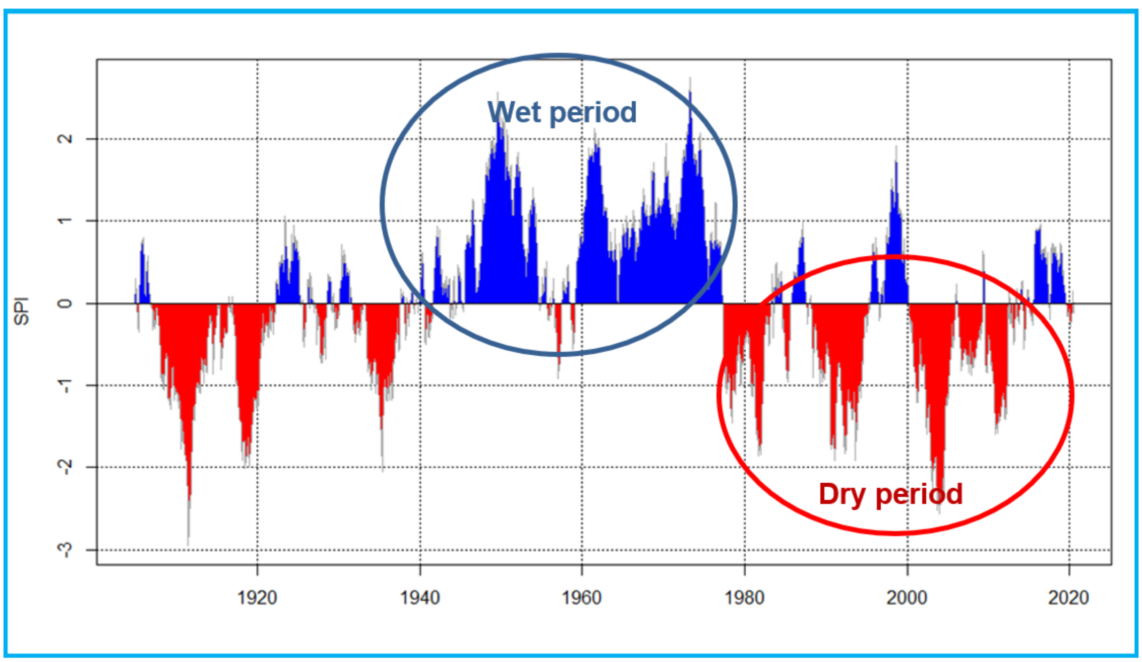

Figure 7. Long-term 60-month Standard Precipitation Index of composite rainfall (Gainesville and local Keystone Heights rainfall stations).

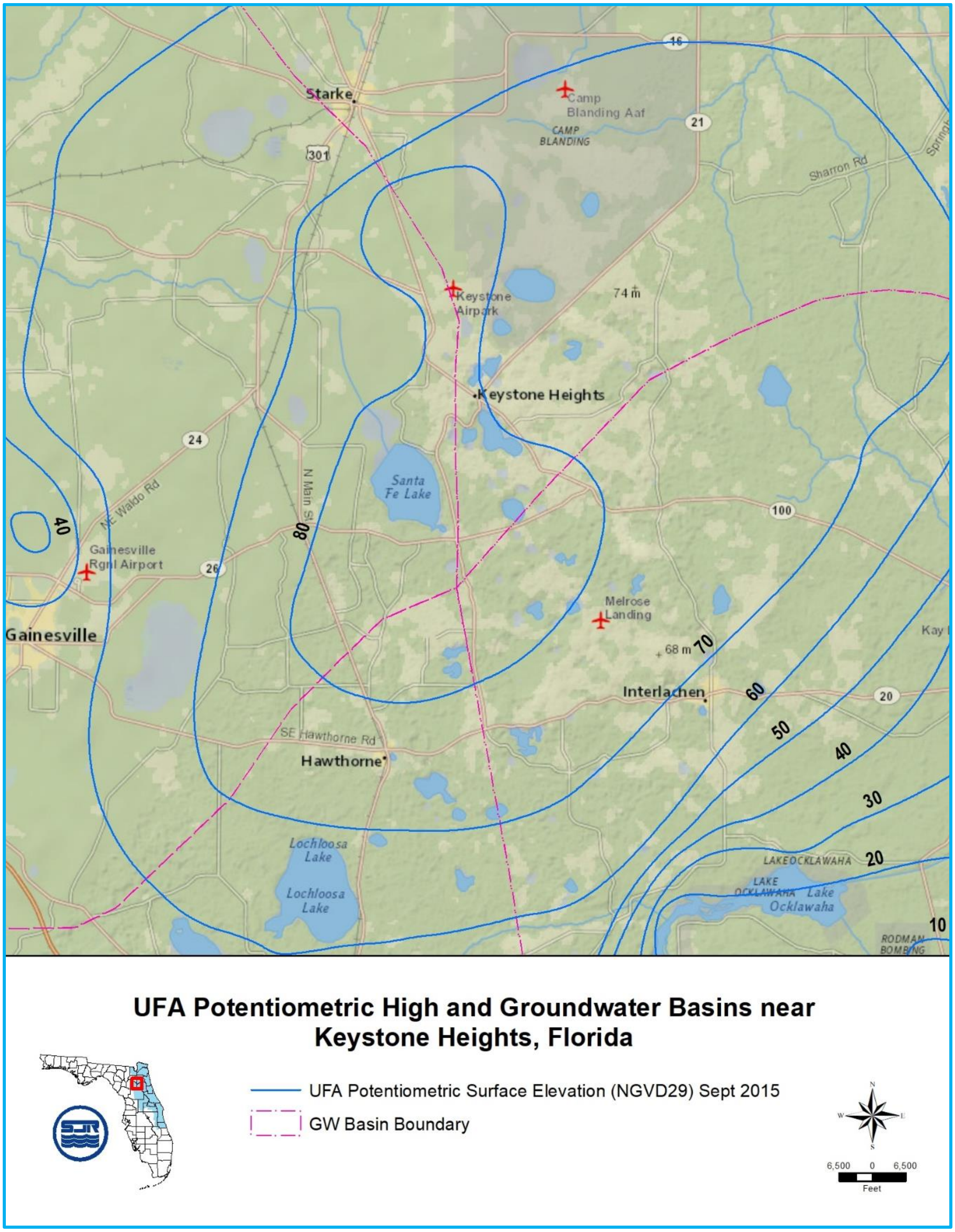

Figure 8. UFA potentiometric high and groundwater basin boundaries near Keystone Heights, Florida.

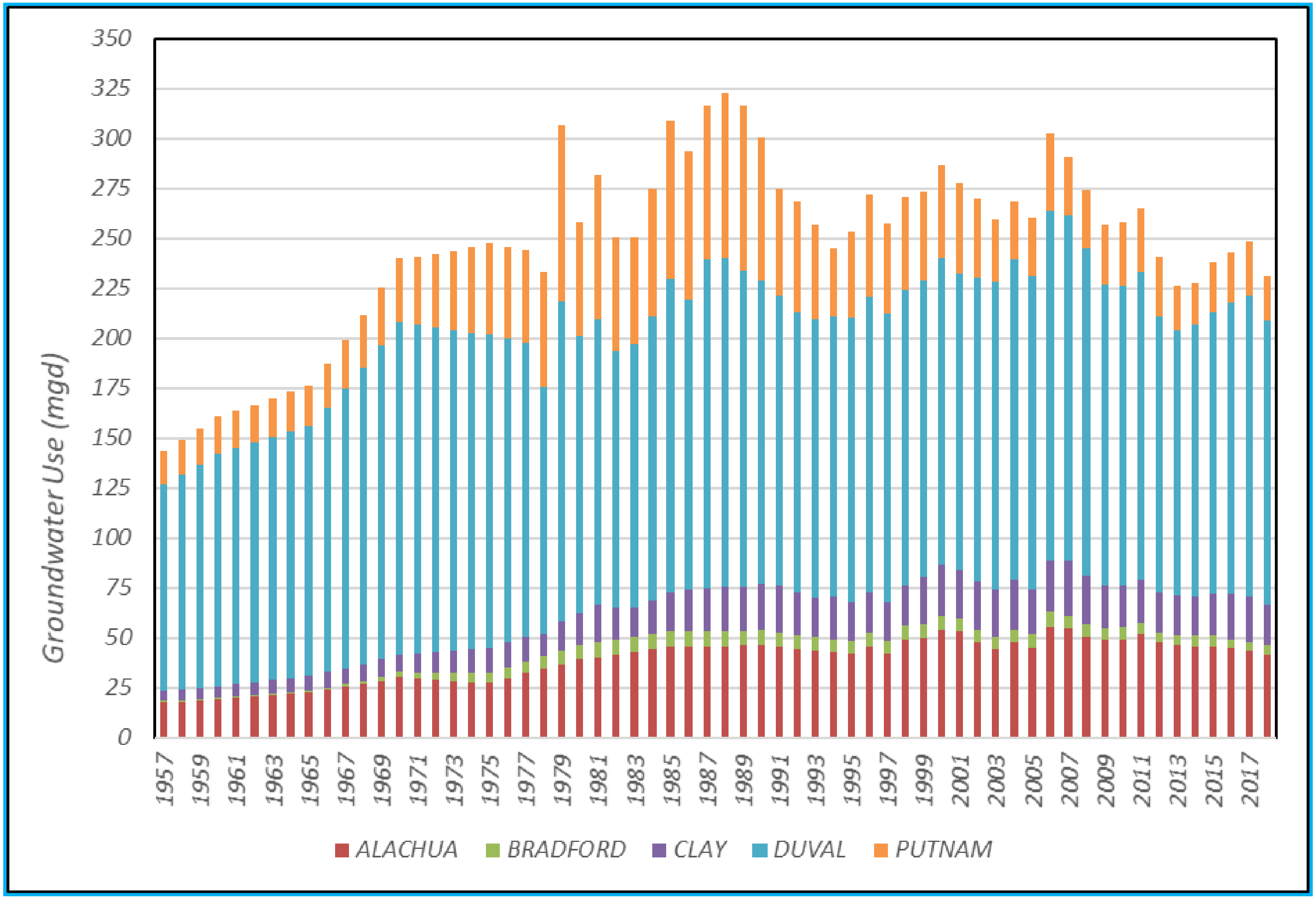

Figure 9. Estimated historical groundwater uses in Alachua, Bradford, Clay, Duval, and Putnam counties.

groundwater use in these counties has the most potential to impact the groundwater levels near Lakes Brooklyn and Geneva. It should also be noted that the groundwater pumping within the aforementioned counties was only used to understand how the UFA responds to regional pumping near the lakes so that groundwater pumping impact from 1957 to 2018 can be estimated. The full impact of groundwater pumping on lake levels were assessed based on the entire groundwater pumping within the NFSEG model domain. As shown in Figure 9, the total groundwater use in these counties reached its highest level in 1988 (323 mgd) and declined until 1994. It increased again until 2006 (302 mgd) and has declined about 20% after 2006. Average groundwater use over the past five years (2014–2018) is approximately 238 mgd. which is similar to groundwater use in the early 1970s.

In addition to the NFSEG regional groundwater flow model, the Keystone Heights subregional transient groundwater model (KHTM) was developed to help assess the impact of groundwater pumping on lake levels (Tetra tech, 2017; SJRWMD, 2020). KHTM can simulate the interaction between groundwater and surface water features such as lakes and streams as well as changes in lake levels and stream flows due to changes in rainfall, ET and pumping in monthly time steps. The model was used to simulate monthly water levels and flows back to 1957. It is common modeling practice to develop a refined local model such as the KHTM for specific areas of concern and to use a regional model to adjust lateral boundary conditions to simulate effects of regional groundwater pumping and recharge. The NFSEG (v1.1) was used in conjunction with KHTM to estimate the impact of regional groundwater pumping on lake levels. Figures 10 and 11 show the estimated monthly lake level declines resulting from pumping from 1957 to 2018 for Lakes Brooklyn and Geneva, respectively.

The impact of pumping on lake levels during a dry period are higher than the impact of pumping on lake levels during a wet period for the same amount of pumping because of the lack of surface water inflows and runoff. Thus, while there was regional pumping in the 1960s, the impact of groundwater pumping on both lakes was relatively low. During that period, the groundwater impact had been masked by the amount of surface water flows coming from the upstream lakes.

For much of the POR, Lake Brooklyn has received surface water flows from the upstream lakes. However, since 1973, the amount of surface flows coming from the upstream lakes to Lake Brooklyn has declined and varied due to rainfall deficits. Because of both variable rainfall and groundwater pumping, the groundwater impact to Lake Brooklyn has exhibited large variation and become more pronounced since 1973.

Lake Geneva has not received any surface flow from Lake Brooklyn since 1973 except for a very brief period in 1998. As a result, the variability of groundwater pumping impacts to Lake Geneva has been lower since 1973. However, like Lake Brooklyn, the magnitude of groundwater pumping impact on Lake Geneva levels has been higher since then.

It should also be noted that the groundwater pumping impact on these lakes has declined considerably due to recent (since 2013) reductions in regional pumping as shown in Figures 10 and 11.

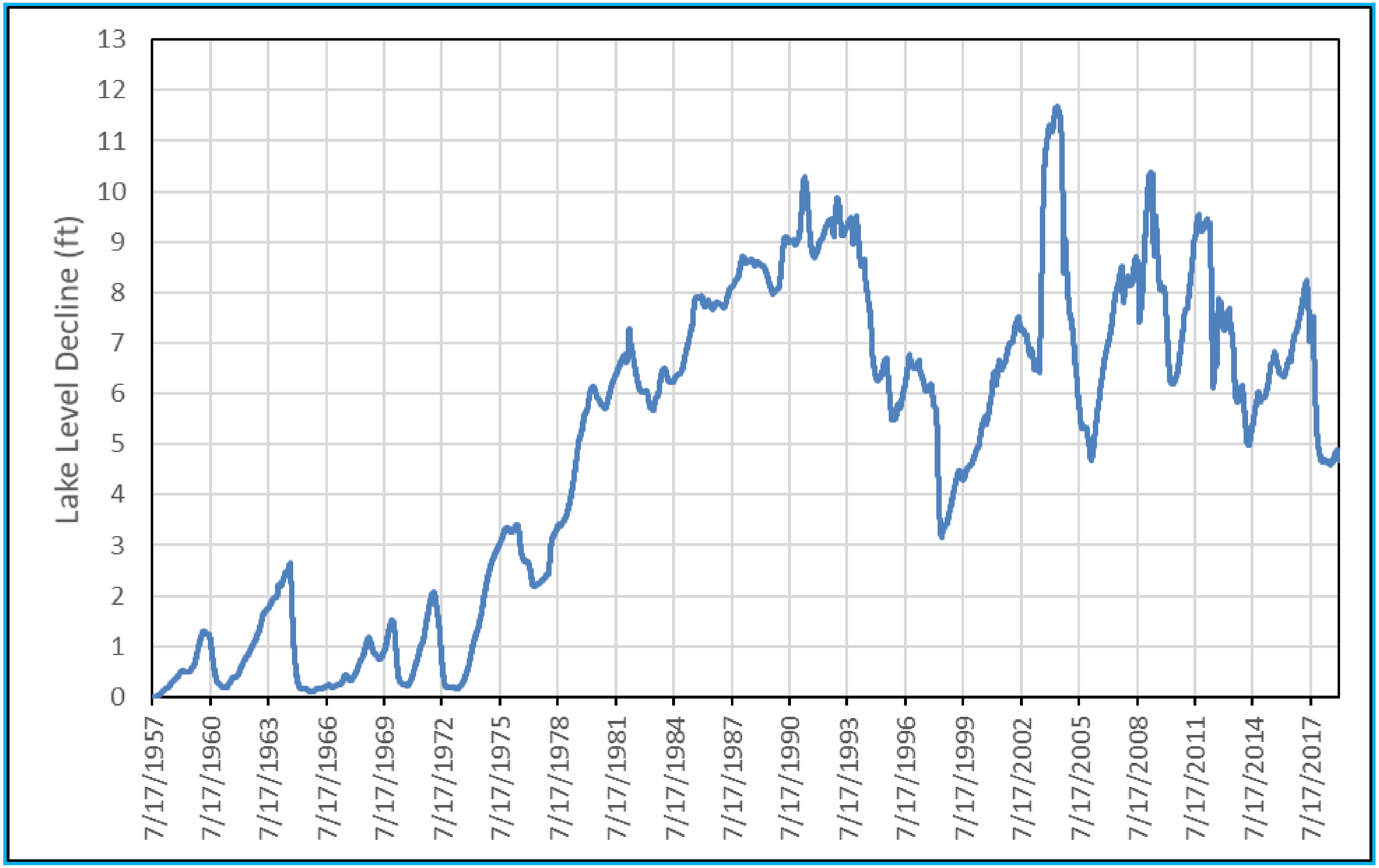

Figure 10. The estimated impact of historical groundwater pumping on Lake Brooklyn levels from 1957 to 2018.

