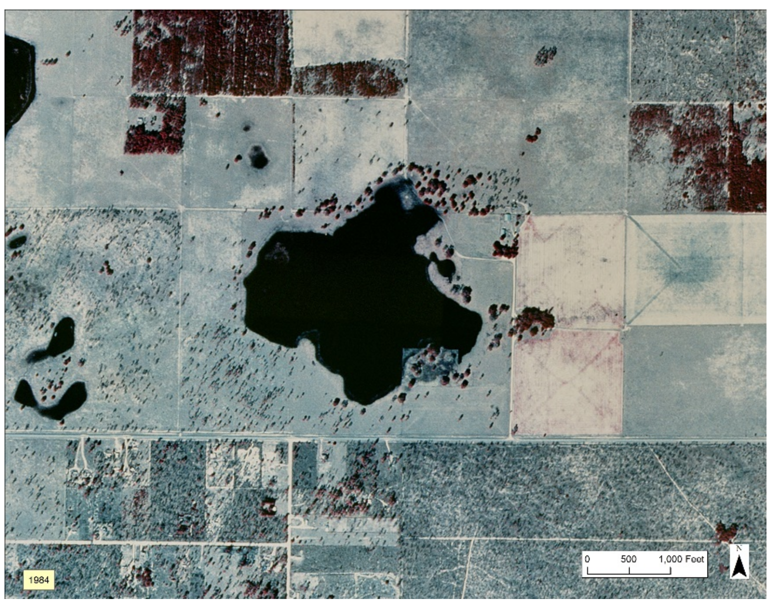
Revised Minimum and Guidance Levels Based on Reevaluation of Adopted Levels for Lake Marion in Levy County, Florida



August 11, 2020

Resource Evaluation Section
Water Resources Bureau
Southwest Florida
Water Management District

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Cover: 2010 and 1984 aerial photographs of Lake Marion showing examples of extreme water level fluctuations exhibited by the lake.

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Definitions

Category 1 Lakes	Lakes with lake-fringing cypress swamp(s) greater than 0.5 acre in size where Structural Alterations have not prevented the Historic P50 from equaling or rising above an elevation that is 1.8 feet below the Normal Pool elevation of the cypress swamp(s).
Category 2 Lakes	Lakes with lake-fringing cypress swamp(s) greater than 0.5 acre in size where Structural Alterations have prevented the Historic P50 from equaling or rising above an elevation that Is 1.8 feet below the Normal Pool and the lake fringing cypress swamp(s) remain viable and perform functions beneficial to the lake despite the Structural Alterations.
Category 3 Lakes	Lakes without lake-fringing cypress swamp(s) greater than 0.5 acre in size.
Control Point Elevation	The elevation of the highest stable point along the outlet profile of a surface water conveyance system that principally controls lake water level fluctuations
Current	A recent Long-term period during which Structural Alterations and hydrologic stresses are stable.
District	Southwest Florida Water Management District (SWFWMD)
Dynamic Ratio	The ratio of a lake's surface area (in square kilometers) to the mean depth of the lake (in meters). Used to determine at what water level a lake is susceptible to decreased water quality, i.e., turbidity, due to wave disturbance of bottom sediments.
F.A.C.	Florida Administrative Code

FDEP	Florida Department of Environmental Protection
F.S.	Florida Statutes
Guidance Levels	Water levels determined by the District and used as advisory information for the District, lake shore residents and local governments, or to aid in the management or control of adjustable structures.
High Guidance Level (HGL)	The expected Historic P10 elevation. Provided as an advisory guideline for the construction of lake shore development, water dependent structures, and operation of water management structures.
High Minimum Lake Level (HMLL)	The elevation that a lake's water levels are required to equal or exceed ten percent of the time on a Long-term basis
Historic	A Long-term period when there are no measurable impacts due to withdrawals, and Structural Alterations are similar to current conditions.
Historic P10	The expected Historic P10 elevation; *I.e.,* the elevation of the water surface of a lake or wetland that is expected to be equaled or exceeded ten percent of the time based on a Long-term period when there are or were no measurable impacts due to withdrawals, and Structural Alterations are similar to current conditions.
Historic P50	The expected Historic P50 elevation; *I.e.,* the elevation of the water surface of a lake or wetland that is expected to be equaled or exceeded fifty percent of the time based on a Long-term period when there are or were no measurable impacts due to withdrawals, and Structural Alterations are similar to current conditions.

Historic P90	The expected Historic P90 elevation; *I.e.,* the elevation of the water surface of a lake or wetland that is expected to be equaled or exceeded ninety percent of the time based on a Long-term period when there are or were no measurable impacts due to withdrawals, and Structural Alterations are similar to current conditions.
Hydrologic Indicators	Biological and physical features, as listed In Section 373.4211(20), Florida Statutes, which are representative or indicative of previous water levels.
Leakance	Relative to groundwater movement, the ratio of the vertical hydrologic conductivity of the confining bed to the thickness of the confining bed (Anderson and Woessner, 2002); a measure of how easily water can pass through a confining unit.
Long-term	An evaluation period utilized to establish minimum flows and levels, to determine compliance with established minimum flows and levels, and to assess withdrawal impacts on established minimum flows and levels, that represents a period which spans the range of hydrologic conditions which can be expected to occur based upon historical records, ranging from high water levels to low water levels. In the context of a predictive model simulation, a Long-term simulation will be insensitive to temporal fluctuations in withdrawal rates and hydrologic conditions, so as to simulate steady-state, average conditions. In the context of an average water level, the average will be based upon the historic expected range and frequency of levels. relative to minimum level establishment and compliance, where there are six years or more of competent data, a minimum of a six-year evaluation period will be used; but the available data and reasonable scientific judgement will dictate whether a longer period is used. Where there are less than six years of competent data, the period used will be dictated by the available data and a determination, based on reasonable scientific

	judgement, that the period is sufficiently representative of Long-term conditions.
Low Guidance Level (LGL)	The expected Historic P90. Provided as an advisory guideline for construction of water dependent structures, information for lakeshore residents, and operation of water management structures.
MFL	Minimum Flows and Levels
Minimum Lake Level (MLL)	The elevation that the lake's water levels are required to equal or exceed fifty percent of the time on a Long-term basis.
NAVD 88	North American Vertical Datum of 1988
NGVD 29	National Geodetic Vertical Datum of 1929
Normal Pool Elevation	An elevation approximating the P10 (see below) elevation which is determined based on hydrologic indicators of sustained inundation
Not Structurally Altered	Refers to a lake where the control point elevation equals or exceeds the Normal Pool elevation, or the lake has no outlet
P10	The percentile ranking represented by the elevation of the water surface of a lake or wetland that is equaled or exceeded ten percent of the time as determined from a Long-term stage frequency analysis.
P50	The percentile ranking represented by the elevation of the water surface of a lake or wetland that Is equaled or exceeded fifty percent of the time as determined from a Long-term stage frequency analysis.

P90	The percentile ranking represented by the elevation of the water surface of a lake or wetland that Is equaled or exceeded ninety percent of the time as determined from a Long-term stage frequency analysis.
Reference Lakes	Lakes from a defined area which are not measurably impacted by water withdrawals. Reference lakes may be used to develop reference lake statistics, including the RLWR50, RLWR90, and the RLWR5090 (see below).
RLWR50	Reference Lake Water Regime 50. The median difference between the P10 and P50 elevations for reference lakes with historic data and similar hydrogeologic conditions as the lake of concern.
RLWR5090	Reference Lake Water Regime 5090. The median difference between the P50 and P90 elevations for reference lakes with historic data and similar hydrogeologic conditions as the lake of concern.
RLWR90	Reference Lake Water Regime 90. The median difference between the P10 and P90 lake stage elevations for reference lakes with historic data and similar hydrogeologic conditions as the lake of concern
SFWMD	South Florida Water Management District
SJRWMD	St. Johns River Water Management District
SWFWMD	Southwest Florida Water Management District

Introduction

Reevaluation of Minimum Flows and Levels

This report describes the development of minimum levels and guidance levels for Lake Marion in Levy County, Florida. These levels were developed based on the reevaluation of minimum and guidance levels approved by the Southwest Florida Water Management District (District) Governing Board in October 2006 and subsequently adopted into District rules. The minimum and guidance levels represent necessary revisions to the previously adopted levels.

Lake Marion was selected for reevaluation based on development of modeling tools used to simulate natural water level fluctuations in lake basins that were not available when the previously adopted minimum levels for the lake were developed.

Following District Governing Board approval on April 28, 2020, the revised minimum levels became effective on August 9, 2020.

Minimum Flows and Levels Program Overview

Legal Directives

Section 373.042, Florida Statutes (F.S.), directs the Department of Environmental Protection or the water management districts to establish minimum flows and levels (MFLs) for lakes, wetlands, rivers and aquifers. Section 373.042(1)(a), F.S., states that "[t]he minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." Section 373.042(1)(b), F.S., defines the minimum water level of an aquifer or surface water body as "…the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area." MFLs are established and used by the Southwest Florida Water Management District (SWFWMD or District) for water resource planning, as one of the criteria used for evaluating water use permit applications, and for the design, construction and use of surface water management systems.

Established MFLs are key components of resource protection, recovery and regulatory compliance, as Section 373.0421(2) F.S., requires the development of a recovery or prevention strategy for water bodies "[i]f the existing flow or level in a water body is below, or is projected to fall within 20 years below, the applicable minimum flow or level established pursuant to S. 373.042." Section 373.0421(2)(a), F.S., requires that recovery or prevention strategies be developed to: "(a) [a]chieve recovery to the established minimum flow or level as soon as practicable; or (b) [p]revent the existing flow or level from falling below the established minimum flow or level." Periodic reevaluation and, as necessary, revision of established minimum flows and levels are required by Section 373.0421(3), F.S.

Minimum flows and levels are to be established based upon the best information available, and when appropriate, may be calculated to reflect seasonal variations (Section 373.042(1), F.S.). Also, establishment of MFLs is to involve consideration of, and at the governing board or department's discretion, may provide for the protection of nonconsumptive uses (Section 373.042(1), F.S.). Consideration must also be 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…", with the requirement that these considerations shall not allow significant harm caused by withdrawals (Section 373.0421(1)(a), F.S.). Sections 373.042 and 373.0421 provide additional information regarding the prioritization and scheduling of minimum flows and levels, the independent scientific review of scientific or technical data, methodologies, models and scientific and technical assumptions employed in each model used to establish a minimum flow or level, and exclusions that may be considered when identifying the need for MFLs establishment.

The Florida Water Resource Implementation Rule, specifically Rule 62-40.473, Florida Administrative Code (F.A.C.), provides additional guidance for the establishment of MFLs, requiring 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, including: a) Recreation in and on the water; b) Fish and wildlife habitats and the passage of fish; c) estuarine resources; d) Transfer of detrital material; e) Maintenance of freshwater storage and supply; f) Aesthetic and scenic attributes; g) Filtration and absorption of nutrients and other pollutants; h) Sediment loads; i) Water quality; and j) Navigation."

Rule 62-40.473, F.A.C., also indicates that "[m]inimum flows and levels should be expressed as multiple flows or levels defining a minimum hydrologic regime, to the extent practical and necessary to establish the limit beyond which further withdrawals would be significantly harmful to the water resources or the ecology of the area as provided in Section 373.042(1), F.S." It further notes that, "…a minimum flow or level need not be expressed as multiple flows or levels if other resource protection tools, such as reservations implemented to protect fish and wildlife or public health and safety, that provide equivalent or greater protection of the hydrologic regime of the water body, are developed and adopted in coordination with the minimum flow or level." The rule also includes provision addressing: protection of MFLs during the construction and operation of water resource projects; the issuance of permits pursuant to Section 373.086 and Parts II and IV of Chapter 373, F.S.; water shortage declarations; development of recovery or prevention strategies, development and updates to a minimum flow and level priority list and schedule, and peer review for MFLs establishment.

Development of Minimum Lake Levels in the Southwest Florida Water Management District

Programmatic Description and Major Assumptions

Since the enactment of the Florida Water Resources Act of 1972 (Chapter 373, F.S.), in which the legislative directive to establish MFLs originated, and following subsequent modifications to this directive and adoption of relevant requirements in the Water Resource Implementation Rule, the District has actively pursued the adoption, i.e., establishment of MFLs for priority water bodies. The District implements established MFLs primarily through its water supply planning, water use permitting and environmental resource permitting programs, and through the funding of water resource and water supply development projects that are part of a recovery or prevention strategy. The District's MFLs program addresses all relevant requirements expressed in the Florida Water Resources Act and the Water Resource Implementation Rule.

A substantial portion of the District's organizational resources has been dedicated to its MFLs Program, which logistically addresses six major tasks: 1) development and reassessment of methods for establishing MFLs; 2) adoption of MFLs for priority water bodies (including the prioritization of water bodies and facilitation of public and independent scientific review of proposed MFLs and methods used for their development); 3) monitoring and MFLs status assessments, i.e., compliance evaluations; 4) development and implementation of recovery strategies; 5) MFLs compliance reporting; and 6) ongoing support for minimum flow and level regulatory concerns and prevention strategies. Many of these tasks are discussed or addressed in this Minimum Levels report; additional information on all tasks associated with the District's MFLs Program is summarized by Hancock *et al.* (2010).

The District's MFLs Program is implemented based on three fundamental assumptions. First, it is assumed that many water resource values and associated features are dependent upon and affected by long-term hydrology and/or changes in long-term hydrology. Second, it is assumed that relationships between some of these variables can be quantified and used to develop significant harm thresholds or criteria that are useful for establishing MFLs. Third, the approach assumes that alternative hydrologic regimes may exist that differ from non-withdrawal impacted conditions but are sufficient to protect water resources and the ecology of these resources from significant harm.

Support for these assumptions is provided by a large body of published scientific work addressing relationships between hydrology, ecology and human-use values associated with water resources (e.g., see reviews and syntheses by Postel and Richter 2003, Wantzen *et al.* 2008, Poff *et al.* 2010, Poff and Zimmerman 2010). This information has been used by the District and other water management districts within the state to identify significant harm thresholds or criteria supporting development of MFLs for hundreds of water bodies, as summarized in the numerous publications associated with these efforts (e.g., SFWMD 2000, 2006, Flannery *et al*. 2002, SRWMD 2004, 2005, Neubauer *et al.* 2008, Mace 2009).

With regard to the assumption associated with alternative hydrologic regimes, consider a historic condition for an unaltered river or lake system with no local groundwater or surface water withdrawal impacts. A new hydrologic regime for the system would be associated with each increase in water use, from small withdrawals that have no measurable effect on the historic regime to large withdrawals that could substantially alter the regime. A threshold hydrologic regime may exist that is lower or less than the historic regime, but which protects the water resources and ecology of the system from significant harm. This threshold regime could conceptually allow for water withdrawals, while protecting the water resources and ecology of the area. Thus, MFLs may represent minimum acceptable rather than historic or potentially optimal hydrologic conditions.

Consideration of Changes and Structural Alterations and Environmental Values

When establishing MFLs, the District considers "…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…" in accordance with Section 373.0421(1)(a), F.S. Also, as required by statute, the District does not establish MFLs that would allow significant harm caused by withdrawals when considering the changes, alterations and their associated effects and constraints. These considerations are based on review and analysis of best available information, such as water level records, environmental and construction permit information, water control structure and drainage alteration histories, and observation of current site conditions.

When establishing, reviewing or implementing MFLs, considerations of changes and structural alterations may be used to:

- adjust measured flow or water level historical records to account for existing changes/alterations;
- model or simulate flow or water level records that reflect long-term conditions that would be expected based on existing changes/alterations and in the absence of measurable withdrawal impacts;
- develop or identify significant harm standards, thresholds and other criteria;
- aid in the characterization or classification of lake types or classes based on the changes/alterations;
- evaluate the status of water bodies with proposed or established MFLs (i.e., determine whether the flow and/or water level are below, or are projected to fall below the applicable minimum flow or level); and
- support development of lake guidance levels (described in the following paragraph).

The District has developed specific methodologies for establishing minimum flows or levels for lakes, wetlands, rivers, estuaries and aquifers, subjected the methodologies to independent, scientific peer-review, and incorporated the methods for some system types, including lakes, into its Water Level and Rates of Flow rules (Chapter 40D-8, F.A.C.). The rules also provide for the establishment of Guidance Levels for lakes, which serve as advisory information for the District, lakeshore residents and local governments, or to aid in the management or control of adjustable water level structures.

Information regarding the development of adopted methods for establishing minimum and guidance lake levels is included in Southwest Florida Water Management District (1999a, b) and Leeper *et al.* (2001). Additional information relevant to developing lake levels is presented by Schultz et al. (2004), Carr and Rochow (2004), Caffrey *et al.* (2006, 2007), Carr *et al.* (2006), Hancock (2006), Hoyer *et al*. (2006), Leeper (2006), Hancock (2006, 2007) and Emery *et al.* (2009). Independent scientific peer-review findings regarding the lake level methods are summarized by Bedient *et al.* (1999), Dierberg and Wagner (2001) and Wagner and Dierberg (2006).

For lakes, methods have been developed for establishing Minimum Levels for systems with fringing cypress-dominated wetlands greater than 0.5 acre in size, and for those without fringing cypress wetlands. Lakes with fringing cypress wetlands where water levels currently rise to an elevation expected to fully maintain the integrity of the wetlands are classified as Category 1 Lakes. Lakes with fringing cypress wetlands that have been structurally altered such that lake water levels do not rise to levels expected to fully maintain the integrity of the wetlands are classified as Category 2 Lakes. Lakes with less than 0.5 acre of fringing cypress wetlands are classified as Category 3 Lakes.

Categorical significant change standards and other available information are developed to identify criteria that are sensitive to long-term changes in hydrology and can be used for establishing minimum levels. For all lake categories, the most sensitive, appropriate criterion or criteria are used to develop minimum levels. For Category 1 or 2 Lakes, a significant change standard, referred to as the Cypress Standard, is developed. The Cypress Standard is 1.8 feet below the normal pool elevation. For Category 3 lakes, six significant change standards are typically developed. Other available information, including potential changes in the coverage of herbaceous wetland and submersed aquatic plants, is also considered when establishing minimum levels for Category 3 Lakes. The standards and other available information are associated with the environmental values identified for consideration in Rule 62-40.473, F.A.C., when establishing MFLs (Table 1). The specific standards and other information evaluated to support development of minimum levels for Lake Marion are provided in subsequent sections of this report. More general information on the standards and other information used for consideration when developing minimum lake levels is available in the documents identified in the preceding sub-section of this report.

Table 1: Environmental values from the Water Resource Implementation Rule (62-40.473, F.A.C.), and the Significant Change Standards (and other information) associated with each that are considered when establishing minimum flows and levels.

Environmental Value	Associated Significant Change Standards and Other Information for Consideration
Recreation in and on the water	Basin Connectivity Standard, Recreation/Ski Standard, Aesthetics Standard, Species Richness Standard, Dock-Use Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Fish and wildlife habitats and the passage of fish	Cypress Standard, Wetland Offset, Basin Connectivity Standard, Species Richness Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Estuarine resources	NA[1]
Transfer of detrital material	Cypress Standard, Wetland Offset, Basin Connectivity Standard, Lake Mixing Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Maintenance of freshwater storage and supply	NA[2]
Aesthetic and scenic attributes	Cypress Standard, Dock-Use Standard, Wetland Offset, Aesthetics Standard, Species Richness Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Filtration and absorption of nutrients and other pollutants	Cypress Standard Wetland Offset Lake Mixing Standard Herbaceous Wetland Information Submersed Aquatic Macrophyte Information
Sediment loads	NA[1]
Water quality	Cypress Standard, Wetland Offset, Lake Mixing Standard, Dock-Use Standard, Herbaceous Wetland Information, Submersed Aquatic Macrophyte Information
Navigation	Basin Connectivity Standard, Submersed Aquatic Macrophyte Information

NA[1] = Not applicable for consideration for most priority lakes;
NA[2] = Environmental value is addressed generally by development of minimum levels based on appropriate significant change standards and other information and use of minimum levels in District permitting programs

Lake Classification

Lakes are classified as Category 1, 2, or 3 for Minimum Levels development. According to Rule 40D-8.624, F.A.C., Lake Marion meets the classification as a Category 3 lake, as the lake has no fringing cypress wetlands. The standards associated with Category 3 lakes described below will also be developed in a subsequent section of this report.

Lake-specific significant change standards and other available information are developed for establishing Minimum Levels for Category 3 Lakes. The standards are used to identify thresholds for preventing significant harm to cultural and natural system values associated with lakes in accordance with guidance provided in the Florida Water Resource Implementation Rule (62-40.473, F.A.C.). Other information taken into consideration includes potential changes in the coverage of herbaceous wetland vegetation and aquatic plants.

The Recreation/Ski Standard is developed to identify the lowest elevation within the lake basin that will contain an area suitable for safe water skiing. The standard is based on the lowest elevation within the basin that can contain a 5-foot deep ski corridor delineated as a circular area with a radius of 418 feet, or a rectangular ski corridor 200 feet in width and 2,000 feet in length (the Ski Elevation), and use of Historic lake stage data or region-specific Reference Lake Water Regime statistics where Historic lake data are not available.

The Dock-Use Standard is developed to provide for sufficient water depth at the end of existing docks to permit mooring of boats and prevent adverse impacts to bottom-dwelling plants and animals caused by boat operation. The standard is based on the elevation of lake sediments at the end of existing docks, a two-foot water depth for boat mooring, and use of Historic lake stage data or region-specific Reference Lake Water Regime statistics.

The Wetland Offset Elevation is developed to protect lake fringing non-cypress wetlands. Based on the rationale used to develop the Cypress Wetland Standard for Category 1 and 2 lakes (1.8 feet below the Normal Pool elevation), a Wetland Offset Elevation for Category 3 Lakes was developed. Because Hydrologic Indicators of sustained inundation used to determine the Normal Pool elevation usually do not exist on Category 3 Lakes, another datum, in this case the Historic P50 elevation, was used in the development of the Wetland Offset Elevation. Based on an evaluation of the relationship of the Cypress Wetland Standard with the Historic P50 for hydrologically unimpacted cypress wetlands, the Wetland Offset Elevation for Category 3 Lakes was established at an elevation 0.8 feet below the Historic P50 elevation (Hancock, draft report, 2007).

The Aesthetics Standard is developed to protect aesthetic values associated with the inundation of lake basins. The standard is intended to protect aesthetic values associated with the median lake stage from diminishing beyond the values associated with the lake when it is staged at the Low Guidance Level. The Aesthetics Standard is established at the Low Guidance Level.

The Species Richness Standard is developed to prevent a decline in the number of bird species that may be expected to occur at or utilize a lake. Based on an empirical relationship between lake surface area and the number of birds expected to occur at a lake, the standard is established at the lowest elevation associated with less than a fifteen percent reduction in lake surface area relative to the lake area at the Historic P50 elevation.

The Basin Connectivity Standard is developed to protect surface water connections between lake basins or among sub-basins within lake basins to allow for movement of aquatic biota, such as fish, and support recreational use of the lake. The standard is based on the elevation of lake sediments at a critical high spot between lake basins or lake sub-basins, identification of water depths sufficient for movement of biota and/or watercraft across the critical high spot, and use of Historic lake stage data or the region-specific Reference Lake Water Regime statistics where Historic lake data are not available.

The Lake Mixing Standard is developed to prevent significant changes in patterns of wind-driven mixing of the lake water column and sediment re-suspension. The standard is established at the highest elevation at or below the Historic P50 elevation where the dynamic ratio (see Bachmann *et al.* 2000) shifts from a value of <0.8 to a value >0.8, or from a value >0.8 to a value of <0.8.

Herbaceous Wetland Information is also taken into consideration to determine the elevation at which changes in lake stage would result in substantial changes in potential wetland area within the lake basin (i.e., basin area with a water depth of four feet or less) (Butts *et al*. 1997). Similarly, changes in lake stage associated with changes in lake area available for colonization by rooted submersed or floating-leaved macrophytes are also evaluated, based on water transparency values. Using methods described in Caffrey (2006), mean secchi disk depth (SD) is used to calculate the maximum depth of colonization (MDC) for aquatic plants using regression equation log(MDC) – 0.66log(SD) + 0.30, where all values are represented in meters. The MDC depth is then used to calculate the total acreage at each lake stage that is available for aquatic plant colonization.

Minimum and Guidance Levels

Two Minimum Levels and two Guidance Levels are typically established for lakes. Upon completion of a public input/review process and, if necessary completion of an independent scientific review, either of which may result in modification of the proposed levels, the levels are then adopted by the District Governing Board into Chapter 40D-8, F.A.C. (see Hancock *et al.* 2010 for more information on the adoption process). The levels, which are expressed as elevations in feet above the National Geodetic Vertical Datum of 1929 (NGVD29), include the following (refer to Rule 40D-8.624, F.A.C.):

- A **High Guidance Level** that is provided as an advisory guideline for construction of lake shore development, water dependent structures, and operation of water management structures. The High Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ten percent of the time on a long-term basis.

- A **High Minimum Lake Level** that is the elevation that a lake's water levels are *required* to equal or exceed ten percent of the time on a long-term basis.

- A **Minimum Lake Level** that is the elevation that the lake's water levels are *required* to equal or exceed fifty percent of the time on a long-term basis.

- A **Low Guidance Level** that is provided as an advisory guideline for water dependent structures, information for lakeshore residents and operation of water management structures. The Low Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ninety percent of the time on a long-term basis.

The District is in the process of converting from use of the NGVD29 datum to use of the North American Vertical Datum of 1988 (NAVD 88). While the NGVD29 datum is used for most elevation values included within this report, in some circumstances, notations are made for elevation data that was collected or reported relative to mean sea level or relative to NAVD88 and converted to elevations relative to NGVD29.

Development of Minimum and Guidance Levels for Lake Marion

Lake Setting and Description

Lake Marion (Figure 1) is located in east-central Levy County, Florida (Sections 1 and 2, Township 14, Range 17) within the Wekiva River drainage basin in the Waccasassa River watershed, within the Southwest Florida Water Management District.

The lake's watershed (Figure 2) has a drainage area of 138 acres (approximately 0.22 square miles). The lake is a closed basin and has no inlets or outlets (Figure 3). There are currently no surface water withdrawals from the lake permitted by the District. There are, however, several permitted groundwater withdrawals in the lake vicinity.

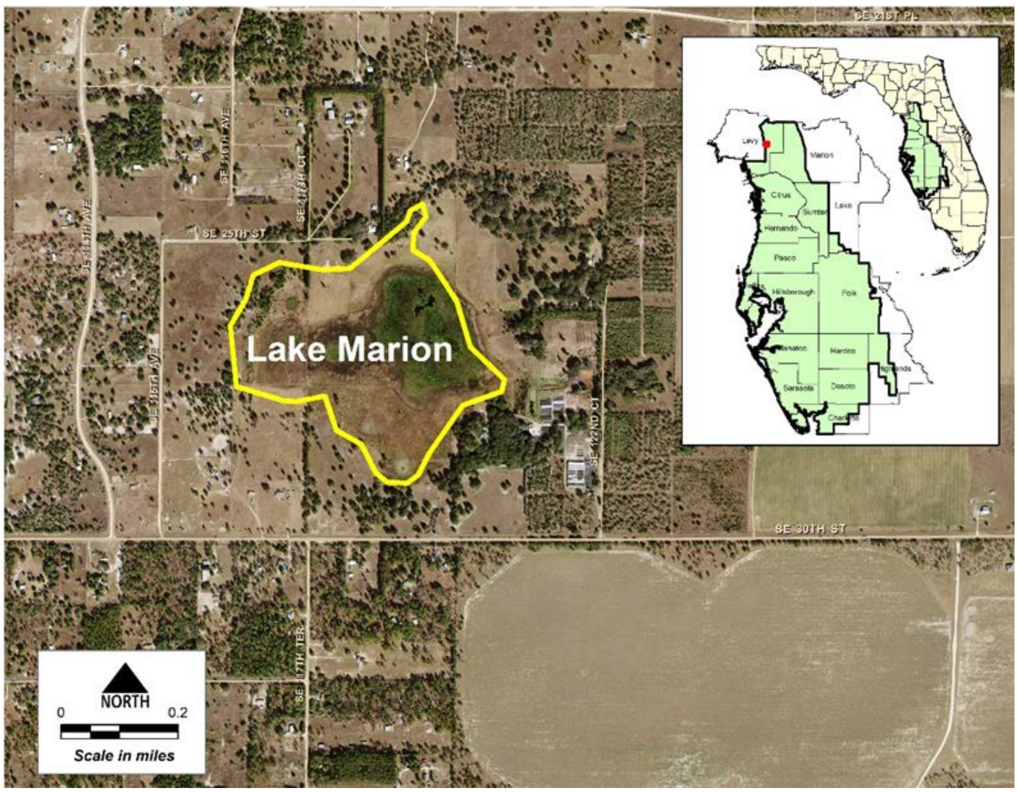

Figure 1: Location of Lake Marion in Levy County, Florida.

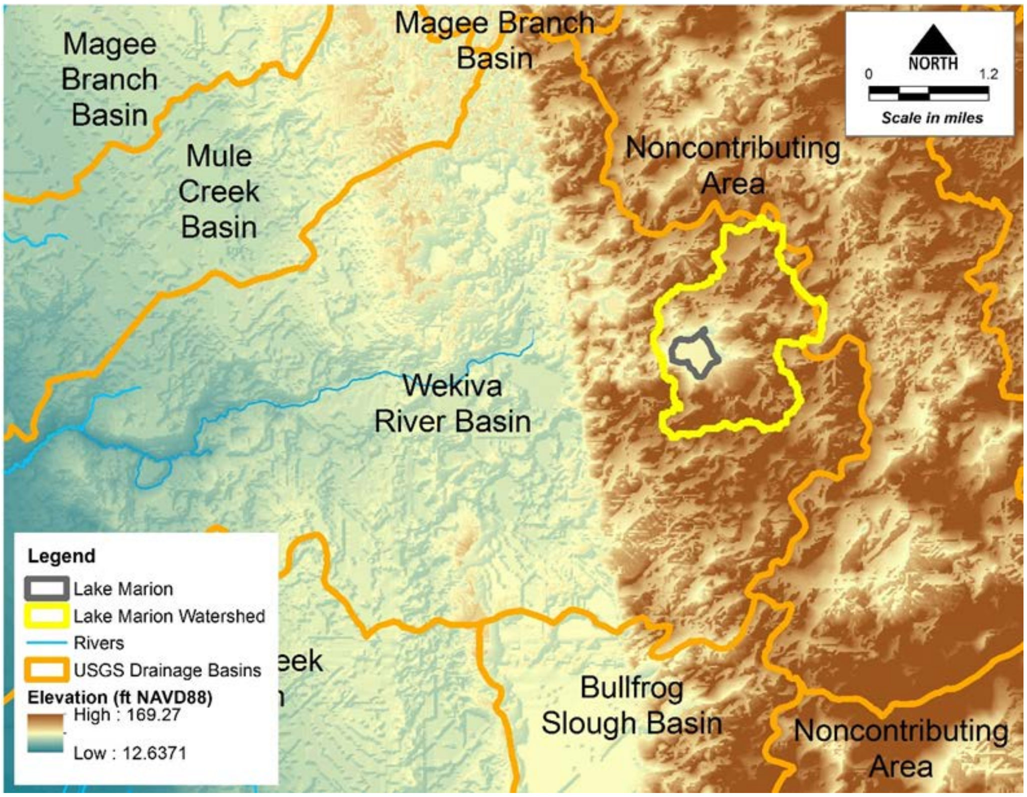

Figure 2: Watershed Delineation and Topography.

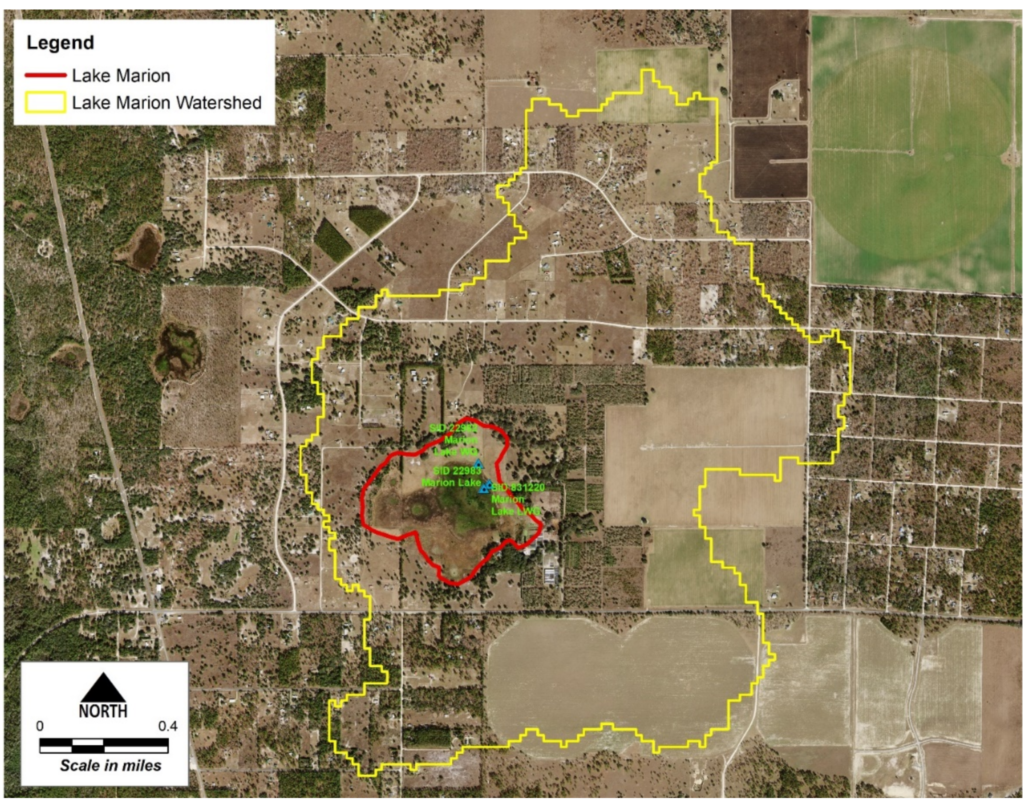

Figure 3: Lake Marion Watershed and District Gages.

Land Use Land Cover

An examination of the 1990 and more current 2017 Florida Land Use, Cover, and Forms Classification System (FLUCCS) maps revealed that there has been some change to the landscape (specifically the dominant land forms) in the vicinity of the lake during this period (Figure 4 and Figure 5). In 1990 (Figure 4) the majority of the land surrounding Lake Marion was classified as agriculture or other open lands. There was some low-density residential land, as well. By 2017 (Figure 5), much of the agriculture had been replaced with low-density residential lands. Figure 6 through Figure 11 aerial photography chronicles landscape changes to the immediate lake basin from 1940 through 2017.

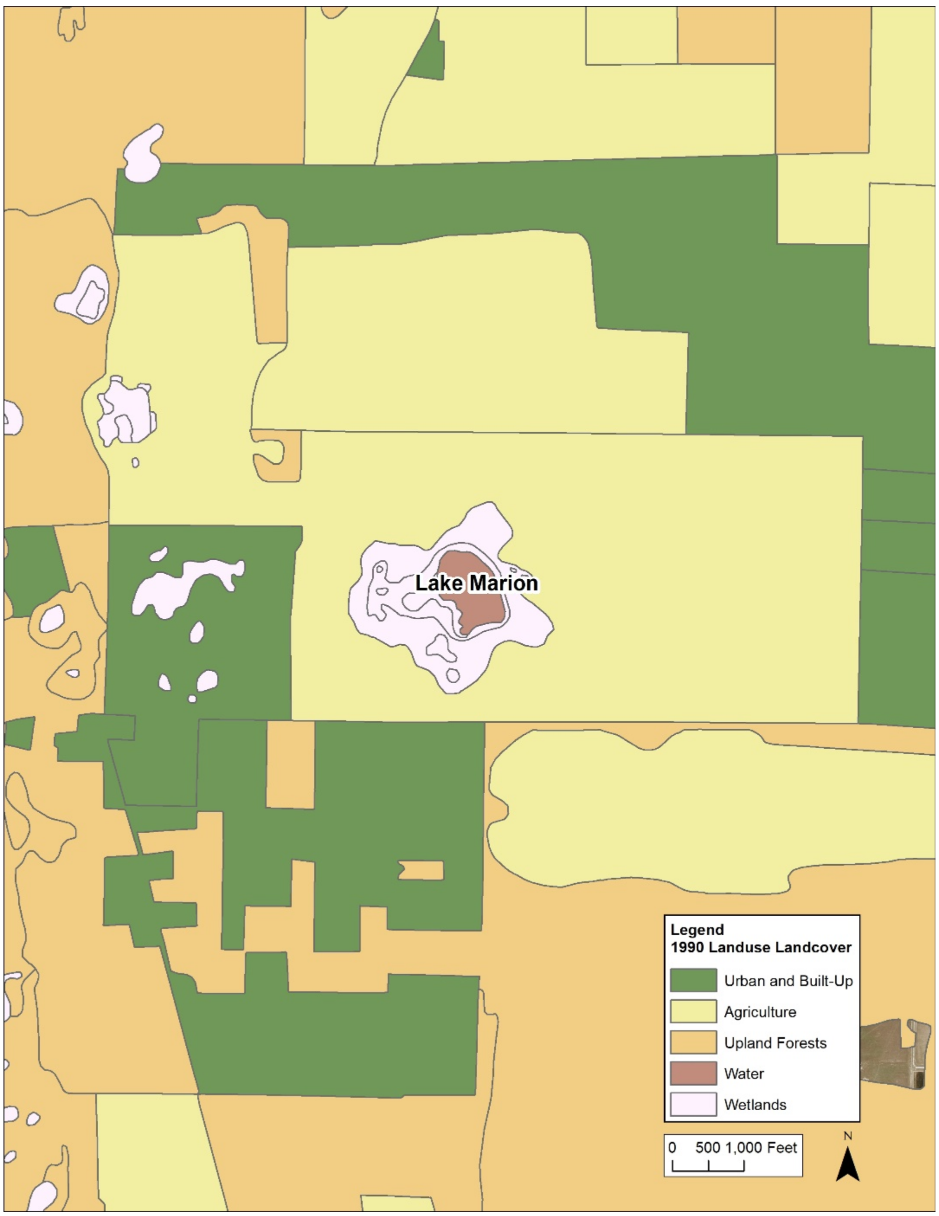

Figure 4: 1990 Land Use Land Cover Map of the Lake Marion Vicinity.

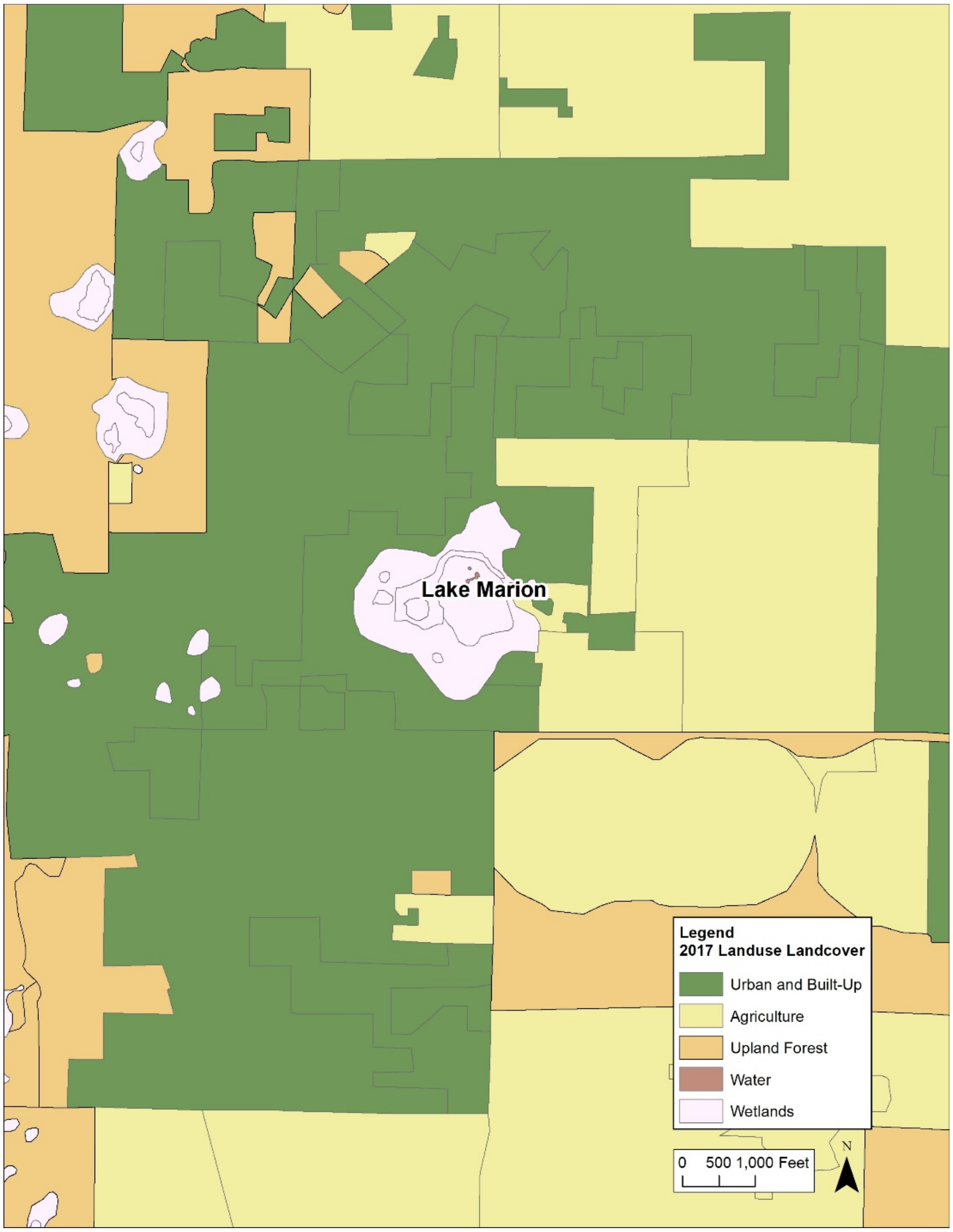

Figure 5: 2017 Land Use Land Cover Map of the Lake Marion Vicinity.

Figure 6: 1940 Aerial Photograph of Lake Marion

Figure 7: 1952 Aerial Photograph of Lake Marion

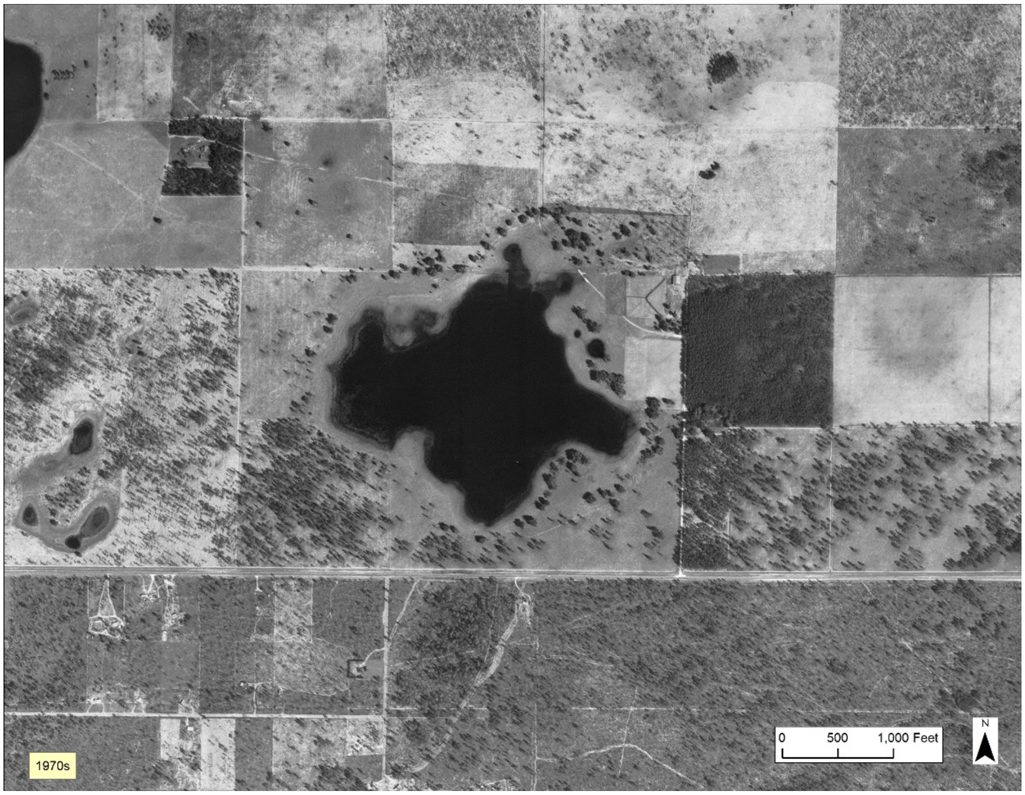

Figure 8: 1970s Aerial Photograph of Lake Marion

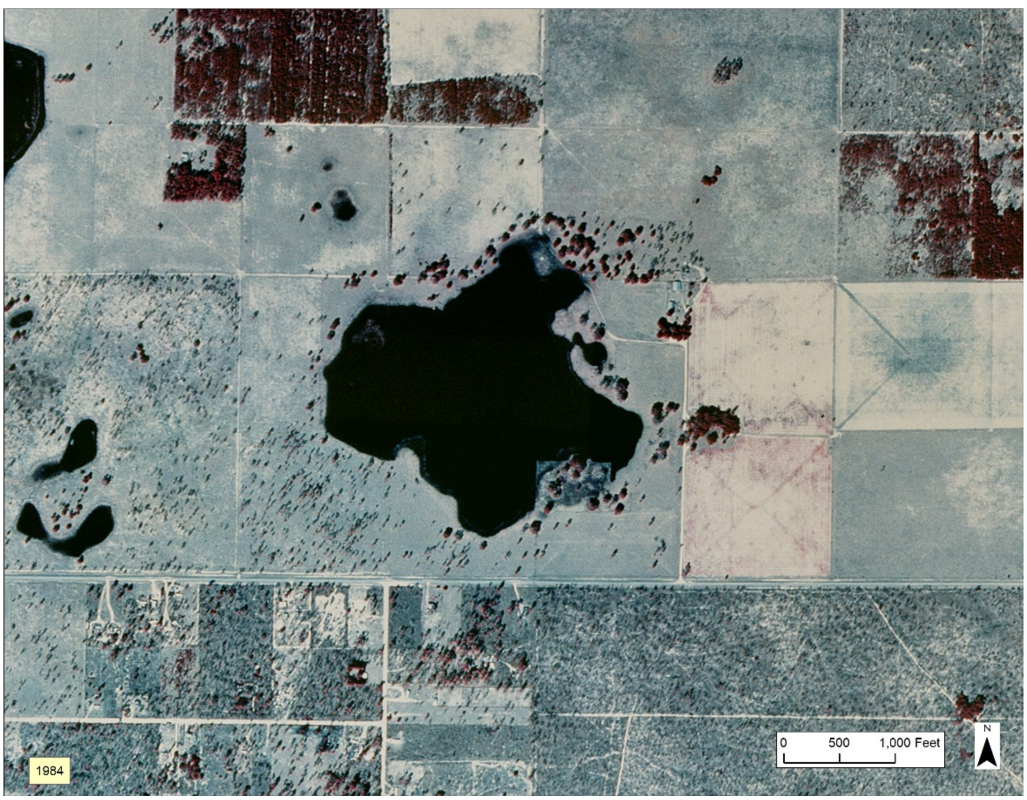

Figure 9: 1984 Aerial Photograph of Lake Marion

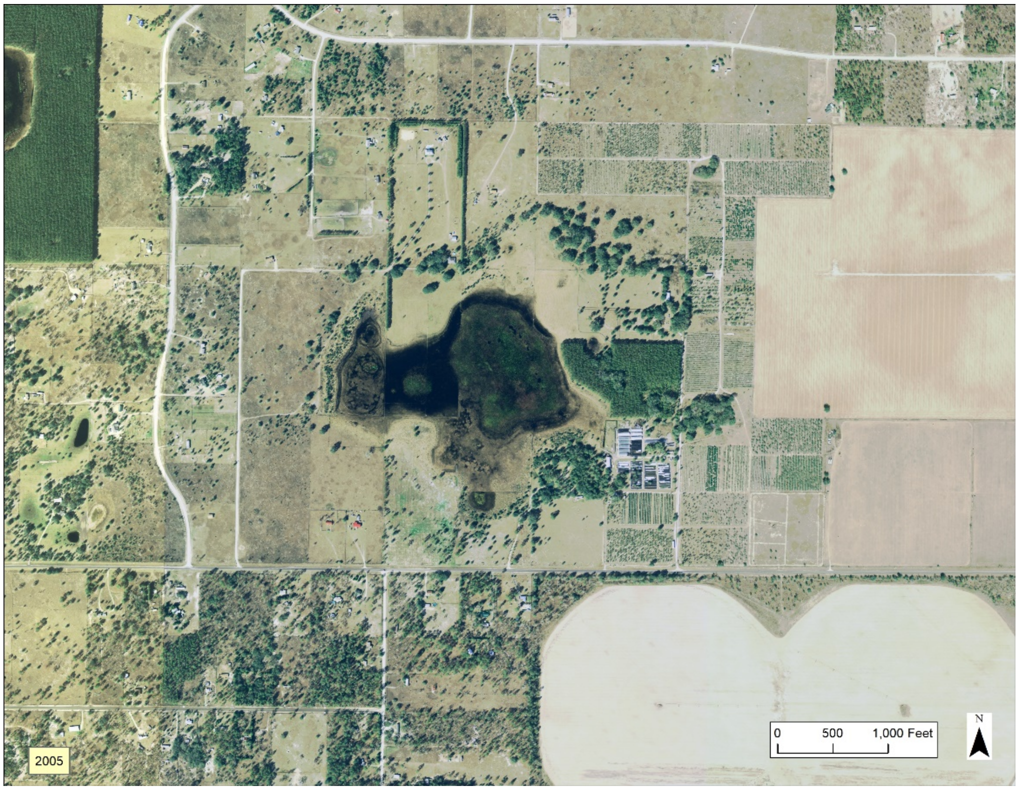

Figure 10: 2005 Aerial Photograph of Lake Marion

Figure 11: 2017 Aerial Photograph of Lake Marion

Bathymetry Description and History

One-foot interval bathymetric data gathered from field surveys resulted in lake-bottom contour lines from 40 ft. to 57 ft., NGVD29 (Figure 12). These data revealed that the lowest lake bottom contour (40.1 ft. NGVD29), or the deepest part of the lake, is located in the northeast quarter of the lake. Additional morphometric or bathymetric information for the lake basin is discussed in the Methods, Results and Discussion section of this report.

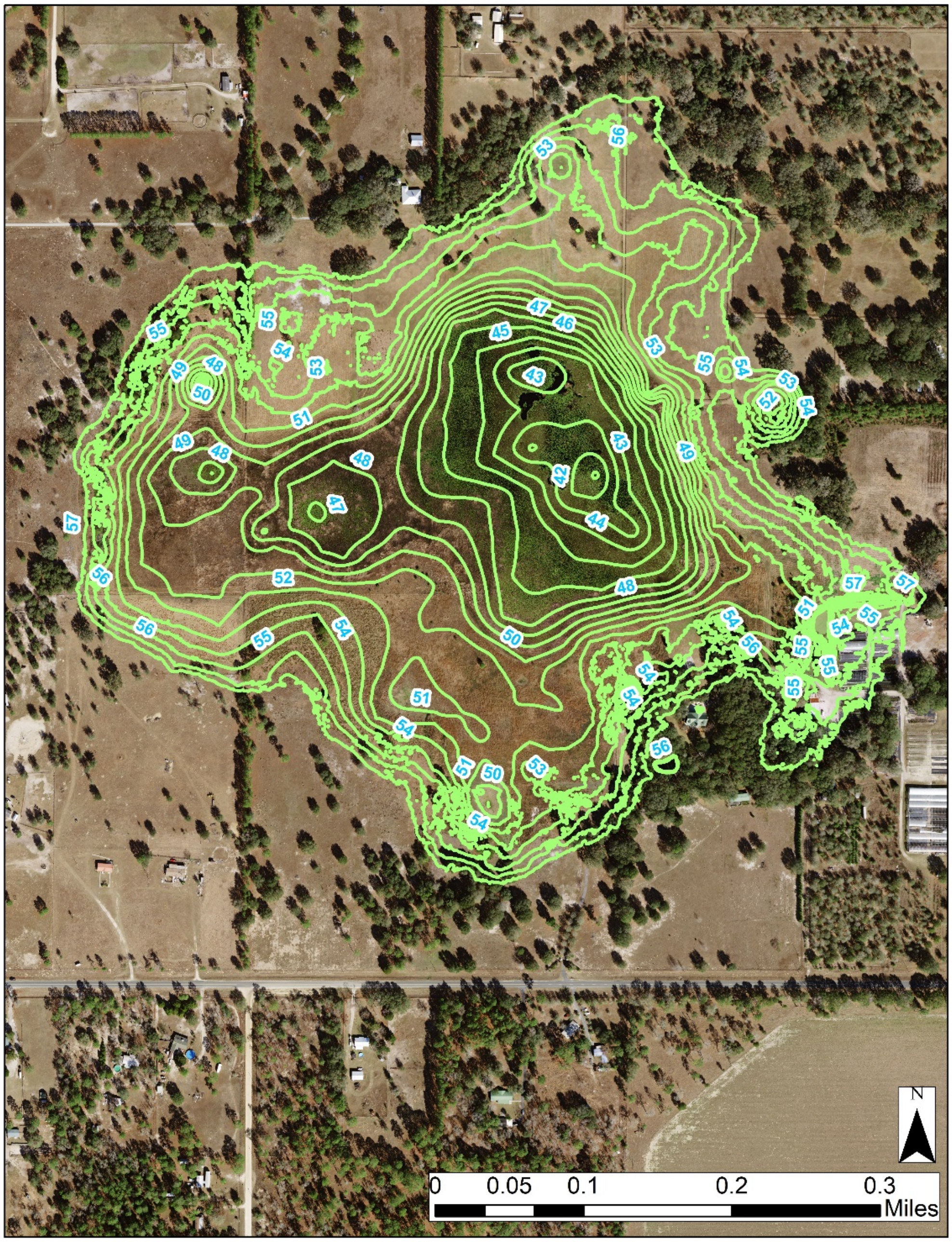

Figure 12: Lake Bottom Contours (ft., NGVD29) on a 2017 Natural Color Aerial Photograph

Water Level (Lake Stage) Record

Lake stage data, i.e., surface water elevations, are available for Lake Marion from the District's Water Management Information System (SID 22983 and 831220) (Figure 13). Data collection began March 1992 from SID 22983. Data collection from SID 831220 began June 2000. SID 22983 is a low water gauge and SID 831220 is a high water gauge, so the data from both gauges are combined to get a nearly continuous record from 1992 to current. On March 13, 2014, the datum for the SID 22983 gauge was adjusted from NGVD29 to NAVD88, with a measured shift (downward) of -0.79 ft.

The highest lake stage elevation on record is 56.15 ft. (NGVD) and occurred on September 17, 2019. The lowest lake stage elevation on record is 43.26 ft. (NGVD) and occurred on April 12, 2012.