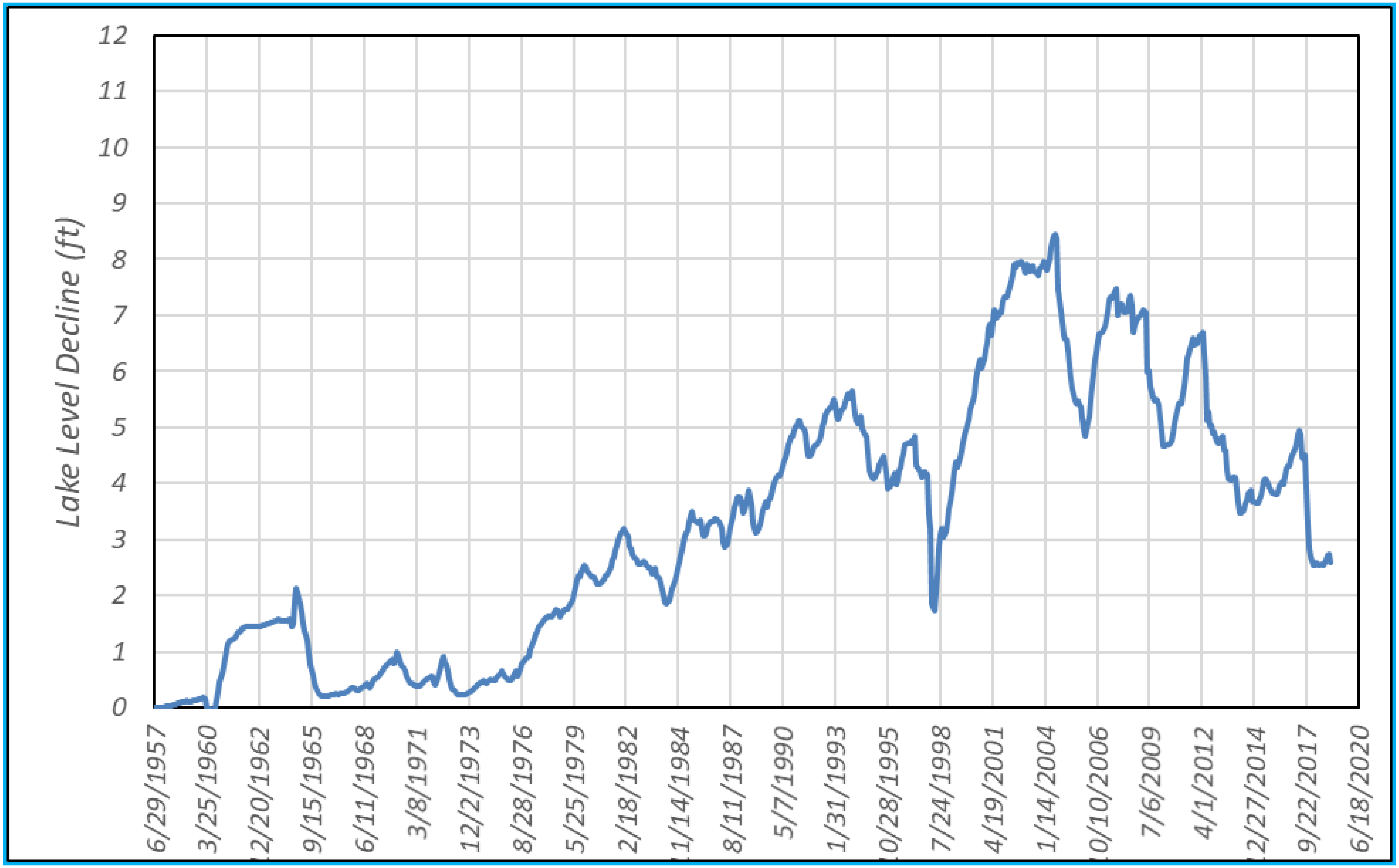

Figure 11. The estimated impact of historical groundwater pumping on Lake Geneva levels from 1957 to 2018.

Discussion

The analysis of long-term water level declines indicates that both long-term rainfall deficits and regional groundwater pumping have played a critical role in lowering lake levels over the past 40–50 years. Both lakes' levels have declined considerably since 1973 not only due to increases in regional groundwater pumping but also due to reductions in surface water inflows and direct runoff resulting from rainfall deficits. However, the impact on lake levels due to groundwater pumping has declined over the past five years because of reductions in regional pumping of approximately 20%, since 2006. The analysis also suggests that it may take many years of above-average rainfall to offset the effect of prolonged periods of drought on these lakes.

MFLs Determination

The MFLs determination for Lakes Brooklyn and Geneva involved both hydrological and environmental analyses. The *Hydrological Analyses* section below provides a brief description of modeling and data analyses used to develop long-term lake level timeseries, to develop minimum lake levels for both lakes. More details on hydrological analyses are provided in Appendix B.

The *Environmental Analyses* section provides a brief description of each of the environmental criteria evaluated for the Lakes Brooklyn and Geneva MFLs reevaluation. In addition to methods descriptions, results are also presented, including the calculation of recommended minimum lake levels based on each criterion. Criteria were chosen based on their potential to protect environmental values and beneficial uses, as mandated by Rule 62-40.473, F.A.C.

The protection of these environmental values, also called Water Resource Values (WRVs), is discussed further in the *MFLs Assessment* section. The current and future status of each lake, based on the most constraining criterion, is also presented in the *MFLs Assessment* section.

Hydrological Analyses

Determining MFLs and assessing the status of water bodies requires substantial hydrological analysis. The main purpose of the hydrological analyses is to better understand the impact from groundwater pumping on lake levels and to develop no-pumping and current-pumping condition long-term lake levels for MFLs determination and assessment. Several steps were involved in performing these hydrological analyses, including:

1. Review of available data;
2. Long-term rainfall analysis;
3. Historical groundwater pumping impact assessment;
4. Development of lake level datasets representing no-pumping and current-pumping conditions; and
5. Estimating available water (freeboard or deficit).

Available water level data, long-term rainfall analysis and groundwater pumping impact assessment are discussed in the *Hydrology* subsection under the *Setting and Description* section. For MFLs determinations and assessment, long-term lake level time series, representative of a no-pumping condition and a current impacted (current-pumping) condition, are needed.

In order to develop the no-pumping condition lake level datasets, an estimate of lake level decline due to historical groundwater pumping (shown in Figures 10 and 11) is needed. The estimated lake level decline caused by groundwater pumping is added to the observed dataset to create the no pumping condition dataset. The no-pumping condition time series represent hydrologic conditions of the lakes in which impacts from groundwater pumping are assumed to be minimal (Figures 12 and 13).

The current-pumping condition lake level datasets were developed by subtracting an estimate of impact due to current groundwater pumping (average 2014–2018) from the no-pumping lake level time series. The current-pumping condition lake level dataset represents a reference hydrologic condition of the lakes in which the total regional groundwater pumping impacting the lakes is assumed to be constant from 1957 to 2018 (Figures 12 and 13).

Assuming climatic, rainfall, and other conditions present from 1957 to 2018 are repeated over the next 61 years, the current-pumping condition lake levels would reflect the future condition of lake levels if the average regional groundwater pumping does not change from 2014–2018 condition. Our understanding of possible future climatic conditions is limited and there are significant uncertainties in global climate model predictions. According to the Florida Climate Institute, the climatic cycles such as El Nino Southern Oscillations (ENSO), Atlantic Multidecadal Oscillation (AMO) and the Pacific Decadal Oscillation (PDO) have the strongest influence on Florida's climate variability (Kirtman et al., 2017). ENSO cycles typically range from two to seven years, PDO cycles typically range from 15 to 25 years and AMO cycles typically range 60 to 70 years (Schlesinger and Ramankutty, 1994; Obeysekera et al., 2011; and Kuss and Gurdak, 2014).

There are strong relationships of short and long-term climatic cycles such as ENSO and AMO to rainfall, river flows and groundwater levels in Florida (Enfield et al., 2001, Kelly, 2004 and Kuss and Gurdak, 2014). These strong relationships are not expected to disappear in the foreseeable future. Florida sinkhole lakes usually exhibit different behaviors in terms of frequency of certain water levels during wet and dry periods of long-term climatic cycles. The exceedance probability of a given lake level could easily be different in the1960s than in the 2000s. Because of this, MFLs development requires the use of long-term lake levels to capture the effects of short- and long-term climatic variations such as ENSO and AMO on lake levels.

SJRWMD acknowledges that the MFLs analyses assume that hydrological history will repeat itself. Given the uncertainties in future rainfall and temperature predictions by global climate models, this assumption is thought to be appropriate. MFLs are established to prevent water bodies from being significantly harmed by groundwater pumping. Therefore, using historical conditions to generate current-pumping condition lake levels is reasonable.

Lakes Brooklyn and Geneva water levels were also expressed as exceedance probabilities to facilitate evaluation of certain MFL criteria. An exceedance probability is defined as the percent of time a specified level will be equaled or exceeded over the period of record. Figures 14 and 15 show exceedance probability curves of water levels for Lakes Brooklyn and Geneva, respectively.

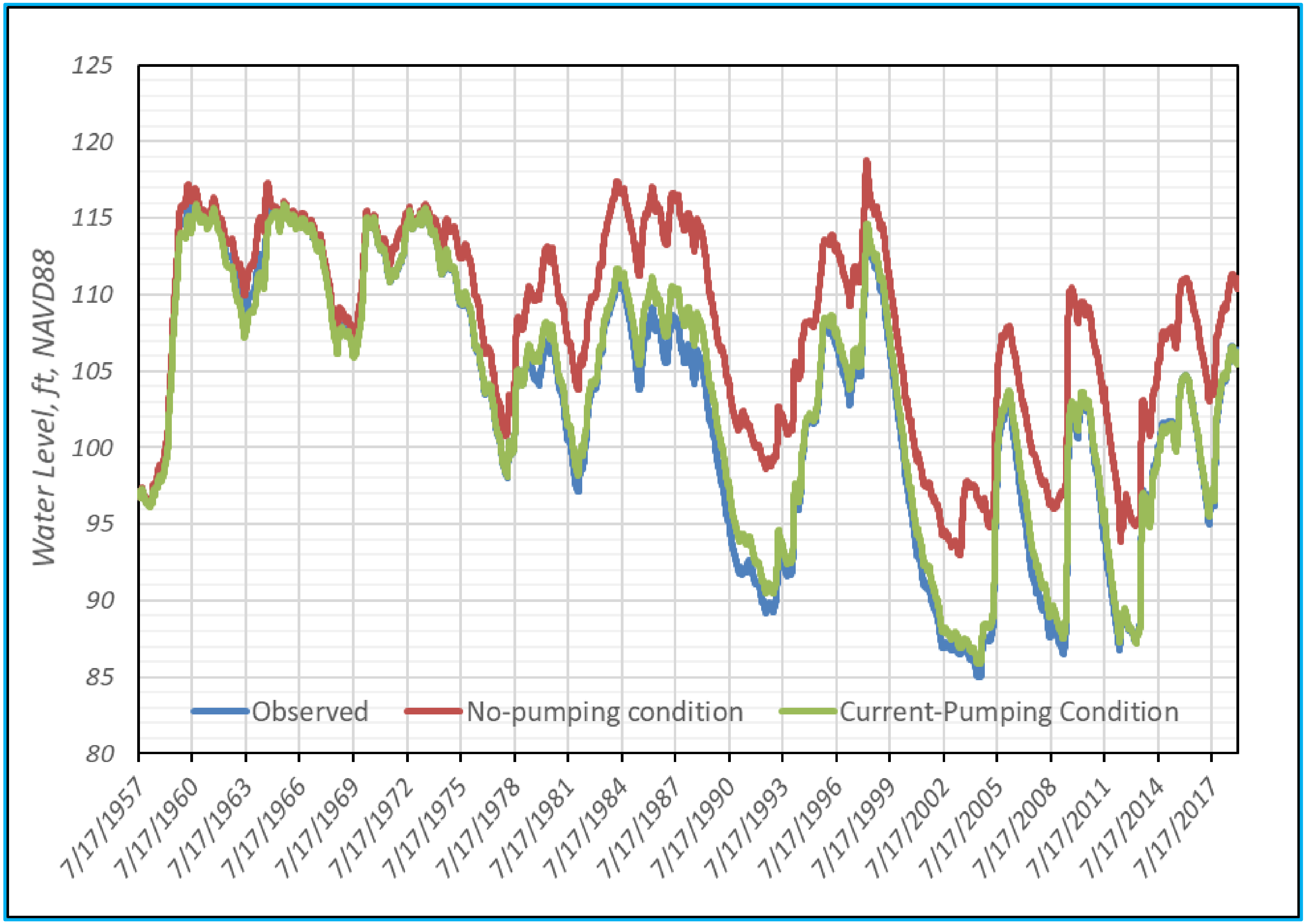

Figure 12. The estimated no-pumping and current-pumping condition levels for Lake Brooklyn.

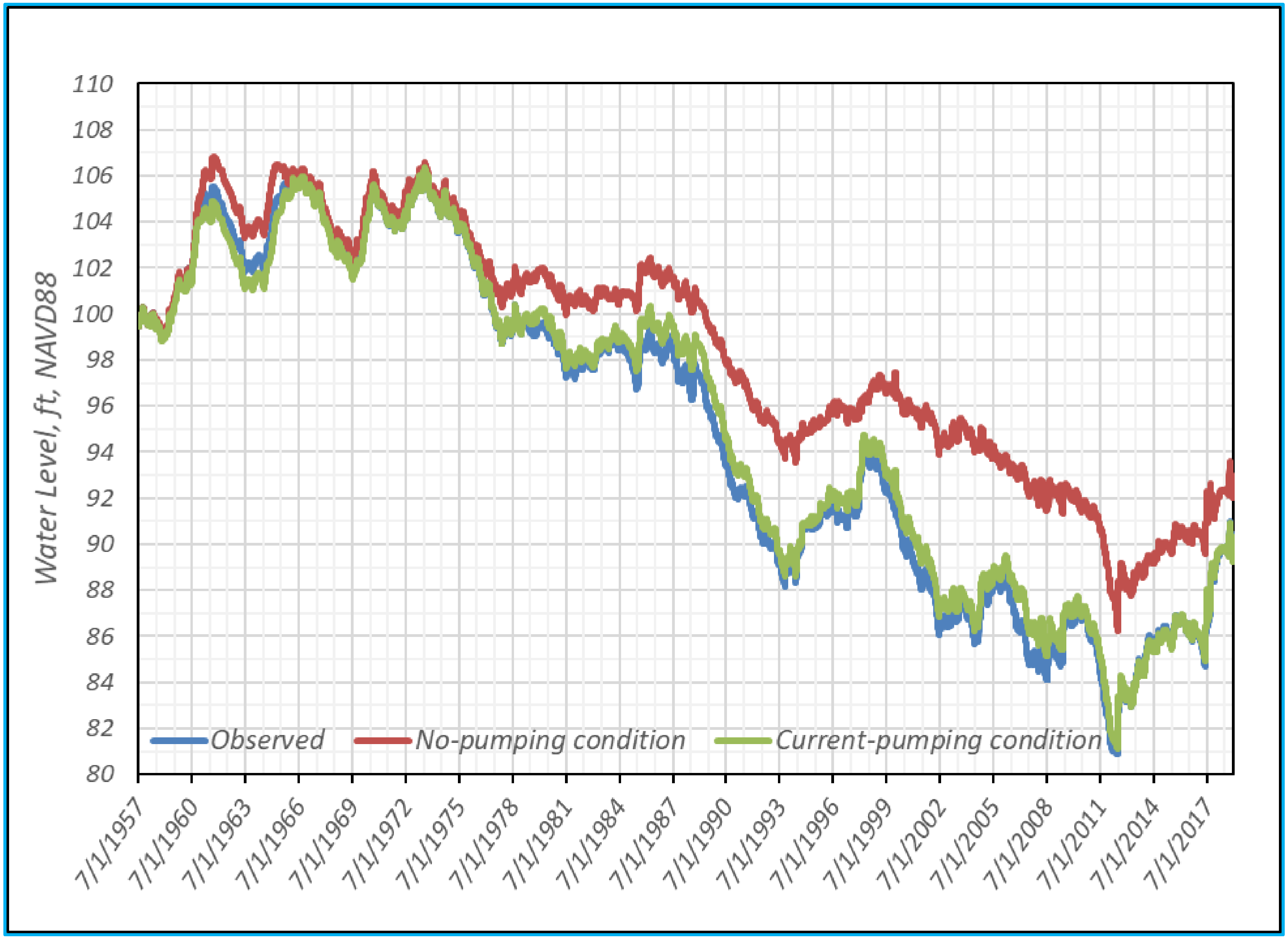

Figure 13. The estimated no-pumping and current-pumping condition levels for Lake Geneva.

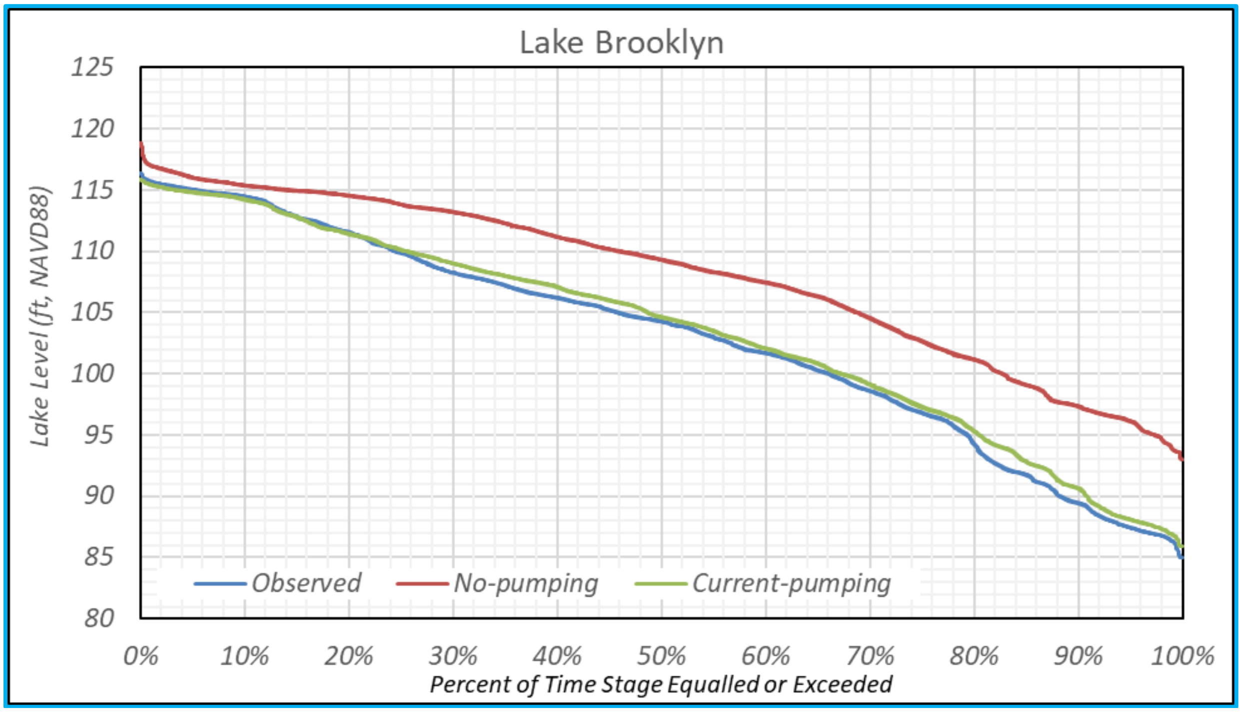

Figure 14. Exceedance probability curve of Lake Brooklyn levels.

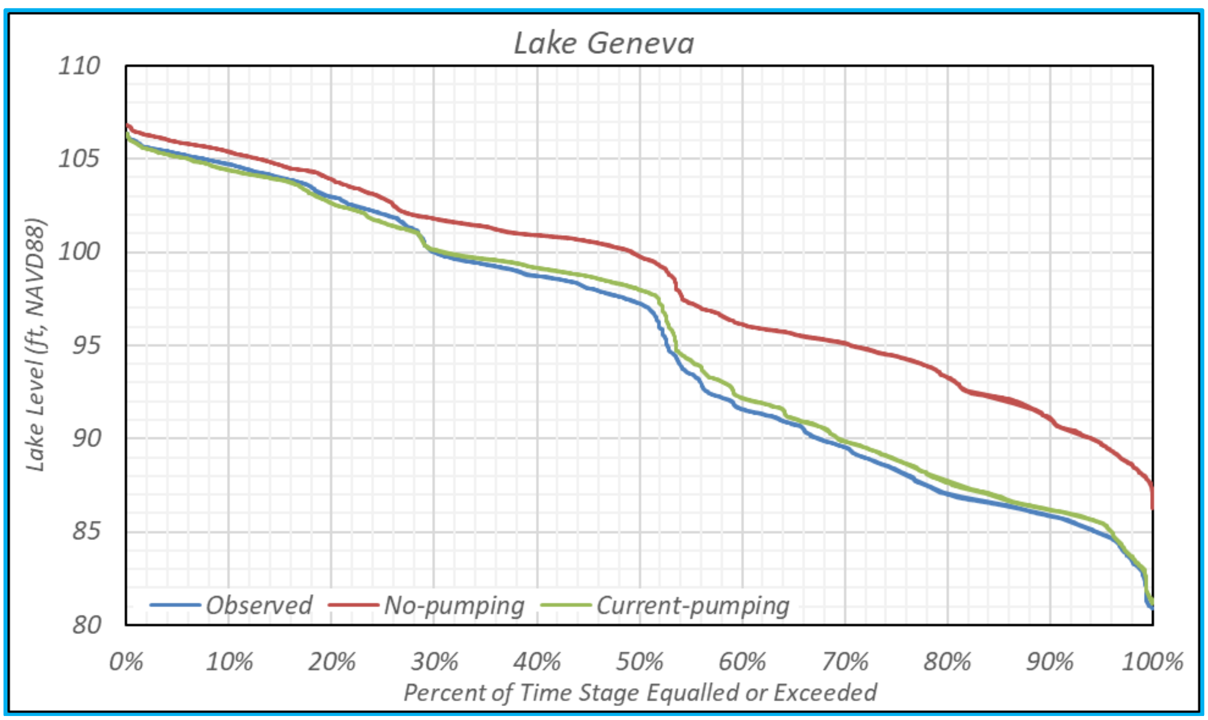

Figure 15. Exceedance probability curve of Lake Geneva levels.

ENVIRONMENTAL ANALYSES

A key component of the MFLs determination is the analysis to determine relevant environmental attributes and beneficial uses for each water body. This analysis involves determining appropriate criteria and thresholds to protect these environmental values. This process typically includes:

- Consideration of site-specific field-based ecological data;
- Environmental data;
- Recreational data;
- Topographical information;
- Data collected at other MFLs sites; and
- Supportive information from scientific literature

Using this information, a determination is made of the most important environmental values for a given water body. Next, appropriate criteria are determined to represent these environmental values, and a minimum hydrologic regime (MFLs condition) is determined, that ensures their protection.

Criteria and Thresholds for Lakes Brooklyn and Geneva

Very little has been published on environmentally protective lake levels, especially compared to the large body of literature for rivers and streams (Tharme 2003, Arthington 2012, Gleeson and Richter 2017). The majority of published studies on lake level thresholds are associated with determining the effects of reservoir regulation alternatives on recreational uses (Cordell and Bergstrom 1993, Hanson et al., 2002) and economic valuations of reservoir water level changes (e.g., home and property values; Allen et al., 2010, Dickies et al. 2011, Dickies and Crouch 2015). Some of these studies allow very large water level reductions from full pool (e.g., reducing reservoir storage by 69%; Shang 2013), while other studies on unregulated lakes suggest a less dramatic reduction (Hoyer and Canfield 1994, Emery et al., 2009). Guidance on protective criteria and thresholds for sandhill/sinkhole lakes is largely absent.

Recommended Environmental Criteria

Numerous environmental criteria were evaluated in an effort to develop protective minimum levels for Lakes Brooklyn and Geneva. Criteria were chosen based on their potential to protect nonconsumptive environmental values and beneficial uses (also called WRVs), as mandated by Rule 62-40.473, F.A.C. A discussion of preliminary criteria considered but not utilized are discussed in Appendix C.

The final recommended environmental metrics, used to establish minimum levels for Lakes Brooklyn and Geneva, include several new environmental criteria, which were developed in an effort to address significant peer reviewer concerns and also ensure the establishment of appropriate protective minimum levels. The remaining sections describe the final environmental criteria that were the basis for developing the recommended minimum levels at Lakes Brooklyn and Geneva.

Minimum Infrequent High

SJRWMD lake MFLs typically include Frequent High, Minimum Average and Frequent Low events with specific target levels, durations and return intervals that are based on protecting a minimum number of flooding events or preventing more than a maximum number of drying events, to protect stable wetland communities and organic soils.

Given the absence of stable wetlands and organic soils at Lakes Brooklyn and Geneva, an event-based approach was used to develop a different type of metric, with the aim of protecting sandhill lakes. This effort resulted in an infrequent flooding criterion — a minimum Infrequent High (IH) — intended to prevent a downhill shift in the upland/wetland boundary of Lakes Brooklyn and Geneva. The IH event for both lakes includes a magnitude component (i.e., elevation) that corresponds to the waterward boundary of the uplands; a duration component of 30 days and a return interval of 25 years. The magnitude component for Lakes Brooklyn and Geneva was calculated by subtracting 1 foot from the land surface elevation of waterward saw palmetto. This is the minimum elevation of the root zone of waterward saw palmetto plants and allows this elevation to be continuously flooded for the prescribed duration.

The recommended duration component of the IH level event is a minimum of 30 days continuously exceeded to flood upland species and maintain the location of the upland/wetland boundary. The recommended duration is thought to be sufficient to kill upland species that become established downslope of the upland boundary. The return interval of 25 years is associated with a flood frequency necessary to kill pine trees and faster growing hardwood species (e.g., laurel oak) and deemed necessary to periodically reset the upland boundary (see Appendix C for more details on the development of the IH for both lakes). The IH events developed for Lakes Brooklyn and Geneva are presented below in Table 3.

Table 3. Minimum Infrequent High for Lakes Brooklyn and Geneva, Clay and Bradford Counties, Florida

System	Minimum Level	Level (ft NAVD88)	Duration (days)	Return Interval (years)
Lake Brooklyn	Infrequent High	114.2	30	25
Lake Geneva	Infrequent High	105.2	30	25

Preliminary modeling results indicated that the high elevations associated with IH events developed for Lakes Brooklyn and Geneva are relatively insensitive to groundwater withdrawal. High water levels for both lakes are driven more by infrequent storm events than by changes in UFA levels. Preliminary analyses suggested that the IH events developed were potentially not protective of lower lake elevations and would therefore not be protective of other environmental functions and values associated with lower elevations (e.g., elevations associated with docks, boat ramps, lake lobe connections). For this reason, additional environmental criteria were evaluated to augment this metric and ensure that important environmental values and beneficial uses are protected. These additional environmental criteria are described below.

Fish and Wildlife Habitat Metrics

Per Rule 62-40.473, *F.A.C.*, water management districts are directed to consider a suite of environmental values, also called water resource values (WRVs), when setting MFLs. One of these WRVs is "*fish and wildlife habitats and the passage of fish*". Typically, SJRWMD addresses this WRV through event-based metrics that are developed to maintain the long-term persistence and integrity of wetland communities.

As discussed above, Lakes Brooklyn and Geneva lack stable wetlands and organic soils. However, they both harbor a diverse community of wetland plant and animal communities that, while unstable (i.e., their locations move over the decades due to climate-driven lake fluctuation), are worth protecting from significant harm due to withdrawals. A new approach was developed to evaluate the effects of water level decline on fish and wildlife habitat, using a Geographic Information System (GIS)-based "hydroperiod tool". This customized tool was developed, with the South Florida Water Management District (SFWMD) and the University of Texas (Austin), to work with ESRI's ArcMap©. The hydroperiod tool functions primarily with raster (grid-based) representations of the environment, in which elevation values from a DEM are subtracted from an interpolated water surface elevation on a grid cell by grid cell basis, producing a new raster surface containing elevation or depth of water for each grid cell (Figure 16). The DEMs for Lakes Brooklyn and Geneva were developed using 2012 LIDAR data, ADP data and elevation data surveyed along numerous transects.