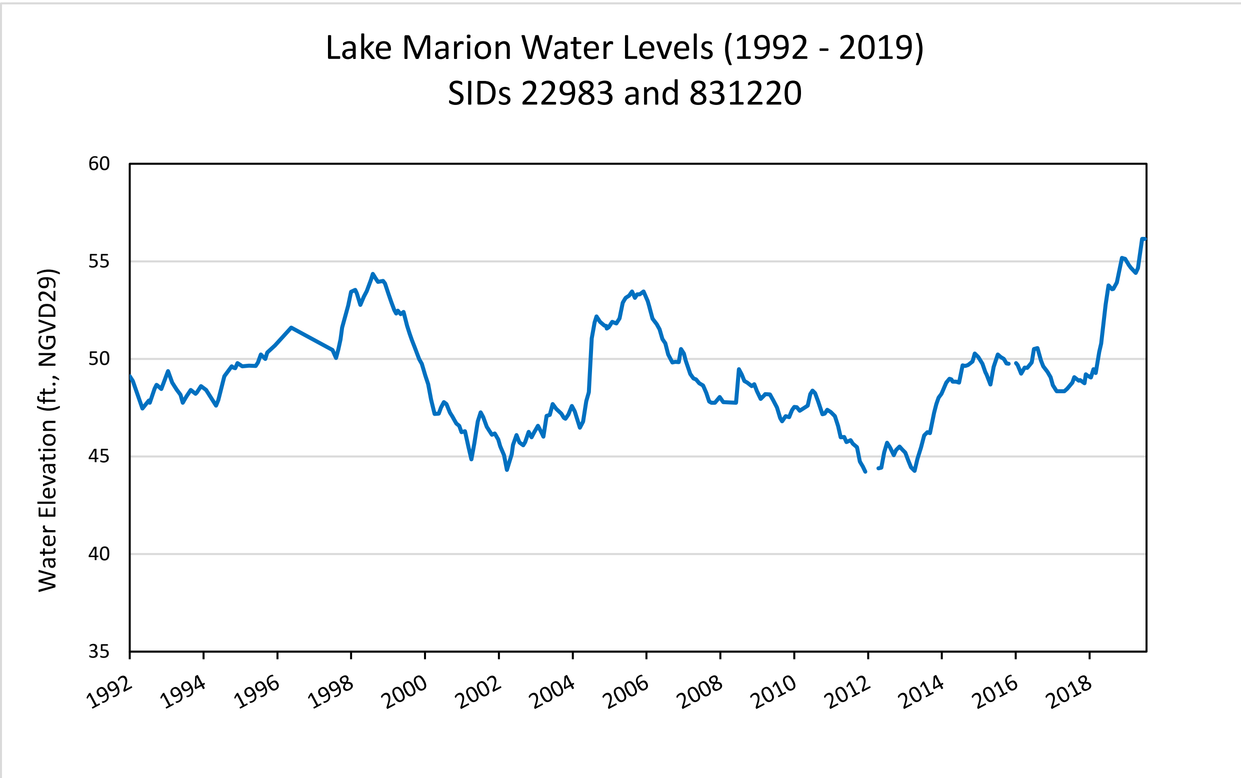

Figure 13: Lake Marion Period of Record Water Elevation Data

Historic Management Levels

The District has a long history of water resource protection through the establishment of lake management levels. With the development of the Lake Levels Program in the mid-1970s, the District began establishing management levels based on hydrologic, biological, physical, and cultural aspects of lake ecosystems. By 1996, management levels for nearly 400 lakes had been adopted into District rules.

The District Governing Board first approved Guidance and Minimum Levels for Lake Marion (Table 2) in October 2006, which were subsequently adopted into Chapter 40D-8, Florida Administrative Code, on February, 12, 2007.

Table 2: Minimum and Guidance Levels adopted February 12, 2007 for Lake Marion

Level	Elevation (ft., NGVD)
High Guidance Level	55.3
High Minimum Level	54.6
Minimum Level	50.7
Low Guidance Level	47.7

Methods, Results and Discussion

The Minimum and Guidance Levels in this report were developed for Lake Marion using the methodology for Category 3 lakes described in Chapter 40D-8, F.A.C. Levels, Standards, and other information used for development of the levels, are listed in Table 3, along with lake surface area for each level. Detailed descriptions of the development and use of these data are provided in subsequent sections of this report.

Table 3: Lake Stage Percentiles, Normal Pool and Control Point Elevations, Significant Change Standards, and Minimum and Guidance Levels with associated surface areas for Lake Marion.

Levels	Elevation in Feet NGVD 29	Lake Area (acres)
Lake Stage Percentiles		
Historic P10 (1946 to 2019)	53.2	74.6
Historic P50 (1946 to 2019)	50.0	38.9
Historic P90 (1946 to 2019)	47.1	20.8
Normal Pool and Control Point		
Normal Pool	NA	NA
Control Point	NA	NA
Significant Change Standards*		
Recreation/Ski Standard	NA	NA
Dock-Use Standard	NA	NA
Wetland Offset Elevation	49.2	32.1
Aesthetics Standard	47.1	20.8
Species Richness Standard	49.4	33.4
Basin Connectivity Standard	54.4	89.5
Lake Mixing Standard	NA	NA
Minimum and Guidance Levels		
High Guidance Level	53.2	74.6
High Minimum Lake Level	52.6	67.0
Minimum Lake Level	49.4	33.4
Low Guidance Level	47.1	20.8

NA - not appropriate
* Used for comparison purposes only

Bathymetry

Relationships between lake stage, inundated area, and volume can be used to evaluate expected fluctuations in lake size that may occur in response to climate, other natural factors, and anthropogenic impacts such as structural alterations or water withdrawals. Long term reductions in lake stage and size can be detrimental to many of the environmental values identified in the Water Resource Implementation Rule for consideration when establishing MFLs. Stage-area-volume relationships are therefore useful for developing significant change standards and other information identified in District rules for consideration when developing minimum lake levels. The information is also needed for the development of lake water budget models that estimate the lake's response to rainfall and runoff, outfall or discharge, evaporation, leakance, and groundwater withdrawals.

Stage-area-volume relationships were determined for Lake Marion by building and processing a digital elevation model (DEM) of the lake basin and surrounding watershed. Elevations of the lake bottom and land surface elevations were used to build the model through a series of analyses using LP360 (by QCoherent) for ArcGIS, ESRI® ArcMap 10.6 software, the 3D Analyst ArcMap Extension, Python, and XTools Pro. The overall process involves merging the terrain morphology of the lake drainage basin with the lake basin morphology to develop one continuous 3D digital elevation model. The 3D digital elevation model is then used to calculate area of the lake and the associated volume of the lake at different elevations, starting at the largest size of the lake at its peak or flood stage, and working downward to the base elevation (deepest pools in the lake).

Two elevation data sets were used to develop the terrain model for Lake Marion. Light Detection and Ranging Data (LiDAR) was processed with LP360 for ArcGIS and merged with bathymetric data collected with both sonar and mechanical (manual) methods. These data were collected using a LEI HS-WSPK transducer (operating frequency = 192kHz, cone angle = 20) mounted to a boat hull, a Lowrance LMS-350A sonar-based depth finder and the Trimble GPS Pathfinder Pro XR/Mapping System (Pro XR GPS Receiver, Integrated GPS/MSK Beacon Antenna, TDC1 Asset Surveyor and Pathfinder Office software).

The DEM created from the combined elevation data sets was used to develop topographic contours of the lake basin and to create a triangulated irregular network (TIN). The TIN was used to calculate the stage areas and volumes using a Python script file to iteratively run the Surface Volume tool in the Functional Surface toolset of the ESRI® 3D Analyst toolbox at one-tenth of a foot elevation change increments. Selected stage-area-volume results are presented in Figure 14.

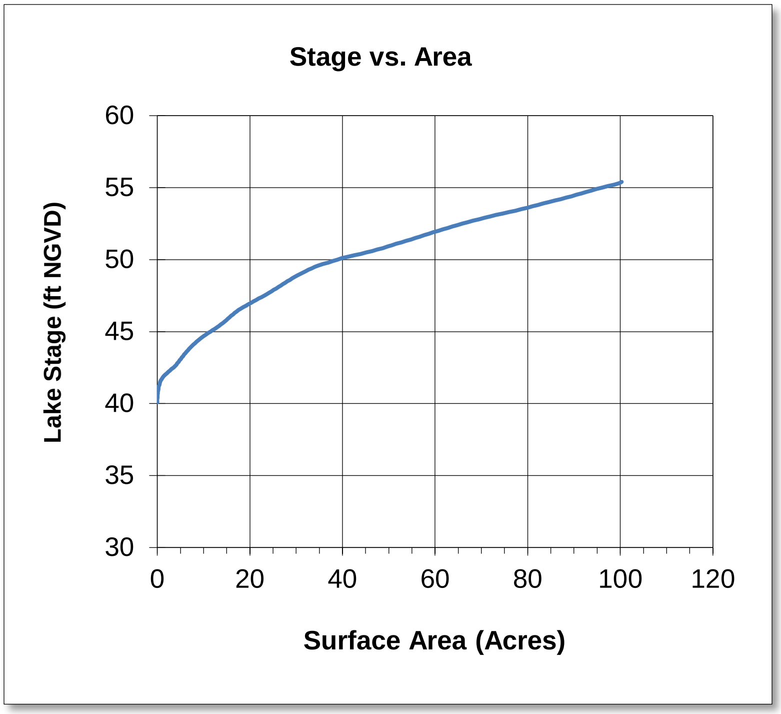

Figure 14: Lake Stage (Ft. NGVD29) to Surface Area (Acres) for Lake Marion.

Development of Exceedance Percentiles

A key part of establishing Minimum and Guidance Levels is the development of exceedance percentiles based on Historic water levels (lake stage data). For the purpose of minimum levels determination, lake stage data are categorized as "Historic" for periods when there were no measurable impacts due to water withdrawals and impacts due to structural alterations were similar to existing conditions. In the context of minimum levels development, "structural alterations" means man's physical alteration of the control point, or highest stable point along the outlet conveyance system of a lake, to the degree that water level fluctuations are affected.

Based on water-use estimates and analysis of lake water levels and regional ground water fluctuations, a modeling approach (see Appendix A) was used to estimate Historic lake levels. This approach was considered appropriate for extending the period of record for lake stage values for developing Historic lake stage exceedance percentiles. Development of this stage record was considered necessary for characterization of the range of lake-stage fluctuations that could be expected based on long-term climatic cycles that have been shown to be associated with changes in regional hydrology (Enfield et al. 2001, Basso and Schultz 2003, Kelly 2004).

The initial approach included developing a water budget model which incorporated the effects of precipitation, evaporation, overland flow, and groundwater interactions (Appendix A). Using the results of the water budget model, regression modeling for lake stage predictions was conducted using a linear line of organic correlation statistical model (LOC) (see Helsel and Hirsch 1992). The procedure was used to derive the relationship between daily water surface elevations for Lake Marion and composite regional rainfall.

A combination of model data produced a hybrid model which resulted in a 73.3-year (1946-2019) Historic water level record. Based on this hybrid data, the Historic P10 elevation, i.e., the elevation of the lake water surface equaled or exceeded ten percent of the time, was 53.2 ft. The Historic P50, the elevation the lake water surface equaled or exceeded fifty percent of the time during the historic period, was 50.0 ft. The Historic P90, the lake water surface elevation equaled or exceeded ninety percent of the time during the historic period, was 47.1 ft. (Figure 15 and Table 3).

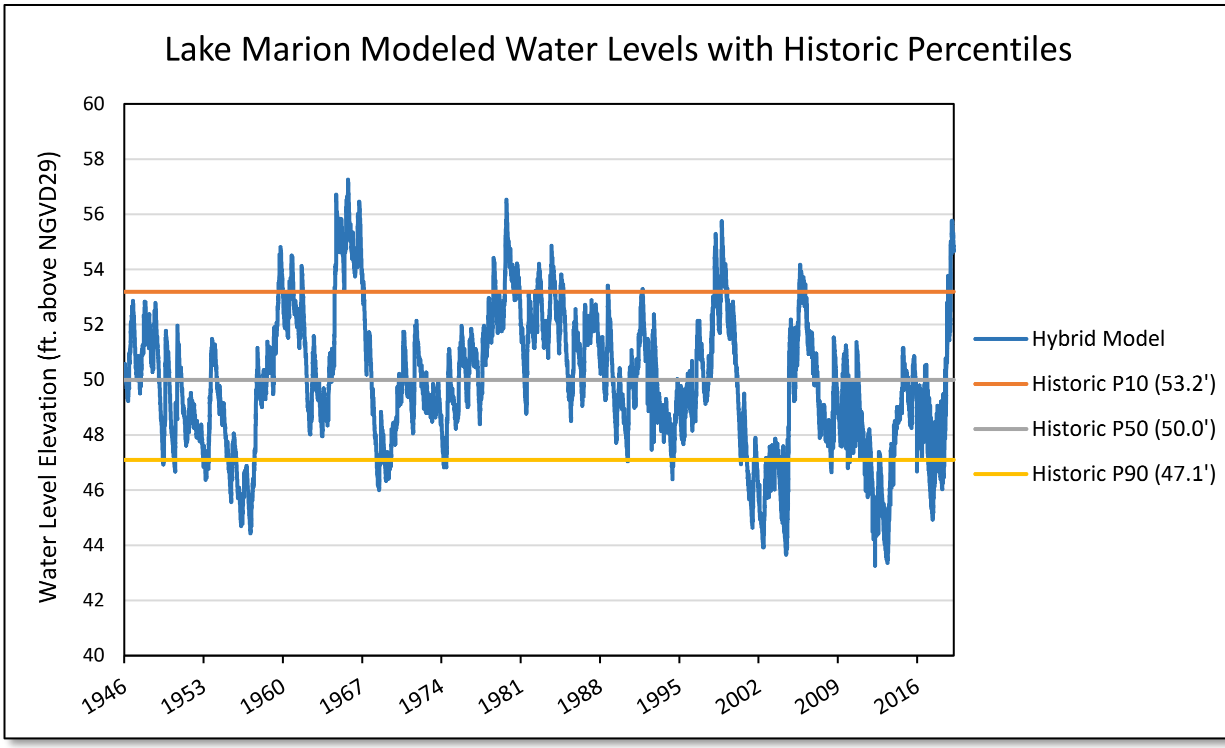

Figure 15: Historic Water Levels (hybrid) Used to Calculate Percentile Elevations (P10, P50, and P90).

Normal Pool Elevation and Additional Information

The Normal Pool elevation, a reference elevation used for development of minimum lake and wetland levels, is established based on the elevation of hydrologic indicators of sustained inundation. The inflection points (buttress swelling) and moss collars on the trunks of cypress trees have been shown to be reliable biologic indicators of hydrologic Normal Pool (Carr et al. 2006). As Lake Marion does not have sufficient cypress trees with adequate hydrologic indicators, a Normal Pool elevation was not determined.

Additional information to consider in establishing Minimum and Guidance Levels are the Control Point elevation and the lowest building floor (slab) elevation within the lake basin (determined by field survey data). The Control Point elevation is the elevation of the highest stable point along the outlet profile of a surface water conveyance system that can principally control the lake water level fluctuations at the high end. As Lake Marion does not have an outlet, there is no Control Point to consider in setting Minimum Levels.

The low floor slab elevation (11750 SE 25th Street), based on survey reports, was established at 60.76 ft.

Guidance Levels

The High Guidance Level (HGL) is provided as an advisory guideline for construction of lakeshore development, water dependent structures, and operation of water management structures. The High Guidance Level is the expected Historic P10 of the lake, and is established using Historic data if it is available, or is estimated using the Current P10, the Control Point elevation and the Normal Pool elevation. Based on the availability of Historic data developed for Lake Marion, the High Guidance Level was established at the Historic P10 elevation, 53.2 ft. Recorded data indicate that the highest levels reached were in August and September 2019, with a peak of 56.2 ft.

The Low Guidance Level (LGL) is provided as an advisory guideline for water dependent structures, and as information for lakeshore residents and operation of water management structures. The Low Guidance Level is the elevation that a lake's water levels are expected to equal or exceed ninety percent of the time on a long-term basis. The level is established using Historic or Current lake stage data and, in some cases, Reference Lake Water Regime (RLWR) statistics. Based on the availability of Historic data for Lake Marion, the Low Guidance Level was established at the Historic P90 elevation, 47.1 ft. The recorded period of record indicates the lowest lake level elevation was 43.3 ft., in April 2012 (Figure 13). The most recent record of the water level dropping below the Low Guidance Level was in November 2013, with a recorded level of 46.2 ft.

Significant Change Standards

Category 3 significant change standards were established for Lake Marion based on the stage-area-volume relationship which was developed. These standards include a Recreation/Ski Standard, Dock-Use Standard, Wetland Offset Elevation, Aesthetics Standard, Species Richness Standard, Basin Connectivity Standard, and Lake Mixing Standard. Each standard was evaluated for minimum levels development for Lake Marion and presented in Table 3.

- The **Recreation/Ski Standard** was not established since a circular ski corridor with a radius of 418 feet or a rectangular corridor 200 x 2,000 feet was not possible. Thus, Lake Marion is classified as a Non-Ski lake.
- The **Dock-Use Standard** was not established since there are no docks on lake Marion.
- The **Wetland Offset Elevation** was established at 49.2 ft., or 0.8 ft. below the historic P50 elevation.
- The **Aesthetic Standard** was established at the Low Guidance Level elevation of 47.1 ft.
- The **Species Richness Standard** was established at 49.4 ft., based on a 15% reduction in lake surface area from that at the Historic P50 elevation.
- The **Basin Connectivity Standard** was established at an elevation of 54.4 ft. based on a critical high spot elevation of 49.5 ft, the addition of 2 feet, plus the difference between the Historic P50 and P90 of 2.9 ft. This critical high spot is the elevation separating the east and west “pools” of Lake Marion.
- The **Lake Mixing Standard** was not established, as the dynamic ratio does not reach a value of 0.8 (Figure 16) (see Bachmann et al. 2000).

Review of changes in potential herbaceous wetland area associated with change in lake stage (Figure 16) did not indicate that use of any of the identified standards would be inappropriate for minimum levels development. Figure 17 shows that as the lake stage increases, the acres available for herbaceous wetland area (acres < 4 ft.) also increase. The area available for aquatic plant colonization could not be determined as there are no Secchi disc data or other means of determining light penetration.

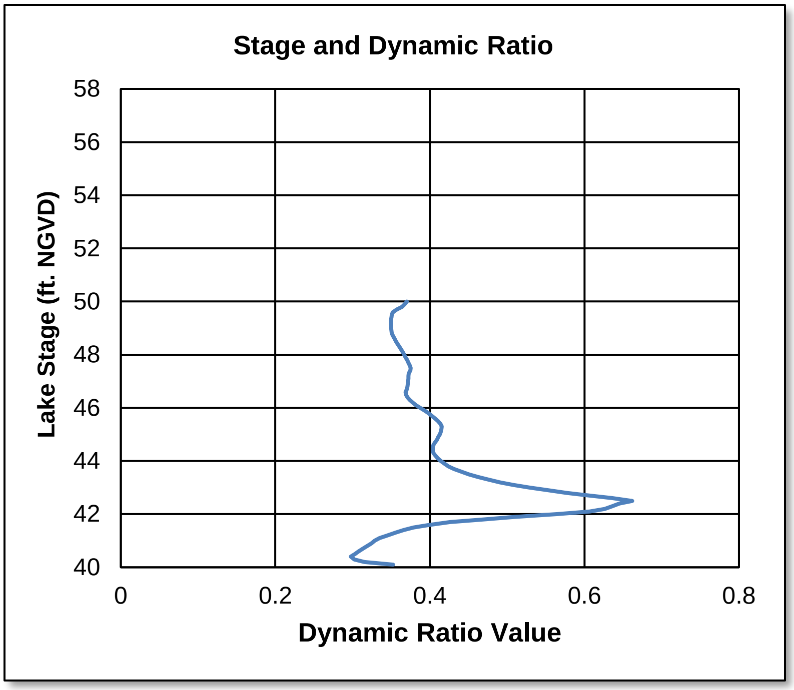

Figure 16. Stage and Dynamic Ratio

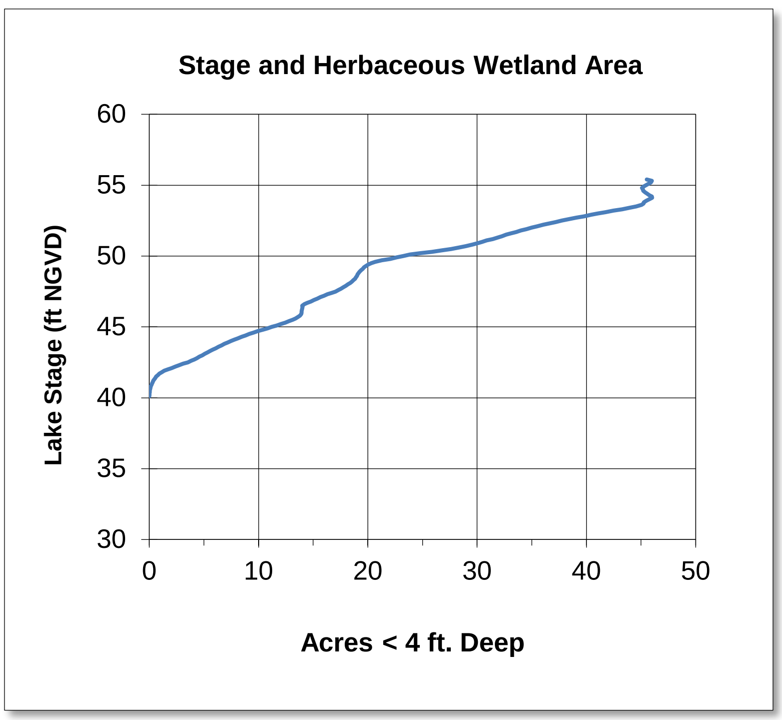

Figure 17: Lake Stage Compared to Available Herbaceous Wetland Area.

Minimum Levels

The Minimum Lake Level (MLL) is the elevation that a lake's water levels are *required* to equal or exceed fifty percent of the time on a long-term basis. For a Category 3 lake, the Minimum Lake Level is established using a process that considers applying professional experience and judgement, and the Standards previously listed. The MLL for Lake Marion is established at the Species Richness Standard elevation of 49.4 ft.

The High Minimum Lake Level (HMLL) is the elevation that a lake's water levels are ***required*** to equal or exceed ten percent of the time on a long-term basis. For a Category 3 lake, Rule 40D-8.624, F.A.C. allows for the HMLL to be established using one of two methods. The High Minimum Lake Level is established at the elevation corresponding to the Minimum Lake Level plus the difference between the Historic P10 and the Historic P50, or alternatively, the HMLL is established at the elevation corresponding to the MLL plus the RLWR value. Due to the availability of Historic percentiles, the HMLL was established using the first method, resulting in a HMLL of 52.6 ft. This elevation accounts for a natural fluctuation of lake levels.

Minimum and Guidance levels for Lake Marion are plotted on the recorded water level record in Figure 17. To illustrate the approximate locations of the lake margin when water levels equal the minimum levels, the levels are imposed onto a 2017 natural color aerial photograph in Figure 18.

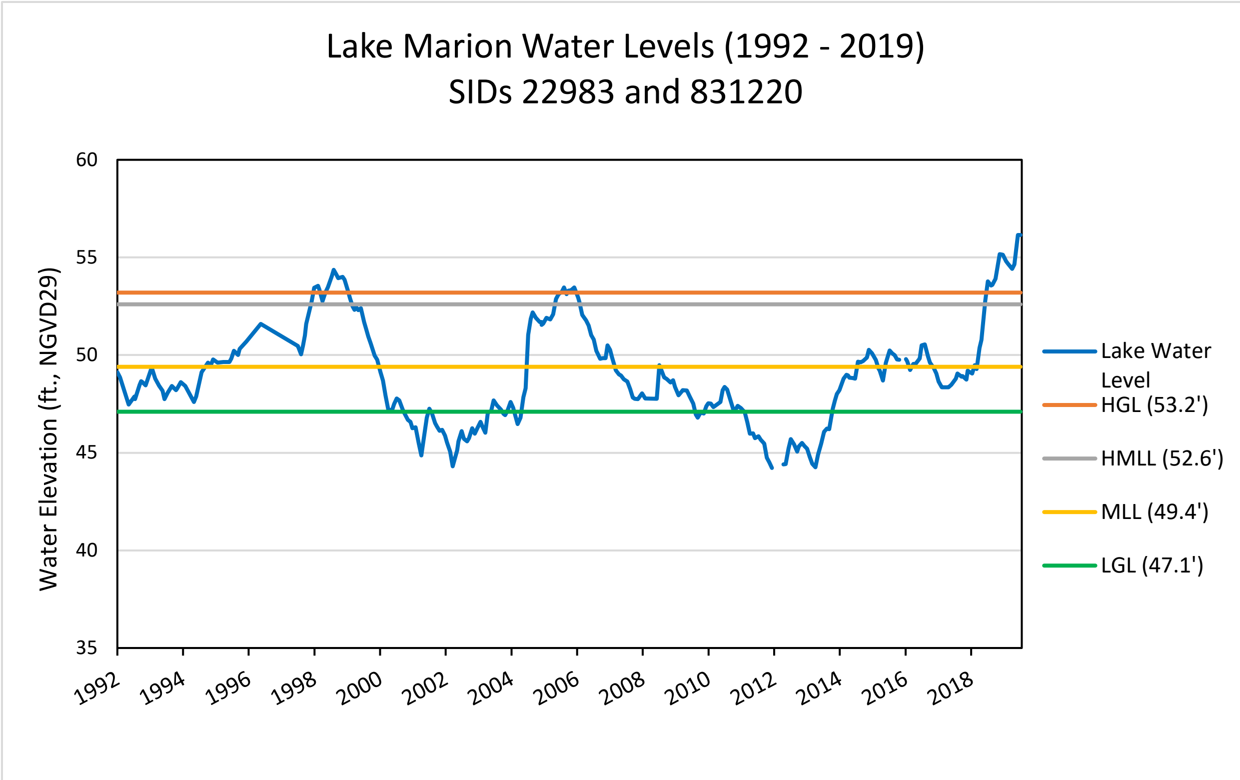

Figure 18: Recorded Water Level Elevations with Guidance and Minimum Lake Levels for Lake Marion.

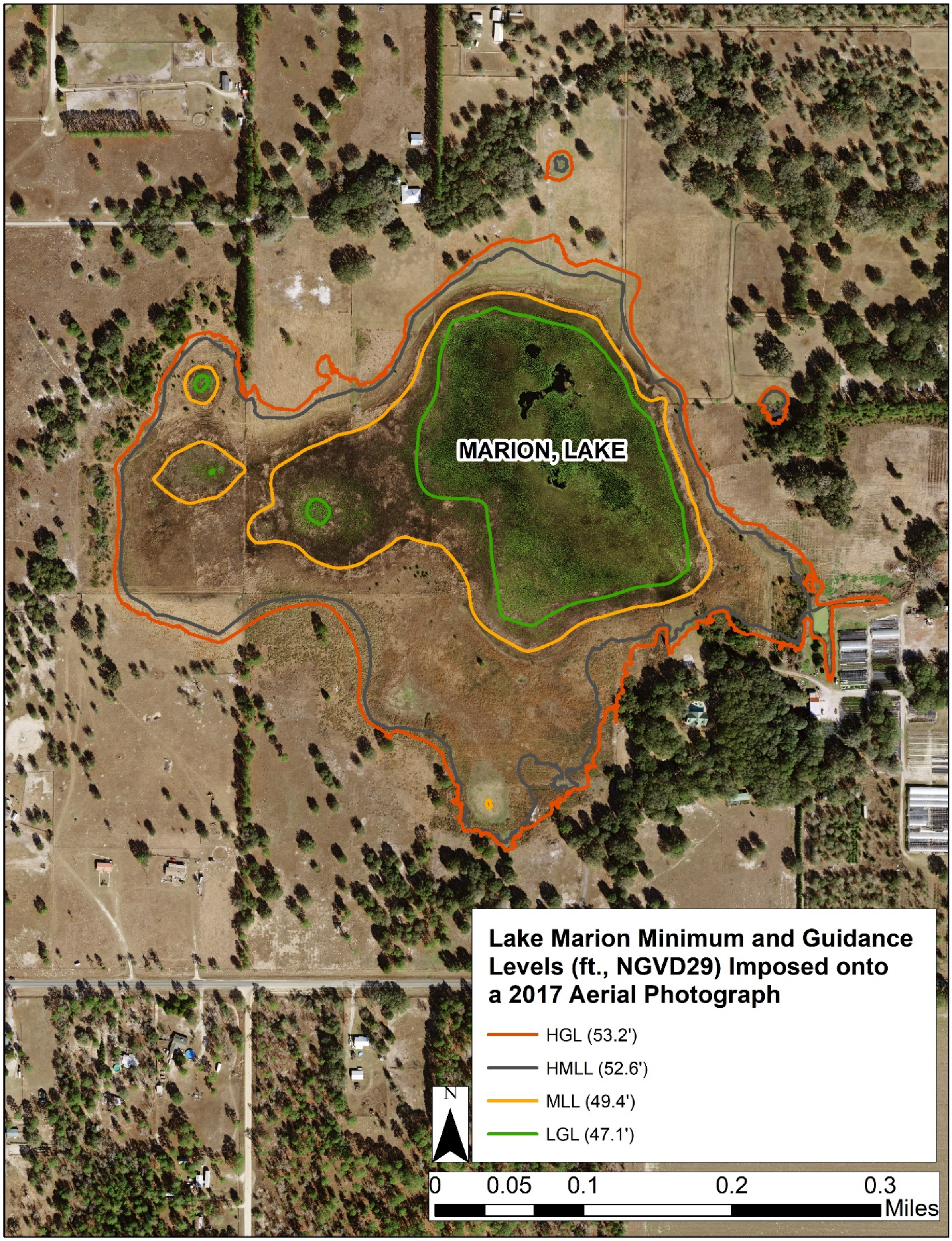

Figure 19: Lake Marion Minimum and Guidance Level Contour Lines Imposed onto a 2017 Natural Color Aerial Photograph.

Many federal, state, and local agencies, such as the U.S. Army Corps of Engineers, the Federal Emergency Management Agency, United States Geological Survey, and Florida's water management districts are in the process of upgrading from the National Geodetic Vertical Datum (NGVD29) standard to the North American Vertical Datum (NAVD88) standard. For comparison purposes, the MFLs for Lake Marion are presented in both datum standards (Table 4). The datum shift was calculated based on third-order leveling ties from vertical survey control stations with known elevations above the North American Vertical Datum of 1988. The NGVD29 datum conversion to NAVD88 is -0.79 ft. for SID 22983 on Lake Marion.

Table 4: Minimum and Guidance Levels for Lake Marion in NGVD29 and NAVD88.

Minimum and Guidance Levels	Elevation in Feet NGVD29	Elevation in Feet NAVD88
High Guidance Level	53.2	52.4
High Minimum Lake Level	52.6	51.8
Minimum Lake Level	49.4	48.6
Low Guidance Level	47.1	46.3

Consideration of Environmental Values

The minimum levels for Lake Marion are protective of relevant environmental values identified for consideration in the Water Resource Implementation Rule when establishing minimum flows and levels (see Rule 62-40.473, F.A.C.). As presented above, when developing minimum lake levels, the District evaluates categorical significant change standards and other available information to identify criteria that are sensitive to long-term changes in hydrology and represent significant harm thresholds.

The Species Richness Standard Elevation was used for developing Minimum Levels for Lake Marion based on its classification as a Category 3 lake. This standard is associated with protection of several environmental values identified in Rule 62-40.473, F.A.C., including: recreation in and on the water, fish and wildlife habitats and the passage of fish, and aesthetic and scenic attributes (Table 1).

In addition, the environmental value of maintenance of freshwater storage and supply is also expected to be protected by the minimum levels based on inclusion of conditions in water use permits that stipulate permitted withdrawals will not lead to violation of adopted minimum flows and levels.

Two environmental values identified in the Water Resource Implementation Rule were not considered relevant to development of minimum levels for Lake Marion. Estuarine resources were not considered relevant because the lake is not connected to an estuarine resource. Sediment loads were similarly not considered relevant for minimum levels development for the lake, because the transport of sediments as bedload or suspended load is a process typically associated with flowing water systems.

Comparison of Revised and Previously Adopted Levels

The High Guidance Level for Lake Marion is 2.1 feet lower than the previously adopted High Guidance Level, while the Low Guidance Level is 0.6 feet lower than the previously adopted Low Guidance Level (Table 5). These differences are associated with application of a new modeling approach for characterization of Historic water level fluctuations within the lake, i.e., water level fluctuations that would be expected in the absence of water withdrawal impacts given existing structural conditions, and additional data since the last evaluation.

The High Minimum Lake Level for Lake Marion is 2.0 feet lower than the previously adopted High Minimum Lake Level. The Minimum Lake Level is 1.3 feet lower than the previously adopted Minimum Lake Level (Table 5). These differences are due to the same factors discussed above for the changes in the Guidance Levels.

The Minimum and Guidance Levels identified in this report replace the previously adopted levels for Lake Marion.

Table 5: Minimum and Guidance Levels for Lake Marion compared to previously adopted Minimum and Guidance Levels.

Minimum and Guidance Levels	Elevations (in Feet NGVD29)	Previously Adopted Elevations (in Feet NGVD29)
High Guidance Level	53.2	55.3
High Minimum Lake Level	52.6	54.6
Minimum Lake Level	49.4	50.7
Low Guidance Level	47.1	47.7

Minimum Levels Status Assessment

To assess if the Minimum and High Minimum Lake Levels for Lake Marion are being met, observed stage data in Lake Marion were used to create a long-term record using a Line of Organic Correlation (LOC) model, similar to what was developed for establishing the Minimum Levels (Appendix A). For the status assessment, the lake stage data used to create the LOC must be from a period representing a time when groundwater withdrawals and structural alterations are reasonably stable, and represent current conditions, referred to as the “Current” period. Current stage data observed on Lake Marion were determined to be from March 1992 through March 2019. Using the Current stage data, the LOC model was created. The LOC model resulted in a 73-year long-term water level record (1946-2019).

For the status assessment, cumulative median (P50) and cumulative P10 water elevations were compared to the Minimum Lake Level and High Minimum Lake Level, respectively, to determine if long-term water levels were above these levels. Results from these assessments indicate that Lake Marion water levels are above both the Minimum Lake Level and the High Minimum Lake Level (see Appendix B). Therefore, development and adoption of a recovery strategy or specific prevention strategy in association with adoption of the revised minimum levels is not necessary at this time.

The District will continue to implement its general, three-pronged prevention strategy that includes monitoring, protective water-use permitting, and regional water supply planning to ensure that the adopted minimum levels for the lake continue to be met. In addition, the District will continue to monitor levels in this and other lakes to further our understanding of lakes and to develop and refine our minimum levels development methods.

Additional information regarding the status of Lake Marion, including the 20-year status projection and ongoing periodic status assessments, can be found in Appendix B, attached.

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DRAFT APPENDIX A

Technical Memorandum

January 13, 2020

TO: Mark Hurst, Senior Environmental Scientist, Water Resources Bureau

THROUGH: Tamera McBride, P.G, Manager, Resource Evaluation, Water Resources Bureau

FROM: Cortney Cameron, G.I.T., Hydrogeologist, Water Resources Bureau
Don Ellison, P.G., Senior Hydrogeologist, Water Resources Bureau

Subject: Draft Lake Marion Water Budget Model, Rainfall Correlation Model, and Historic Percentile Estimations

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A. Introduction

Water budget and rainfall correlation models were developed to assist the Southwest Florida Water Management District (SWFWMD or District) in the reassessment of minimum levels for Lake Marion in northwest Levy County. Lake Marion currently has adopted minimum levels which are being re-assessed in FY2021. This document will discuss the development of the Lake Marion models and use of the models for development of Historic lake stage exceedance percentiles.

B. Background and Setting

Lake Marion is located in east-central Levy County, flanked by SE 115th Avenue to the west, SE 122nd Court to the east, and SE 25th Street to the north. (Figure 1). The lake system lies within the Wekiva River drainage basin in the Waccasassa River watershed. The lake is surrounded by hills with elevations as high as 110 feet above the National Geodetic Vertical Datum of 1929 (ft NGVD29). Lake Marion has no significant inflow other than overland flow. No outflow occurs from the basin currently (see Figure 2).

Physiography and Hydrogeology

Lake Marion lies along the western edge of the northern half of the Brooksville Ridge, just one mile east of the Gulf Coastal Lowlands (White ,1970). This portion of the Ridge, north of the Withlacoochee River, runs approximately 50 miles in length and about 4 to 6 miles in width. The area is characterized by shallow sand deposits overlying clastic sediments of the Bone Valley and Alachua formations, with thicker sand layers

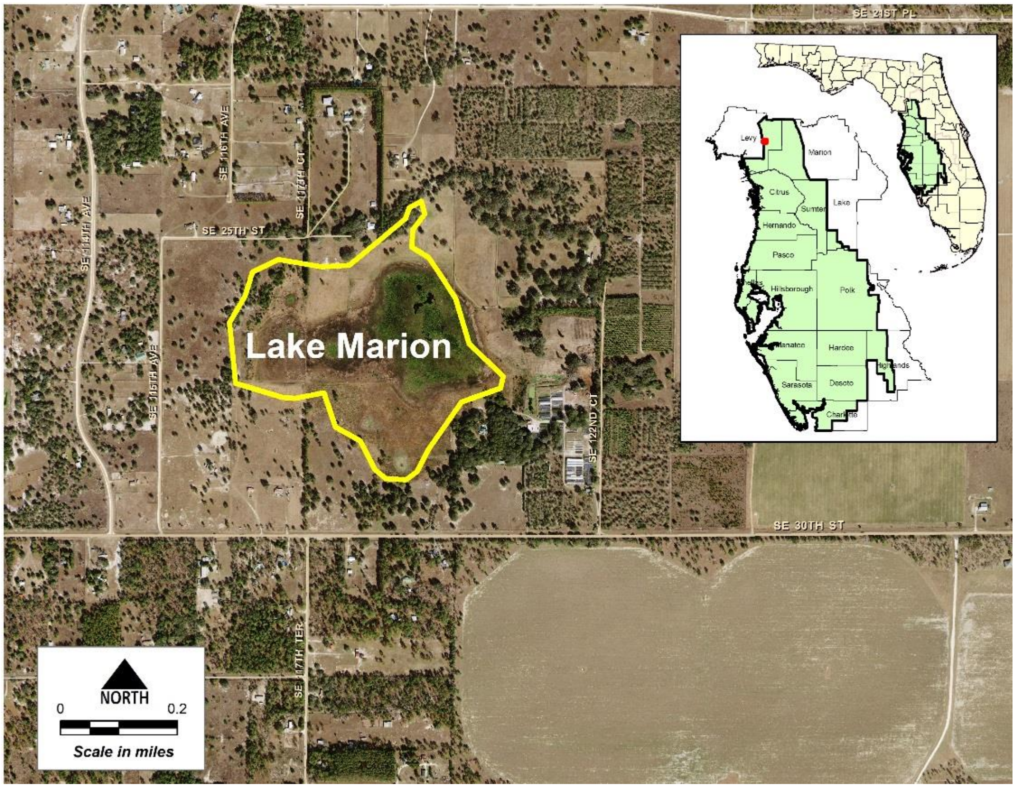

Figure 1. Location of Lake Marion in Levy County, Florida.

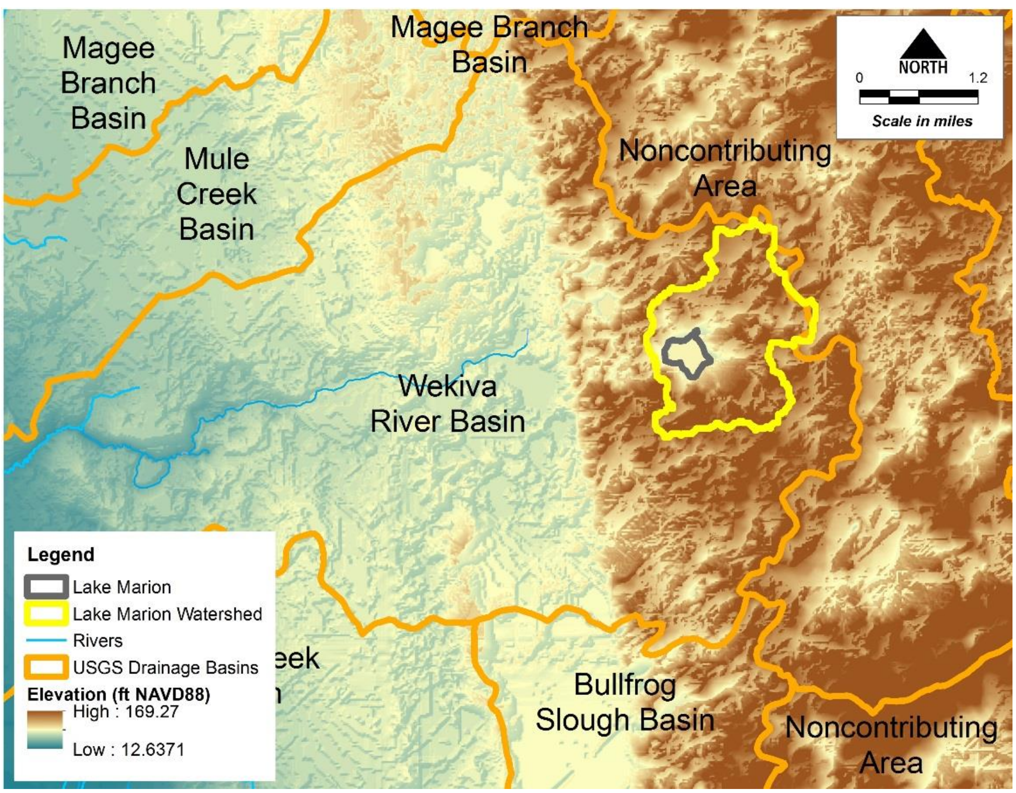

Figure 2. The location of the Lake Marion (thick gray line) watershed (thick yellow line) in the Wekiva River Basin, superimposed on a digital elevation model.

occurring in the western portion of the Ridge. Brooks (1981) categorized the area surrounding the lake as the Newberry Sand Hills of the Ocala Uplift Physiographic District and described the region as deeply weathered sand and clay hills.

The geologic units at Lake Marion include undifferentiated sand and clay sediments at land surface, underlain by low-permeability clayey sediments of the Hawthorn Group, below which occurs the Ocala Limestone (Janosik, 2012). The undifferentiated sediments comprise the surficial aquifer and, based on review of Janosik (2012) and driller's logs for several nearby wells, ranges from about 15 to 30 feet in thickness in the lake vicinity (Table 1 and Figure 3). The Ocala Limestone, an extremely weathered and loosely consolidated wackestone, represents the start of the upper Floridan aquifer, the top of which generally occurs in the area from between 20 to 60 feet below land surface (Janosik, 2012; Table 1). The low-permeability clayey sediments of the Hawthorn Group, ranging from 5 to 30 feet in thickness near the lake, act locally as a confining unit between these two aquifers (Janosik, 2012; Table 1).

Table 1. Base of the surficial aquifer and confining unit (in feet below land surface) from Janosik (2012) and interpreted from driller's logs of wells constructed near Lake Marion.

	Lk. Marion (Janosik, 2012)	657378.01	655090.01	830688	782964.1
Surficial aquifer	29	30	15	15	20
Confining unit	41	60	30	20	40

Data

Water level data for Lake Marion begin in March 1992 (Figure 4), collected by the District via a staff gauge located near the lake's west-northwestern shore (SID 22983), supplemented by a nearby low water staff gauge (SID 831220) starting June 2000. From this data record, Lake Marion has varied from as low as 43.3 ft NGVD29 (April 2012) to as high as 55.2 ft NGVD29 (January 2019), a range of 11.9 feet.

The Upper Floridan monitor well nearest Lake Marion is the Lake Marion U Fldn Monitor (SID 780479), while the surficial aquifer monitor well nearest Lake Marion is the Lake Marion Surf Aq Monitor (SID 780480), both located adjacent to the lake (Figure 5 and Figure 6). These monitor wells and their data collection frequency are further discussed in "Flow from and into the surficial aquifer and Upper Floridan aquifer" under Section E of this Appendix.

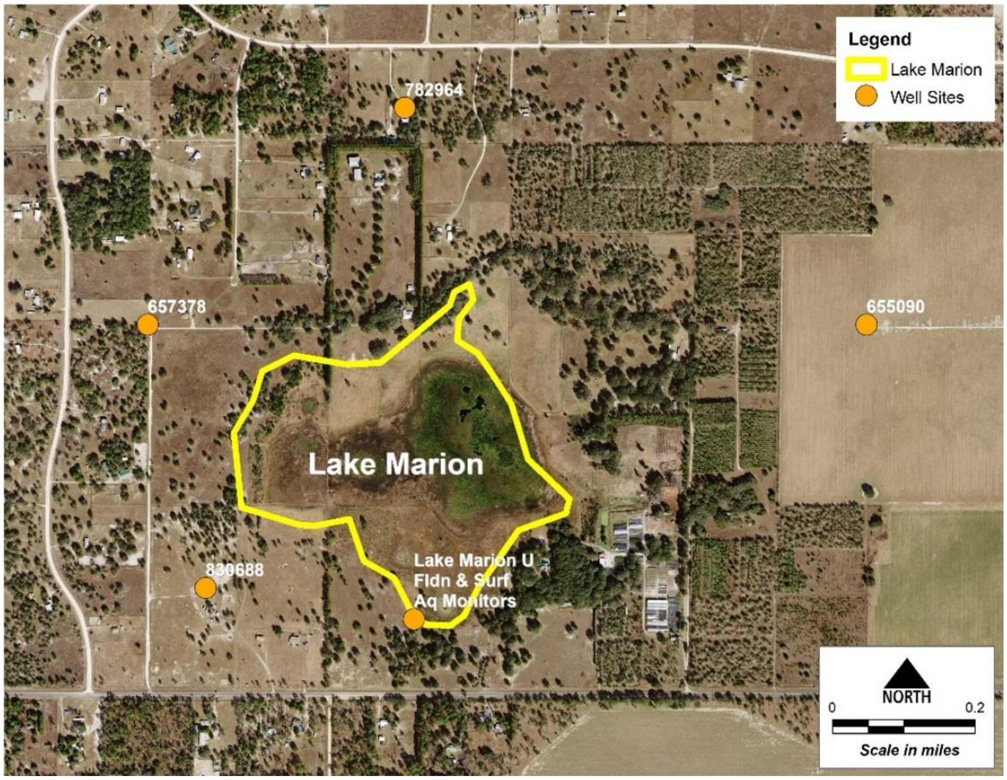

Figure 3. Locations of driller's logs (labeled with Well Construction Permit numbers) and monitor wells (Janosik, 2012) available near Lake Marion. See Table 1.

Figure 4. Lake Marion water levels from March 1992 to May 2019.

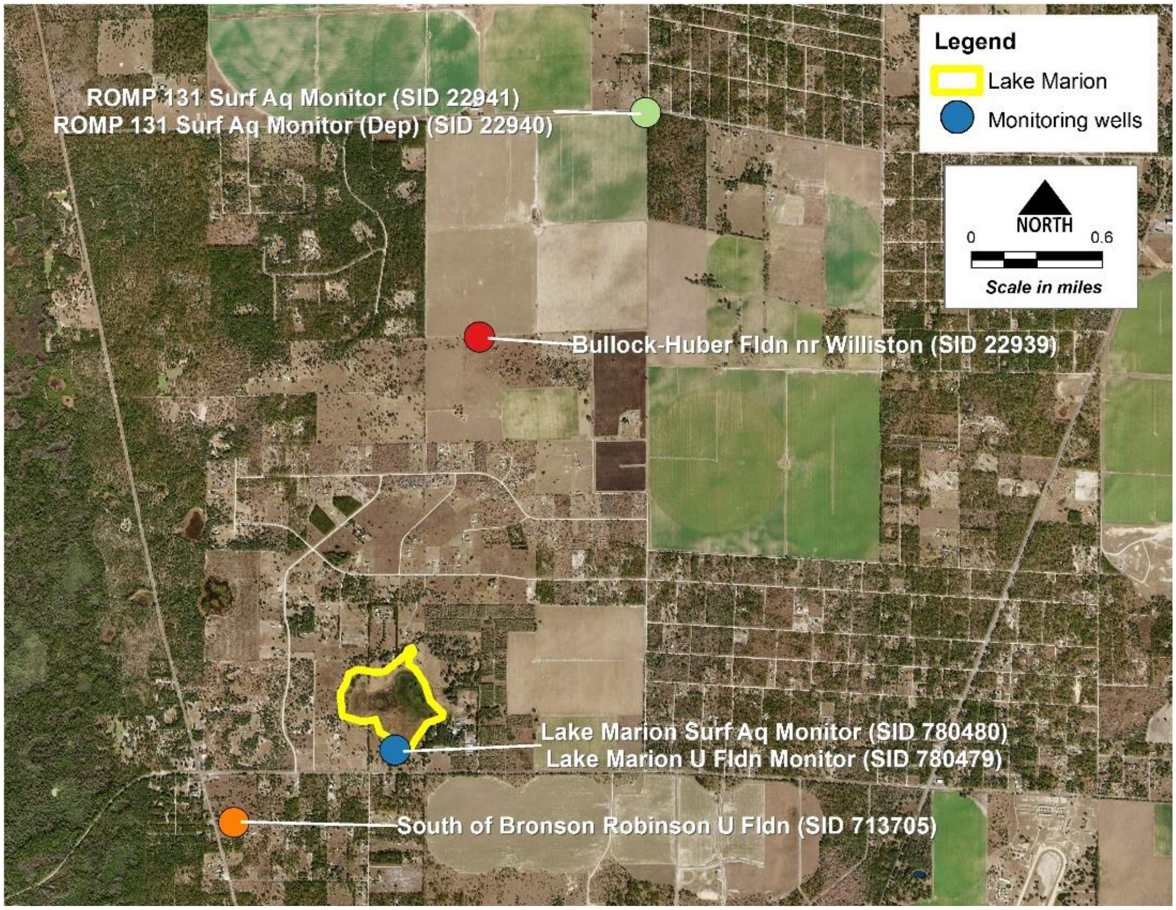

Figure 5. Location of monitor wells near Lake Marion considered for model use. Note that well point colors correspond to lines in Figure 6.

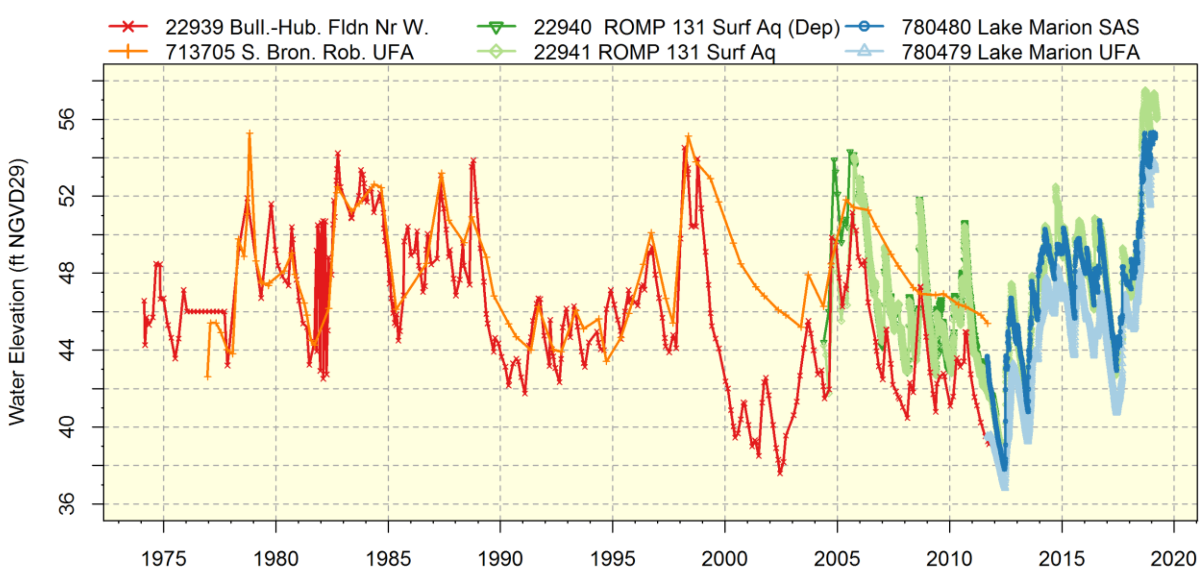

Figure 6. Water levels in monitor wells near Lake Marion. Note that line colors correspond to points in Figure 5.

Land and Water Use

Groundwater withdrawal data in the vicinity of Lake Marion within the District are available starting 1992. Groundwater withdrawals in the vicinity of Lake Marion outside of the District are believed to be relatively small based modeling results (Cameron, 2020), land use (i.e. mainly forests and swamps), and discussion with the Suwanee River Water Management District (Stefani Weeks, pers. comm., 2019), with the nearest permitted withdrawal in Suwanee River Water Management District located over 8 miles from the lake. Since 1992, total groundwater withdrawals (including estimated domestic self-supply) within a 1-mile buffer of Lake Marion in SWFWMD have averaged less than 0.5 mgd (Figure 7). Groundwater withdrawals within 5 miles of the lake in SWFWMD peaked in 2000 and have generally trended downwards since, averaging less than 3 mgd from 2007 to 2016. Most withdrawals in the immediate vicinity of the lake are used for agricultural purposes.

Aerial and satellite imageries of Lake Marion from 1940 to 2017 show that water levels in the lake have varied considerably over that time period (Figure 8). Depending on the time of image capture (e.g. dry season or wet season), variations in lake surface area likely reflect variations in rainfall and groundwater withdrawal conditions.

C. Purpose of Models

Prior to establishment of Minimum Levels, long-term lake stage percentiles are developed to serve as the starting elevations for the determination of the lake's High Minimum Lake Level and the Minimum Lake Level. A critical task in this process is the delineation of a Historic time period. The Historic time period is defined as a period of time when there is little to no groundwater withdrawal impact on the lake, and the lake's structural condition is similar or the same as present day. The existence of data from a Historic time period is significant, since it provides the opportunity to establish strong predictive relationships between rainfall, groundwater withdrawals, and lake stage fluctuation that represent the lake's natural state in the absence of groundwater withdrawals. This relationship can then be used to calculate long-term Historic lake stage exceedance percentiles such as the P10, P50, and P90, which are, respectively, the water levels equaled or exceeded ten, fifty, and ninety percent of the time. If data representative of a Historic time period does not exist, or available Historic time period data is considered too short to represent long-term conditions, then a model is developed to approximate Long-term Historic data.