Over the past two decades, large water level fluctuations at Lakes Brooklyn and Geneva have resulted in the downslope movement of deep marsh, shallow marsh and transitional shrub wetlands. This conclusion is based on SJRWMD staff observations of current wetland locations relative to 1996 surveyed locations collected as part of establishing the original MFLs. As wetlands move downslope during periods of drought, their areal coverage (e.g. total acreage) and habitat volume also change. Changes in the extent of nearshore habitat is related to the combined effect of changing water level and specific lake bathymetry. For example, if "habitat" is defined as portions of the lake with depths ranging from 1 to 2 feet, the areal extent of this habitat will vary with water level and be a function of lake shape and slope. The extent of some habitats may be minimal at high elevations, if banks are steep, and may be extensive at lower elevations that are characterized by low slope (e.g., if there is a large flat shelf or lake bottom). The hydroperiod tool was used to estimate the area of different fish and wildlife habitats and estimate how they change with lake level change (Figure 17).

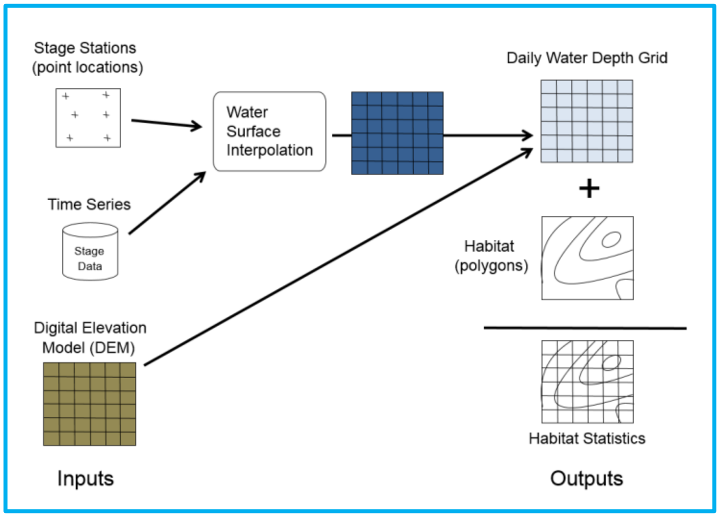

Figure 16. Conceptual diagram of the hydroperiod tool used to estimate the relationship between lake stage and habitat area.

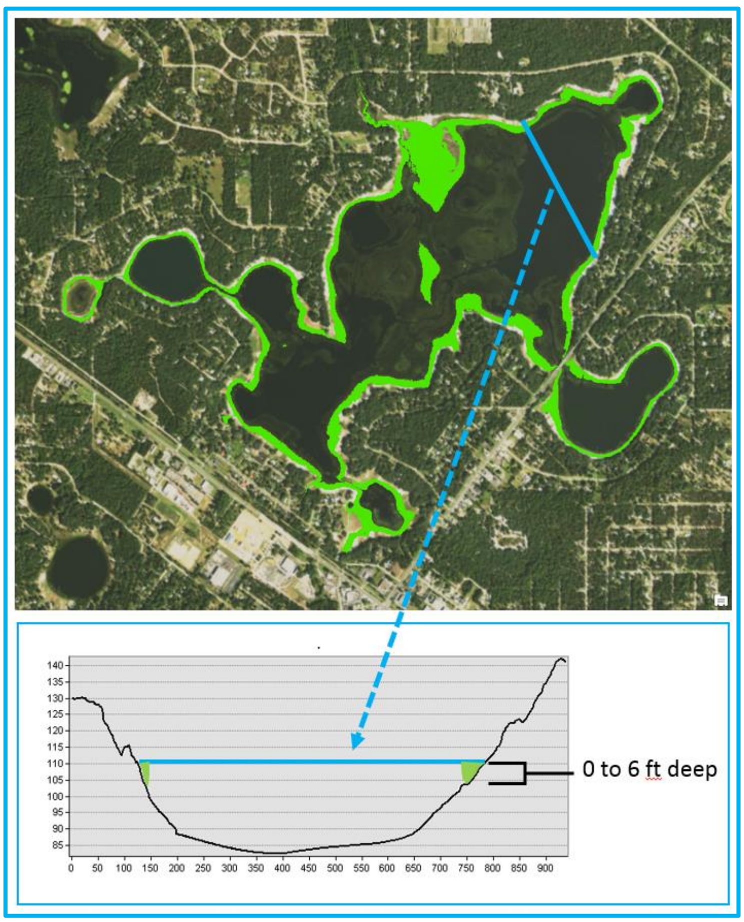

Figure 17. Example hydroperiod tool output showing relationship between water level and habitat (0–6 ft) area.

Impact Threshold

Nearshore wetland communities at Lakes Brooklyn and Geneva change location and change in areal extent as lake levels fluctuate naturally (i.e., due to changes in climate). However, these communities can also change in extent due to withdrawal. Therefore, it was deemed important to understand the relationship between lake level decline and change in habitat extent, to understand whether withdrawal has caused (or will cause) the amount of nearshore habitat to decline beyond an acceptable threshold.

The significant harm threshold used for this metric is a 15% change in areal extent (acreage) of different habitats (*see following sections for habitat descriptions*). A 15% reduction of habitat availability has been used by other water management districts as a significant harm threshold for MFLs (Munson and Delfino 2007). This threshold has been peer reviewed and has been the basis for numerous adopted MFLs (see SWFWMD MFLs for Crystal River, Gum Slough, Chassahowitzka River, and Homosassa River, among others). While many MFLs using this threshold are for flowing systems, a 15% reduction in habitat has also been used as a critical threshold for lakes, and is based on bird species richness studies (Hoyer and Canfield 1994, Leeper et al., 2001, Emery et al., 2009). This threshold is also within the range (10 to 33%) of percent allowable change documented in other studies (Munson and Delfino 2007).

As noted by the peer reviewer of this MFL, this threshold has been supported by others, including Shaw et al. (2005) who states that *"... changes in available habitat due…occur along a continuum with few inflections or breakpoints where the response dramatically shifts.",* and therefore *"…loss or reduction in a given metric occurs incrementally …and in the absence of any clear statutory guidance* [they] *believe that the use of a 15 percent for loss of habitat is reasonable and prudent."*

Average habitat area

Average area was calculated for each fish and wildlife habitat, for each day in the POR, using the stage/habitat area relationship derived from the hydroperiod tool and the simulated water surface elevations for the no-pumping condition. The MFLs condition for fish and wildlife habitat metrics equals a 15% reduction in average habitat area under the no-pumping condition (i.e., habitat area averaged across the entire no-pumping condition lake level timeseries). Assessment of habitat metrics is then simply the comparison of the average habitat area under no-pumping condition to the average habitat area under the current-pumping condition (see MFLs Assessment Section for more details).

Nearshore habitats

The nearshore environment (littoral zone) within Lakes Brooklyn and Geneva provides habitat for numerous native fish and wildlife species, including game fishes and wading birds (SJRWMD staff observations). The shallow littoral zone fringing both lakes provides valuable habitat for various life stages, including refugia and forage habitat for aquatic invertebrates, game fish juveniles and small-bodied fishes. These areas also provide important reproductive habitat for fish, amphibians and reptiles, forage habitat for wading birds, and nesting habitat for the Florida sandhill crane (*Grus canadensis pratensis*).

Five habitats were defined for this analysis. Habitats are areas within the nearshore environment with specific depth ranges and are based on water level requirements of plant and animal species known to inhabit these areas in both lakes (Figure 18; Neubauer 1994; SJRWMD staff observations). These habitats were chosen to ensure that multiple portions of the nearshore environment were evaluated, in case one or more was particularly sensitive to water level change. Each habitat described below was evaluated using the hydroperiod tool to determine the amount of water level decline is associated with a 15% reduction in habitat extent (acres), relative to the long-term average no-pumping condition.

Emergent Marsh Habitat

The littoral zone at Lakes Brooklyn and Geneva includes both shallow and deep marsh habitats, with occasional woody wetland shrubs (e.g., buttonbush, *Cephalanthus occidentalis*). Shallow marsh vegetation is dominated by rush fuirena (*Fuirena scirpoidea*), maidencane (*Panicum hemitomon*), various beakrushes (*Rhynchospora spp*.) and blue maidencane (*Amphicarpum muhlenbergianum*). Deep marsh habitats are dominated by spatterdock (*Nuphar advena*), pickerelweed (*Pontederia cordata*), and soft rush (*Juncus effusus*). Emergent marsh generally extends from the edge of the shore to approximately 6 feet deep. A maximum depth of 6 feet was used based on the known depth ranges for species inhabiting these communities (e.g., maidencane, and spatterdock). Based on this, the emergent marsh habitat depth range used for this analysis is 0 to 6 feet.

Game Fish Spawning Habitat

Recreational species are present at both Lakes Brooklyn and Geneva (FWC 2020; see Appendix C for summary data). These include largemouth bass (*Micropterus salmoides*), black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*) and other bream species (Appendix C). Nearly 30 trophy sized largemouth bass have been caught at these lakes since 2015 (FWC Trophy Catch program: *https://www.trophycatchflorida.com/search-catches.aspx*).

The purpose of this habitat metric is to prevent significant harm to game fish spawning habitat, due to withdrawal. Largemouth bass, black crappie and other lake game fish (e.g., *Lepomis spp.*) typically construct their nests in shallow water in close proximity to emergent vegetation. While the range of nest depths for largemouth bass can vary from less than one foot to over 10 feet, the average depth is typically 1 to 4 feet (Stuber et al., 1982, Bruno et al., 1990, Hill and Cichra 2005, Strong et al., 2010). Therefore, the depth range used for the game fish spawning habitat equals 1 to 4 feet.

This depth range will also provide important refuge habitat for small forage fish that form the base of production for game fish, birds and other wildlife at Lakes Brooklyn and Geneva. Forage fish in Lakes Brooklyn and Geneva include mosquito fish (*Gambusia spp*.), shiners (*Notropis spp*.), golden topminnow (*Fundulus chrysotus*), killifish (*Fundulus spp*.) and other small bodied species (FWC 2020). Shallow marshes provide important refugia and forage

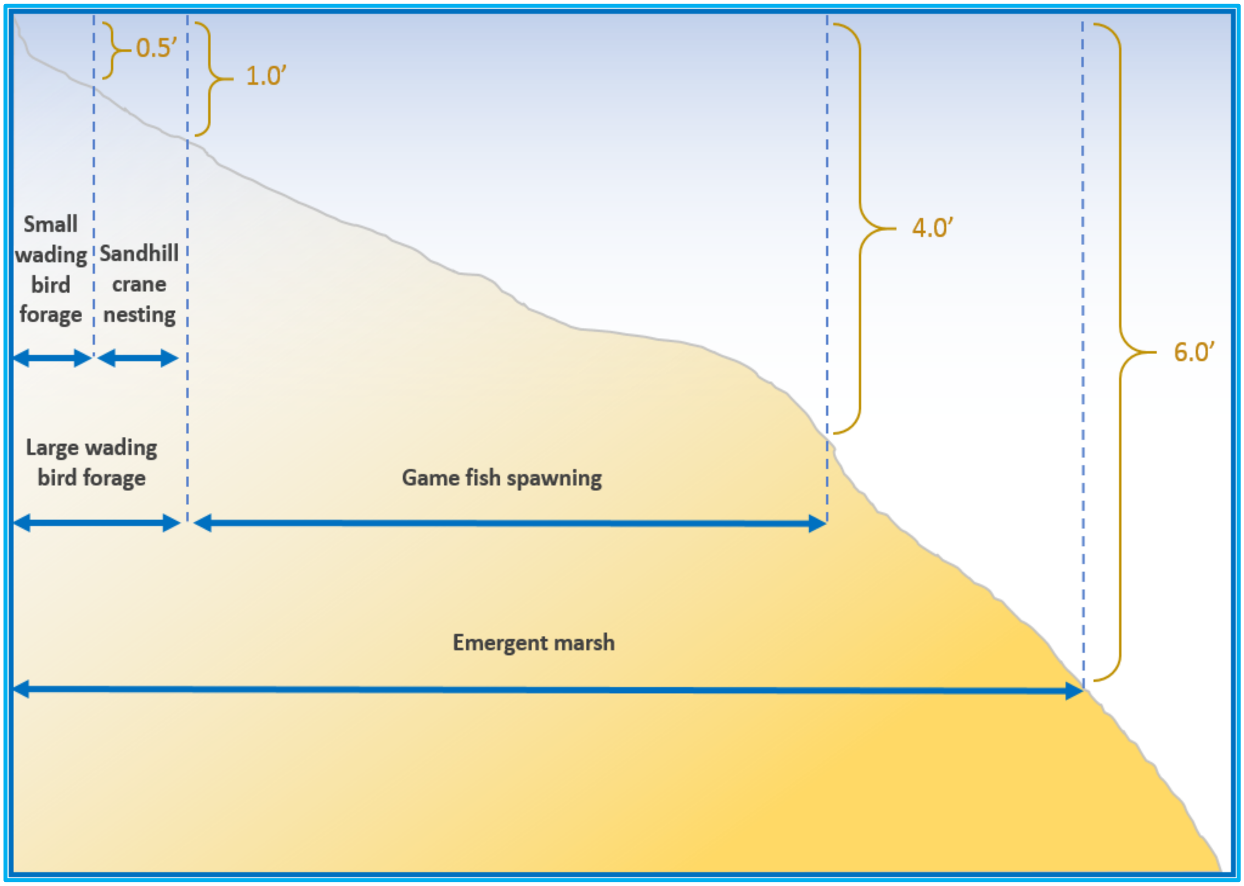

Figure 18. Nearshore habitats and water depth ranges used in fish and wildlife habitat analyses.

habitat for these small fish, as well as for game fish (largemouth bass, bluegill, etc.) young-of-the-year (i.e., fry and juveniles).

These small-bodied fish seek refuge from larger fish, birds and other predators, among the shallow marsh vegetation. Habitat depths of 1 to 4 feet will provide protection for this important component of the aquatic community at these lakes.

Large Wading Bird Habitat

Water depth is a critical component of wading bird habitat (Bancroft et al., 2002, Pierce and Gawlik, 2010, Lantz et al., 2011). Forage success of long-legged wading bird species (e.g., great egret, great blue heron) can be constrained by their leg length (Powell 1987), and typically forage in vegetation in water less than or equal to ~10–12” (Kushlan 1979, Kushlan et al., 1985, Bancroft et al., 1990). Therefore, the depth range used, to prevent a significant shift in forage habitat for large wading birds, is 0 to 1 foot.

Small Wading Bird Habitat

Short-legged wading birds (little blue heron, snowy egret, ibis, etc.) require shallower habitat (~0.5 feet) for suitable foraging (Kushlan 1979, Kushlan et al., 1985). The depth range used, to prevent significant change to forage habitat for small wading birds, is 0 to 0.5 feet.