In the case of Lake Marion, regional withdrawals, while relatively small, have potentially affected lake water levels throughout the stage data period-of-record. The development of lake-specific water budget and rainfall correlation models provides the ability to

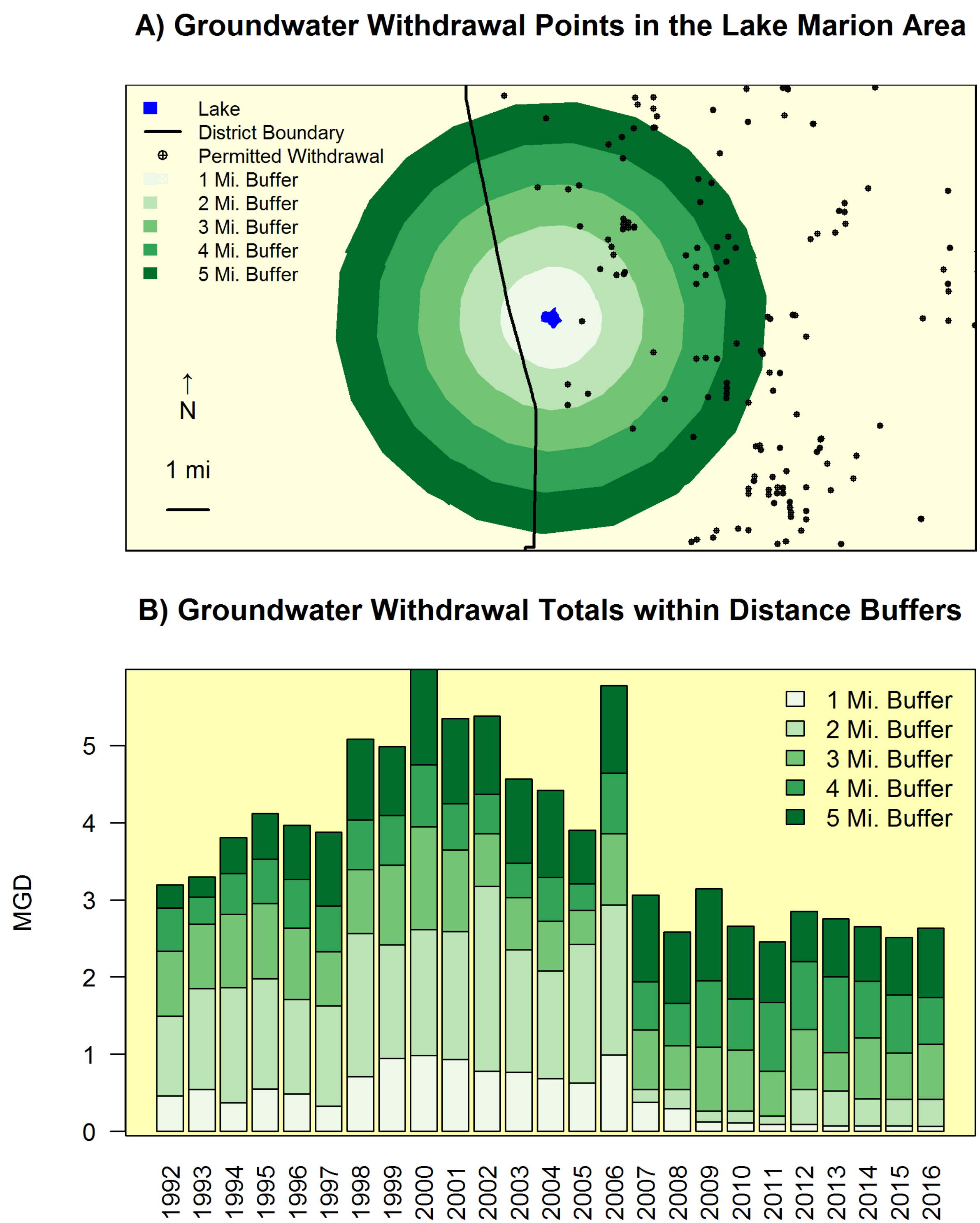

Figure 7. A) Map of permitted groundwater withdrawals occurring near Lake Marion within SWFWMD. B) Stacked groundwater withdrawals occurring in SWFWMD within select buffer distances of Lake Marion, including estimated domestic self-supply (DSS).

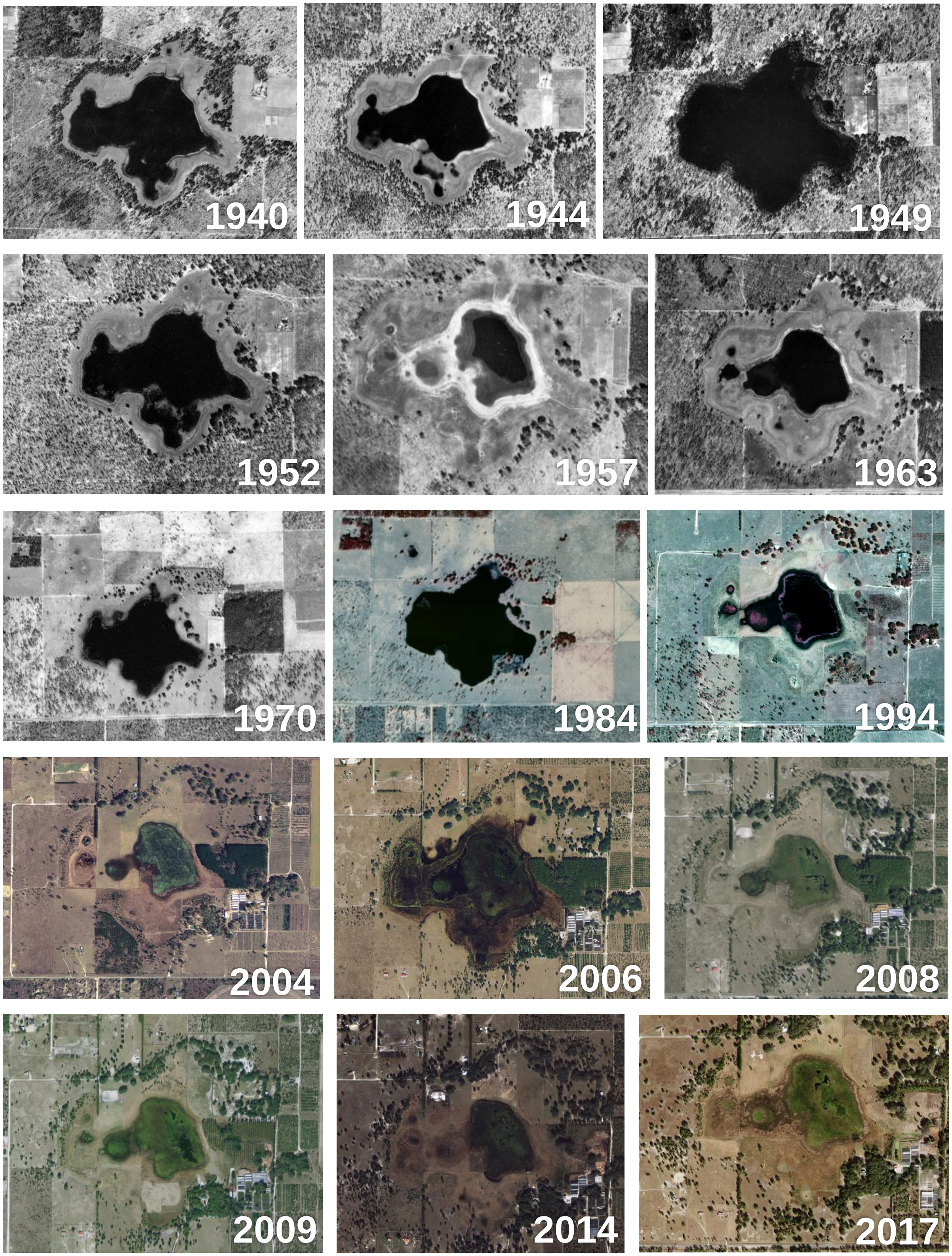

Figure 8. Water level changes in Lake Marion through time, from left to right and top to bottom: 1940, 1944, 1949, 1957, 1963, 1970, 1984, 1994, 2004, 2006, 2008, 2009, 2014, 2017.

simulate and completely remove the effects that groundwater withdrawals have on lake water levels, allowing estimation of the lake’s long-term Historic percentiles.

D. Water Budget Model Overview

The Lake Marion water budget model is a spreadsheet-based tool that includes natural hydrologic processes and engineered alterations acting on the lake’s control volume. The control volume consists of the free water surface within the lake extending down to the elevation of the greatest lake depth. A stage-volume curve was derived for the lake that produced a unique lake stage for any total water volume within the control volume.

The hydrologic processes in the water budget model include:

a. Rainfall and evaporation
b. Overland flow
c. Inflow and discharge via channels
d. Flow from and into the surficial aquifer
e. Flow from and into the Upper Floridan aquifer

The water budget model uses a daily time-step, and tracks inputs, outputs, and lake volume to calculate a daily estimate of lake levels for the lake. The water budget model for Lake Marion is calibrated from March 1992 through March 2019. This period provides the best balance of using available data for all parts of the water budget and the desire to develop a long-term water level record. Lake stages were the temporally limiting data. Model inputs are summarized in Table 2.

Table 2. Model inputs for the Lake Marion water budget model.

Input Variable	Value
Overland Flow Watershed Size (acres)	138
SCS CN of watershed	65
Percent Directly Connected	0
Fl. Aq. Monitor Well(s) Used	Lake Marion U Fldn
Surf. Aq. Monitor Well(s) Used	Lake Marion Surf Aq
Fl. Aq. Leakance Coefficient (ft/day/ft)	0.0005
Surf. Aq. Leakance Coefficient (ft/day/ft)	0.0015
Outflow K*	0.012
Outflow Invert (ft NGVD29)*	67.0
Inflow K	N/A
Inflow Invert (ft NGVD29)	N/A

* Channel outflow never occurred during the model period.

E. Water Budget Model Components

Lake Stage/Volume

Lake stage area and stage volume estimates were determined by building a terrain model of the lake and surrounding watersheds. Lake bottom elevations and land surface elevations were used to build the model with LP360 (by QCoherent) for ArcGIS, ESRI's ArcMap 10.4.1, the 3D Analyst ArcMap Extension, Python, and XTools Pro. The overall process involves merging the terrain morphology of the lake drainage basin with the underlying lake basin morphology to develop one continuous three-dimensional (3D) digital elevation model. The 3D digital elevation model was then used to calculate area of the lake and the associated volume of the lake at different elevations, starting at the extent of the lake at its flood stage and working downward to the lowest elevation within the basin.

Precipitation

After a review of all available rain data in the area of Lake Marion during the water budget model period, a combination of NEXRAD-derived rainfall data and various local and regional rain gauges was selected for use in Lake Marion's water budget model (Figure 9, Figure 10, and Table 3). The general approach was to average radar rainfall (when available) with the nearest available gauge. The overall aim was to use the available data closest to the lake, as long as the data appeared both acceptable in quality and representative of conditions at the lake. The rain gauges are operated by the District or the National Weather Service (NWS) and have varying periods-of-record. NEXRAD (Next Generation Weather Radar) is a network of 160 high-resolution Doppler weather radars controlled by the NWS, Air Force Weather Agency, and Federal Aviation Administration. NEXRAD-derived rainfall data exists from 1995 to present and is supplied at a spatial resolution of 2 km.

Lake Evaporation

The energy budget method is generally held as the most accurate method for estimating evaporation over open water areas (Harwell, 2012). However, this and other appropriate methods of estimating lake evaporation (e.g. Irmak and Haman, 2003) require site-specific data not available at Lake Marion. While Jacobs (2007) provides satellite-derived daily potential evapotranspiration (PET) estimates, the nodes typically include both upland and lake estimates, making this dataset less appropriate, for the purposes of this water budget model, compared to other options.

Namely, the U.S. Geological Survey (USGS) collected monthly energy budget evaporation data at Lake Starr in Polk County from August of 1996 through July of 2011 (Swancar et al., 2000; Swancarr, 2015) (Figure 12). A study comparing evaporation

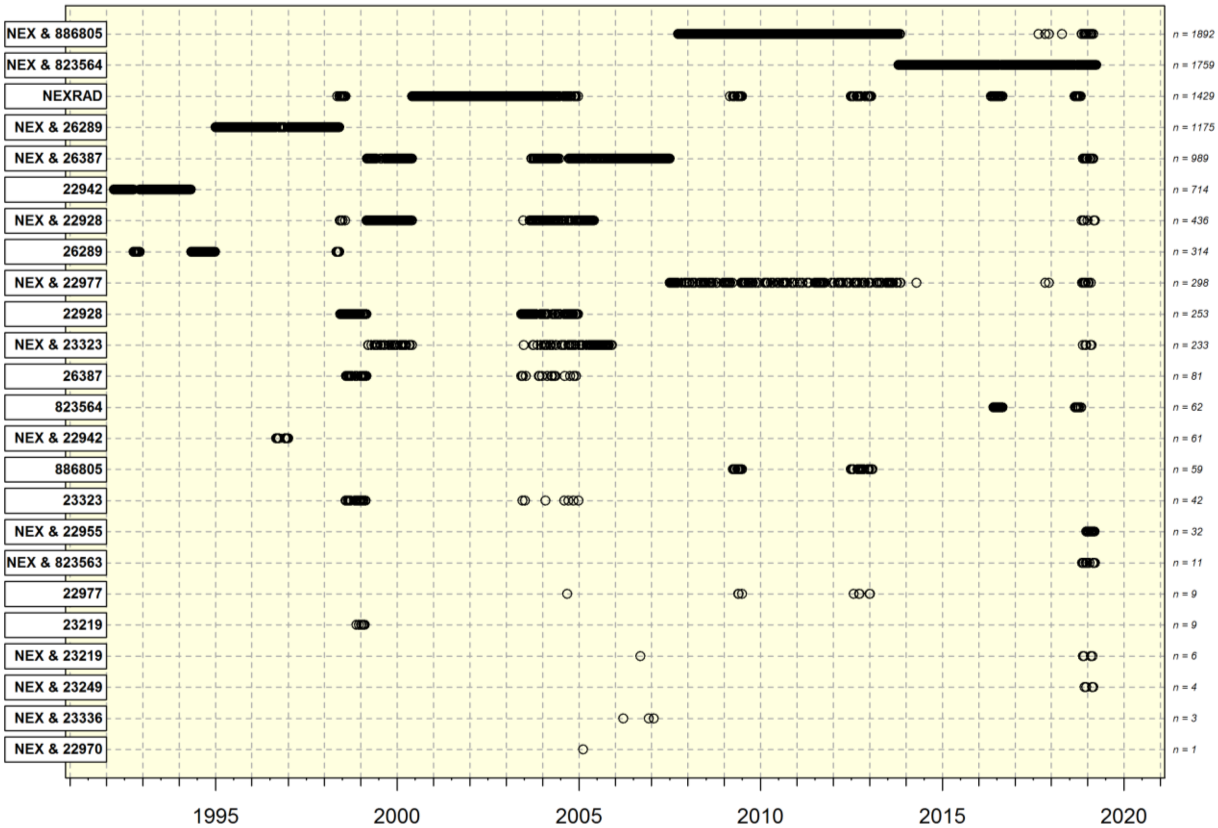

Figure 9. Rainfall data sources and the timing and frequency of their use in the water budget model. Site IDs are displayed on the y-axis. Each point represents a day.

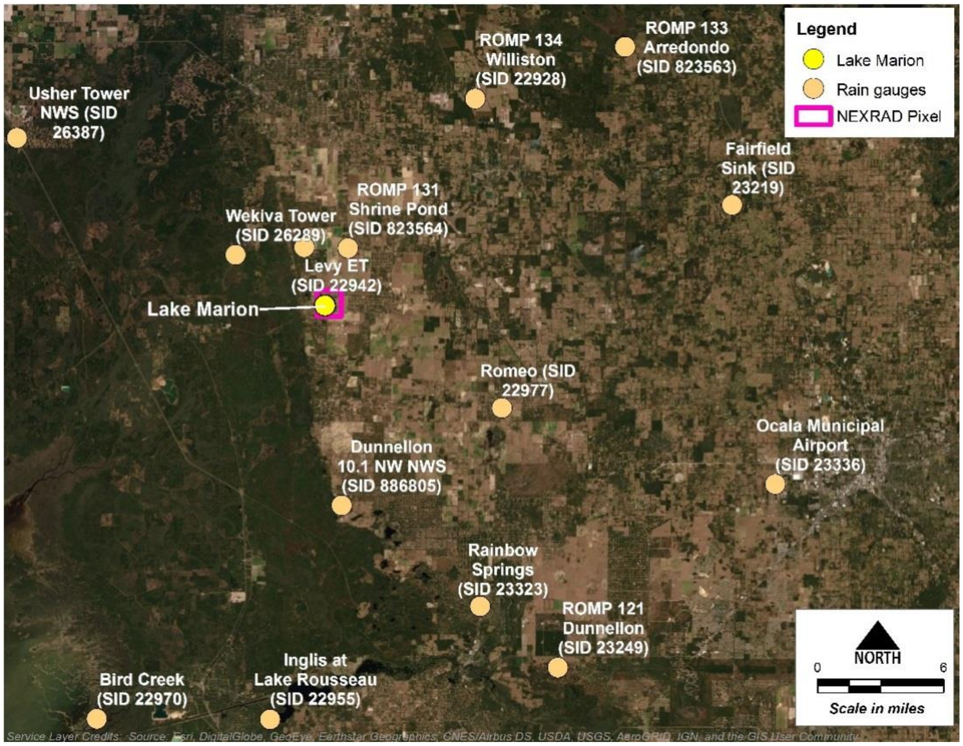

Figure 10. Map of rain gauges and NEXRAD pixel used in the water budget model.

Table 3. List of rainfall data used in the Lake Marion water budget (WB) and rainfall correlation (LOC) models. In the water budget, since stations were oftentimes averaged, the total number of data days exceeds the total number of days in the water budget model. Stations are ordered by total number of days used in the models, greatest first.

Site ID	Site Name	Miles from Lake Marion	Number of Days Used in WB	Number of Days Added to LOC
-	NEXRAD Pixel 133502	-	8329	0
26387	Usher Tower NWS	16.6	1070	6888
26289	Wekiva Tower	4.8	1489	5898
26339	Gaines. U. of Fl. NWS	28.3	0	7189
886805	Dunn. 10.1 NW NWS	9.6	1951	0
823564	ROMP 131 Sh. Pond	2.9	1821	0
22958	Inglis 3E NWS	18.8	0	1102
26340	Gaines. 3 WSW NWS	26.8	0	992
22942	Levy ET	2.9	775	76
22928	ROMP 134 Williston	12.2	689	0
22977	Romeo	9.8	307	31
26356	Ocala NWS	30.5	0	333
23323	Rainbow Springs	16.1	275	0
26388	Ced. Key 1 WSE NWS	30.7	0	193
22955	Inglis at Lake Rouss.	19.9	32	0
23219	Fairfield Sink	20.0	15	0
823563	ROMP 133 Arredondo	18.9	11	0
23017	Crystal River Tower	22.8	0	7
22998	Blichton Tower	14.9	0	6
20573	Brooksv. Ch. Hill NWS	48.3	0	5
23249	ROMP 121 Dunnellon	20.5	4	0
23336	Ocala Municipal Airport	23.1	3	0
22970	Bird Creek	22.4	1	0
26291	Lebanon Tower	9.8	0	1

data from Lakes Starr and Calm (Hillsborough County) found that, despite 60 miles of (mostly zonal; Figure 11) distance between the lakes, their evaporation rates were nearly identical, with small differences attributable to measurement error and latent heat differences associated with differences in lake depth (Swancar, 2015).

Swancar (2015) concluded that seasonal evaporation rates measured at Lake Starr should be generally representative of lakes in central Florida with similar depths; shallower lakes, despite their decreased ability to store heat, were expected to display similar if somewhat different annual evaporation rates.

Thus, despite Lake Marion's shallower mean depth (about 3 feet versus 15 feet and 10 feet, respectively, for Lakes Starr and Calm), the Lake Starr evaporation data represented the dataset most suitable for use in Lake Marion's water budget model. However, all else being equal, Lake Marion's higher latitude, slightly lower average temperatures, and somewhat differing climate conditions relative to Lake Starr could result in slightly lower evaporation at Lake Marion than at Lakes Starr and Calm. Namely, lake evaporation isolines estimated by Visher and Hughes (1975) and Hanson (1991) predict slightly lower evaporation at Lake Marion than at Lakes Starr and Calm, the latter two differing in latitude by only 0.2 degrees and falling along similar isolines. Lake Marion, meanwhile, falls 1.3 decimal degrees north (110 miles northwest) of Lake Starr and 1.2 decimal degrees north (80 miles north) of Calm Lake (Figure 11).

Abtew (1999) found that solar radiation followed by temperature explain most of the variability in lake evaporation in south Florida, and developed several equations that linearly relate (via multiplication with empirical coefficients) solar radiation or the product of solar radiation and temperature to wetland evaporation in south Florida. Assuming that this relationship applies to Lake Marion and Lake Starr and that the coefficients for Lake Starr and Lake Marion are identical (such that the coefficients cancel during division), a rough estimate of the percentage difference in evaporation between the two lakes can then be found as the product of the ratio of solar radiation and ratio of temperature between the two lakes.

Local irradiance is calculated as $S*\cos(d)*(1-a)$, where S is the solar constant (W/m^2), d is the solar zenith angle (or effective latitude; radians), and a is albedo (unitless). Assuming identical albedo, during the equinoxes, the ratio of irradiance at Lake Marion to Lake Starr is then $\cos(29.3°)/\cos(28.0°)$ or approximately 99%. Using March 1992 to March 2019 temperature data from Usher Tower NWS (located 16.6 miles northwest of Lake Marion; Figure 10) and Mountain Lake NWS (located 1.3 miles southwest of Lake Starr), the mean ratio of maximum daily temperature at Lake Marion to Lake Starr is approximately 96%. The product of these two ratios provides a rough estimate that Lake Marion experiences 95% of (approximately 3 inches per year less than) the evaporation that occurs at Lake Starr. This relatively small difference falls within Swancar's (2015) estimated error of 10% and agrees with her expectation of similar but slightly different annual rates, while providing for somewhat lower evaporation in the Lake Marion area (versus Lake Starr) as suggested by Visher and Hughes (1975) and Abtew et al. (2003).

Therefore, monthly Lake Starr evaporation data were reduced by 5% and disaggregated into a daily time series (assuming a uniform distribution) for use in the Lake Marion water budget model from 1996 to 2011 (the period for which Lake Starr evaporation data are available). For months in the water budget model that occur outside of the temporal span of Lake Starr's evaporation data, period-of-record means for the month of the year (also reduced by 5%) were used (i.e. a repeating evaporation time series;

Figure 12). Compared to a linear model developed with temperature data ($E = 0.21*T - 12.5$, where E is evaporation in inches per month at Lake Starr and T is the monthly mean maximum temperature at Mountain Lake NWS in degrees Fahrenheit; NSE = 0.80), the repeating annual time series performed better at estimating monthly evaporation at Lake Starr (NSE = 0.92; Figure 12).

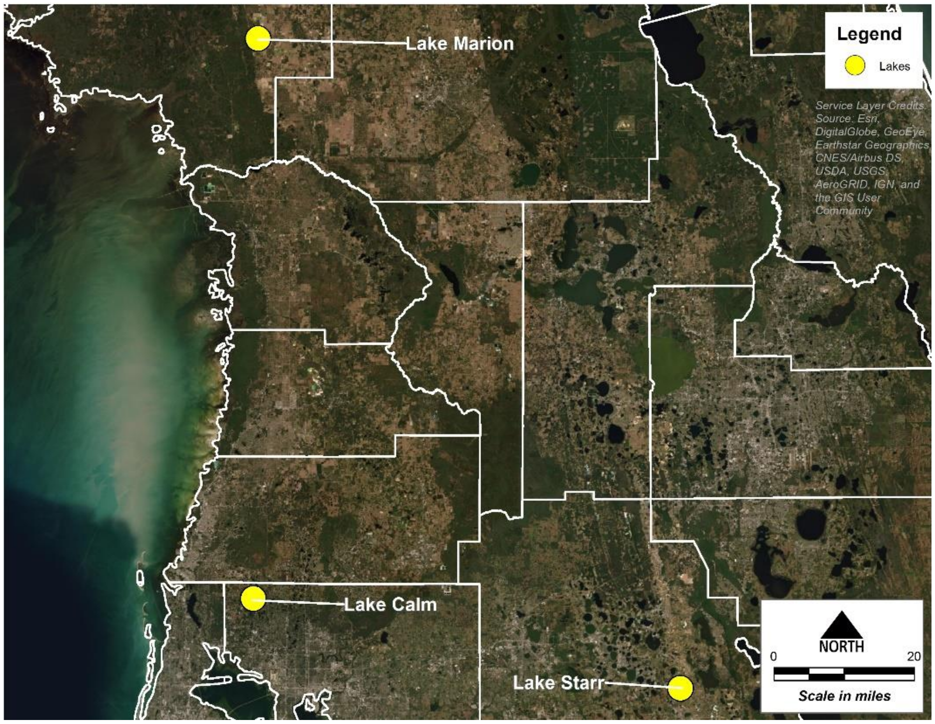

Figure 11. Location of (clockwise) Lakes Marion, Calm and Starr.

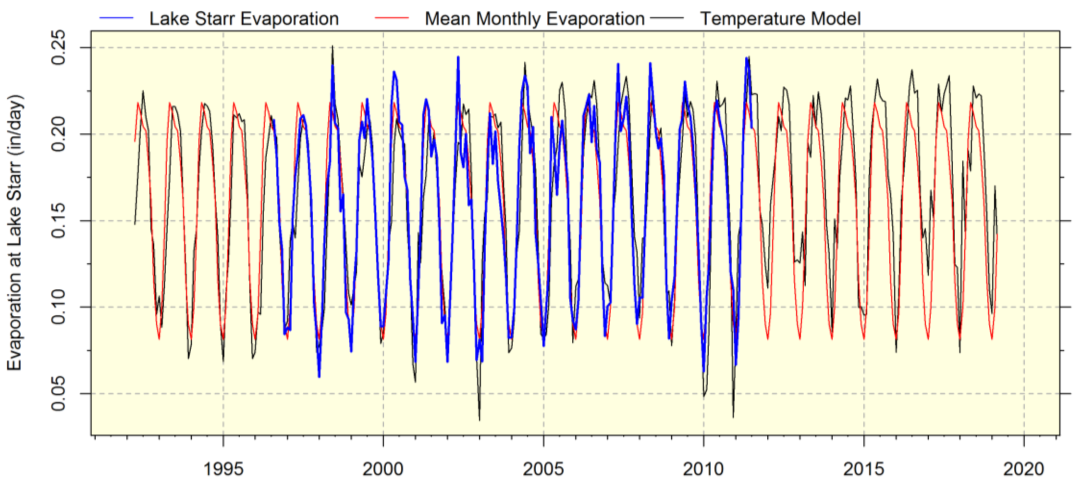

Figure 12. Monthly evaporation estimates (inches/day) for Lake Starr using the energy budget method (blue line; from Swancar et al., 2000 and Swancarr, 2015), a repeating mean monthly time series thereof, and a temperature-based linear model (black line).

Overland Flow

The water budget model estimates overland flow via a modified version of the U.S. Department of Agriculture, Soil Conservation Service (SCS) Curve Number method (SCS, 1972) and via directly connected impervious area calculations. The free water area of each lake is subtracted from the total watershed area at each time step to estimate the watershed area contributing to surface runoff. The directly connected impervious area (DCIA) was subtracted from the watershed for the SCS calculation, and then added to the lake water budget separately. Additionally, the curve number (CN) chosen for the watershed of the lake considers the amount of DCIA in the watershed that has been handled separately.

The modified SCS method was suggested for use in Florida by CH2M HILL (2003), and has been used in several other analyses. The modification adds a fourth category of antecedent moisture condition (AMC) to the original SCS method (SCS, 1972) to account for Florida's frequent rainfall events.

No preexisting watershed delineation was identified for Lake Marion. Therefore, a watershed was delineated using the GRASS (2019) functions r.watershed and r.water.outlet in QGIS (2019) with a 2008 USGS National Elevation Data digital elevation model (DEM), which has a resolution of 30 meters. For the purposes of delineation, a potential lake outlet was identified at a low point along western apex of the lake, although stage records for the lake indicate that outflow rarely, if ever, occurs. The results of the automated delineation were manually assessed and deemed reasonable for the purposes of this model (Figure 13). The entire area of the lake's watershed is thus estimated to be approximately 138 acres (including the lake), as shown in Table 2.

The DCIA and SCS CN used for the direct overland flow portion of the watershed are listed in Table 2. Curve numbers are difficult to assess. The vast majority of soils in Lake Marion's watershed are well-drained Group A soils, mainly Candler fine sands with lesser amounts of Adamsville, Tavares, and Astatula fine sands (Figure 14). A thin rim of Group A/D soils, specifically depressional Placid and Popash soils, wraps around the lake perimeter. For purposes of this model, a CN of 65 was deemed appropriate given the combination of Group A soils and agricultural and rural residental land covers that dominate the lake's watershed (Figure 14). No direct discharges to the lake were identified, so the DCIA of the watershed is zero.