Sandhill Crane Nesting Habitat

The Florida sandhill crane typically nests in shallow herbaceous wetlands, dominated by maidencane, pickerelweed, rush and/or smartweed (*Polygonum spp*.; Stys 1997). The shallow maidencane marshes at Lakes Brooklyn and Geneva provide nesting and forage habitat for sandhill cranes and other birds. Sandhill cranes have been observed in shallow maidencane marsh habitat at Lake Brooklyn, and they likely nest in the large emergent marshes in both lakes. Average water depths for suitable sandhill crane nesting ranges from approximately 0.5 to 1 feet (Stys 1997). This is the depth range used for evaluation of this habitat metric.

Fish and Wildlife Habitat Analyses Results

Hydroperiod tool output data show a different relationship between fish and wildlife habitat and lake elevation at Lakes Brooklyn versus Lake Geneva (Figures 19 and 20; Tables 4 and 5). Habitat area data were smoothed using local regression (LOESS) with a 10 ft window. Data were smoothed to minimize noise in the dataset which may be due to uncertainty in bathymetry data as well as uncertainty related to the lakes splitting into smaller lobes at certain elevations.

At Lake Brooklyn, the five fish and wildlife habitats generally increased with decreasing water level from the highest elevation to approximately 100 feet (Figure 19). Below this elevation, habitats decline with decreasing water levels. The average no-pumping condition habitat area was highest for emergent marsh, and game fish spawning habitat, with the remaining three habitats having lower average areas (Table 4).

At Lake Geneva, the five fish and wildlife habitats generally increased with decreasing water level for the entire range of elevations (Figure 20). As with Lake Brooklyn, the average no-pumping condition habitat area at Lake Geneva was highest for emergent marsh, and game fish spawning

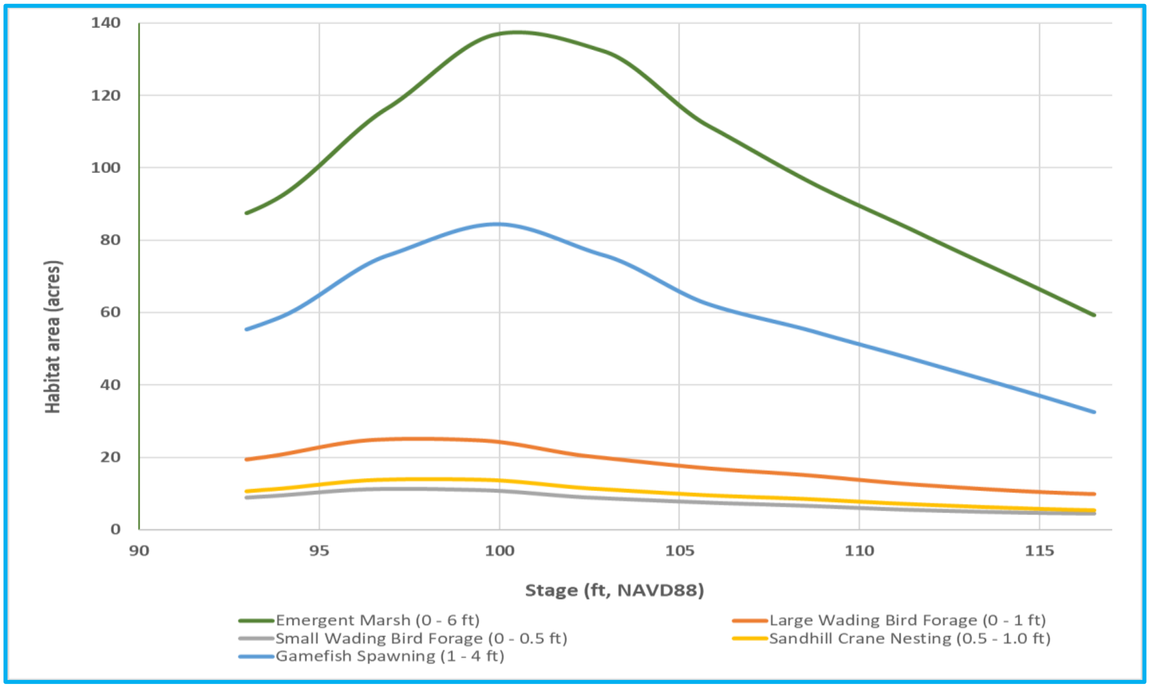

Figure 19. Hydroperiod tool output of habitat area (acres) versus lake stage for different habitats for Lake Brooklyn, Clay County, Florida. Hydroperiod tool output data are presented as LOESS smoothed data.

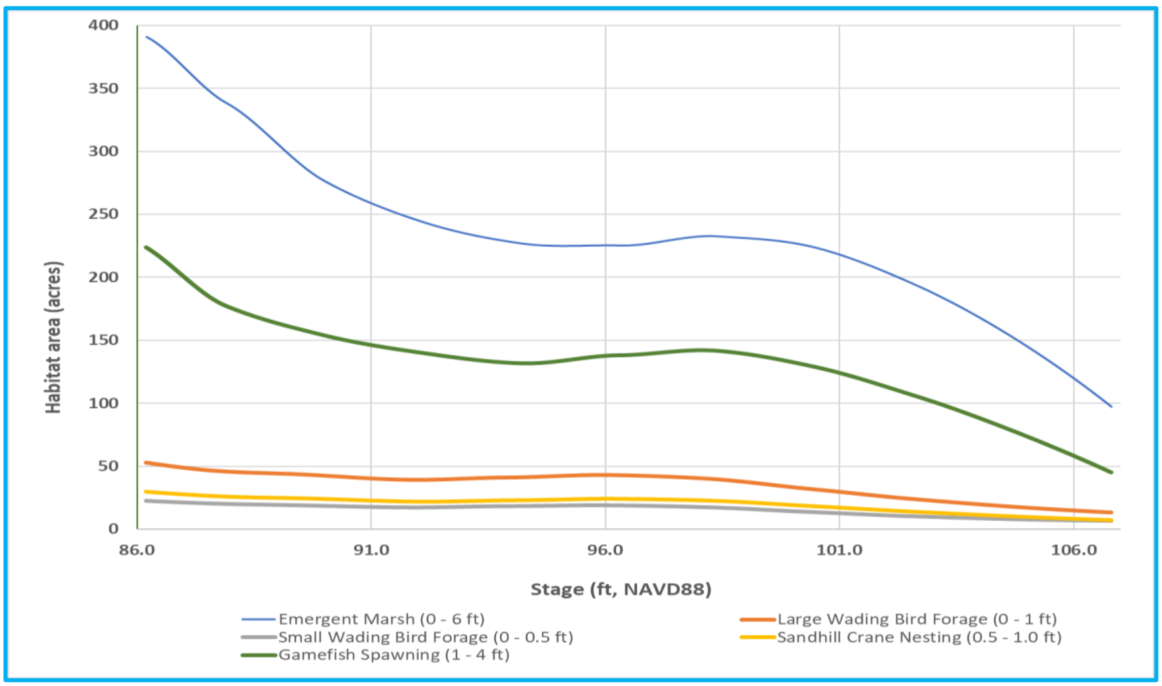

Figure 20. Hydroperiod tool output of habitat area (acres) versus lake stage for different habitats for Lake Geneva, Clay and Bradford counties, Florida. Hydroperiod tool output data are presented as LOESS smoothed data.

habitat, with the remaining three habitats having lower average areas (Table 5). Fish and wildlife habitat areas for the no-pumping condition and MFLs condition (i.e., 15% reduction in average NP area) for Lakes Brooklyn and Geneva area presented in Tables 6 and 7, respectively.

Table 4. Summary of fish and wildlife habitat area range under no-pumping condition for Lake Brooklyn, Clay County, Florida.

	No-Pumping Condition Habitat Area (acres)		
Nearshore Habitat	Minimum	Average	Maximum
Emergent Marsh	54.1	94.5	137.6
Game fish	29.2	55.2	84.5
Large Wading Bird	9.6	15.8	25.2
Small Wading Bird	4.5	7.0	11.2
Sandhill Crane	5.2	8.8	14.0

Table 5. Summary of fish and wildlife habitat area range under no-pumping condition for Lake Geneva, Clay and Bradford counties, Florida.

	No-Pumping Condition Habitat Area (acres)		
Nearshore Habitat	Minimum	Average	Maximum
Emergent Marsh	97.4	212.0	391.0
Game fish	45.1	119.8	223.8
Large Wading Bird	52.6	32.3	13.4
Small Wading Bird	6.6	14.2	22.7
Sandhill Crane	7.0	18.1	29.5

Table 6. Summary of fish and wildlife allowable elevation change associated with 15% reduction in habitat area for Lake Brooklyn, Clay County, Florida.

Nearshore Habitat	Average No-pumping Habitat Area (acres)	MFLs Condition (15% Reduction in Average No-pumping Habitat Area) (acres)
Emergent Marsh	94.5	80.3
Game fish	55.2	46.9
Large Wading Bird	15.8	13.4
Small Wading Bird	7.0	6.0
Sandhill Crane	8.8	7.5

Table 7. Summary of fish and wildlife allowable elevation change associated with 15% reduction in habitat area for Lake Geneva, Clay and Bradford counties, Florida.

Nearshore Habitat	Average No-pumping Habitat Area (acres)	MFLs Condition (15% Reduction in Average No-pumping Habitat Area) (acres)
Emergent Marsh	212.0	180.0
Game fish	119.8	102.0
Large Wading Bird	32.3	27.5
Small Wading Bird	14.2	12.1
Sandhill Crane	18.1	15.4

Open-Water Area Metric

In addition to fish and wildlife habitat WRV, Rule 62-40.473, *F.A.C.*, also mandates consideration of other environmental values and beneficial uses. One of these WRVs is "recreation, in and on the water," the purpose of which is to protect water depths necessary to safely operate motorboats and allow water depths for other recreational activities (e.g., fishing, swimming, etc.). Recreation in and on Lakes Brooklyn and Geneva is an important beneficial use, both historically and currently. Both lakes are surrounded by residential homes and there is a YMCA camp on the north shore of Lake Brooklyn. Residents, members of the summer camp, and others use both lakes for fishing, boating and other recreational activities.

Based on peer reviewer recommendation (Cardno 2018), an open-water metric has been developed to prevent significant change from areas that are free from submerged obstacles, providing benefits for recreation, fish and wildlife, and water quality. This metric was suggested as an alternative to several original metrics deemed inappropriate for Lakes Brooklyn and Geneva. The dock-access metric, aesthetics metric, SWFWMD Lake Mixing standard and Recreation/Ski standard had different issues regarding their applicability for these two lakes (see above and Appendix C). The peer reviewer suggested that instead of using these criteria, it may be valuable to consider a metric based on an open-water area with a specific safety depth. SJRWMD agrees with this recommendation and is moving forward with an open-water metric designed to protect recreational values (e.g., boating, swimming) by providing for open areas free of submerged obstacles (i.e., areas beyond the zone of emergent and floating plants). As discussed below, this metric also provides protection for ecological values and water quality.

Open water is defined, for this metric, as those areas of the lake greater than or equal to 5 feet deep. A 5-ft boating safety depth is recommended based on the US Coast Guard's (USCG) depth guideline for water skiing (http://www. use gboating.org/index.aspx). The USCG suggests a 5 to 6 ft minimum depth, and the minimum of this range (i.e., 5 ft) is being used.

While the USCG guideline is focused on waterskiing, the primary purpose of the recommended safety depth is to ensure that boating and other water-related recreation are in areas free from obstacles. The majority of emergent and floating-leaved plants in Lakes Brooklyn and Geneva grow in water ranging in depths from 0 to 5 ft. Therefore, using a 5-ft safety depth provides for recreation in deep areas that are beyond the littoral zone. This metric is supported by the peer reviewers of the original MFLs who pointed out that open-water areas are "*…required for [not just] water skiing but also the amount of depth needed for safe operation of power boats.*" (Cardno 2018). Further, Leeper et al. (2001) note that "*…lake areas exceeding three to six feet in depth may be considered suitable for most recreational activities.*"

Similar to the fish and wildlife habitat metrics described above, the open-water metric was evaluated using the SJRWMD GIS-based hydroperiod tool (see above for description of hydroperiod tool). Average open-water area was calculated for each day in the POR, using the stage/open-water area relationship derived from the hydroperiod tool and the simulated water surface elevations for the no-pumping condition (See Appendix C for the stage/area curve for the open-water metric).

The MFLs condition for the open-water metric equals a 15% reduction in the average open-water area (lake area ≥ 5 feet deep) under the no-pumping condition (i.e., open-water area averaged across the entire no-pumping condition lake level timeseries). As discussed above, the use of a 15% loss of area is reasonable and prudent (Shaw et al. 2005, Cardno 2018).

As with the fish and wildlife habitat metrics, assessment of the open-water metric is simply the comparison of the allowable average open-water area (15% reduction of area under no-pumping condition) to the average open-water area under the current-pumping condition (*see MFLs Assessment Section for more details*).

Additional Benefits of Open-Water Area

In addition to providing protection for recreational uses, the open-water area metric will also protect deep water habitats that provide important refuge habitat for fish and other organisms, especially during periods of low water due to drought and/or increased groundwater pumping. In many water bodies, aquatic organisms require refuge from drought. Although droughts are natural phenomena, water withdrawal can mimic and exacerbate drought and drying of aquatic ecosystems (Magoulick and Kobza 2003).

Drought refugia is important for fish and other organisms. During periods of low water (whether from drought and/or pumping) decreasing volumes of water can result in increases in extremes of abiotic conditions (e.g., high temperature and low dissolved oxygen) and increases in concentrations of organisms (Magoulick and Kobza 2003). In drought refugia, fish are concentrated into increasingly small areas, competing for space and resources, increasing their exposure to competition, predation (e.g., from birds and other fish) and disease (Lowe-McConnell 1975, Magoulick and Kobza 2003, Matthews and Marsh-Matthews 2003, Lennox et al. 2019).

As lakes recede, fish and other organisms move from shallow nearshore habitats to deeper areas (Gaeta et al. 2014). These open-water deep areas within lakes are more resistant than shallow areas to water level decline, and thus provide critical refugia for fish and other species (White et al. 2016). Deep areas in lakes provide protection for fish from both predation (e.g., avian predators) and protection from high temperatures. Deeper, cool water refugia are important habitats for game fish species throughout Florida (FWC, personal communication). The recommended open-water area metric provides protection of thermal refugia for game fish and other species. Deep areas of relatively cool water reduce physiological stress caused by high temperatures and low dissolved oxygen, especially during summer months and prolonged drought periods (Lennox et al. 2019). The open-water area metric will help prevent significant harm from occurring by the reduction of important thermal refuge habitats at these lakes, relative to the no-pumping condition.

As discussed above, largemouth bass, bluegill, black crappie and other game fish species are present in Lakes Brooklyn and Geneva (FWC 2020; see Appendix C for summary of fish data), and trophy-sized (> 8 lb.) largemouth bass are regularly caught at both lakes (Appendix C; *https://www.trophycatchflorida.com/search-catches.aspx*). These recreational species rely on open-water habitats most of the year (i.e., not just during hot or dry months), especially black crappie that resides in open-water areas most of the time, moving to nearshore habitats in the spring to spawn (Mesing and Wicker 1986, Bull et al., 1995, Matthias et al., 2014). Protection of open water habitats is positively correlated with the diversity of fish and other aquatic species. Fish are known to prefer an intermediate mixture of open water and littoral habitat (Wiley et al. 1984, Aho et al. 1986, Trebitz and Nibbelink 1996, Miranda and Pugh 2011). A lack of open water can reduce both the abundance and diversity of game fish species (Colle and Shireman 1980, Allen and Tugend 2002, SFWMD 2011).

Water level decline due to drought and/or withdrawal can also negatively affect lake water quality, indirectly affecting fish and other organisms. As lake levels decline, remaining refuge areas become warmer, have higher solar irradiation, and increased concentration of nutrients (Lennox et al. 2019). These factors can lead to the increased potential for increased algal growth and decreased water quality. The open-water metric will benefit Lakes Brooklyn and Geneva water quality by reducing the potential for these negative effects on water quality. As discussed above (see *Water Quality* section) there is an inverse relationship between water level and both TP and chlorophyll-a at Lake Brooklyn. In years where Lake Brooklyn water levels have been low, chlorophyll-a (an indicator of algae biomass) has increased above the state standard. By limiting the reduction of deep open-water areas, this metric will help prevent significant harm from occurring due to reduction in water quality, relative to the no-pumping condition.

The open-water metric serves as a substitute for the originally proposed SWFWMD Lake Mixing Standard, which proved to not be appropriate for highly fluctuating systems (see Appendix C for detail on SWFWMD Lake Mixing Standard). Water depth, relative to surface water area, mediates wind-driven mixing of sediments and nutrients in surface waters

(Magoulick and Kozba 2003). By ensuring areas of deeper water are not reduced significantly, relative to a no-pumping condition, the open-water area metric will help maintain summer stratification and reduce the likelihood of wind-driven mixing of sediments and nutrients.

Deep open-water areas moderate a variety of negative effects of water level decline, including increased temperature, decreased dissolved oxygen, increased mixing and suspension of sediments, reduced water quality, reduced habitat (area, perimeter, cover), and reduced movement and access of fish to shallow spawning sites (Lennox et al. 2019, Seitz et al. 2020).

Drought-related reductions in habitat area/volume, increased physical and chemical extremes, and increased negative biotic interactions (i.e., predation and competition) naturally occur in aquatic ecosystems (Magoulick and Kozba 2003, Humphries and Baldwin 2003). However, these stressors can be exacerbated by human-induced alterations (Lennox et al. 2019), including water level declines due to withdrawal (Magoulick and Kozba 2003). In addition to protecting recreational functions, the open-water metric will also help minimize these negative effects of water level decline on ecological values and water quality at Lakes Brooklyn and Geneva.

Open-Water Area Results

Open-water area at Lake Brooklyn increases from approximately 119 acres at 93 feet (NAVD88) to just over 617 acres at 116.5 feet (NAVD88), the outlet elevation (See Appendix C for graph of relationship between water level and open-water area, based on hydroperiod output data). There is a positive, generally linear, relationship between elevation and open-water area for Lake Brooklyn. Open-water area for the no-pumping condition and MFLs condition (i.e., 15% reduction in average NP area) for Lake Brooklyn is presented in Table 8. The allowable change from the no-pumping condition (449 acres) to the MFLs condition (382 acres) is 67 acres.

Table 8. Average no-pumping and MFLs condition (15% reduction in no-pumping condition) open-water area (acres ≥ 5 ft deep) for Lakes Brooklyn and Geneva, Clay and Bradford counties, Florida.

System	Average No-pumping Open-water Area (acres ≥ 5 ft deep)	Average MFLs Condition Open-water Area (acres ≥ 5 ft deep)	Allowable change in Open-water Area (acres ≥ 5 ft deep)
Lake Brooklyn	449	382	67
Lake Geneva	981	834	147

The relationship between open-water area and lake elevation at Lake Geneva is positive and generally linear, increasing from approximately 271 acres at 86.2 feet (NAVD88) to approximately 1,334 acres at 106.8 feet (NAVD88) (See Appendix C for graph of relationship between water level and open-water area, based on hydroperiod output data).

Open-water area for the no-pumping condition and MFLs condition (i.e., 15% reduction in average NP area) for Lake Geneva is presented in Table 8. The allowable change from the no-pumping condition (981 acres) to the MFLs condition (834 acres) is 147 acres.

Recreation-Lake Lobe Connection Metric

A lake-lobe connection metric has been developed to prevent a significant change due to water withdrawal, relative to historical conditions, in the duration of continuous surface-water connections between lake lobes. This metric is based on the minimum elevation required for lake lobe connectivity (i.e., to provide a connected lake for the majority of residents), to which an offset (boat draft) is added to provide sufficient depth for boating of other forms of recreation.

Critical elevation

A lake lobe connectivity threshold (critical elevation) was calculated for Lakes Brooklyn and Geneva by adding a 2-ft boat draft to the highest elevation that was surveyed among canals and/or lake bottom between different lobes (Figures 21 and 22). Lake lobe connection elevations were estimated from the digital elevation model created for the hydroperiod tool (i.e., 2012 LIDAR data and 2019 acoustic doppler profiler data; see above for description of hydroperiod tool).

Impact threshold

Because of the large range of water level fluctuations of Lakes Brooklyn and Geneva, criteria meant to protect recreational uses must be based on an acceptable change from the pre-withdrawal (no-pumping) condition, not based on absolute levels below which each lake cannot decline. As discussed above, few studies provide guidance for protective thresholds for lakes. Those studies that do suggest thresholds are primarily related to managed reservoirs that provide an allowable reduction from a "full pool" elevation (Cordell and Bergstrom 1993, Hanson et al., 2002, Allen et al., 2010, Dickies et al., 2011, Dickies and Crouch 2015). However, numerous adopted MFLs have used a threshold of 15% for allowable reduction in exceedance of elevations related to both recreation and wildlife habitat (e.g., SRWMD MFLs for the Lower Santa Fe and Ichetucknee Rivers and Priority Springs; and numerous SWFWMD MFLs). Based on this previous work, the threshold for recreational uses is set at 15%.

This threshold allows no more than a 15% reduction, relative to a no-pumping condition, in the temporal exceedance of critical lake lobe connection elevations. In other words, the amount of time the critical elevation is equaled or exceeded can be reduced by a maximum of 15% over the long term, relative to the no-pumping condition. After determining the critical elevation, the next step involved determining its exceedance (i.e., percentile) under the no-pumping condition. The MFL condition was calculated by shifting the time exceeded under the no-pumping condition by 15%. This was done for four lake lobe connection elevations for Lake Brooklyn (Figure 21) and three lake lobe connection elevations for Lake Geneva (Figure 22).

The critical elevation used to evaluate this metric is the lake lobe connection elevation that, when connected, resulted in the majority of lake parcels (i.e., pieces of property adjacent to

Figure 21. Lake lobe connections (yellow dots) for Lake Brooklyn, Clay County, Florida.

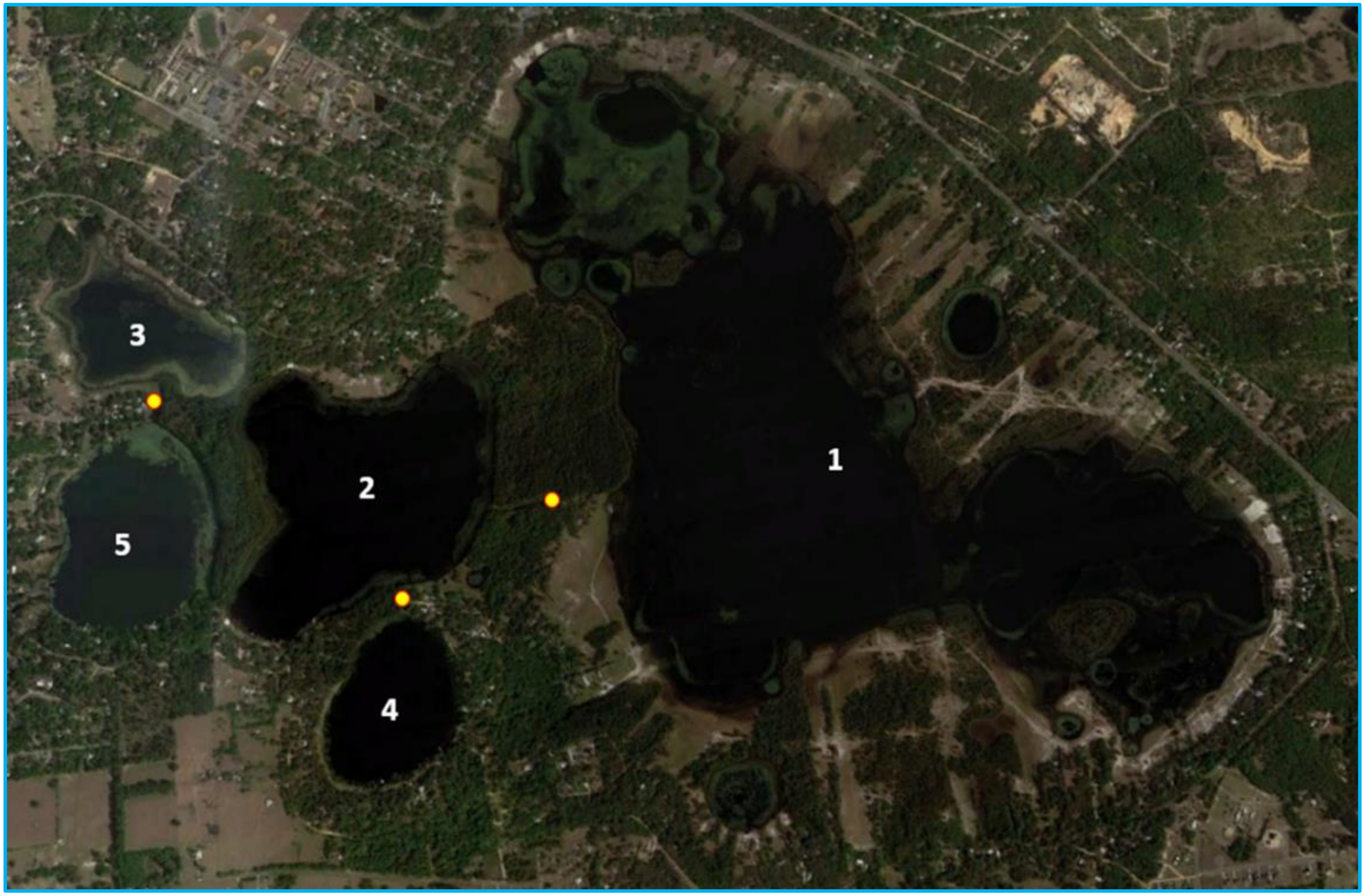

Figure 22. Lake lobe connections (yellow dots) for Lake Geneva, Bradford and Clay counties, Florida.

the lake) being connected to the main body of the lake (lobe 1 for both lakes; Figures 21 and 22). The number of parcels surrounding each lake lobe was based on 2018 tax maps from Clay and Bradford counties (Tables 9 and 10).

Recreation-Lake Lobe Connection Results

The lake lobe connection elevation evaluated for Lake Brooklyn was the one that connects the main body of the lake (lobe 1) to lobe 3. This elevation (101.6 feet, NAVD88) connects approximately 84% of the parcels around Lake Brooklyn (Table 9). The lake lobe connection evaluated for Lake Geneva was the one that connects the main body of the lake (lobe 1) to lobes 2 and 3. This elevation (98.5 feet, NAVD88) connects approximately 80% of the parcels around Lake Geneva (Table 10)).

The no-pumping exceedance percentiles for the critical elevations for Lakes Brooklyn and Geneva are 78.0 and 53.3, respectively (Table 11). A 15% shift in time exceedance at these percentiles equals 11.7% and 8.0%, respectively. The resulting percentile shift at each lake was subtracted from the no-pumping percentile to yield the MFLs condition percentile for Lakes Brooklyn and Geneva, which are 66.3 and 45.3, respectively. For Lake Brooklyn, a median (P50) lake level reduction of 4.3 feet, from the no-pumping condition, results in a time exceedance reduction of 11.7%. For Lake Geneva, a P50 lake level reduction of 2.1 feet, from the no-pumping condition, results in a time exceedance reduction of 8.0% (Table 11).

Lake Morphology Metrics

Average Lake Surface Area

The average lake surface area metric provides protection from significant change to aesthetic and scenic values. Maintaining the scenic value of a lake is often not a function of preserving water depth, but rather surface area. In other words, even very shallow areas across a lake add to the overall coverage with water, reduce exposed areas and add to scenic value.

Preventing significant change to lake surface area will ensure that the amount of exposed shoreline does not increase significantly. Studies have shown that shoreline exposure due to low water levels is perceived as a primary impact to the aesthetic value of lakes (Hoyer et al., 2006, Kashian and Winden 2015), and can negatively affect lakeshore property value (Loomis and Feldman 2003).

In addition to aesthetics, lake surface area is also positively correlated with species richness and is a key component of the SWFWMD Species Richness Standard (see Appendix C; Hoyer and Canfield 1994, Emery et al. 2009). This metric is similar to the species richness metric, in that it sets an allowable change to lake surface area. However, SWFWMD’s metric is only calculated for the P50 lake surface area. Because of the differential sensitivity to pumping across the entire range of lake levels, using a P50 lake surface area criterion would likely not capture large changes to surface area that occur at water levels lower than the median.

Table 9. Number, percent and cumulative percent of parcels (i.e., properties) surrounding each lake lobe for Lake Brooklyn, Clay County, Florida. Also presented are connection elevations and critical elevations for each lobe.

Lobe	Clay County Parcels	Bradford County Parcels	Total Parcels per Lobe	% of Total Parcels	Cumulative % of Total Parcels	Connection Elevation (ft, NAVD88)	Critical Elevation (Connection + 2') (ft, NAVD88)
1	223	0	223	58	58	NA	NA
2	59	0	59	15	73	94.6	96.6
3	**43**	**0**	**43**	**11**	**84**	**99.6**	**101.6**
4	41	0	41	10	94	103.2	105.2
5	9	13	22	6	100	108.0	110.0

Table 10. Number, percent and cumulative percent of parcels (i.e., properties) surrounding each lake lobe for Lake Geneva, Clay and Bradford counties, Florida. Also presented are connection elevations and critical elevations for each lobe.

Lobe	Clay County Parcels	Bradford County Parcels	Total Parcels per Lobe	% of Total Parcels	Cumulative % of Total Parcels	Connection Elevation (ft, NAVD88)	Critical Elevation (Connection + 2') (ft, NAVD88)
1	251	0	251	57	57	NA	NA
2 & 3	**72**	**29**	**101**	**23**	**80**	**96.5**	**98.5**
4	49	0	49	11	91	98.6	100.6
5	14	28	42	9	100	99.2	101.2

Table 11. Critical lake lobe connection elevations and allowable shift in exceedance for Lakes Brooklyn and Geneva, Clay and Bradford Counties, Florida

System	Critical Lake Lobe Elevation (ft NAVD88)	No-pumping percentile	% shift of percentile that equals 15% reduction in exceedance	MFLs condition percentile	Allowable shift at the median (P50) lake level from no-pumping to MFLs condition (ft)
Lake Brooklyn	101.6	78.0	11.7	66.3	4.3
Lake Geneva	98.5	53.3	8.0	45.3	2.1

The average lake surface area metric was evaluated using the SJRWMD hydroperiod tool (see above for description of hydroperiod tool). Average lake surface area was calculated for each day in the POR, using the stage/area relationship derived from the hydroperiod tool and the simulated water surface elevations for the no-pumping condition. The MFLs condition for this metric equals a 15% reduction in the average lake surface area under the no-pumping condition (i.e., lake surface area averaged across the entire no-pumping condition lake level timeseries).