Inflow and Discharge via Channels from Outside Watersheds

While inflow and outflow via channels to or from the lake's watershed (i.e. channel flow) can be an important component of the water budget a lake, in the case of Lake Marion,

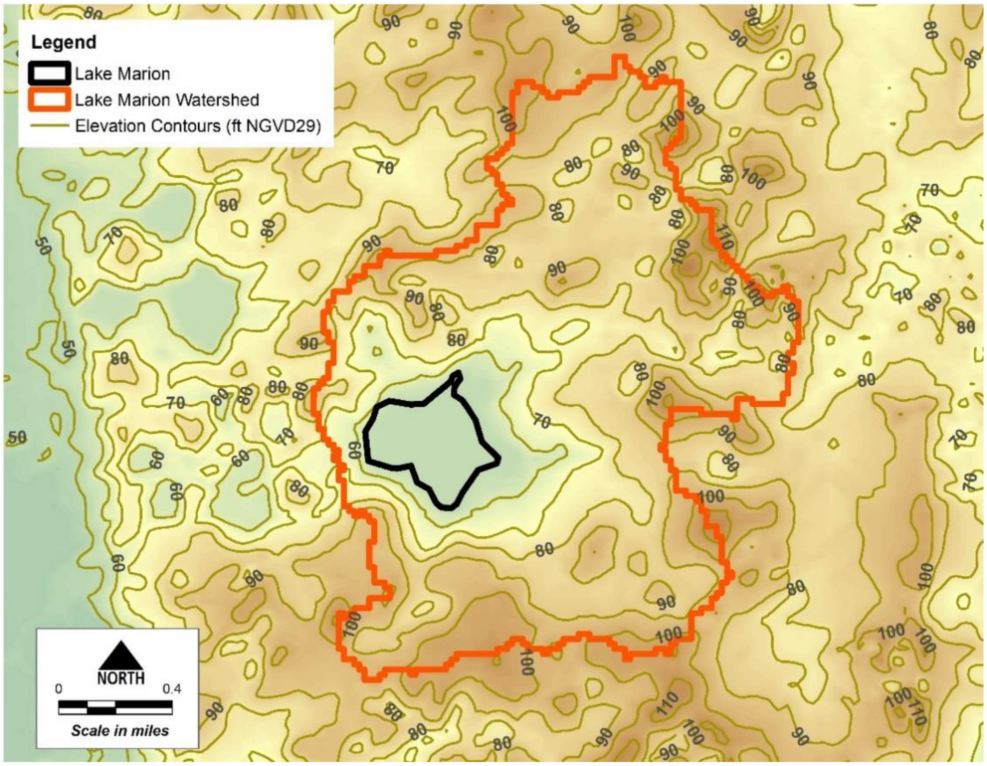

Figure 13. Watershed of Lake Marion as used in the water budget model.

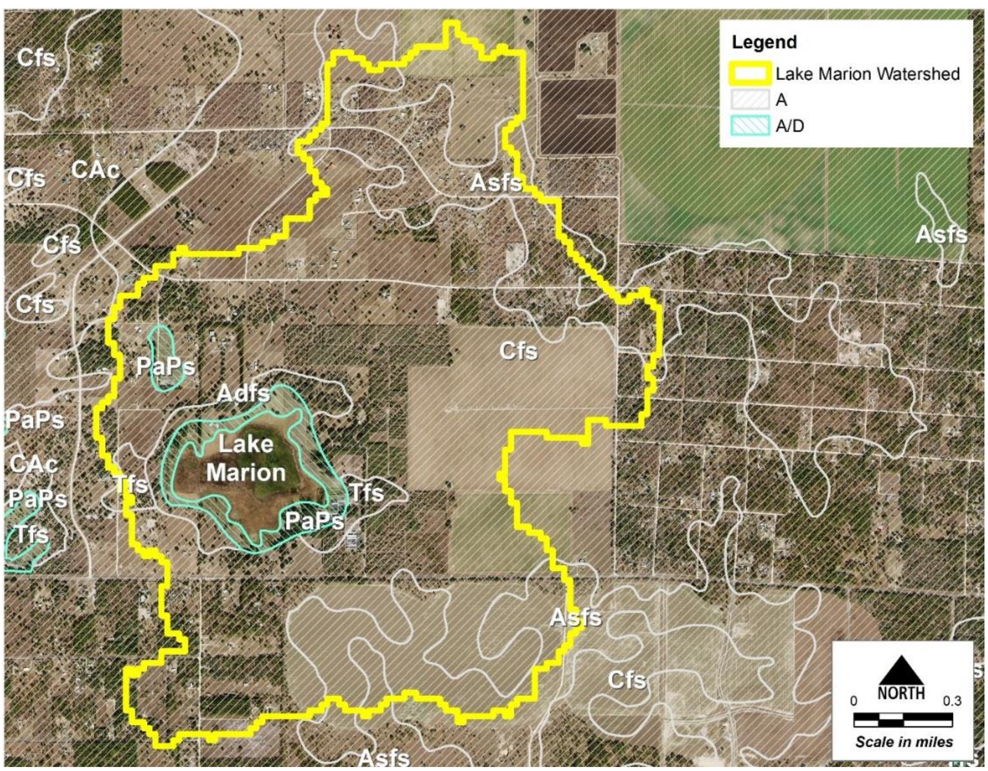

Figure 14. Soils in the Lake Marion area. Adfs = Adamsville fine sand; Asfs = Astatula fine sand; CAc = Candler-Apopka complex; Cfs = Candler fine sand; Tfs = Taveras fine sand; PaPs = Placid and Popash soils.

the lake is currently considered to have a closed basin, with neither regular channel inflow nor outflow.

Based on LiDAR elevation data, outflow from Lake Marion could occur under current structural conditions at an elevation range of approximately 60 to 65 ft NGVD29 (Figure 13). The period-of-record maximum stage value for Lake Marion is 55.17 ft NGVD29, which occurred in January 2019 (Figure 4). Thus, Lake Marion is considered a closed basin lake for the purposes of this model.

To estimate flow out of Lake Marion, the predicted elevation of the lake from the previous day is compared to the controlling elevation. If the lake elevation is above the controlling elevation, the difference is multiplied by the current area of the lake and an "outflow coefficient." The coefficient represents a measure of channel and structure efficiency, and produces a rough estimate of volume lost from the lake. This volume is then subtracted from the current estimate of volume in the lake. However, channel outflow never occurred in the time period of the water budget model.

Flow from and into the surficial aquifer and Upper Floridan aquifer

Water exchange between Lake Marion and underlying aquifers is estimated using a leakance coefficient and the head difference between the lake and the aquifer levels. For each model time step, surficial aquifer and Upper Floridan aquifer leakage volumes were calculated independently. Leakance coefficients for each aquifer were determined through calibration.

Upper Floridan aquifer. The Upper Floridan aquifer monitor well nearest Lake Marion is the Lake Marion U Fldn Monitor (SID 780479)—located on the southern shore of the lake, approximately 0.2 miles from the lake's centroid—for which daily data begin in September 2011 (Figure 5 and Figure 6). Given the proximity of the well to Lake Marion, no adjustment was required to represent the represent the potentiometric surface at the lake. Gaps or missing data were bilinearly interpolated.

Other upper Floridan aquifer wells in the immediate area include the Bullock-Huber Fldn nr Williston well (SID 22939), located approximately 1.7 miles north of the lake and typically sampled six to nine times per year from 1974 to 2011, and the South of Bronson Robinson U Fldn well (SID 713705), located approximately 0.9 miles southwest of the lake and sampled typically twice per year from 1976 to 2011 (Figure 5 and Figure 6). Data collection at both wells was discontinued in 2011.

Surficial aquifer. The surficial aquifer monitor well nearest Lake Marion is the Lake Marion Surf Aq Monitor (SID 780480)—located on the southern shore of the lake, approximately 0.2 miles from the lake's centroid—for which daily data begin in September 2011 (Figure 5 and Figure 6). Given the proximity of the well to Lake Marion, no adjustment was required to represent the elevation of the surficial aquifer under Lake Marion. Gaps or missing data were bilinearly interpolated.

Other surficial aquifer wells in the immediate area include the ROMP 131 Surf Aq Monitor (SID and ROMP 131 Surf Aq Monitor (Dep) wells (SID 22941 and SID 22940, respectively), located approximately 2.9 miles northeast of the lake (Figure 5 and Figure 6). Data collection at both wells began in May 2004, with daily data collection beginning in 2006. Data collection continues to present for ROMP 131 Surf Aq Monitor but was discontinued at ROMP 131 Surf Aq Monitor (Dep) in 2012.

Extension of groundwater level data. Lake stage data for Lake Marion begin in March 1992, but data at the Lake Marion wells do become available until September 2011. To extend groundwater level data (and thus the water budget model) to March 1992, linear models were developed using overlapping periods with nearby wells. As the wells nearest the Lake Marion wells lack sufficient overlap or data collection frequency for the purposes of this model, the search radius was expanded to capture Tidewater 1 Fldn (SID 22980), located approximately 11.5 miles south of the lake, and ROMP 134 U Fldn Aq (Ocal-Avpk-Oldm) Monitor (SID 22929), located approximately 12.2 miles northeast of the lake (Figure 15 and Figure 16).

Data collection at Tidewater 1 Fldn began in October 1981 and has typically been daily throughout, with various gaps. Data collection at ROMP 134 U Fldn Aq (Ocal-Avpk-Oldm) Monitor (SID 22929) began in September 1981 with once to twice annually, and became daily in August 1992, with various gaps (Figure 16). Despite the distance of these wells from Lake Marion, they correlate very strongly with both surficial and Upper Floridan groundwater levels at the lake ($R^2 \geq 0.9$; $df \geq 2{,}400$). Since linear models developed using both wells performed similarly well, the Tidewater 1 Fldn well was selected for having fewer missing data (152 days versus 430 days) during the 1992 to 2011 period of interest.

Using the period of data overlap from September 2011 to March 2019, a linear model was derived to estimate Marion Surf Aq Monitor (SID 780480) as a function of Tidewater 1 Fldn (SID 22980) such that

$$MARIONSAS = 1.594*TW - 38.593,$$

where this relationship was used to hindcast groundwater levels at Marion Surf Aq Monitor from 1992 to 2004 (Figure 17; $R^2 = 0.91$; $p < 0.01$; df = 2,464; NSE = 0.93; MAE = 0.8 feet). These estimated water levels were prepended to the observed water levels for Marion Surf Aq Monitor, then any remaining data gaps in the combined time series were bilineary interpolated (Figure 16).

Similarly, using the period of data overlap from September 2011 to March 2019, a linear model was derived to estimate Lake Marion U Fldn Monitor (SID 780479) as a function of Tidewater 1 Fldn (SID 22980) such that

$$MARIONUFA = 1.773*TW - 50.730,$$

where this relationship was used to hindcast groundwater levels at Lake Marion U Fldn Monitor from 1992 to 2004 (Figure 17; $R^2 = 0.89$; $p < 0.01$; df = 2,530; NSE = 0.90; MAE = 1.1 feet). These estimated water levels were prepended to the observed water levels for Lake Marion U Fldn Monitor, then data gaps any remaining in the combined time series were bilinear interpolated (Figure 16).

F. Water Budget Model Approach

The primary reason for the development of the water budget model was to estimate Historic lake stage exceedance percentiles that could be used to support development of Minimum and Guidance Levels for the lake.

Model calibration was therefore focused on matching long-term percentiles based on measured water levels, rather than short-term high and low levels. Measured data from the lake were used for comparison with modeled water levels. Daily values are generated from the model but only actual lake data points are used for the calibration.

Figure 18 presents the calibration results for the model. Table 4 presents a comparison of the percentiles of the measured data versus the model results. Table 5 presents modeled water budget components for the model calibration.

G. Water Budget Model Calibration Discussion

Based on a visual inspection of Figure 18, the model appears to be reasonably well calibrated. The mean and median differences of the residuals (observed less predicted values) are -0.02 feet; the the mean absolute error (MAE) is 0.40 feet and the root mean square error is 0.51 feet. The Nash-Sutcliffe efficiency (NSE) coefficient is 0.96.

A review of Table 4 shows that the P50 of the lake data and model is the same (within 0.1 feet), while the model P10 of the model is 0.4 feet lower and the P90 is 0.4 feet higher. A Kolmogorov–Smirnov test did not suggest a significant difference between the distributions of the data and model output ($p = 0.92$).

There are periods when the peaks in the modeled hydrograph are higher or lower than the measured values, and these differences contributed to minor differences between the modeled and measured percentiles associated with higher and lower lake levels, i.e., the P10 and P90 percentiles. The minimum and maximum differences are -1.71

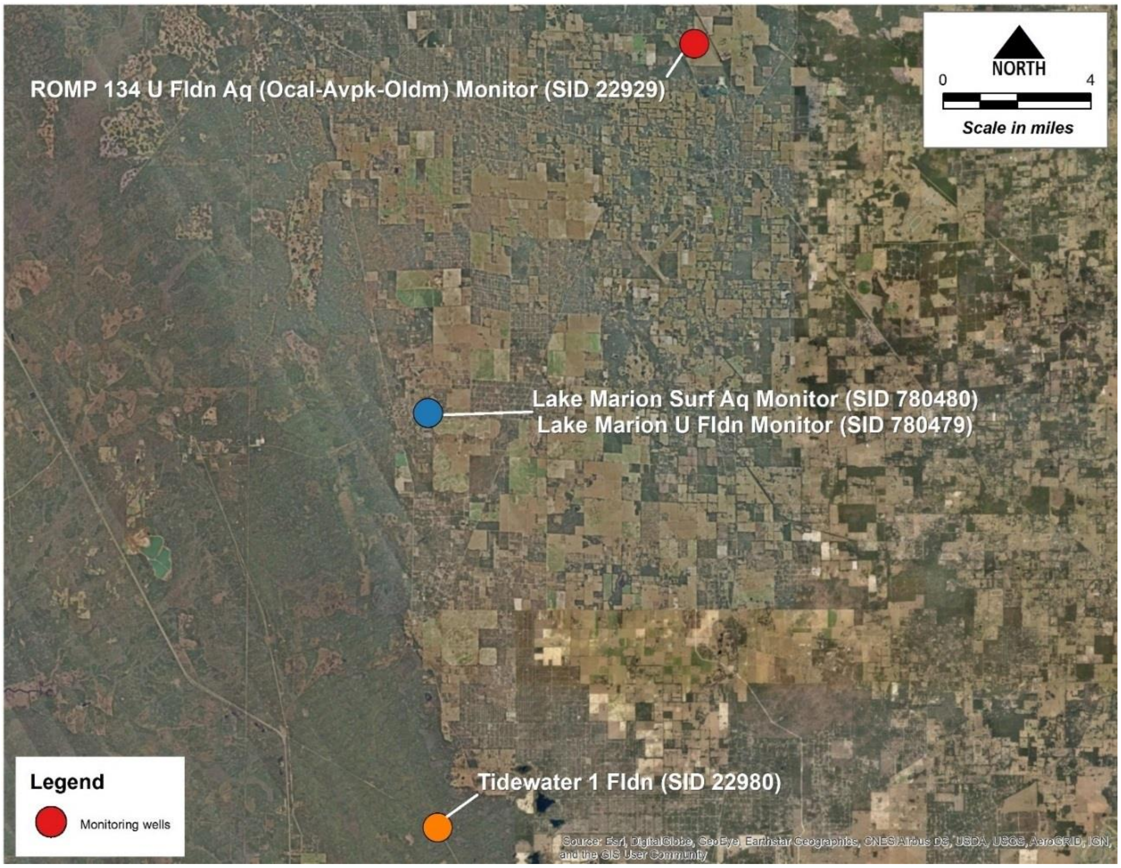

Figure 15. Locations of monitor wells considered for extension of Lake Marion groundwater level data. Note that well point colors correspond to lines in Figure 16.

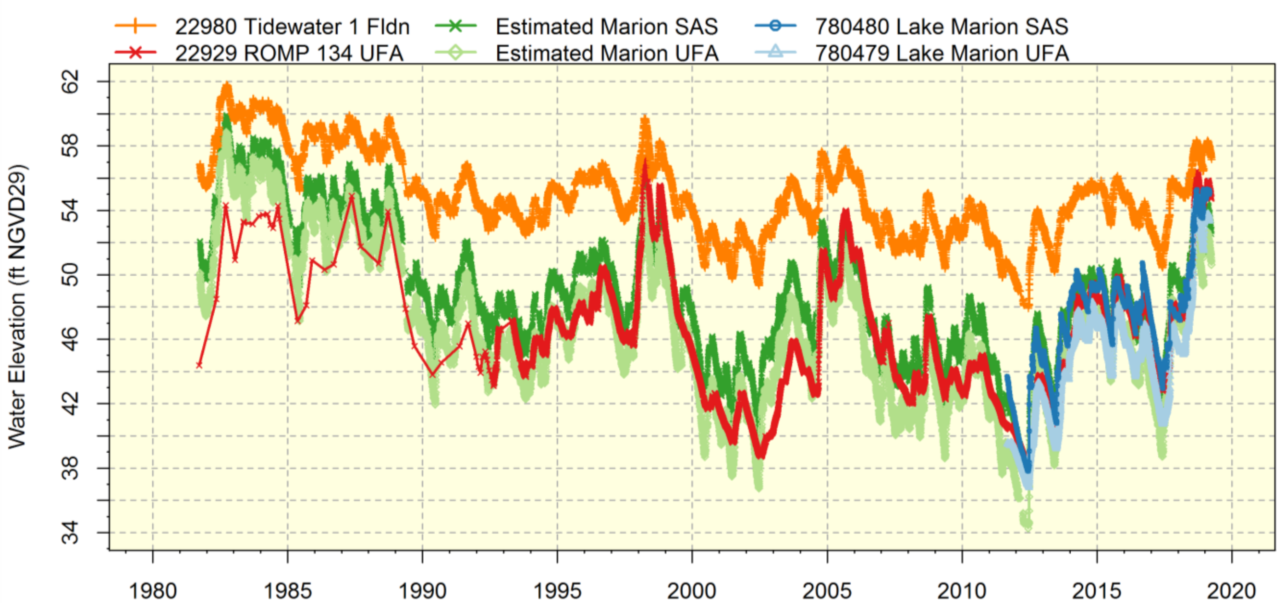

Figure 16. Water levels in monitor wells near Lake Marion. Note that lines colors correspond to well points in Figure 15.

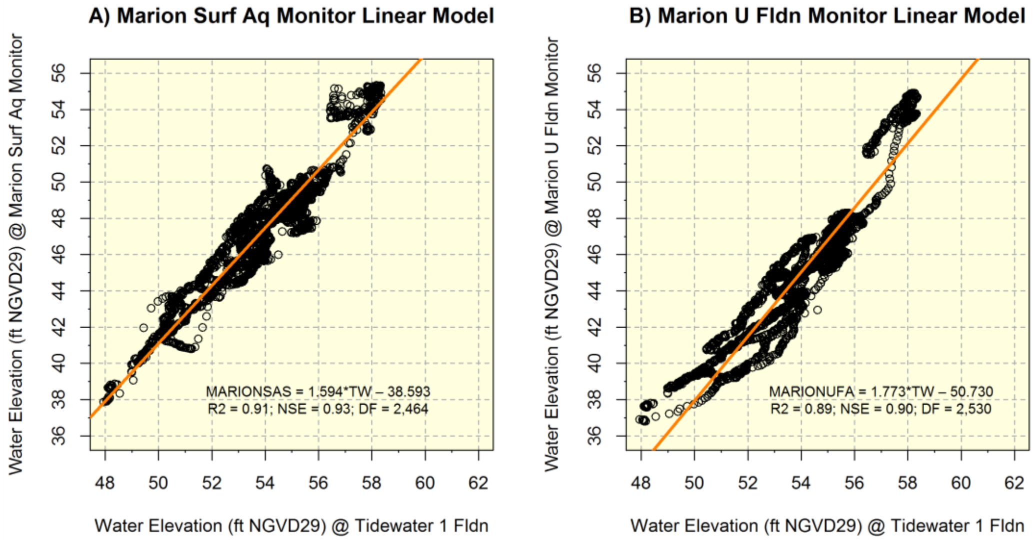

Figure 17. Linear models used to estimate A) the Lake Marion Surf Aq Monitor and B) Mairon U Fldn Aq Monitor wells as functions of Tidewater 1 Fldn.

and 1.40 feet, respectively. Reduced precision in the higher and lower ranges of the stage-volume relationships for the lake may also have contributed to the percentile differences.

The water budget component values in the model can be difficult to judge since they are expressed as inches per year over the average lake area for the period of the model run (Table 5). Leakage rates (and leakance coefficients), for example, represent conditions below the lake only, and may be very different than those values expected in the general area. Runoff also represents a volume over the average lake area, and when the resulting values are divided by the watershed area, they represent low runoff rates.

H. Historic Water Budget Model Results

Groundwater withdrawals are not directly included in the Lake Marion water budget model, but are indirectly represented by their effects on water levels in the surficial and Upper Floridan aquifers. Metered and estimated groundwater withdrawal rates in the vicinity of Lake Marion are available throughout the period of the calibrated model, so if a relationship between withdrawal rates and aquifer potentiometric levels can be established, the effect of changes in groundwater withdrawals can be estimated by adjusting aquifer levels in the model.

The Northern District Model, Version 5.0 (NDM5), is a regional groundwater model covering 8,000 square miles in north-central Florida (HGL and DS, 2016). The regional model grid consists of 212 columns and 275 rows with uniform grid spacing of 2,500 feet. Seven active layers in the model represent the primary geologic and hydrogeologic

Figure 18. Modeled water levels predicted for the calibrated Lake Marion water budget model (green squares) and measured levels used for the model calibration (blue triangles).

Table 4. Comparison of percentiles of measured lake level data compared to calibration percentiles from the model (all in ft NGVD29).

	Data	**Model**
P10	52.9	52.5
P50	48.8	48.8
P90	46.1	46.5

Table 5. Lake Marion Water Budget (March 1992 – March 2019).

Inflows	Rainfall	Surficial Aquifer Groundwater Inflow	Floridan Aquifer Groundwater Inflow	Runoff	DCIA Runoff	Inflow via channel	Total
Inches/year	55.5	1.1	0.0	21.1	0.0	0.0	77.7
Percentage	71.4	1.4	0.0	27.2	0.0	0.0	100.0
Outflows	Evaporation	Surficial Aquifer Groundwater Outflow	Floridan Aquifer Groundwater Outflow			Outflow via channel	Total
Inches/year	55.2	11.5	8.9			0.0	75.6
Percentage	72.9	15.2	11.8			0.0	100.0

units. The domain of NDM5 includes the Lake Marion area and represents the most current understanding of the hydrogeologic system in the area.

NDM5 was used to determine the drawdown in the surficial aquifer and Upper Floridan aquifer in response to groundwater withdrawals in the area. Specifically, three different groundwater withdrawal scenarios were simulated in NDM5 (Cameron, 2020). The first and second scenarios utilized actual groundwater pumping distributions for 2010 and 2015, respectively, while the third scenario involved setting all withdrawals to zero (i.e. no pumping). Drawdown was calculated as the difference between the no-pumping run and the pumping run. For both the surficial and upper Floridan aquifers in both 2010 and 2015, drawdown under Lake Marion was predicted as approximately 0.1 feet (Cameron, 2020).

To estimate lake levels without the influence of groundwater withdrawals, the Upper Floridan aquifer and surficial aquifer wells in the water budget model were adjusted to represent zero withdrawals. A single adjustment period is used, corresponding to an long-term average drawdown over the water budget model period. Adjustments to each Upper Floridan aquifer and surficial aquifer well for this period are found in Table 6.

Table 6. Aquifer water level adjustments to the Lake Marion water budget model to represent Historic percentiles.

Well	Adjustment (feet) 1992 through 2019
Floridan aquifer	0.1
Surficial aquifer	0.1

Figure 19 presents measured water level data for the lake along with the model-simulated lake levels in the lake under Historic conditions, i.e. with structural alterations similar to current conditions and in the absence of groundwater withdrawals and augmentation. Table 7 presents the Historic percentiles based on the model output. Figure 20 depicts the difference between Historic and calibrated stages; a run-up period is evident through approximately 1994, but even after this, differences are small (less than 0.1 feet), reflecting the low drawdown expected at the lake (Table 6). Also a function of this low drawdown, compared to the calibrated water budget, the Historic percentiles are unchanged for the P50 and just 0.1 feet higher for the P10 for the P90.

I. Rainfall Correlation Model

A line of organic correlation (LOC) was performed using the results of the water budget model and long-term rainfall to extend the data set used to determine the Historic percentiles. These Historic percentiles are considered in development of the Minimum Levels. The LOC is a linear fitting procedure that minimizes errors in both the *x* and *y*

Figure 19. Measured lake levels (Data; blue triangles) and Historic water levels (Model; green squares) predicted using the calibrated Lake Marion model adjusted for drawdown.

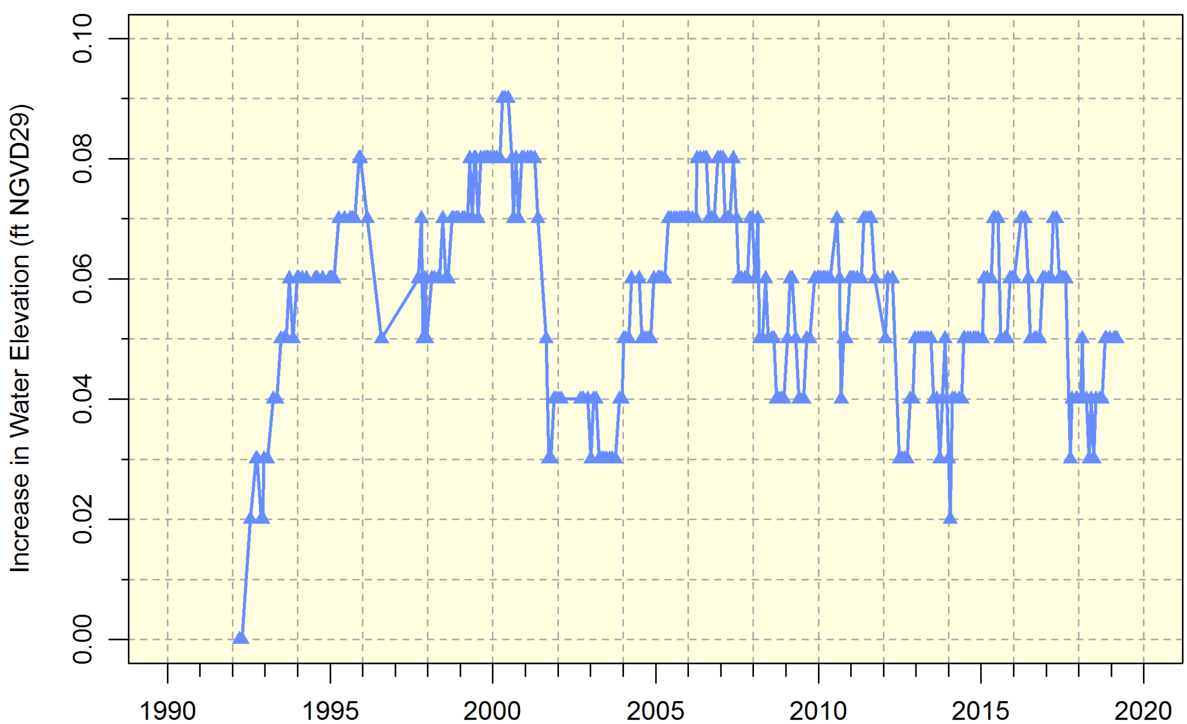

Figure 20. The difference between Historic and calibrated water budget model stages for Lake Marion.

directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch, 2002). LOC is preferable for this application since it produces a result that best retains the variance (and therefore best retains the "character") of the original data.

In this application, the simulated lake water levels representing Historic conditions were correlated with Long-term rainfall. For the correlation, additional representative rainfall records were prepended to the rainfall records used in the water budget model. Similar to the approach employed for the water budget model rainfall record, the available data closest to the lake were used. Stations used are shown in Figure 21, Figure 22, and Table 3.

Rainfall is correlated to lake water level data by applying a linear inverse weighted sum to the rainfall. The weighted sum gives higher weight to more recent rainfall and less weight to rainfall in the past. In this application, weighted sums varying from 6 months to 10 years are separately used, the results are compared, and the correlation with the highest correlation coefficient (R^2) is chosen as the best model.

Rainfall was correlated to the Historic water budget model results from March 1994 to March 2019 (Figure 23 and Figure 24); the first two years of water budget model output were excluded in order to account for the evident run-up period (Figure 20 and Figure 24). The resulting stage-rainfall relationship was used with rainfall to produce daily lake water elevations from January 1946 to March 2019 (73.3 years).