Average Lake Surface Area Results

Lake surface area at Lake Brooklyn increases from approximately 209 acres at 93 feet (NAVD88) to just over 672 acres at 116.5 feet (NAVD88), the outlet elevation (See Appendix C for graph of relationship between water level and surface area, based on hydroperiod output data). There is a positive, generally linear, relationship between elevation and lake surface area for Lake Brooklyn. Lake surface area for the no-pumping condition and MFLs condition (i.e., 15% reduction in average NP area) for Lake Brooklyn is presented in Table 12. The allowable change from the no-pumping condition (540 acres) to the MFLs condition (459 acres) is 81 acres.

Table 12. Average no-pumping and MFLs condition (15% reduction in no-pumping condition) lake surface area for Lakes Brooklyn and Geneva, Clay and Bradford counties, Florida.

System	Average No-pumping Lake Surface Area (acres)	Average MFLs Condition Lake Surface Area (acres)	Allowable change in Lake Surface Area (acres)
Lake Brooklyn	540	459	81
Lake Geneva	1,177	1,000	177

The relationship between lake surface area and lake elevation at Lake Geneva is positive and generally linear increasing from approximately 637 acres at 86.2 feet (NAVD88) to approximately 1,430 acres at 106.8 feet (NAVD88) (See Appendix C for graph of relationship between water level and surface area, based on hydroperiod output data). Lake surface area for the no-pumping condition and MFLs condition (i.e., 15% reduction in average NP area) for Lake Geneva is presented in Table 12. The allowable change from the no-pumping condition (1,177 acres) to the MFLs condition (1,000 acres) is 177 acres.

Average Lake Depth

Lake depth is important for maintaining the physical, chemical, and biological processes in lakes (Cardno 2018). Deeper habitats help to regulate nutrient dynamics, water quality, and habitat, and helps to minimize lake mixing. A reduction in lake depth can increase wind-driven sediment resuspension, water temperatures, and light availability. These factors can increase algal growth, leading to reduced water quality. Increased heat can also decrease dissolved oxygen concentrations, impacting fish, invertebrates and other aquatic species.

Increased photosynthetic activity, and subsequent senescence and decomposition of algae can negatively affect fish and other biota through increased biological oxygen demand and subsequent lowered dissolved oxygen concentration.

As with the lake surface area metric, the average lake depth metric was evaluated using the SJRWMD hydroperiod tool. Average lake depth was calculated for each day in the POR, using the stage/average depth relationship derived from the hydroperiod tool and the simulated water surface elevations for the no-pumping condition. The MFLs condition for this metric equals a 15% reduction in the average lake depth under the no-pumping condition (i.e., lake depth averaged across the entire no-pumping condition lake level timeseries).

Average Lake Depth Results

Lake depth at Lake Brooklyn increases from approximately 13.3 feet at 93 feet (NAVD88) to just over 37.8 feet at 116.5 feet (NAVD88), the outlet elevation (See Appendix C for graph of relationship between water level and average depth, based on hydroperiod output data). There is a positive, generally linear, relationship between elevation and lake depth for Lake Brooklyn. Lake depth for the no-pumping condition and MFLs condition (i.e., 15% reduction in average NP area) for Lake Brooklyn is presented in Table 13. The allowable change from the no-pumping condition (27.1 feet) to the MFLs condition (23.0 feet) is 4.1 feet.

The relationship between lake depth and elevation at Lake Geneva is positive and generally linear, increasing from approximately 9.4 feet at 86.2 feet (NAVD88) to approximately 35.9 feet at 106.8 feet (NAVD88) (See Appendix C for graph of relationship between water level and average depth, based on hydroperiod output data). Lake depth for the no-pumping condition and MFLs condition (i.e., 15% reduction in average NP area) for Lake Geneva is presented in Table 13. The allowable change from the no-pumping condition (24.4 feet) to the MFLs condition (20.7 feet) is 3.7 feet.

Table 13. Average no-pumping and MFLs condition (15% reduction in no-pumping condition) lake depth for Lakes Brooklyn and Geneva, Clay and Bradford counties, Florida.

System	Average No-pumping Lake depth (ft)	Average MFLs Condition Lake depth (ft)	Allowable change in Lake depth (ft)
Lake Brooklyn	27.1	23.0	4.1
Lake Geneva	24.4	20.7	3.7

MFLs Determination Summary

Final environmental criteria and MFLs conditions (i.e., minimum condition for each criterion) for Lakes Brooklyn and Geneva are summarized in Table 14. This list represents the final environmental criteria, chosen after peer review and evaluation of numerous preliminary criteria. The status assessment of these minimum levels (i.e., whether they are being met currently and in future) is discussed in the *MFLs Assessment* section.

Table 14. Summary of environmental criteria and MFLs condition for each criterion for Lakes Brooklyn and Geneva, Clay and Bradford counties, Florida

Environmental Criterion	Environmental value(s) protected	MFLs Condition					
		Lake Brooklyn			Lake Geneva		
		Level (ft NAVD88)	Duration (days)	Return Interval (years)	Level (ft NAVD88)	Duration (days)	Return Interval (years)
Minimum Infrequent High	Upland/wetland boundary	114.2	30	25	105.2	30	25
Emergent marsh habitat	Fish and wildlife habitat	Min. avg. acres = 80.3			Min. avg. acres = 180		
Game fish spawning habitat	Fish and wildlife habitat	Min. avg. acres = 46.9			Min. avg. acres = 102		
Large wading bird foraging habitat	Fish and wildlife habitat	Min. avg. acres = 13.4			Min. avg. acres = 27.5		
Small wading bird foraging habitat	Fish and wildlife habitat	Min. avg. acres = 6.0			Min. avg. acres = 12.1		
Sandhill crane nesting habitat	Fish and wildlife habitat	Min. avg. acres = 7.5			Min. avg. acres = 15.4		
Open-water area	Recreation / aesthetics/ water quality / fish habitat	Min. avg. acres = 382			Min. avg. acres = 834		
Lake lobe connection exceedance	Boating / fishing / fish passage	Min. exceed. % = 66.3			Min. exceed. % = 45.3		
Average lake surface area	Aesthetics	Min. avg. acres = 459			Min. avg. acres = 1,000		
Average lake depth	Water quality / fish habitat	Min. avg. acres = 23.0			Min. avg. acres = 20.7		

MFLs Assessment

MFLs are not meant to represent optimal conditions, but rather set the limit to withdrawals, beyond which significant harm would occur. A fundamental assumption of SJRWMD's approach is that alternative hydrologic regimes exist that are lower than pre-withdrawal conditions but still protect the environmental functions and values of water bodies from significant harm caused by water withdrawals. The MFLs determination defined a minimum hydrologic regime (MFLs condition) for relevant environmental criteria (Table 14).

The MFLs assessment compares the MFLs condition with the current hydrologic regime (current-pumping condition) to assess whether the MFLs are being achieved under the current-pumping condition, and to determine if there is water available for withdrawal (freeboard), or whether water is necessary for recovery (deficit). If any of the MFLs are not being achieved under the current-pumping condition, indicating a deficit of water, a recovery strategy is necessary. If the MFLs are currently being achieved, but a deficit is projected within the 20-year planning horizon, a prevention strategy is needed.

No-pumping and current-pumping condition lake level datasets developed for Lakes Brooklyn and Geneva were used to calculate freeboard or deficit in the lakes and determine whether each lake is in recovery, prevention or neither (*see Hydrological Analyses section and Appendix B for more details*).

Current Status

Current MFLs status for Lakes Brooklyn and Geneva was based on the 2014–2018 current-pumping condition and was assessed for each of the final environmental criteria used in the MFLs determination (Table 14). The MFLs condition and current-pumping condition were compared, resulting in a lake freeboard or deficit for each environmental criterion.

Lake freeboard or deficit was determined at the median (P50) for environmental criteria, to facilitate comparison among metrics. Freeboards and deficits were compared to determine the most constraining environmental criterion, which is the basis for the adopted minimum levels for each lake. Current status assessment details are provided in Appendix D. A summary of the current status results, including freeboard or deficit for each metric, is presented below.

Summary of Lake Freeboard / Deficit

Based on the current status assessment for Lake Brooklyn, six of the 10 environmental criteria have freeboard (i.e., they are met under the current-pumping condition; Table 15; Appendix D). Six of these have a relatively large amount of freeboard (i.e., 5 to 10 feet of available water), and are ecological metrics, including the minimum infrequent high and the five fish and wildlife habitat metrics. The remaining four metrics have deficits at the P50 (i.e., these metrics do not meet their MFLs condition under the current-pumping condition). These include the open-water area metric (deficit = 1.6 feet), lake lobe connection metric (deficit = 1.3 feet), average lake depth metric (deficit = 0.6 feet), and average lake surface area metric (deficit = 0.5 feet) (Table 15).

For Lake Geneva, nine of the 10 metrics are met under the current-pumping condition (Table 15). As with Lake Brooklyn, the ecological metrics have a relatively large amount of freeboard, and the lake lobe connection and lake morphology metrics have less freeboard. The open-water area metric has a deficit of 0.3 feet at the P50.

Because the most constraining metrics at Lakes Brooklyn and Geneva have deficits (1.6 feet and 0.3 feet, respectively), both lakes are in recovery and a recovery strategy must be developed and adopted concurrently with the MFLs.

Table 15. Lake freeboards or deficits (at the P50) for MFLs environmental criteria assessed for Lakes Brooklyn and Geneva, Clay and Bradford counties, Florida.

Environmental Criterion	Environmental Value(s) Protected	Lake Freeboard or Deficit at the P50 (ft, NAVD88)	
		Lake Brooklyn	Lake Geneva
Minimum Infrequent High	Upland / wetland boundary	> 10.0	> 3.0
Emergent marsh habitat	Fish and wildlife habitat	> 5.0	> 5.0
Game fish spawning habitat	Fish and wildlife habitat	> 5.0	> 5.0
Large wading bird foraging habitat	Fish and wildlife habitat	> 5.0	> 5.0
Small wading bird foraging habitat	Fish and wildlife habitat	> 5.0	> 5.0
Sandhill crane nesting habitat	Fish and wildlife habitat	> 5.0	> 5.0
Open-water area	Recreation / aesthetics/ water quality / fish habitat	- 1.6	- 0.3
Lake lobe connection exceedance	Boating / fishing / fish passage	-1.3	0.2
Average lake surface area	Aesthetics	- 0.5	1.0
Average lake depth	Water quality / fish habitat	- 0.6	0.0

CONSIDERATION OF ENVIRONMENTAL VALUES UNDER 62-40.473, F.A.C.

The minimum flows and levels section of the State Water Resources Implementation Rule (rule 62-40.473, Florida Administrative Code [F.A.C.]) requires that "consideration shall be given to…environmental values associated with coastal, estuarine, riverine, spring, aquatic, and wetlands ecology." The environmental values described by the rule include:

1. Recreation in and on the water;
2. Fish and wildlife habitats and the passage of fish;
3. Estuarine resources;
4. Transfer of detrital material;
5. Maintenance of freshwater storage and supply;
6. Aesthetic and scenic attributes;
7. Filtration and absorption of nutrients and other pollutants;
8. Sediment loads;
9. Water quality; and
10. Navigation.

These 10 environmental values were evaluated to determine if they are protected by the recommended MFLs condition for each lake. The MFLs condition represents the minimum hydrologic regime necessary to protect environmental criteria evaluated (i.e., it is based on the most constraining metric at each lake; Table 15). The P50 lake deficits for Lakes Brooklyn and Geneva equal 1.6 feet, and 0.3 ft, respectively. The MFLs condition timeseries for each lake is based on increasing (i.e., recovering) the current-pumping condition timeseries by these deficits.

The suite of 10 environmental values were evaluated based on the protections afforded by the metrics described in the MFLs determination and based on the difference in exceedance of critical elevations between the no-pumping and MFLs conditions. WRV 3 (Estuarine resources), WRV 8 (Sediment loads) and WRV 10 (Navigation) were deemed not relevant to Lakes Brooklyn and Geneva, and thus were not assessed.

The WRVs assessment results indicate that the seven WRVs relevant to Lakes Brooklyn and Geneva are protected by the recommended MFLs (Table 16). See Appendix E for specific details regarding the evaluation of each WRV.

Table 16. Criteria evaluated to determine protection of 62-40.473 environmental values by the recommended MFLs for Lakes Brooklyn and Geneva.

WRV	Criteria	Protected by the MFLs Condition?
Recreation in and on the water	Open-water area and lake lobe connections	Yes
Fish and wildlife habitats and the passage of fish	wetland / upland boundary; fish and wildlife habitat area	Yes
Estuarine resources	NA	NA
Transfer of detrital material	wetland area protection	Yes
Maintenance of freshwater storage and supply	other relevant WRVs are protected by the MFLs condition	Yes
Aesthetic and scenic attributes	lake surface area protection	Yes
Filtration and absorption of nutrients and other pollutants	TP, TN, chl-a and TSI assessment	Yes
Sediment loads	NA	NA
Water quality	chemical parameter data sparse but within normal ranges	Yes
Navigation	NA	NA

MFLs Condition versus No-pumping Condition

Hydroperiod tool output data were used to illustrate the difference between the recommended MFLs condition and the no-pumping condition for Lakes Brooklyn and Geneva. Contour elevations corresponding to the P25, P50 and P75 for both conditions were superimposed on aerial photographs to depict the approximate change in perimeter and area resulting from the MFLs condition, relative to the no-pumping condition (Figures 23 through 28). The percentiles depicted represent above normal, normal and below normal conditions.

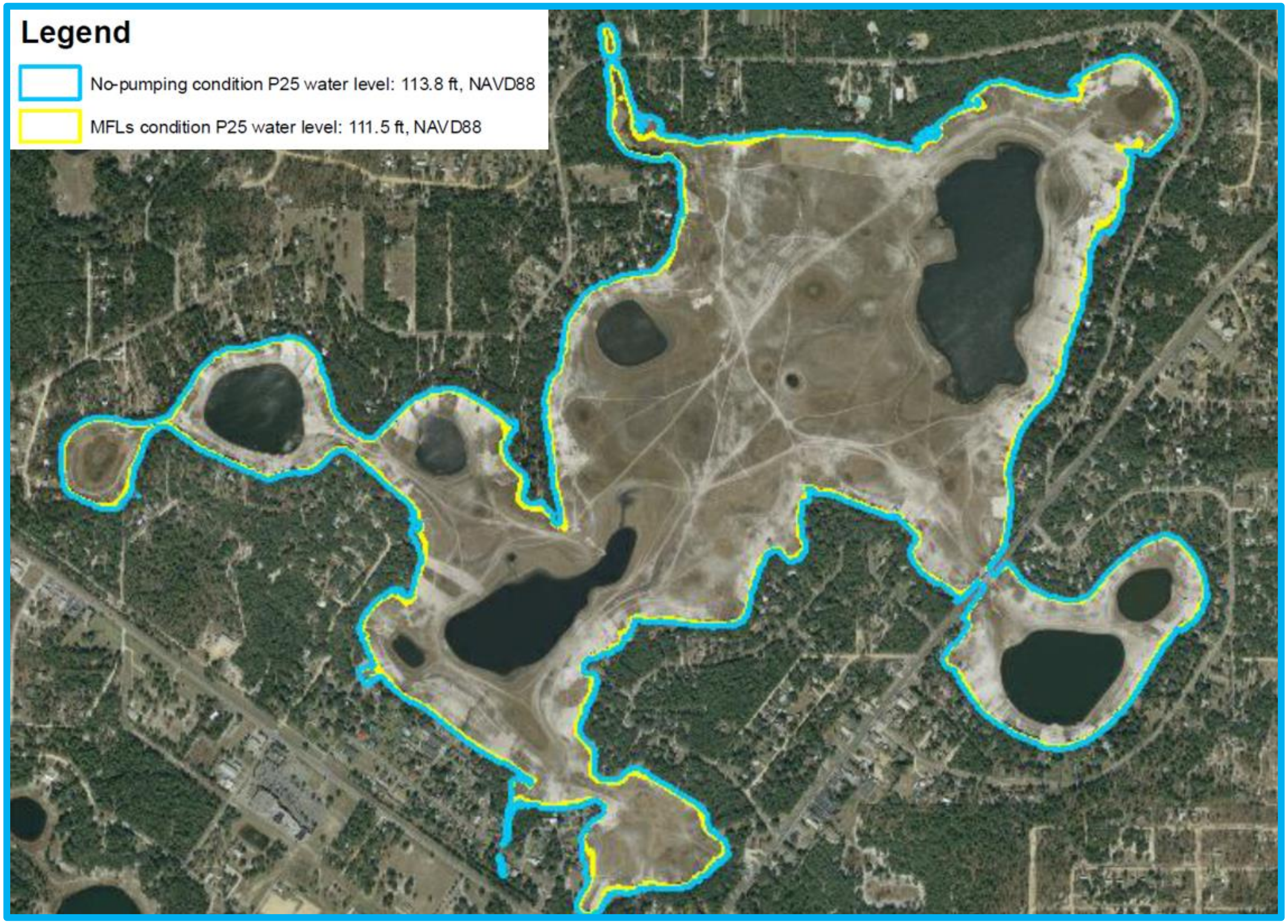

Figure 23. Difference between the no-pumping and MFLs condition for Lake Brooklyn at the P25 lake level.

Figure 24. Difference between the no-pumping and MFLs condition for Lake Brooklyn at the P50 lake level.

Figure 25. Difference between the no-pumping and MFLs condition for Lake Brooklyn at the P75 lake level.

Figure 26. Difference between the no-pumping and MFLs condition for Lake Geneva at the P25 lake level.

Figure 27. Difference between the no-pumping and MFLs condition for Lake Geneva at the P50 lake level.

Figure 28. Difference between the no-pumping and MFLs condition for Lake Geneva at the P75 lake level.

CONCLUSIONS AND RECOMMENDATIONS

Minimum levels for Lakes Brooklyn and Geneva were originally adopted in January 1996. The reevaluated minimum levels recommended for both lakes are based on implementation of updated methods and more appropriate environmental criteria. The updated methods include results from a new regional steady state groundwater model and a local scale transient groundwater model used to quantify the effects of local and regional groundwater withdrawals, and the analysis of an additional 20 years of hydrologic data. The proposed minimum levels for Lakes Brooklyn and Geneva are based on the most up-to-date methods, criteria and data.

Numerous criteria were investigated to ensure that proposed minimum levels would protect important environmental values and beneficial uses. Some preliminary criteria were determined to be inappropriate for these sandhill lakes, given their very large water level fluctuation range. The criteria evaluated included an event-based metric (i.e., the Minimum Infrequent High), SWFWMD lake change standards, criteria based on fish and wildlife habitat change, and several criteria used to protect recreational uses and aesthetics.

MFLs and current-pumping conditions were compared to determine lake freeboards/deficits for both lakes. After peer review and staff evaluation of numerous criteria, 10 environmental metrics were chosen for evaluation and assessment at Lakes Brooklyn and Geneva (Table 14). The most constraining of these were used to develop a minimum hydrologic regime (MFLs condition) for each lake. The KHTM and NFSEG groundwater models were used for MFLs criteria determinations and assessment, including the development of the no-pumping, current-pumping and MFLs lake level timeseries for both lakes *(*see Hydrological Analyses section above and Appendix B for more details).

RECOMMENDED MINIMUM LEVELS

An MFLs condition timeseries was developed for Lake Brooklyn and for Lake Geneva, each based on the most constraining environmental metric for that lake. The most constraining metric for both lakes is the open-water area metric. Based on this metric, there is a 1.6 feet deficit for Lake Brooklyn and 0.3 feet deficit for Lake Geneva at the median (P50) lake level. The MFLs condition timeseries for each lake was developed by recovering (increasing) the current-pumping condition timeseries by their respective deficits.

Three minimum levels, a minimum P25, P50 and P75, are recommended for both Lake Brooklyn and Lake Geneva (Figures 29 and 30; Table 17). These three percentiles were calculated from the MFLs condition exceedance curve for each lake. The 25th percentile (P25) water level is an indicator of wet climate cycles, and “above normal” hydrologic conditions; the 50th percentile (P50) is the central tendency and an indicator of “normal” conditions, and the 75th percentile (P75) is an indicator of dry climate cycles and “below normal” conditions (USGS 2002, USGS-SAWSC 2016). By helping to maintain the shape of the exceedance curve, adopting three levels will ensure the protection of MFLs condition hydrologic regime for each lake.

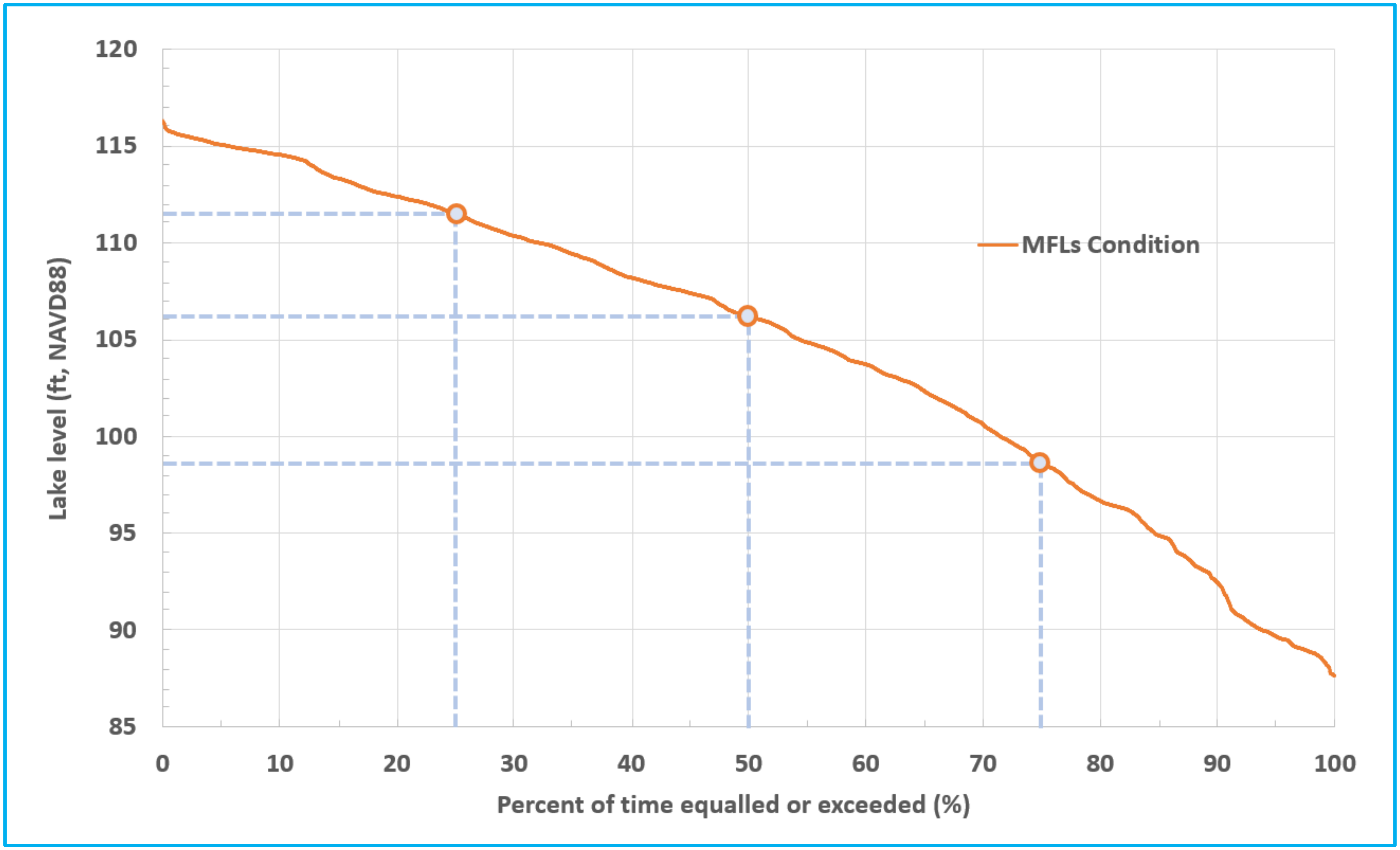

Figure 29. MFLs condition exceedance curve for Lake Brooklyn, Clay County, Florida. Minimum P25, P50 and P75 are depicted.

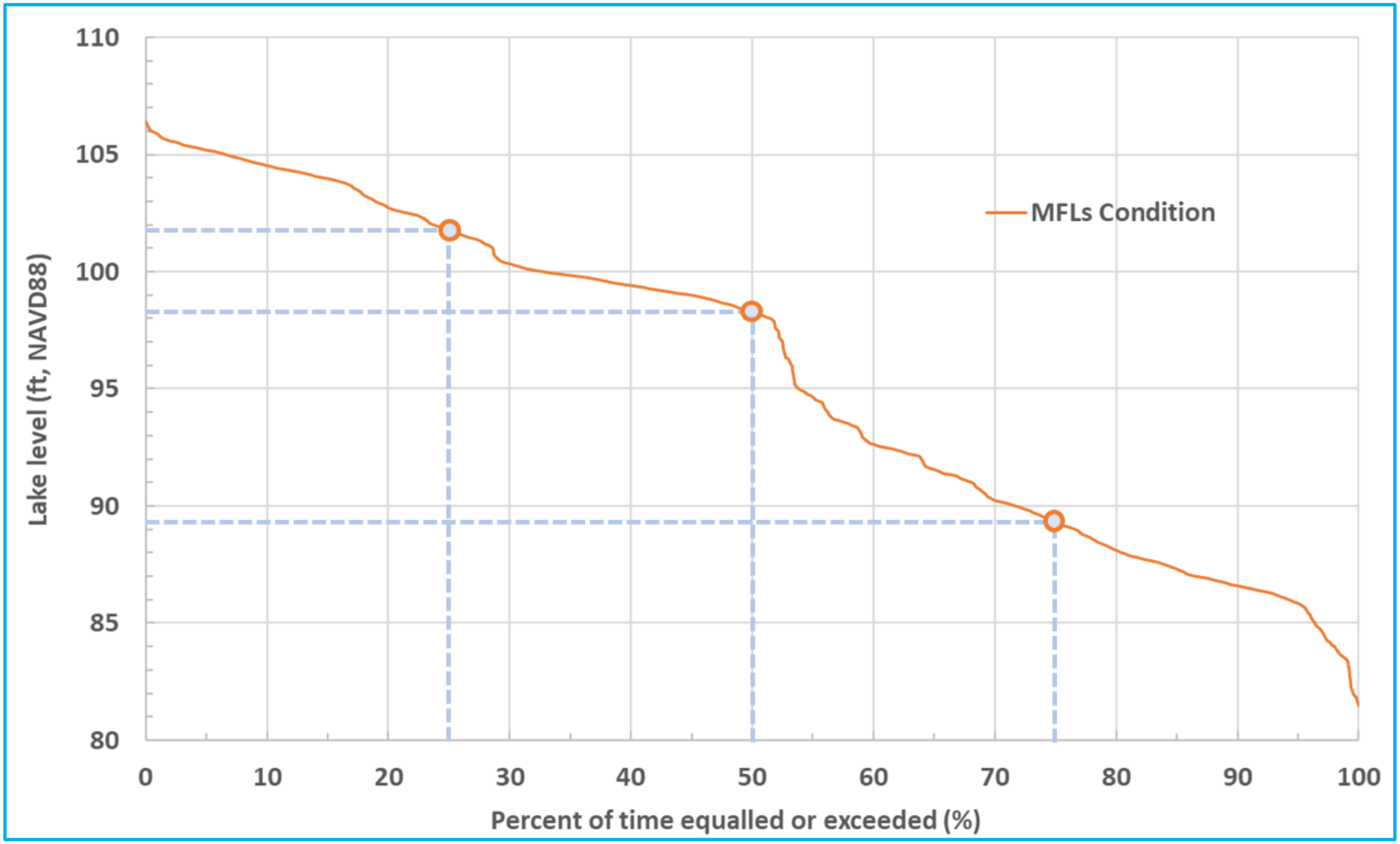

Figure 30. MFLs condition exceedance curve for Lake Geneva, Clay and Bradford counties, Florida. Minimum P25, P50 and P75 are depicted.

Table 17 Recommended minimum levels for Lakes Brooklyn and Geneva, Clay and Bradford counties, Florida.

System	Percentile	Recommended minimum lake level (ft; NAVD88)
Lake Brooklyn	25	111.5
	50	106.2
	75	98.6
Lake Geneva	25	101.7
	50	98.3
	75	89.3

The MFLs status assessment indicates that Lakes Brooklyn and Geneva are currently not meeting their proposed minimum levels. A comparison of the MFLs and current-pumping conditions for Lakes Brooklyn and Geneva yields a P50 lake deficit of 1.6 feet. and 0.3 feet, respectively.

Therefore, Lakes Brooklyn and Geneva are in recovery, and a recovery strategy must be adopted concurrently with the MFLs. Consistent with the provisions for establishing and implementing MFLs provided for in section 373.0421, F.S., the recovery strategy for the Lakes Brooklyn and Geneva MFLs identifies a suite of projects and measures that, when implemented, will recover these lakes from impacts due to groundwater pumping withdrawals and prevent the MFLs from not being met due to future consumptive uses of water. The recovery strategy will also provide sufficient water supply options to meet existing and projected reasonable beneficial uses.

SJRWMD concludes that the recommended minimum levels for Lakes Brooklyn and Geneva will protect the relevant environmental values described in Rule 62-40.473, *F.A.C.* The recommended MFLs presented in this report are preliminary and will not become effective until adopted by the SJRWMD Governing Board, as directed in Rule 40C-8.031, *F.A.C.*

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APPENDICES