The results are presented in Figure 24, which displays the lake's predicted behavior in the absence of withdrawals. For Lake Marion, the 3-year weighted model had the highest correlation coefficient, with an R^2 of 0.78 ($p < 0.01$; df = 9,870; NSE = 0.74; MAE = 0.96 feet). Lakes in the northern Tampa Bay region typically display decays between 2 and 5 years. For Lake Brooklyn, located approximately 50 miles northeast of Lake Marion, Merrit (2001) and Gordu et al. (2014) found a 5-year decay.

To produce Historic percentiles that apply significant weight to the results of the water budget models, the rainfall LOC results for the period of the water budget model are replaced with the water budget model results. Therefore, the LOC rainfall model results are used for the period of January 1946 through February 1992, while the water budget results are used for the period of March 1992 through March 2019. These results are referred to as the "hybrid model." The Historic percentiles for the hybrid model are presented in Table 8. Note that the the P10, P50, and P90 percentiles for the Historic water budget model (Table 7) differ from those of the Historic hybrid rainfall model (Table 8) for Lake Marion by 0.6, 1.2, and 0.4 feet, respectively.

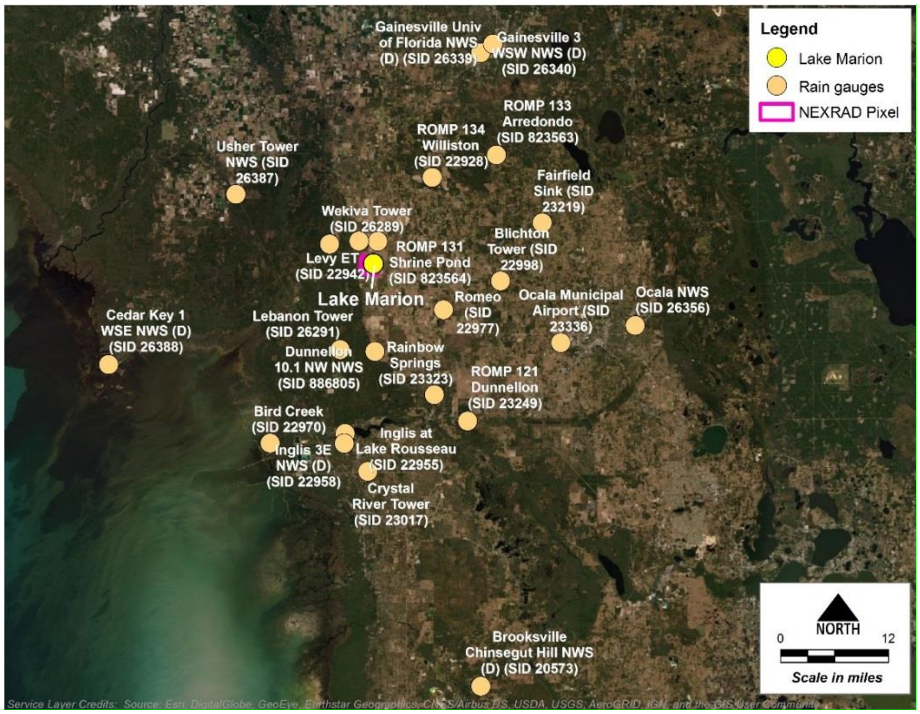

Figure 21. Locations of additional rain stations used for the rainfall correlation model.

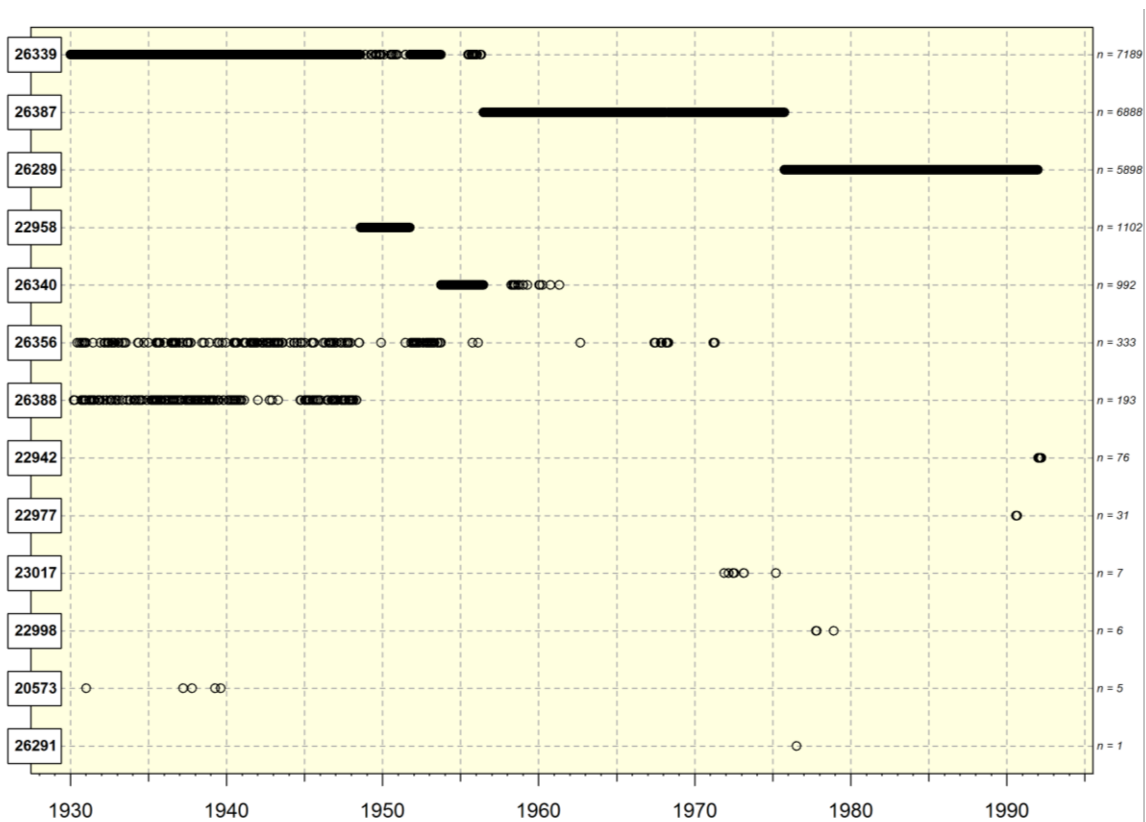

Figure 22. Rainfall data sources and the timing and frequency of their use in the rainfall correlation model extension. Site IDs are displayed on the y-axis. Each point represents a day.

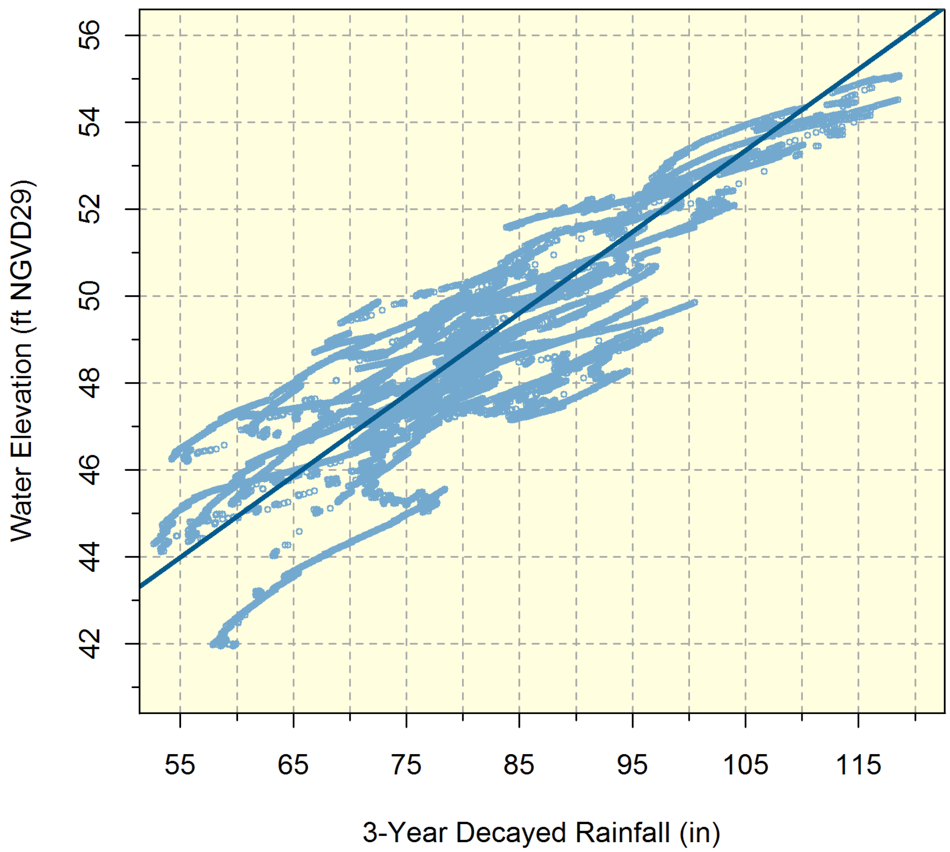

Figure 23. Linear model for Lake Marion (ft NGVD29; y-axis) as a function of 3-year summed decayed rainfall (inches; x-axis).

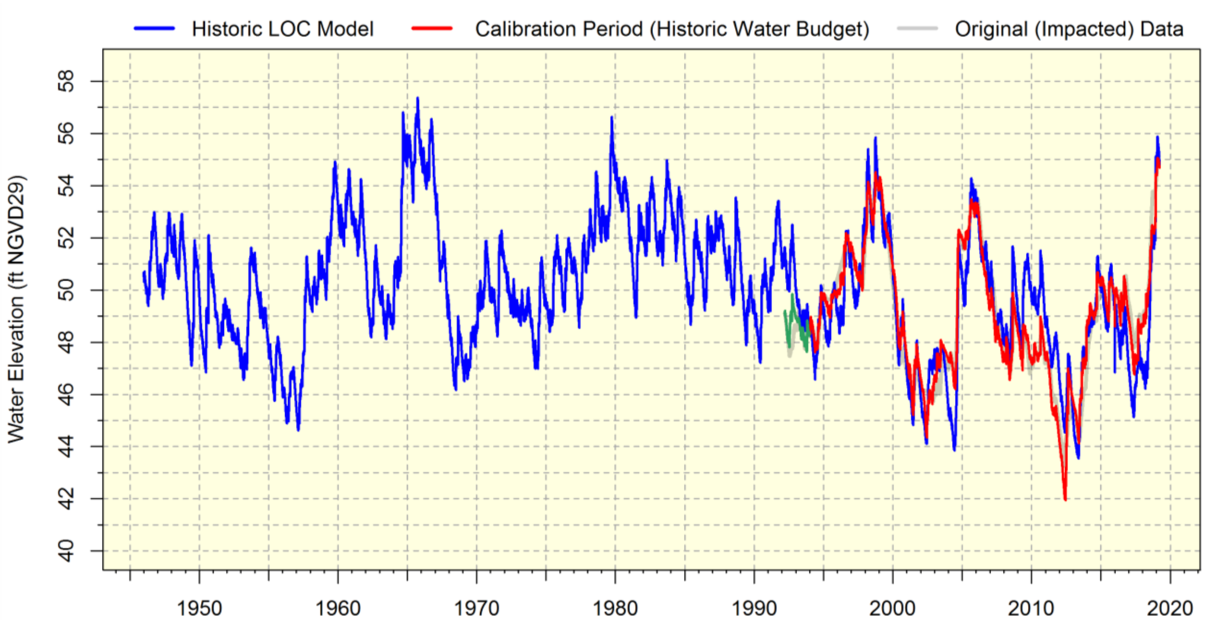

Figure 24. Historic LOC model (blue line) and water budget (red line) results for Lake Marion. The green line shows the excluded water budget model run-up period.

Table 7. Historic percentiles (in ft NGVD29) estimated using the Lake Marion water budget model (March 1992 to March 2019).

Percentile	Elevation
P10	52.6
P50	48.8
P90	46.6

Table 8. Historic percentiles as estimated by the hybrid model from January 1946 to March 2019 (ft NGVD29).

Percentile	Elevation
P10	53.2
P50	50.0
P90	47.1

J. Conclusions

Based on the model results and the available data, the Lake Marion water budget and LOC rainfall models are useful tools for assessing long-term percentiles in the lake. Based on the same information, lake stage exceedance percentiles developed through use of the models appear to be reasonable estimates for Historic conditions.

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DRAFT APPENDIX B

Technical Memorandum

January 13, 2020

TO: Tamera S. McBride, P.G., Manager, Resource Evaluation, Water Resources Bureau

FROM: Cortney Cameron, G.I.T., Hydrogeologist, Water Resources Bureau
Don Ellison, P.G., Senior Hydrogeologist, Water Resources Bureau

Subject: Draft Lake Marion Initial Minimum Levels Status Assessment

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A. Introduction

The Southwest Florida Water Management District (District) is reevaluating adopted minimum levels for Lake Marion and is proposing revised minimum levels for the lake, in accordance with Section 373.042 and 373.0421, Florida Statutes (F.S). Documentation regarding development of the revised minimum levels is provided by Cameron and Ellison (2020) and Hurst and others (2020).

Section 373.0421, F.S. requires that a recovery or prevention strategy be developed for all water bodies that are found to be below their minimum flows or levels, or are projected to fall below the minimum flows or levels within 20 years. This document provides information and analyses to be considered for evaluating the status (i.e., compliance) of the revised minimum levels proposed for Lake Marion and any recovery that may be necessary for the lake.

B. Background and Setting

Lake Marion is located in east-central Levy County, flanked by SE 115th Avenue to the west, SE 122nd Court to the east, and SE 25th Street to the north. (Figure 1). The lake system lies within the Wekiva River drainage basin in the Waccasassa River watershed. The lake is surrounded by hills with elevations as high as 110 feet above the National Geodetic Vertical Datum of 1929 (ft NGVD29). Lake Marion has no significant inflow other than overland flow. No outflow occurs from the basin currently.

C. Revised Minimum Levels Proposed for Lake Marion

Revised minimum levels proposed for Lake Marion are presented in Table 1 and discussed in more detail by Hurst and others (2020). Minimum levels represent long-term conditions that, if achieved, are expected to protect water resources and the ecology of the area from significant harm that may result from water withdrawals. The Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed fifty percent of the time on a long-term basis. The High Minimum Lake Level is the elevation that a lake's water levels are required to equal or exceed ten percent of the time on a long-term basis. The Minimum Lake Level therefore represents the required 50th percentile (P50) of long-term water levels, while the High Minimum Lake Level represents the required 10^{th} percentile (P10) of long-term water levels. To determine the status of minimum levels for Lake Marion or minimum flows and levels for any other water body, long-term data or model results must be used.

Table 1. Proposed Minimum Levels for Lake Marion.

Proposed Minimum Levels	**Elevation in ft NGVD29**
High Minimum Lake Level	52.6
Minimum Lake Level	49.4

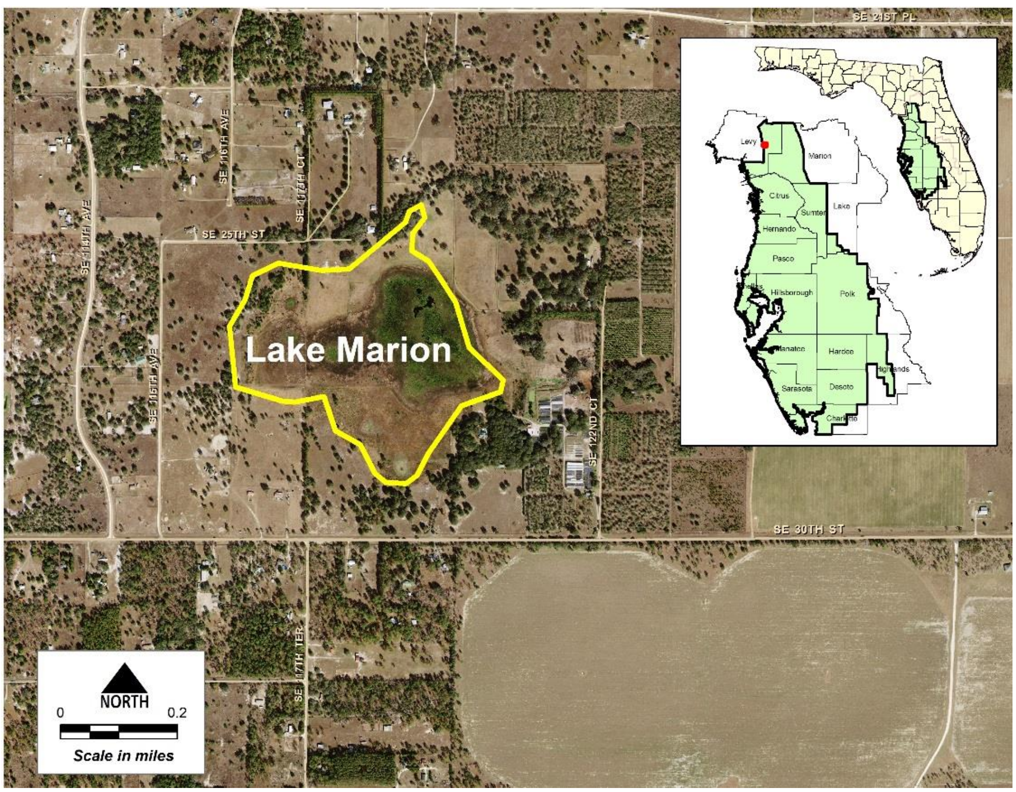

Figure 1. Location of Lake Marion in Levy County, Florida.

D. Status Assessment

The lake status assessment approach involves using actual lake stage data for Lake Marion from March 1992 through March 2019, which was determined to represent the “Current” period. As demonstrated in Cameron and Ellison (2020), groundwater withdrawals during this period were relatively consistent. The Current period represents a recent “Long-term” period when hydrologic stresses (including groundwater withdrawals) and structural alterations are reasonably stable. “Long-term” is defined as a period that has been subjected to the full range of rainfall variability that can be expected in the future.

To create a data set that can reasonably be considered “Long-term,” a regression analysis using the line of organic correlation (LOC) method was performed on the lake level data from the Current period (Figure 2). The LOC is a linear fitting procedure that minimizes errors in both the *x* and *y* directions and defines the best-fit straight line as the line that minimizes the sum of the areas of right triangles formed by horizontal and vertical lines extending from observations to the fitted line (Helsel and Hirsch, 2002). The LOC is preferable for this application since it produces a result that best retains the variance (and therefore best retains the “character”) of the original data. This technique was used to develop the minimum levels for Lake Marion (Cameron and Ellison, 2020). By using this technique, the limited years of Current lake level data can be projected back to create a simulated data set representing over 70 years of lake levels, based on the current relationship between lake water levels and actual rainfall.

The same rainfall data set used for setting the minimum levels for Lake Marion was used for the status assessment (Cameron and Ellison, 2020). The best resulting correlation for the LOC model created with measured data (April 2010 to March 2019) was the 3-year weighted period, with a coefficient of determination of 0.72. The results are presented in Table 2 and Figure 3, which displays the lake’s predicted behavior under Current withdrawal conditions.

As an additional piece of information, Table 2 also presents the percentiles calculated directly from the measured lake level data for Lake Marion for the period from March 1992 through March 2019. A limitation of these values is that the resulting lake stage exceedance percentiles are representative of rainfall conditions during only the past 27 years, rather than the longer-term rainfall conditions represented in the January 1946 to March 2019 LOC model simulation.

A comparison of the LOC model with the revised minimum levels proposed for Lake Marion indicates that the Long-term P10 is 0.6 feet above the proposed High Minimum Lake Level, and the Long-term P50 is 0.4 feet above the proposed Minimum Lake Level. The P10 elevation derived directly from the March 1992 to March 2019 measured lake data is 0.3 feet above the proposed High Minimum Lake Level, and the P50 elevation is 0.6 feet below the proposed Minimum Lake Level. Differences in rainfall between the shorter March 2010 to March 2019 period and the longer 1946 to March 2019 period used for the LOC modeling analyses likely contribute to the differences between derived and measured lake stage exceedance percentiles. Additionally, differences between actual withdrawal and augmentation rates and those used in the models may have contributed to some of the differences in the percentiles.

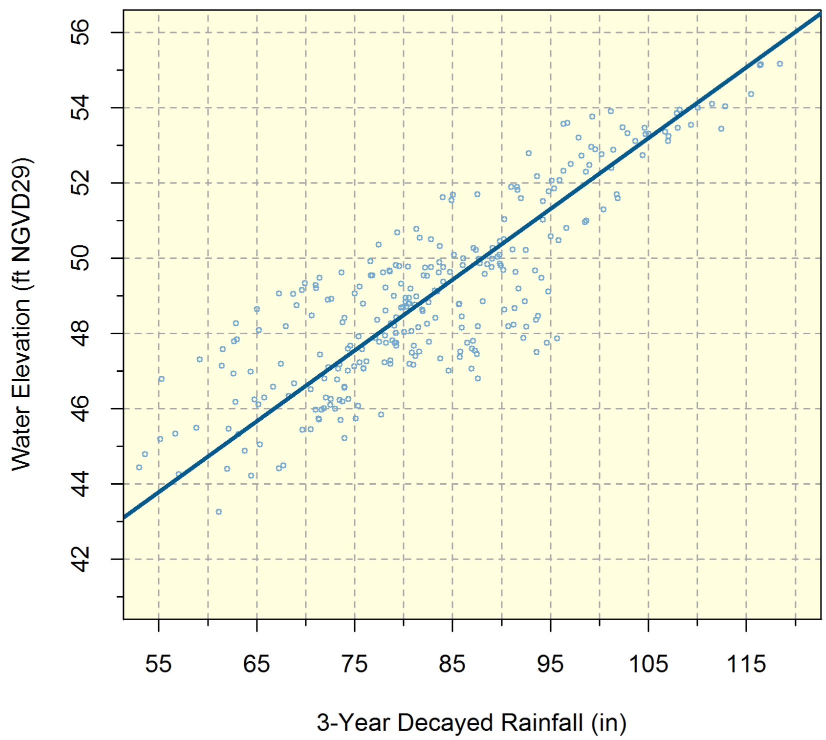

Figure 2. Linear model for Lake Marion (ft NGVD29; y-axis) as a function of 3-year decayed rainfall (in; x-axis).

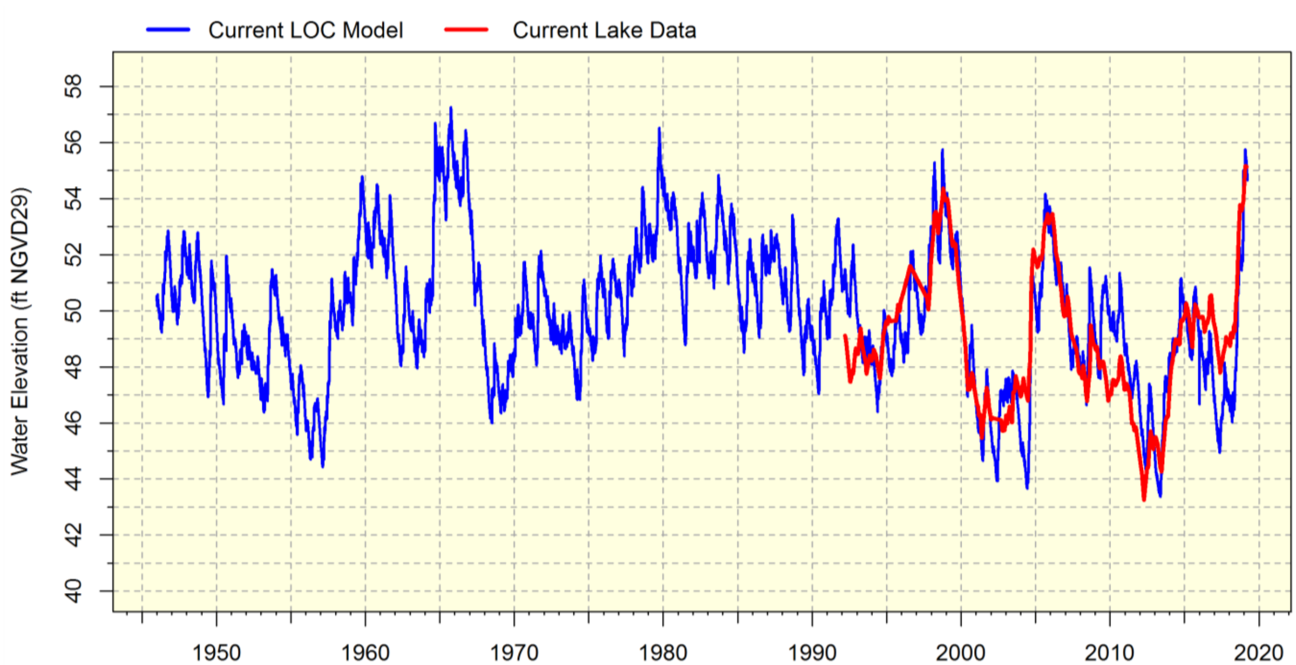

Figure 3. Current LOC model (blue line) and water budget (red line) results for Lake Marion.

Table 2. Comparison of lake stage exceedance percentiles derived from the lake stage/LOC results, exceedance percentiles of the March 1992 to March 2019 data, and the revised minimum levels proposed for Lake Marion. All elevations in ft NGVD29.

Percentile	Proposed Minimum Levels	Long Term LOC Model Results (1946 to 2019*)†	LOC Model Results Percentage of Time At or Above Level (1946 to 2019*)†	Measured Lake Levels for Current Period (1992 to 2019*)
P10	52.6	53.2	13%	52.9
P50	49.4	49.8	57%	48.8

* March 2019

† LOC model based on Current Period extended using rainfall for January 1946 to March 2019.

E. Projected 2040 Status Assessment

To estimate Lake Marion water level behavior under 2040 withdrawal conditions, the calibrated water budget model for Lake Marion (Cameron and Ellison, 2020) was adjusted using projected 2040 drawdowns (Cameron, 2020). The 2040 water budget model results from March 1994 to March 2019 (allowing a 2-year run-up period for the water budget model, as in Cameron and Ellison, 2020) were then used with the rainfall regression procedure described above to predict lake water levels under 2040 withdrawal conditions over a time period of 73.3 years. The best correlation for the rainfall regression model was the 3-year weighted period, with a coefficient of determination of 0.78. The results are presented in Table 3, which shows the lake's predicted Long-term behavior under projected 2040 withdrawal conditions.

Table 3. Comparison of lake stage exceedance percentiles derived from the projected 2040 status assessment and the revised minimum levels proposed for Lake Marion. All elevations in ft NGVD29.

Percentile	Proposed Minimum Levels	Projected 2040 Status Assessment
P10	52.6	53.1
P50	49.4	49.8

F. Conclusions

Based on the information presented in this memorandum, it is concluded that Lake Marion water levels are above the revised Minimum Lake Level and revised High Minimum Lake Level proposed for the lake. Additionally, the lake is not projected to fall below its proposed minimum levels in the next 20 years. These conclusions are supported by comparison of percentiles derived from Long-term LOC modeled lake stage data with the proposed minimum levels.

Minimum flow and level status assessments are completed on an as-needed basis in response to withdrawal-permit requests and renewals, on an annual basis, and on a five-year basis as part of the regional water supply planning process. If water levels in Lake Marion are found to not be meeting or projected to not meet the minimum levels adopted for the lake, a recovery or prevention strategy will, respectively, be developed.

G. References

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DRAFT APPENDIX C

Technical Memorandum

January 13, 2020

TO: Mark Hurst, Staff Environmental Scientist, Resource Evaluation Bureau
Cortney Cameron, G.I.T., Staff Hydrogeologist, Water Resources Bureau

FROM: Cortney Cameron, G.I.T., Staff Hydrogeologist, Water Resources Bureau

Subject: Evaluation of Groundwater Withdrawal Impacts to Lake Marion

A. Introduction

Lake Marion is located in east-central Levy County in north-central Florida (Figure 1). Prior to establishment of a Minimum Level (ML), an evaluation of hydrologic changes in the vicinity of the lake is necessary to determine if the water body has been significantly impacted by groundwater withdrawals. The establishment of the ML for Lake Marion is not part of this report. This memorandum focuses on the results of groundwater model scenarios near Lake Marion. A description of the local and regional hydrogeology is available in Cameron and Ellison (2020), HGL (2010), and Miller (1986).

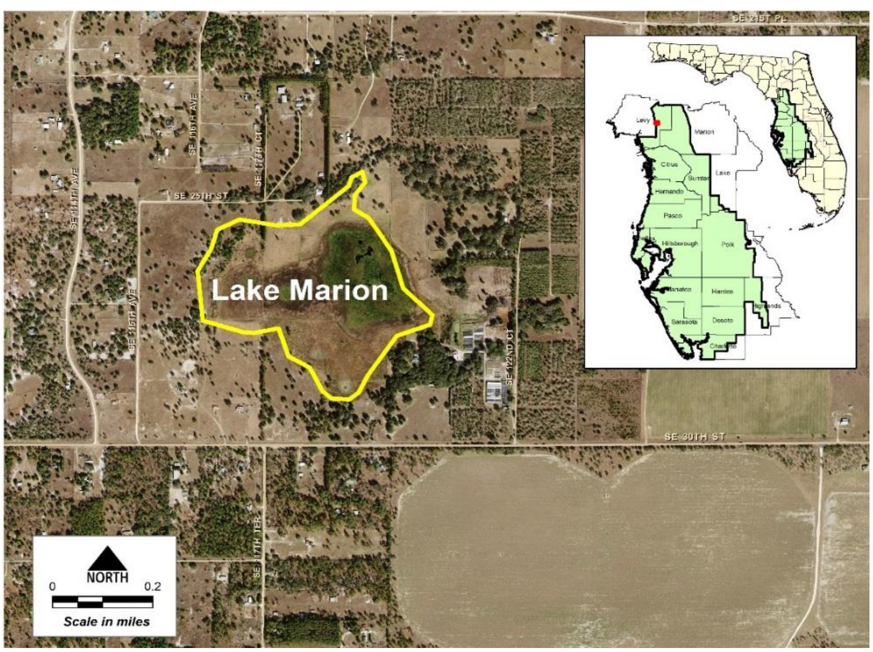

Figure 1. Location of Lake Marion in Levy County.

B. Overview of the Northern District Model

The Northern District Model (NDM) was originally developed in 2008 by HydroGeoLogic, Inc. (HGL, 2008). Since that time, there have been several refinements to the original model, with the subsequent Version 2.0 in 2010 and Version 3.0 in 2011. In 2013, Version 4.0 was completed by expanding the model grid slightly northward and east to the St. Johns River. This was done as a cooperative effort between the District, St. Johns River Water Management District (SJRWMD), Marion County, and the Withlacoochee River Regional Water Supply Authority (HGL, 2013). The domain of the NDM includes portions of the SWFWMD, the SJRWMD, and the Suwannee River Water Management District. The flow model encompasses the entire extent of the Central West-Central Florida Groundwater Basin (CWCFGWB) and the Northern West-Central Florida Groundwater Basin (NWCFGWB) and portions of the Northern East-Central Florida Groundwater Basin. The eastern boundary of the regional groundwater flow model extends to the St. Johns River, while the western boundary of the model domain extends approximately five miles offshore in the Gulf of Mexico (Figure 5-18). Version 5.0 of the NDM was completed in August 2016 (HGL and DS, 2016). Versions 4.0 and 5.0 were peer reviewed by Dr. Mark Stewart, P.G. and Dr. Pete Anderson, P.E. in a cooperatively-funded project for SJRWMD and SWFWMD (Anderson and Stewart, 2016). Dr. Stewart indicated in his most recent peer review that the “NDM, Version 5.0, is the best numerical groundwater flow model currently available for assessing the effects of withdrawals in the central (Florida) springs region.”

The regional model grid consists of 212 columns and 275 rows with uniform grid spacing of 2,500 feet (Figure 1). The active model grid covers about 8,000 square miles in north-central Florida. Seven active layers in the model represent the primary geologic and hydrogeologic units including: 1) Surficial Sand, 2) Intermediate Confining Unit, 3) Suwannee Limestone, 4) Ocala Limestone, 5) Upper Avon Park Formation, 6) Middle Confining Units I and II, and 7) Lower Avon Park Formation or Oldsmar Formation. The upper Floridan aquifer (UFA) is composed mainly of the Suwannee Limestone (where it exists), Ocala Limestone, and Upper Avon Park Formation. The lower Floridan aquifer (LFA) is composed of the permeable parts of both the Lower Avon Park and the Oldsmar Formations. A description of the conceptual geologic and hydrogeologic frameworks underlying the model is available in HGL (2010). Because of the permeability contrast between the units, each unit is simulated as a discrete layer rather than using a single layer to represent a thick sequence of permeable formations within the UFA. This model is unique for west-central Florida in that it is the first regional flow model that represents the groundwater system as fully three-dimensional. Prior modeling efforts, notably Ryder (1982), Sepulveda (2002), Knowles et al. (2002), and Motz and Dogan (2004), represented the groundwater system as quasi-three dimensional.

A tremendous amount of hydrologic and geologic data was utilized to construct and calibrate the NDM. The District utilized hydraulic and geologic information from more than 50 Regional

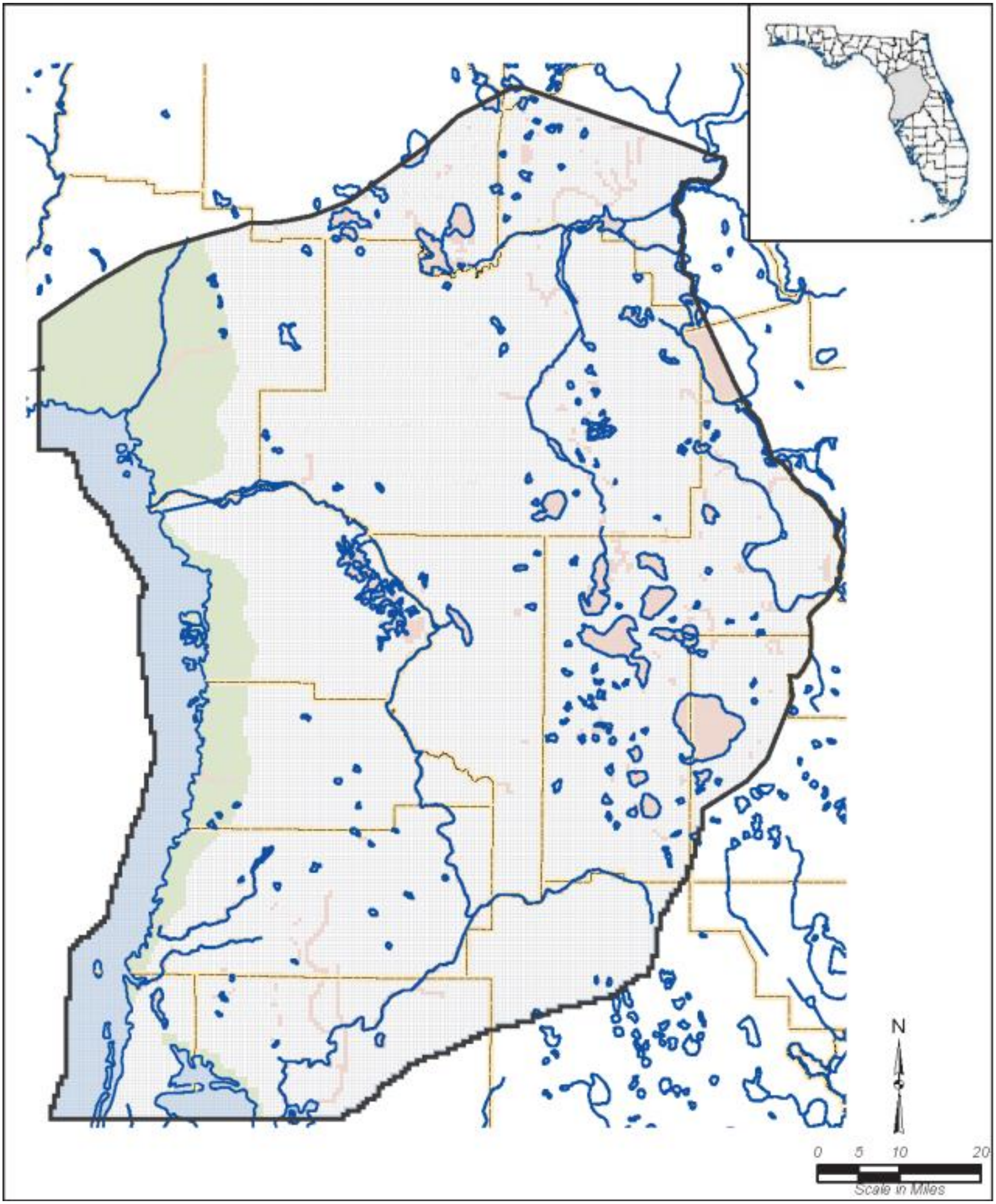

Figure 2. Groundwater grid used in the NDM.

Observation and Monitoring-Well Program (ROMP) sites in the SWFWMD model area. At nearly every site, coring of the earth materials occurred from land surface to more than 1,000 feet below land surface. Aquifer permeability was tested via slug tests and packer tests at specified intervals within each aquifer. Monitor wells were installed in each aquifer to measure water levels through time. The District installs continuous recorders or manually measures these monitor well water levels every month. This data is stored within the District's Water Management Information System (WMIS); some of the wells have a water level history of 30 to 50 years. Aquifer performance tests were conducted at some of the sites to measure water level responses in the UFA under temporary pumping at high rates. This information all serves to increase understanding of how the aquifer system responses to groundwater withdrawals and results in improved models that represent the real world.

The NDM Version 5.0 (NDM5) was calibrated to steady-state 1995 calendar year conditions and transient conditions from 1996 through 2006 using monthly stress periods. The model was also verified for 2010 steady-state conditions. The calibration process involves modifying aquifer parameters within a reasonable range in the model to best match measured aquifer water levels at wells and springflows recorded by the United States Geological Survey. This process accounts for some of the uncertainty in aquifer parameters between data points.

If a model can closely replicate aquifer water levels and flow through time, then it is deemed well calibrated. This in turn provides confidence that it is an effective tool to make predictions. In 2010, water levels from over 384 observation wells in the Upper Floridan aquifer were compared with simulated water levels at each well location within the model domain. The groundwater flow and solute transport modeling computer code MODHMS was used for the groundwater flow modeling (HGL, 2011). MODHMS is an enhanced version of the USGS modular, three-dimensional groundwater flow code (McDonald and Harbaugh 1988). This code was selected because of its powerful ability to simulate variably saturated conditions in Layer 1, coupled with its ability to model saltwater intrusion as a solute transport model in the northern region of the District.

In NDM Version 5.0, mean water level error (simulated minus observed) in the UFA for 1995 and the 1996-2006 average transient period was +0.17 feet and +0.41 feet, respectively (HGL and DS, 2016). The mean absolute error varied from 3.77 to 3.61 feet for both periods, respectively, based on 137 wells in 1995 and 157 wells from 1996-2006. These statistics are for wells within the NWCFGWB.

C. Results of Northern District Model Scenarios

The calibrated NDM5 model was used to simulate four different groundwater withdrawal scenarios. The first and second scenarios utilized actual groundwater pumping distributions for 2010 and 2015, respectively. The third scenario utilized projected groundwater pumping quantities and distributions for 2040 (Cameron, 2019). The fourth scenario involved setting all withdrawals to zero (i.e. no pumping).

Taking the difference in simulated heads between the 2010 pumping and non-pumping runs, the average predicted drawdown in the surficial aquifer near Lake Marion was 0.1 feet in both the surficial and Upper Floridan aquifers (Figure 3 and Figure 4).

Taking the difference in simulated heads between the 2015 pumping and non-pumping runs, the average predicted drawdown in the surficial aquifer near Lake Marion was 0.1 feet in both the surficial and Upper Floridan aquifers (Figure 5 and Figure 6).

Taking the difference in simulated heads between the 2040 projected pumping and non-pumping runs, the average predicted drawdown in the surficial aquifer near Lake Marion was 0.2 feet in both the surficial and Upper Floridan aquifers (Figure 7 and Figure 8).

Table 1 presents the predicted drawdown in the surficial and the Upper Floridan aquifers based on the NDM model results.

Table 1. Predicted drawdowns (feet) for Lake Marion using NDM5 model scenarios.

	Drawdown (feet) Predicted under 2010 Withdrawals	**Drawdown (feet) Predicted under 2015 Withdrawals**	**Drawdown (feet) Predicted under 2040 Projected Withdrawals**
Surficial Aquifer System	0.1	0.1	0.2
Upper Floridan Aquifer	0.1	0.1	0.2

* Average drawdown from model cells intersecting lake

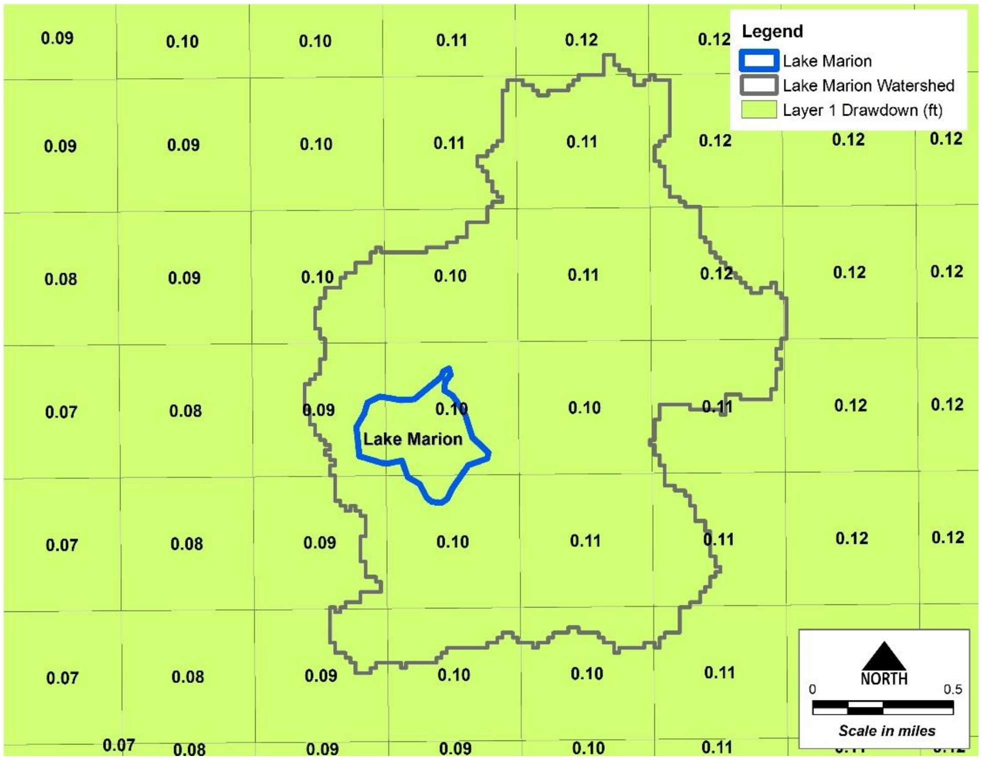

Figure 3. Predicted drawdown (in feet) in the surficial aquifer due to 2010 groundwater withdrawals.

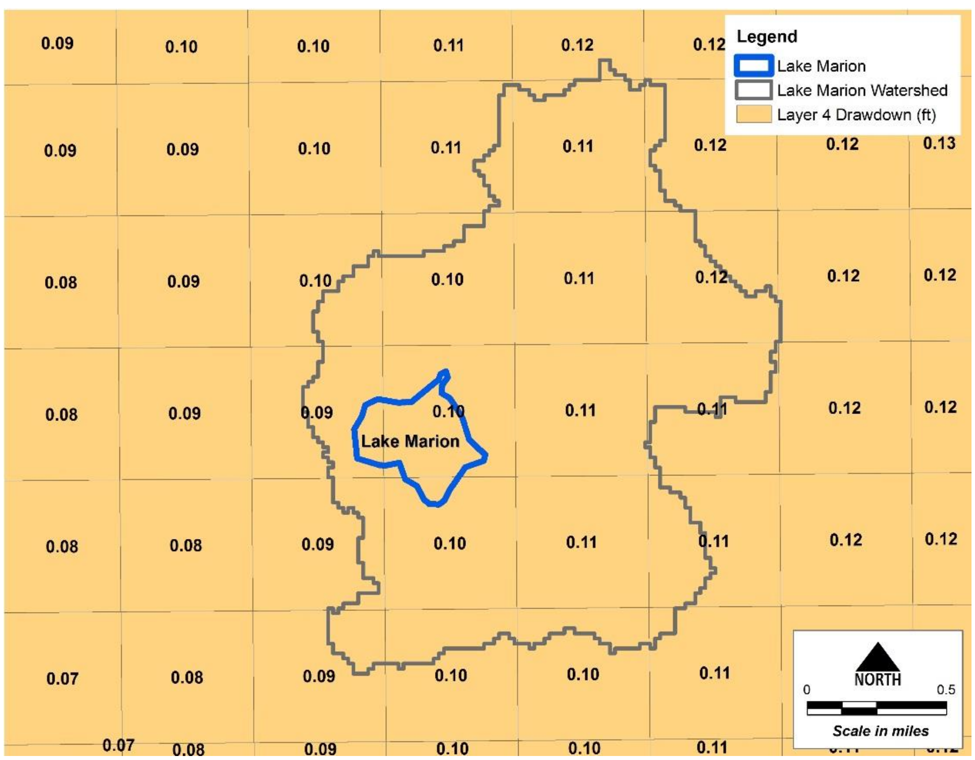

Figure 4. Predicted drawdown (in feet) in the Upper Floridan aquifer due to 2010 groundwater withdrawals.

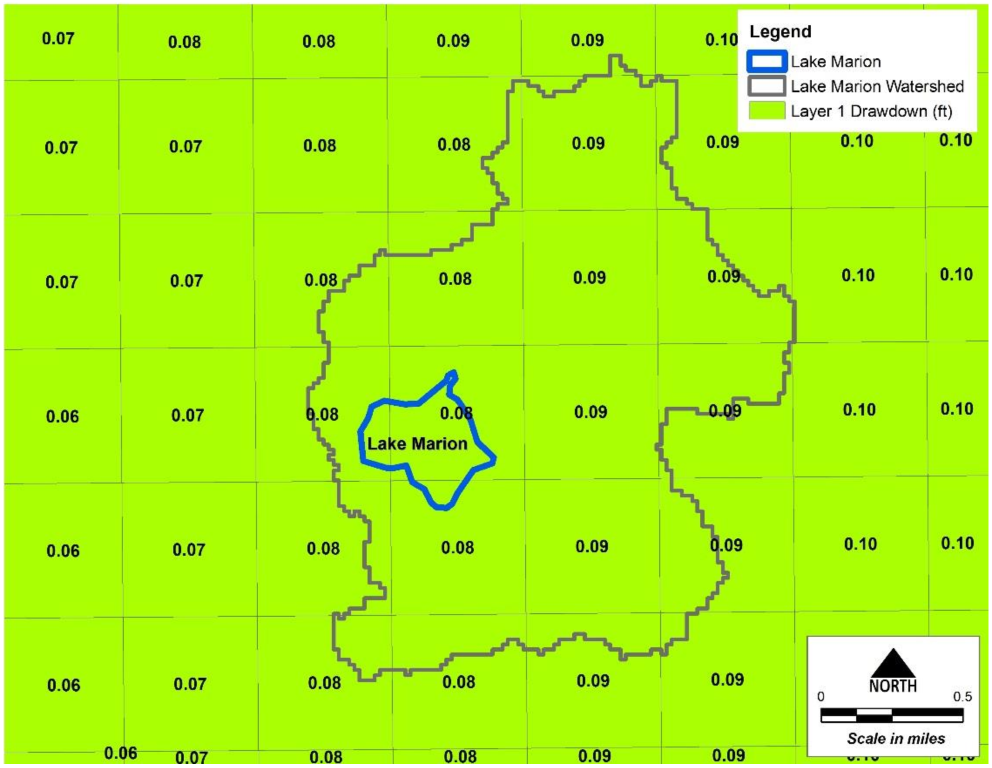

Figure 5. Predicted drawdown (in feet) in the surficial aquifer due to 2015 groundwater withdrawals.

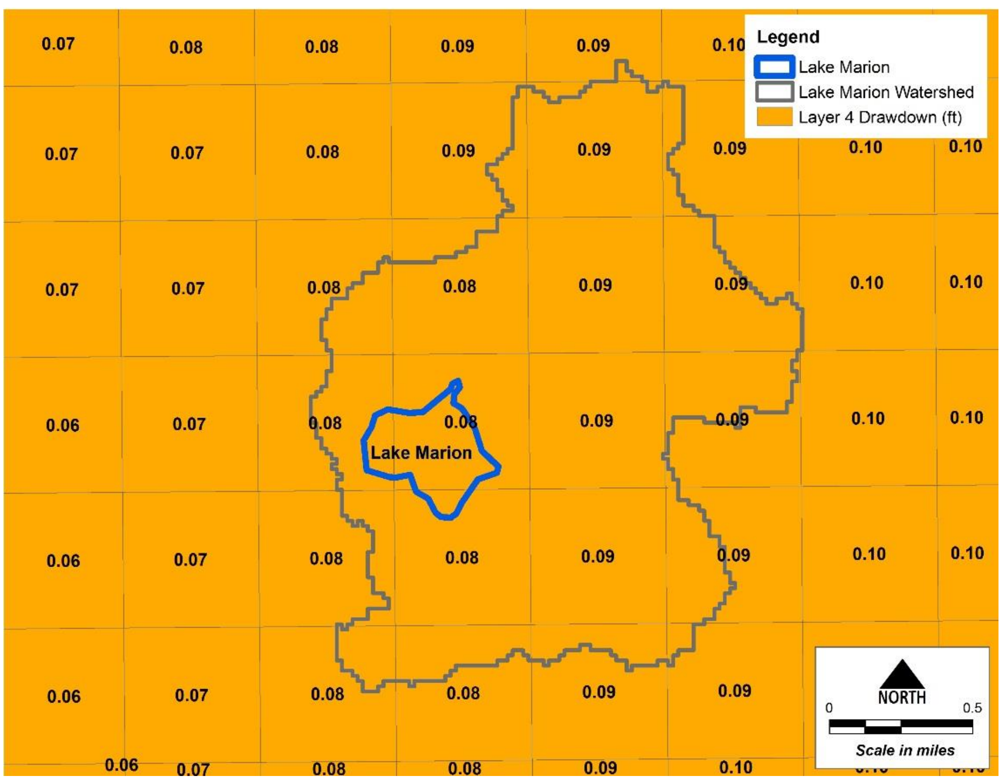

Figure 6. Predicted drawdown (in feet) in the Upper Floridan aquifer due to 2015 groundwater withdrawals.

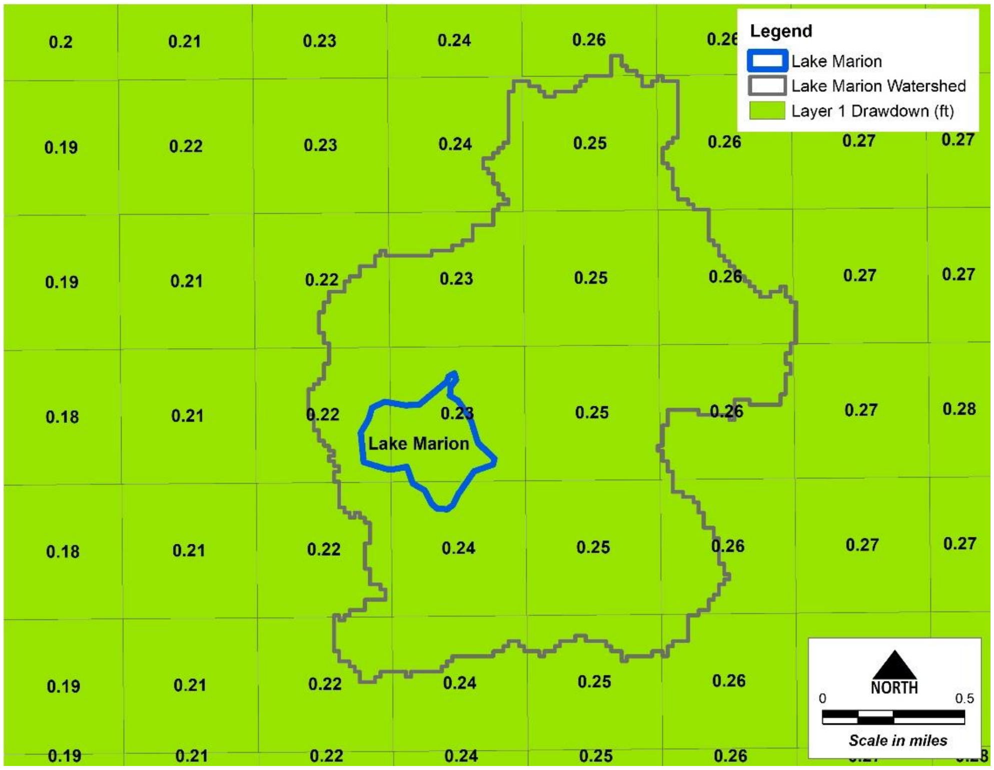

Figure 7. Predicted drawdown (in feet) in the surficial aquifer due to projected 2040 groundwater withdrawals.

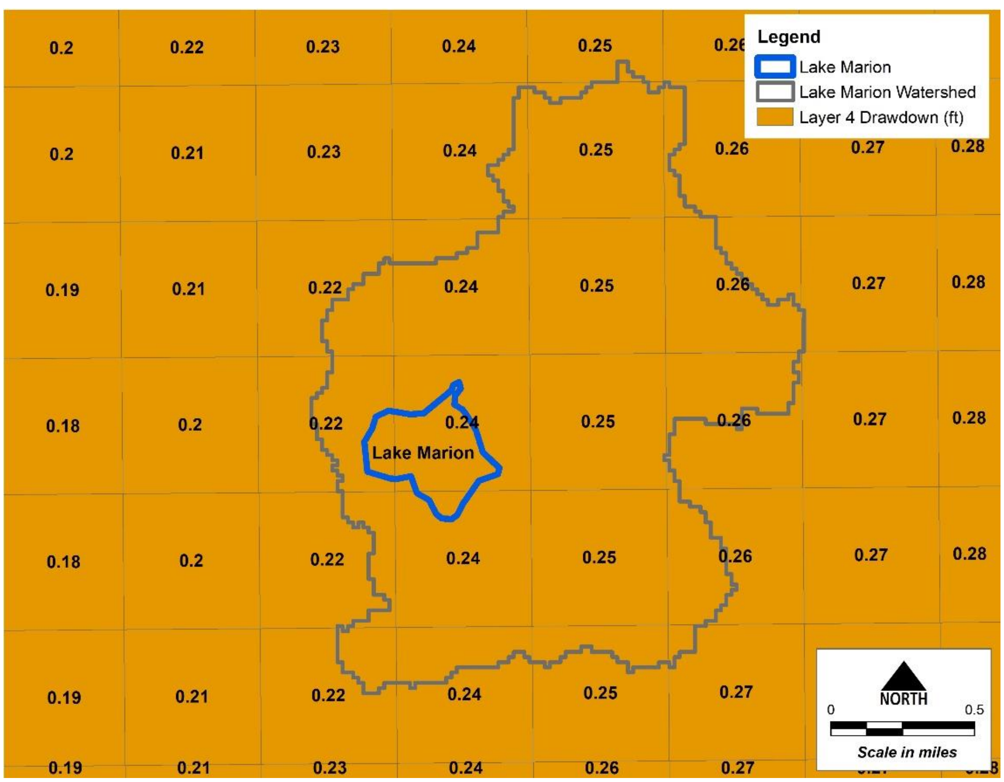

Figure 8. Predicted drawdown (in feet) in the Upper Floridan aquifer due to projected 2040 groundwater withdrawals.

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